Ferruginous Hawk Climate Change Adaptation Plan for Alberta

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Preface

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The primary goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province, the ABMI has assembled a massive biodiversity database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

The ABMI undertakes focused projects to apply this capacity to specific management challenges, and demonstrate the value of the ABMI's long-term monitoring data to addressing these challenges. In some cases, these applied research projects also evaluate potential solutions to pressing management challenges. In doing so, the ABMI has extended its relevance beyond its original vision.

The ABMI continues to be guided by a core set of principles – we are independent, objective, credible, accessible, transparent and relevant.

This report was produced in support of the ABMI's Biodiversity Management and Climate Change Adaptation project, which is developing knowledge and tools to support the management of Alberta's biodiversity in a changing climate.

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Executive Summary

The Ferruginous Hawk (FEHA) is a specialized, open-country buteo limited to grassland and shrub-steppe environments. The Alberta population has declined precipitously since the early 1990s leading to the species being listed as *Endangered* under the *Alberta Wildlife Act*. The *Alberta Ferruginous Hawk Recovery Plan 2009 – 2014* identifies climate change as a factor potentially threatening the recovery of the species in Alberta. This report is intended to supplement the provincial Recovery Plan by examining in detail the scope and scale of past and projected changes in climate within the Alberta range of the FEHA, by summarizing current knowledge of the potential effects of climate change on FEHAs, and by exploring the adaptive responses that might be undertaken to allow FEHAs to adapt to a changing climate.

Alberta's climate has been changing rapidly in the recent past with mean annual temperature in the southern part of the province increasing by 0.3°C per decade over the past 30 years. The pace of change is expected to accelerate with temperatures being as much as 2.7°C warmer by the 2050s. The extra energy pumped into the atmosphere by temperature increases will alter precipitation patterns and intensify extremes in temperature, rainfall and wind. All of these factors can be expected to affect the population status of FEHAs.

Contrary to expectations, there is little evidence to suggest average or extreme weather parameters have changed significantly in the Alberta range of the FEHA during the critical spring and summer nesting period. Several published studies and analyses by the authors suggest that prairie summers have not changed in recent decades with respect to mean or extreme temperature, precipitation and wind speed. This appears to be an anomaly relative to other seasons and areas of the Province. However, there is strong consensus over numerous studies that future mean temperature and extreme temperature, rainfall, drought, and wind events will all increase dramatically in the future.

The set of climatic conditions currently experienced by FEHAs in Alberta is likely to expand in northwards. The Grassland Region is expected to expand northwards resulting in a reduction in trees and shrubs and a replacement of mid-grasses by short-grasses. Some aspects of these ecological changes are likely to benefit FEHAs and others to present challenges.

Increases in mean temperature, drought, and extreme precipitation, rainfall and wind events may result in changes in disease incidence, breeding asynchrony, increased nestling mortality from exposure and nest collapse, and changes in prey numbers and hunting success all of which have documented or potential population consequences.

Recommendations for mitigating these threats are hampered by inadequate information suggesting that considerably more monitoring and research is required to focus on better understanding the effects of climate change on Richardson's ground squirrels, availability of FEHA nesting substrates, FEHA migration behaviour, breeding chronology and success, and range expansion. The most immediate concrete action that could be undertaken is to enhance the ability of existing nests to withstand extreme weather events and to provide additional weather-resistant nesting opportunities.

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1 Introduction

The climate on Alberta's grasslands is changing. Shank and Nixon (2014) showed that in the past 100 years, the average annual temperature in southern Alberta increased by 1.1°C, or 0.1°C per decade, with the pace increasing to 0.3°C per decade in the past 30 years. Their projections suggest that mean annual temperatures in southeastern Alberta in the 2050s could exceed 2.7°C warmer than those of the recent past (1971 – 2000) with a corresponding decline in available moisture. The extra energy pumped into the atmosphere by temperature increases will alter precipitation patterns and intensify extremes in temperature, rainfall and wind (Karl et al. 2008).

Wild species can be affected by climate change both as a result of gradual, directional changes in mean weather conditions and as a response to changes in frequency and intensity of severe weather events. Recent studies have suggested that such extreme climatic events increase the frequency of reproductive failure and reduce adult survival resulting in potential population declines in many species (e.g., McKechnie and Wolf 2009, Fisher et al., in press).

The Alberta Ferruginous Hawk Recovery Plan 2009 – 2014 (Alberta Ferruginous Hawk Recovery Team 2009) provides strategies for achieving viable, self-sustaining populations for Ferruginous Hawks (*Buteo regalis*), hereafter referred to as FEHAs, across suitable habitat in Alberta. The Plan identifies climate change as a potential threat factor through its possible effects on nest blow downs, prey numbers and migratory behaviour.

This paper is intended to supplement the provincial Recovery Plan by examining in detail the scope and scale of past and projected changes in climate within the Alberta range of the FEHA, by summarizing current knowledge of the potential effects of climate change on FEHAs, and by exploring the management responses that might be undertaken to allow FEHAs to adapt to a changing climate. Suggested management actions are limited to those related to climate change and do not address broader aspects of species recovery.

Schmutz et al. (2008) concluded that over the period subsequent to 1990, when the FEHAs declined in Alberta, there was no corresponding change in adult or first-year survival. Therefore, major changes in the population were most likely driven by reproductive success, and possibly by variation in immigration/emigration rates. Consequently, this paper will focus only on climate change in Alberta, its possible effects on breeding populations, and management actions appropriate for Alberta.

2 The Ferruginous Hawk

Figure 1. The Ferruginous Hawk. Photo courtesy of Janet Ng.

2.1 Description

The FEHA is Canada's largest buteo and is similar in many ways to the Golden Eagle (*Aguila chyrseatos*) (Bechard and Schmutz 1995). Light phase adults have rufous back and shoulders, nearly white underparts, a white or gray tail and a diagnostic rufous V formed by the dark legs and tarsi held under the rump in flight (Bechard and Schmutz 1995). The less common dark phase adults have brown underparts. FEHAs in all plumages can be identified in flight by having "three points of light"; two at the wingtips and one the underside of the tail (Dunne et al. 1988). From above, the wings in all plumages are grey-brown with white patches, similar to a juvenile Golden Eagle. FEHAs hover frequently and soar with slightly uplifted wings. When gliding with wings drawn back, they "look like a buteo with the bearing of an eagle and the sympathies of a falcon" (Dunne et al. 1988).

3 Distribution

FEHAs breed from the Canadian Prairies south to northern Arizona and New Mexico. They winter from central Mexico north to California, Colorado and western Kansas (Figure 2). A detailed verbal description of the species' range is found in (Bechard and Schmutz 1995).

In Alberta, FEHAs are limited to the southeastern part of the province (Figure 3). Schmutz and Schmutz (1980 in COSEWIC, 2008) estimated that only 48% of the original Canadian range is still occupied, while Schmutz (1984) indicated that the species has disappeared from the northern 40% of its Alberta range. He attributed this to fewer grass fires allowing invasion of trees from the Parkland and to increasing cultivation on the southern fringe of the Parkland.

Figure 2. Global range of the FEHA (from Berchard and Schmutz 1995)

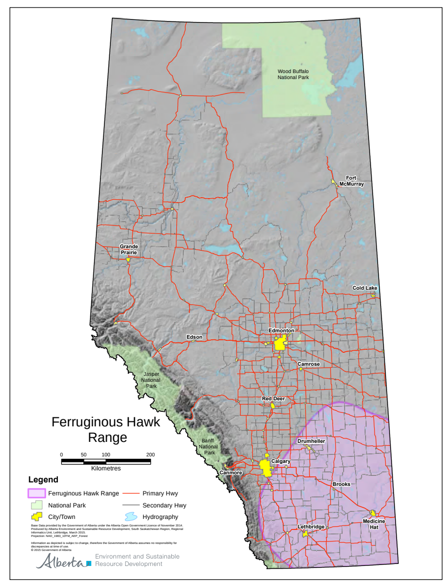

Figure 3. Ferruginous Hawk distribution in Alberta (courtesy of Government of Alberta).

3.1 Habitat

FEHAs are specialized, open-country birds limited to flat and rolling terrain in grassland and shrub-steppe regions (Bechard and Schmutz 1995). In Alberta, the species occupies the Dry Mixedgrass, Mixedgrass, Foothills Fescue and Northern Fescue Natural Subregions of the Grassland Natural Region (Alberta Sustainable Resource Development and Alberta Conservation Association 2006). FEHAs prefer sparse and short vegetation (Schmutz 1987b) and avoid aspen parkland, montane forests and areas of intensive agriculture (COSEWIC 2008). Schmutz (1989) showed a non-linear relationship between nest density and proportion of cultivation. Nesting densities increased from grassland (0-10% cultivation) to moderate cropland (11-30%), and then decreased steadily with increasing levels of cultivation. Zelenak and Rotella (1997) suggested that FEHA nest success may be higher in areas with some (≈ 20%) cultivation. The favoured prey of Ferruginous Hawks in Alberta, the Richardson's ground squirrel (*Urocitellus richardsonii*), also increases in abundance with increasing cultivation up to 30% and declines with greater cultivation (Schmutz 1989).

Nesting is usually on elevated locations such as isolated trees, cliffs, rock outcrops, utility structures, and haystacks (review in Bechard and Schmutz 1995). FEHAs will nest on the ground if no elevated sites are available (Bechard and Schmutz 1995), although ground-nesting behavior is less common in Alberta than elsewhere.

3.2 Diet

FEHAs are highly specialized predators. East of the Rockies they depend upon ground squirrels and prairie dogs while west of the continental divide they utilize mainly lagomorphs (Bechard and Schmutz 1995). In Alberta, (Schmutz et al. 1980) found ground squirrels, almost entirely Richardson's ground squirrels (hereafter RGS), to make up 88.8 – 89.4% of prey biomass, with white-tailed jackrabbit (*Lepus townsendii*) comprising 3.5 - 9.1% and birds and microtines constituting the rest. Schmutz et al. (2008) cited reliance on RGS as 95% of total diet in Alberta and Saskatchewan.

Where ground squirrels are the major prey item, number of nesting FEHAs is influenced by density of ground squirrels (review in Olendorff 1994). In Alberta, Schmutz et al. (2008) documented ground squirrel abundance by weight of unconsumed animals in the nest over 22 years and by counting occupied ground squirrel burrows along a transect over 8 years and concluded that declines in densities of FEHA numbers were explained by low abundance of ground squirrels. Downey et al. (2004) established a robust ground squirrel inventory protocol and found a significant spatial relationship between densities of RGSs and FEHA nests.[1] Schmutz and Hungle (1989) quantified ground squirrel abundance in terms of the amount of poisons sold to ranchers, which indicated a population peak in ground squirrels in 1986 and 1987 coinciding with the highest number of FEHAs in the 5-year surveys (Moltzahn 2011).

3.3 Life History

In Alberta, FEHAs arrive from the wintering grounds in late March or early April (Schmutz et al. 1980 Fig. 5) and begin pair formation. Bayne et al. (2014) cited a mean arrival date of 15 April, although this was estimated by back-dating from hatch date (Janet Ng, pers. comm. December 2014) and is therefore a rough estimate of arrival. Powers (1981) noted the difficulty in establishing arrival date through observation. It is not known whether the onset of breeding activity is dictated by arrival or by environmental cues. Egg-laying occurs in April or early May (Alberta Sustainable Resource Development and Alberta Conservation Association 2006). Schmutz et al. (1980) reported hatch dates ranging from May 18 – June 10 and averaging between May 26 – June 4 in three years (1975-1977). Bayne et al. (2014) reported a similar mean hatch date (May 29) over four years, although they used a different aging technique; Schmutz et al. used length of the 4th primary feather and Bayne et al. used a photographic feather development guide (Moritsch 1985). Young begin to leave the nest at 38 – 50 days (review in Bechard and Schmutz 1995) and generally remain near the nest until August when they begin to disperse and migrate (Alberta Sustainable Resource Development and Alberta Conservation Association 2006). The approximate chronology of reproduction is shown in Figure 4.

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[1] The protocol was used at Lethbridge, Medicine Hat and Brooks from 2003 – 2006 and at Hanna from 2003 -2005, but was discontinued due to a lack of resources. A full survey (33 plots) will be undertaken in 2015 as part of the 5-year Ferruginous Hawk survey (Brad Downey, pers. comm., February 2015).

MAR				APR				MAY			
			Arrival	Arrival/ Pairing	Nest Building	Nest Building	Egg-laying/ Incubation	Egg-laying/ Incubation	Incubation	Incubation	Hatch/ Brooding
JUN				JUL				AUG			
Hatch/ Brooding	Brooding	Brooding	Nestling/ Fledging	Fledging	Semi-Dependence	Semi-Dependence	Semi-Dependence	Dispersal	Dispersal		

Figure 4. Generalized nesting chronology of FEHAs in Alberta.

3.4 Population Trend and Current Status

FEHA inventories have been undertaken at near-regular intervals in Alberta since 1982 (Schmutz 1982; Schmutz 1987a; Schmutz 1993). The estimated number of pairs increased from 1082 (653 – 1511)[2] in 1982 to peak numbers of 1791 (1307 – 2275) in 1987 and 1702(1181 – 2223) in 1992 and then declined precipitously to 731 (364 – 1097) in 2000 and remained low and unchanged in 2005 and 2010 at 618 (456–780) and 618 (453-783)[3] pairs respectively (Moltzahn 2011) (Figure 5).

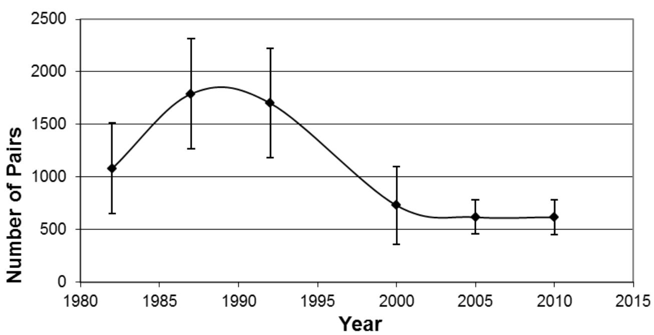


Figure 5. Estimated number of Alberta FEHA pairs and confidence limits for the stratified mean of all sample units (Moltzahn 2011 Figure 2).

Regular population surveys have not been undertaken in Saskatchewan and Manitoba, but indications are that populations in these provinces have declined as well (COSEWIC 2008). Although there may be methodological difficulties, the Christmas Bird Count suggests an increasing trend while the Breeding Bird Survey suggests a stable or increasing population throughout the species range (summary in COSEWIC 2008). The Raptor Population Index (RPI) project trend maps (Crewe et al. 2013) show six hawk watches in the US with no significant trend in fall migration numbers and 2 sites with significant declines.

The Alberta Ferruginous Hawk Recovery Team (2009) listed a variety of factors potentially causing population decline and range contraction in Alberta including loss of suitable grassland habitat, reduced prey availability, loss of suitable nest sites, human disturbance, human-caused mortality, mortality on the wintering range, and climate change. As noted earlier, stable survival rates in adult and first year FEHAs before and after the post-1990 decline (Schmutz et al. 2008)

[2] Range reflects the 95% confidence limits for the stratified population total.

[3] The 2010 figure originally cited in Moltzahn (2011) has been updated (Brandy Downy, pers. comm., February 2015).

suggest population size is likely mediated through reproductive success rather than post-fledging and adult survival.

The IUCN Red List previously considered FEHAs as *Near Threatened*, but they were downlisted to *Least Concern* in 2008 (BirdLife International 2012). The Committee of Endangered Wildlife in Canada (COSEWIC) listed FEHAs as *Threatened* in 1980. The species was downlisted to *Special Concern* in 1995 and again listed as *Threatened* in 2008 based on criterion a2b (population reduction of ≥30% over the last 10 years or 3 generations). NatureServe lists the FEHA as G4 (global population "Apparently Secure") while the Alberta Conservation Information Management System (ACIMS) lists it as S2S3 (provincial population "Imperiled/Vulnerable"). The General Status of Alberta Wild Species 2010 lists the FEHA as *At Risk*. FEHAs are considered as *Endangered* under the Alberta Wildlife Act.

A FEHA national recovery strategy for Canada was developed in 1994 (Schmutz et al. 1994) and a new national recovery plan is currently under development.

4 Climate Trends in the Alberta Range of FEHAs

4.1 Historical Trend in Climate

An assessment of the effects of climate change on FEHAs first entails understanding past weather patterns and determining their potential effects on FEHA populations.

4.1.1 Recent Temperature Means and Extremes

Environment Canada weather data indicates that since 1970, there has been a statistically significant warming trend on the prairies for annual temperature (p = 0.027), but not for spring (p = 0.998) or summer temperature (p = 0.627). The temperature variation between years in spring is much greater than for summer (Figure 6).

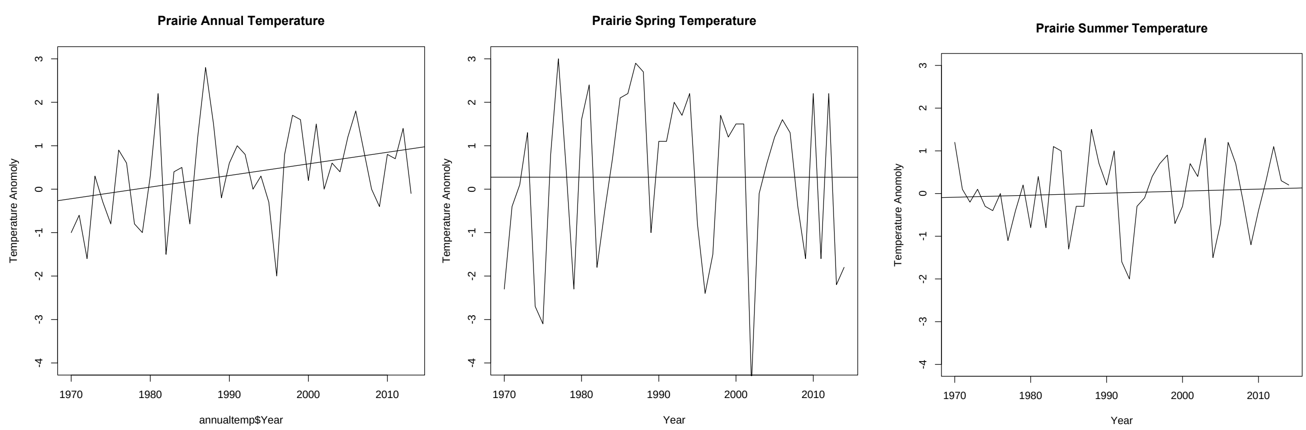


Figure 6. Annual, spring and summer temperatures anomalies for the Prairies, 1970 - 2013-14. Data from Science and Technology Branch, Environment Canada.

There are conflicting conclusions in the literature as to whether temperature maximums have increased recently in the Alberta range of FEHAs during the breeding season. Across North America the number of days exceeding the 90th percentile of maximum temperature has increased since 1960 (Peterson et al. 2008, Figure 2). Cutforth (2000) found a slight (0.0174°C per year) but statistically significant increase in the average maximum temperature during May-June-July-August from 1950 to 1998 in a 15,000 km^2 area near Saskatoon. Zhang et al. (2000) showed an approximate 0.5°C increase in summer daily maximum temperature on the Prairies in the period 1900 – 1998, but the trend is not statistically significant. Bonsal et al. (2001) found that the number of very hot days in summer did not change from 1900 – 1998 in southern Canada.

For the nestling period (15 May – 30 June) of 2007 – 2014, daily maximum temperature data were retrieved from the *Current and Historical Alberta Weather Station Data Viewer*[4] for seven stations distributed throughout the Alberta range of FEHAs. These stations were chosen on the basis of their distribution throughout the Alberta FEHA range and their having complete data sets.

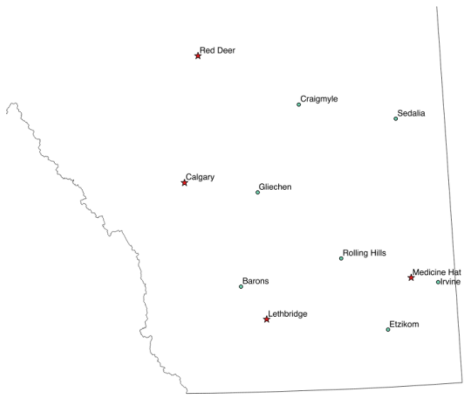


Figure 7. Location of seven weather stations from which extreme weather values were collected from the *Current and Historical Alberta Weather Station Data Viewer.*

Maximum daily temperature has declined at seven stations in Figure 7 for the nestling period from 2007-2014. The warmest year was 2008 where the highest temperature recorded was 35.4°C at Irvine. The number of days above 30°C has declined during that period (Figure 8).

In summary, there appears to be little evidence that spring or summer temperatures on the prairies have changed significantly in the recent past.

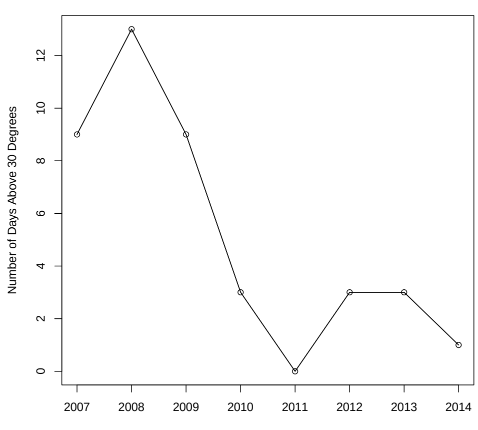


Figure 8. Sum of number of days above 30 °C at seven sites in southeastern Alberta for the period 15 May – 30 from June 2007 - 2014. Data for Gleichen in 2007 is missing.

[4] http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp

4.1.2 Recent Precipitation Means and Extremes

Environment Canada weather records show that since 1970, there has been no significant change in annual ($p = 0.195$) or spring ($p = 0.405$) precipitation on the prairies and that summer precipitation shows a slight, but non-significant increase ($p = 0.083$) (Figure 9).

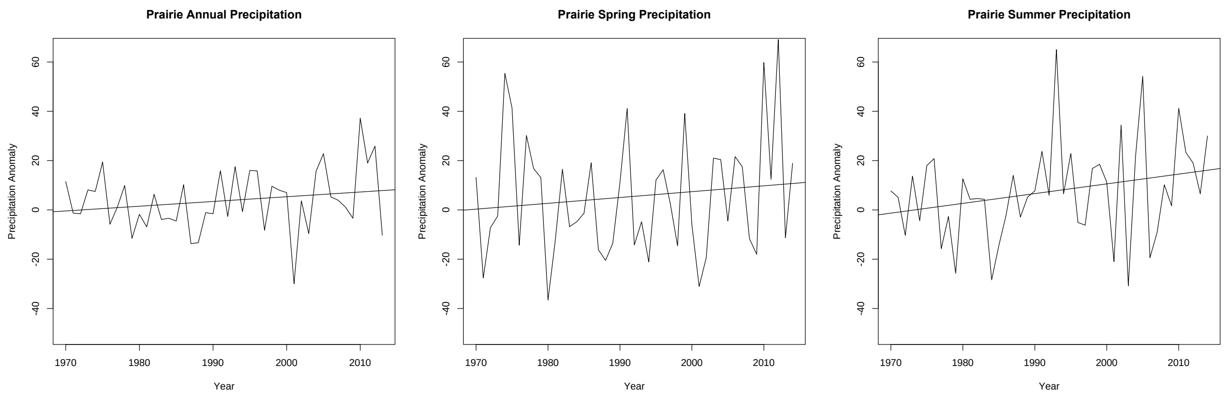


Figure 9. Annual, spring and summer precipitation anomalies for the prairies, 1970 to 2013 -14 . Data provided on request by the Science and Technology Branch, Environment Canada.

Karl et al. (2008) stated that one of the clearest trends in the US weather record has been an increase in frequency and intensity of heavy precipitation events, a conclusion also reached by many other climate researchers (e.g. Groisman et al. 2005; Janssen et al. 2014). However, the literature for Canada as a whole does not support this conclusion.

Vincent and Mekis (2006) and Zhang et al. (2001) conclude that there has been no historical trend in the frequency or intensity of extreme precipitation for Canada. Mekis and Hogg (1999) state that although there has been an increase in Canada in the fraction of annual precipitation falling in heavy events, this is mainly due to the increase in the Canadian North. Francis and Hengeveld (1998) conclude that extreme precipitation events in southern Canada have declined over the course of the 20th century.

Data on the annual occurrence of extreme precipitation on the prairies is contradictory. Janssen et al. (2014) concluded that the Northern Great Plains region of the US, which abuts FEHA range in Alberta, has shown no discernable trend in annual extreme precipitation events over the past century and is the only region in the US not to do so. Mekis and Hogg (1999, Table 3) show a decline in annual precipitation falling in heavy (>90th percentile) in the prairies from 1940 -1995. Akinremi et al. (1999) reported a non-significant decline in rainfall events of >25 mm across the Canadian prairies. Vincent and Mekis (2006, Fig. 5) showed insignificant increasing annual trends in very wet days (≥95th percentile) and a few areas with a significant decline in very wet days (≥10mm) in the FEHA range from 1950 – 2003. In contrast, Groisman et al. (2013) showed a 21% increase in the heaviest 1% of daily events for the Great Plains from 1958 – 2010/2011, which is statistically significant at the 0.1 level.

A few studies break the annual data down into seasons for the prairie region. Extremes appear to be less pronounced in summer than in other seasons. Groisman et al. (2013, Fig. 5.1.15) showed a 16% increase in the precipitation falling as very heavy precipitation (heaviest 1%) during the summer months (June-July-August) from 1958-2010/2011 for the US Great Plains region, but the change is not statistically significant. Stone et al. (2000, Fig. 2) show two southern Alberta stations with minimal change in annual extreme events for June-July-August from 1950 – 1990.

Their Figure 10, showing a significant trend for southwestern Canada for May-June-July and a near significant one for April-May-June, includes the BC coastal region which exhibits very different trends than the Prairies and is therefore not relevant. Zhang et al. (2001) concluded that the change in the proportion of summer rains falling as heavy events on the Alberta prairies during the period 1950 – 1998 was not significant.

For the representative station of Sedalia (Figure 7), there is no trend (p = 0.654) in the maximum daily precipitation during the period of May 15 – June 30 over the years 1987 – 2013.

The general conclusion is that neither mean nor extreme precipitation on the prairies has changed much in the recent past during the FEHA breeding season.

However, very significant extreme precipitation events do occur during FEHA breeding season. Table 1 shows the ten largest one-day and 3-day precipitation events during the core FEHA nestling period (15 May and 30 June) for 2007 – 2014 for seven locations in the Alberta FEHA range. Data were retrieved from the *Current and Historical Alberta Weather Station Data Viewer*. The largest single day event was 84.5 mm at Rolling Hills on 29 May 2010. The largest 3-day event was 95.9 mm at Irvine on 18 June 2010.

Table 1. Dates and amount of precipitation for the ten largest one-day and three-day storms over the period 2007 - 2014. Sites are those depicted in Figure 7.

Etzikom				Irvine				Rolling Hills			
1-day		3-day		1-day		3-day		1-day		3-day	
19-Jun-13	22.4	21-Jun-12	42.4	30-Jun-14	18.6	22-May-10	39.9	24-May-13	19.4	28-Jun-12	39.8
10-Jun-12	22.5	19-Jun-14	47.7	13-Jun-14	19.7	06-Jun-09	41.8	22-May-08	20.6	27-Jun-12	39.9
18-Jun-12	22.5	17-Jun-10	48.8	18-Jun-12	22.4	23-May-10	43.8	19-Jun-11	20.7	26-Jun-12	40.1
18-Jun-10	23.7	27-May-10	54.8	05-Jun-09	23.2	24-May-10	43.8	07-Jun-11	22.7	04-Jun-11	40.9
28-May-07	28.8	19-Jun-10	58.7	10-Jun-12	23.3	07-Jun-09	45.1	17-Jun-14	23.1	17-Jun-10	54.3
27-May-12	31.7	20-Jun-12	64.9	17-Jun-10	24.7	20-Jun-12	50.3	11-Jun-08	23.6	19-Jun-10	58.9
17-Jun-10	34.9	19-Jun-12	65.5	27-May-12	26.2	19-Jun-12	54.6	02-Jun-11	30.3	27-May-10	67.2
17-Jun-14	38.5	28-May-10	65.8	19-Jun-12	27.8	20-Jun-10	60.0	26-Jun-12	38.8	18-Jun-10	68.1
19-Jun-12	42.1	18-Jun-10	67.3	22-May-10	39.7	19-Jun-10	84.7	17-Jun-10	41.8	28-May-10	68.8
27-May-10	54.8	29-May-10	77.0	18-Jun-10	59.5	18-Jun-10	95.9	27-May-10	67.2	29-May-10	84.5

Barons				Craigmyle				Gliechen* 1970 data missing				Sedalia			
1-day		3-day		1-day		3-day		1-day		3-day		1-day		3-day	
24-May-08	21	23-May-08	48.2	18-Jun-14	21	18-Jun-07	41.8	30-May-13	15.8	26-Jun-12	38.6	02-Jun-11	19.1	20-Jun-13	34.8
26-May-11	21	20-Jun-14	48.9	29-May-10	21.6	22-Jun-13	43.3	21-May-08	16.3	26-May-13	39.2	29-Jun-14	19.8	22-Jun-13	36.3
06-Jun-07	22	20-Jun-13	50.8	18-Jun-11	24.7	21-May-08	45.0	17-Jun-10	22.5	24-May-13	40.6	22-May-12	20.0	21-Jun-13	38.1
22-May-08	26	17-Jun-14	51.8	10-Jun-10	25.5	21-Jun-13	47.0	18-Jun-14	23.4	28-May-10	43.5	06-Jun-07	20.0	10-Jun-10	38.9
19-Jun-13	27	24-May-08	54.6	17-Jun-07	26.6	09-Jun-10	50.3	26-Jun-12	24.7	22-May-08	44.29	22-May-10	20.1	18-Jun-10	47.0
23-May-13	28	27-May-10	59.2	29-Jun-07	27.3	15-Jun-12	52.4	27-Jun-12	24.7	23-May-08	46.4	09-Jun-10	20.7	17-Jun-10	47.9
17-Jun-10	31	28-May-10	61.6	21-Jun-13	28.4	22-May-08	56.2	22-May-08	26.8	25-May-13	46.7	17-Jun-07	23.5	19-Jun-10	49.4
17-Jun-14	40	29-May-10	75.4	15-Jun-12	30.2	23-May-08	56.5	16-Jun-09	27.6	28-Jun-12	49.4	20-Jun-13	30.1	29-Jun-12	75.1
18-Jun-14	42	18-Jun-14	85.4	09-Jun-10	42.3	11-Jun-10	67.8	24-May-13	32.5	27-Jun-12	49.6	17-Jun-10	40.3	28-Jun-12	87.5
27-May-10	59	19-Jun-14	88.4	21-May-08	44.8	10-Jun-10	74.6	27-May-10	37.0	29-May-10	56.4	27-Jun-12	73.5	27-Jun-12	92.3

4.1.3 Recent Drought Trend

Because available moisture is a function of both precipitation and evapotranspiration, drought can increase with increasing temperature even if precipitation is unchanged or increasing. The Mixedgrass Ecoregion (roughly equivalent to the Dry Mixedgrass Subregion in the Natural Subregions of Alberta) is the core range of FEHA and is the most drought-prone of the five prairie ecoregions (Sauchyn and Kulshreshtha 2008). Close examination of Figure 7 in Dai et al. (2004) indicates that central Alberta underwent a large increase in drought in the period 1950 – 2002, but that southeastern Alberta has seen a lesser increase in the frequency of drought. Bruce

(2012) interpreted this figure as a "significant increase" in drought frequency for southern Alberta.

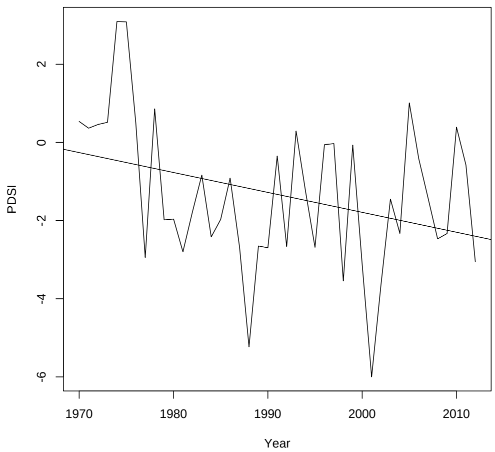


Figure 10. Yearly mean Palmer Drought Severity Index (PDSI) data for Hanna, Alberta from 1970 – 2012. Negative values indicate drought conditions.

The Palmer Drought Severity Index[5] for Hanna, Alberta (Figure 10) shows a statistically significant trend toward more drought conditions for the period 1970 – 2012 ($p = 0.028$). The severe droughts of 1988 and 2001 show clearly on the figure. However, the trend is largely driven by very moist conditions in the early 1970s. Removal of the years 1970 – 1975 removes any suggestion of a trend in drought conditions during the past 35 years ($p = 0.977$).

4.1.4 Recent Snowmelt Trend

Snowmelt data were collected for the townships encompassing Sedalia and Barons in the northeastern and southwestern parts of the Alberta FEHA range (Figure 7). Estimated snow water equivalent on the ground was downloaded from the *Current and Historical Alberta Weather Station Viewer* for the years 1987 – 2012. Date of first day without snow was defined as the first day between 1 January and 30 June in which the snow water equivalent on the ground was nil. Date of last snowmelt is intended to capture the occurrence of late spring snowstorms and was arbitrarily defined as the first day with no snow on the ground following the last snowfall of >2 mm water equivalent.

Median date of first melt is much earlier at Barons (01 March) than at Sedalia (24 March), but median date of last melt is later at Barons (16 April) than Sedalia (07 April) (Figure 11).

There is no statistically significant trend in dates of first or last melts at either Sedalia or Barons (Table 2). Date of snowmelt has not changed since 1987. Spring temperature is related to date of both first and last snowmelt at Barons while spring precipitation is associated with date of last melt at Sedalia (Table 2).

[5] http://www.cgd.ucar.edu/cas/catalog/climind/pdsi.html

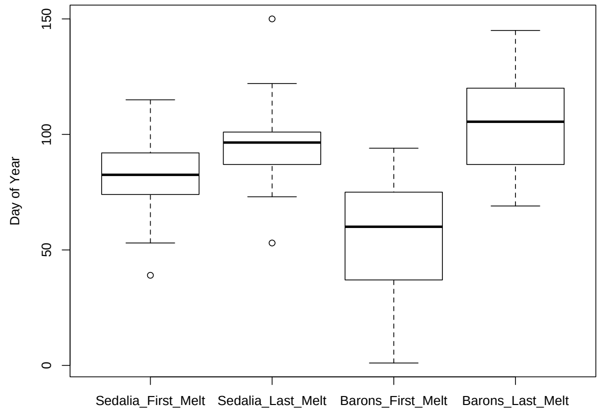


Figure 11. Boxplot of ordinal day for first and last snowmelts for the years 1987 – 2012 at Sedalia and Barons (locations shown in Figure 7).

Table 2. Significance level for factors potentially influencing dates of first and last snowmelt at Sedalia and Barons (Figure 7). The asterisk indicates statistical significance at p-levels <0.05 for linear regression.

	Sedalia		Barons	
	First Melt	Last Melt	First Melt	Last Melt
Year	0.952	0.351	0.372	0.085
Spring Temperature	0.926	0.723	0.031*	0.003*
Spring Precipitation	0.282	0.003*	0.843	0.348

There is no statistically significant correlation between dates of first (p = 0.118) or last snowmelt (p = 0.217) between Sedalia and Barons. The conclusion is that patterns of snowmelt within the Alberta range of FEHAs are quite variable between years and locations and the relationship of snowmelt to spring weather is not consistent between locations.

Lane et al. (2012) showed that date of last snowmelt has been significantly delayed in recent years in the Alberta foothills despite no change in mean spring temperature. Late spring snowstorms result in Columbian ground squirrels (*Urocitellus columbianus*) emerging later from hibernation with resulting losses in fitness. By contrast, Inouye et al. (2000) report that springs have become warmer in Colorado, but date of snowmelt has not changed, and yellow-belled marmots (*Marmota flaviventris*) are emerging earlier. We know of no data linking date of first snowmelt or spring snowstorms to RGS emergence. The spatial variability in melt suggests that establishing a relationship between snowmelt and RGS emergence will require that snow measurements be made in the same location as the RGS observations.

4.1.5 Recent Wind Means and Extremes

Mean wind speeds during summer in southeastern Alberta are 4 – 7 m/sec (ca. 14 – 25 kph), much lower than in the Alberta mountains and foothills (Figure 12). Examination of the Canadian Wind Energy Atlas maps indicates that average wind speeds in summer tend to be less than in other seasons. The highest mean summer wind speeds (ca. 23 – 25 kph) tend to be in the area just to south and southeast of Hanna, the core range of FEHA in Alberta.

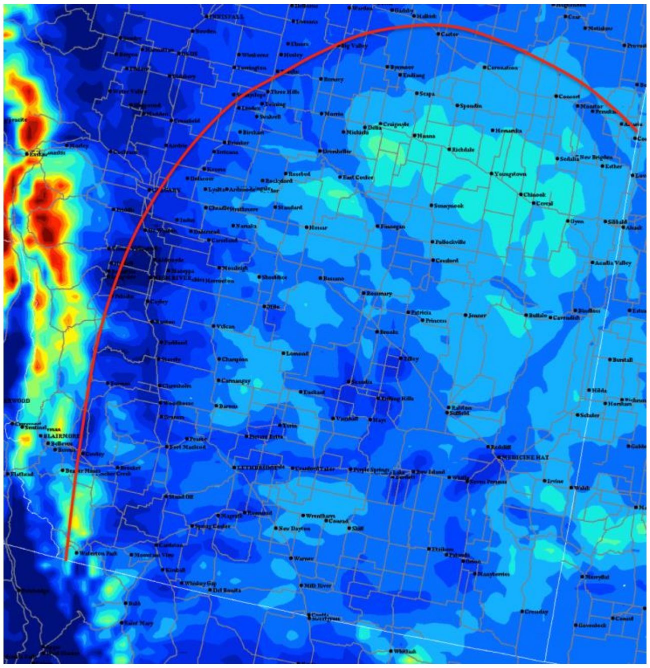
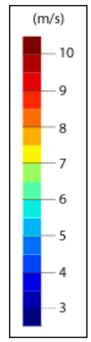


Figure 12. Average summer (June-July-August) wind speed (m/s) at 30 m above ground level from Canada Wind Energy Atlas (http://www.windatlas.ca/en/maps.php). The red line indicates approximate limits of FEHA recent observations.



The few data addressing the issue do not indicate that average wind speeds have increased in the FEHA breeding area in the recent past. Flannigan and Wang (2012, Fig. 12) reported no trend in average wind speed in Alberta "boreal prairies" (i.e., the boreal portion of prairie Canada) during summer from 1979-2010. For the Swift Current area in Saskatchewan, Cutforth (2000) concluded that mean wind speeds in May-June-July-August decreased from 1970 to 1997-1998.

Flesch and Wilson (1993) provided data on extreme wind speed intensity during summer for Lethbridge and Medicine Hat based on 29 – 34 years of data ending in 1988 (Table 3). The maximum wind gust recorded for Lethbridge was 171 kph and 148 kph for Medicine Hat Flesch and Wilson (1993, Fig. 3).

Table 3. Return intervals for 4 wind speeds for three locations in southern Alberta during summer (from Flesch and Wilson (1993). Measurements at 30 m above ground level.

	Return Interval (years)			
	70 kph	90 kph	110 kph	>130 kph
Lethbridge	1.0	1.0	2.3	12.5
Medicine Hat	1.0	1.4	4.3	17.8
Calgary	1.0	1.3	8.5	96.0

Table 4 is a tabular interpretation of the wind roses provided by Flesch and Wilson (1993) for extreme wind gusts. Most extreme winds come from westerly or northerly directions.

Table 4. Directional frequencies for annual summer extreme wind gusts (Flesch and Wilson 1993).

	Daily frequency of annual extreme wind gusts (%)							
	N	NE	E	SE	S	SW	W	NW
Lethbridge	0	0	0	0	0	9	91	0
Medicine Hat	31	0	8	5	0	15	30	11

Calgary	40	0	0	5	0	0	43	12

Cheng et al. (2014) provide historical wind speed data (30-40 years) for Lethbridge and for an area extending through the Prairies from Calgary to Kenora. Lethbridge experiences considerably more extreme wind than the broader prairie region.

Table 5. Number of days experiencing high wind speeds at Lethbridge and in the broader W5 Region. Data from (Cheng et al. 2014).

	Number of Days with Extreme Wind			
	≥28 kph	≥40 kph	≥70 kph	≥90 kph
Lethbridge	244	200	6	18
Region W5	244	171	19	3

Table 6 presents maximum wind gusts at 2 m height for the ten windiest days at seven stations (Figure 7) during the nestling period of 25 May – 30 June for the 5-year period 2009 – 2014. The maximum wind gusts recorded were at Etzikom (83.1 kph) and Sedalia (82.1). The mean maximum daily wind gusts for all 282 days sampled varied from 33.2 kph at Craigmyle to 37.2 at Sedalia.

Table 6. The ten most extreme wind events recorded (2 m above ground level) at 7 locations (Figure 7) in southern Alberta between 2009 and 2014.

Etzikom		Rolling Hills		Irvine		Barons		Gliechen		Craigmyle		Sedalia	
22-May-13	62.8	25-Jun-09	58.9	31-May-09	60.3	25-Jun-10	56.3	19-May-09	56.5	22-May-13	55.4	25-Jun-09	61.0
03-Jun-10	63.6	19-Jun-13	60.3	22-May-13	60.5	19-May-09	56.9	20-Jun-13	57.4	25-Jun-11	56.0	15-Jun-12	62.2
07-Jun-13	66.3	15-May-11	60.5	25-Jun-09	60.5	26-May-14	57.6	05-Jun-14	57.7	15-May-11	56.1	17-May-09	62.5
30-Jun-10	67.4	16-May-11	60.5	03-Jun-10	62.4	17-Jun-10	61.3	06-Jun-12	57.8	23-May-13	56.7	05-Jun-10	62.7
15-May-11	69.2	05-Jun-14	60.8	19-Jun-13	63.7	25-Jun-09	61.7	10-Jun-12	58.1	05-Jun-12	59.8	05-Jun-12	65.1
20-May-10	69.2	03-Jun-10	63.2	18-Jun-10	65.1	20-May-10	62.9	17-Jun-12	59.1	05-Jun-13	60.5	22-May-12	65.7
19-Jun-13	70.0	19-May-09	63.7	20-May-10	65.4	20-Jun-13	65.1	04-Jun-14	61.7	30-Jun-10	60.7	15-May-11	66.5
19-May-09	76.1	05-Jun-12	66.0	27-Jun-12	66.4	24-May-09	65.4	16-Jun-09	65.5	16-May-12	63.4	18-Jun-13	66.6
23-May-13	77.3	21-May-10	66.0	15-May-11	67.7	03-Jun-10	70.3	26-May-14	68.9	04-Jun-14	64.1	16-May-12	68.4
05-Jun-12	83.1	20-May-10	69.4	19-May-09	68.2	06-Jun-12	77.4	05-Jun-12	75.4	25-Jun-09	78.5	27-Jun-12	82.1

In summary, the prairies are normally very windy with frequent severe wind events. However, there is no indication that average wind speed or extreme wind events have increased, but there remains significant spatial variation in wind speeds throughout the FEHA range in Alberta.

4.1.6 Spatial Extent of Storms

Very heavy rainfalls are associated with strong convection such as thunderstorms and tend to occur at small scales (Zhang et al. 2001). Because they have a small radius, they often occur between recording stations, which adds to the uncertainty of regional trend estimates (Karl et al. 2008). Extreme weather events causing nestling death have larger population consequences when storms cover a large geographical area. For these reasons, it is important to get some idea of the spatial extent of storms during the FEHA breeding season.

Figure 13 shows the percentage of 1-day and 3-day extreme precipitation events and 1-day extreme wind events between 15 May and 30 June that occurred at more than one of the 7 stations depicted in Figure 7.

A total of 49% and 47% of the 10 largest one-day and three days precipitation events respectively occurred at more than one site. The most widespread single-day extreme precipitation events were on 17 June 2010 (6 of 7 sites) and 27 May 2010 (4 of 7 sites). The broadest 3-days precipitation events ended on 28 and 29 May 2010 and 18 and 19 June 2010.

In total, 49% of the most extreme wind events from 2009 – 2014 occurred at more than one location. The most widespread (5 of 7 stations) extreme wind events occurred on 19 May 2009, 25 June 2009, 15 May 2011 and 05 June 2012.

Because the seven sites from which data were recorded are widely distributed throughout FEHA range (Figure 7), it can be concluded that at least half of extreme rain and wind events are regional in scale and not simply localized squalls.

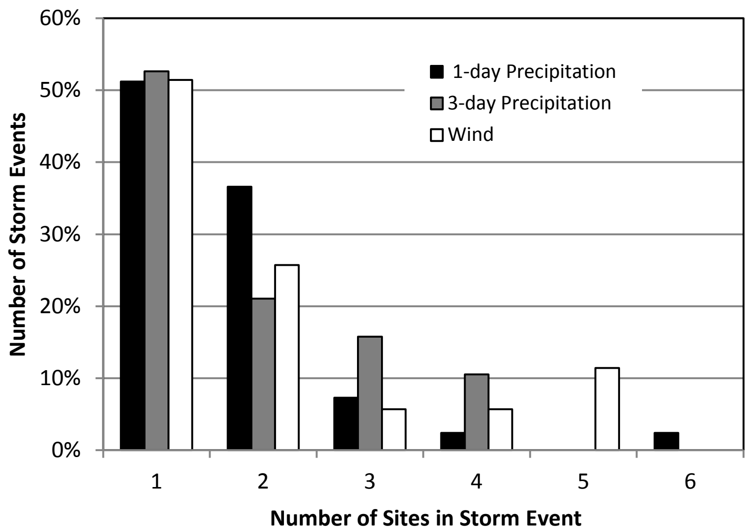


Figure 13. Percentage of the ten most extreme one-day and three-day precipitation and one-day wind events occurring at one or more sites of the seven sites shown in Figure 7.

4.1.7 Combination of Extreme Wind and Rain

Of the ten most extreme wind events at each of the seven stations (Figure 7) during the period 15 May – 30 June from 2009 – 2014, 39 (55%) were accompanied by rainfall. In five cases (7%), the most extreme wind and rain events for each site occurred at the same time (Table 7). These events represent the most extreme weather conditions experienced within the FEHA range during the nestling period. Each of these five extreme wind/rain events occurred in the latter half of the nestling period. The event of 27 June, 2012 resulted in recorded FEHA nestling deaths (Section 3.2.3).

Table 7. Incidences of the ten most extreme wind and rain events coinciding at a single site. Site locations shown in Figure 7. Data from http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp.

Site	Date	Wind (kph)	Rain (mm)
Etzikom	19-Jun-13	70	22.4
Gliechen	16-Jun-09	65.48	27.6
Barons	17-Jun-10	61.25	30.5
Irvine	18-Jun-10	65.13	59.5
Sedalia	27-Jun-12	82.1	73.5

Summary of Recent Weather Trends in Alberta FEHA Range

- Mean annual temperature has increased, but there has been no change in mean spring or summer temperature.
- Maximum daily temperatures have declined recently during the FEHA nestling period.
- There has been no change in annual, spring or summer precipitation on the Prairies.
- Literature review indicates no trend in extreme precipitation or wind.
- Drought conditions have not changed since 1975.
- At least half of extreme wind and precipitation events are regional in scale.
- Dates of first and last snowmelt have not changed for 2 locations in FEHA range.
- In general, there is little indication of recent change in mean or extreme weather conditions on the Alberta prairie during the FEHA breeding season. Consequently, there is no evidence that climate change has caused the observed decline in Alberta's FEHA population.

4.2 Future Changes in Climate

4.2.1 Predicted Changes in Mean and Extreme Temperature

Mean annual temperature is expected to rise dramatically within the Alberta range of FEHAs. Figure 14 shows that the mean annual temperature in southeastern Alberta varied from 3°C to 6°C in the recent past while in the median model it is expected to increase to 6°C to >9°C by the 2080s . The IPCC (2012) concluded that it is *likely*[6] there will be an overall increase in the number of warm days in North America. Weisheimer and Palmer (2005) showed that by the end of century in North America, temperature extremes that currently occur every 20 years could occur every three years. We have been unable to find projections for the recurrence of extreme high summer temperatures for the Alberta range of the FEHA.

4.2.2 Predicted Changes in Mean and Extreme Precipitation

Mean annual precipitation is not expected to change dramatically within the Alberta range of FEHAs. Figure 15 shows that the mean annual precipitation in southeastern Alberta varied from about 250 – 450 mm in the recent past and is expected to remain approximately the same in the 2080s.

Current understanding of climate processes suggests that a warmer climate will lead to a greater incidence of very heavy rainfalls events (Francis and Hengeveld 1998). A warmer atmosphere

[6] The IPCC differentiates between metrics of confidence, expressed qualitatively, and uncertainty, measured quantitatively. Accepted terminology for confidence is *very low, , medium, high, and very high.* Qualifiers of uncertainty are *virtually certain*, 99–100% probability; *extremely likely*, 95–100%; *very likely*, 90–100%; *likely*, 66–100%; *more likely than not*, >50–100%; *about as likely as not*, 33–66%; *unlikely*, 0–33%; *very unlikely*, 0–10%; *extremely unlikely*, 0–5%; and *exceptionally unlikely*, 0–1%.

will hold more water resulting in a more dynamic hydrological cycle and more extreme events (Stone et al. 2000), although not necessarily more average annual precipitation (Karl et al. 2008).

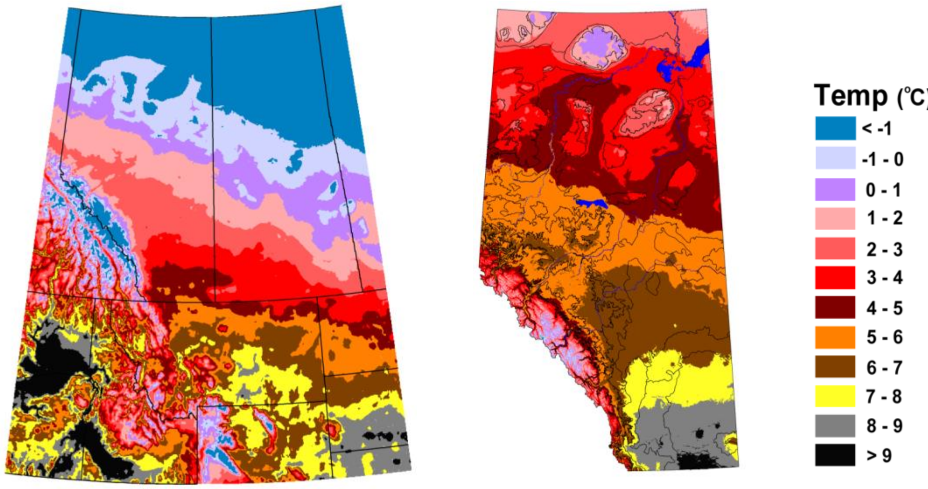


Figure 14. Mean annual temperature in 1961 - 1990 (left) and in the 2080s (right) for the median model (from Schneider 2013).

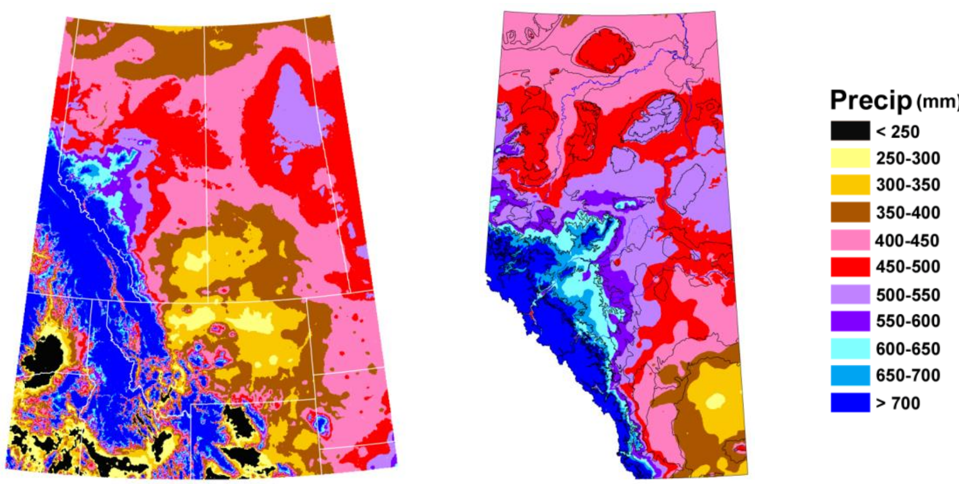


Figure 15. Mean annual precipitation in 1961 - 1990 (left) and in the 2080s (right) for the median model (from Schneider 2013).

In contrast to the historical data, the literature is unanimous in predicting that extreme precipitation events will increase in the future and will increase more than average precipitation (Kharin and Zwiers 2000; Kharin and Zwiers 2005). For North America, the amount of precipitation falling as light events is projected to decline slightly by 2090s, while under a high emissions scenario, there could be a >40% increase in amount of rain falling in the highest 5% of events (Karl et al. 2009, p. 32).

For North America, the current 20-year return interval for extreme rainfall is predicted to decline to 12 – 15 years by mid-century and to 6 -8 years at end of century (Kharin et al. 2007). Sillmann et al. (2013) projected median precipitation in "very wet days" (>95th percentile) to increase by ca. 20 – 30% in 2046 – 2065 for Western North American (WNA) as a whole. Karl et al. (2008) predicted that 20-year extremes in precipitation are likely to occur approximately every 10-14 years in the Alberta FEHA range. Kharin et al. (2013) suggested that the prairies will see extreme events that happened only every 20 years during the period 1986 - 2005 will do so every 10 – 15 years both in the 2046 – 2065 and 2081 – 2100 periods.

4.2.3 Predicted Changes in Drought

Figure 16 indicates that the CMI in the Alberta FEHA range will decline from the -10 to -35 range of the recent past to values of -25 to -60 under the Median climate model. Severe droughts are projected to be twice as frequent on the Prairies (Sauchyn and Kulshreshtha 2008) by 2050.

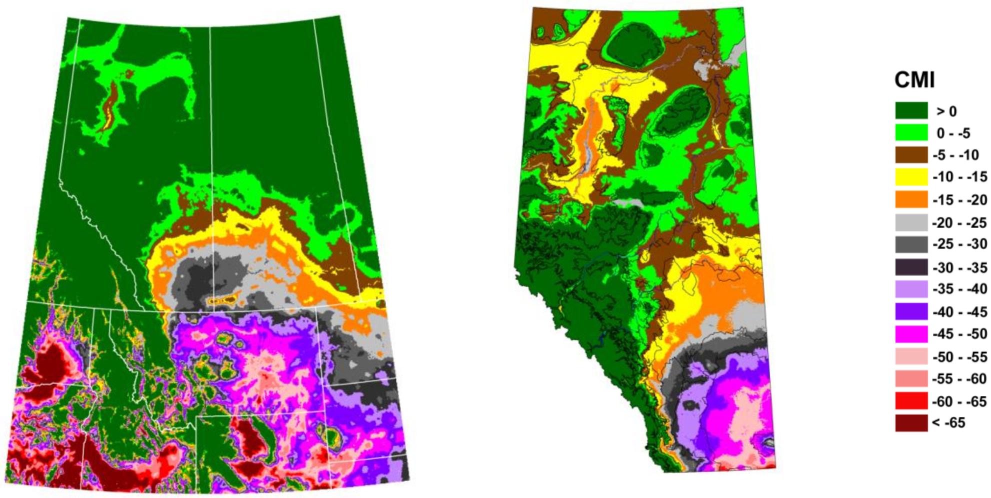


Figure 16. Climate Moisture Index (CMI) for 1961 – 1990 and in 2080s for the Median model (from Schneider 2013).

4.2.4 Predicted Changes in Mean and Extreme Wind

Cheng et al. (2014, Table 1) reviewed the literature on projected wind regimes at the global scale. It appears that there is little consensus regarding future trends in mean and extreme wind speeds throughout the world.

Flannigan and Wang's (2012) projections show no significant change in median wind speed for Alberta prairies during the fire seasons of 2020, 2050 and 2080 relative to 1970 – 2010, but a clearly increasing incidence of extreme wind events.

Cheng et al. (2014, Fig. 6) predicted that the number days at Lethbridge with wind gusts ≥90 kph is expected to increase by ca. 15 - 20% in the period 2046 – 2065. ending on the emission scenario. tle more extreme wind than the prairie region. t f the world will show increases and decreases For the period of 2081 – 2100, the increases are expected to be ca. 25 - 40%. .

Summary of Projected Changes in Mean and Extreme Weather

- Mean annual temperature on the Prairies is expected to increase about 3°C by the 2080s under a moderate scenario.
- Increases in extreme temperatures are expected to increase, but no precise information is available.
- Mean annual precipitation is not expected to change significantly.
- A greater proportion of precipitation is expected to fall as extreme events, which may as much as double in frequency.
- Available moisture will decline and frequency of severe droughts will double by the 2050s.
- It is not clear whether average wind speeds will change in future, but extreme wind events will become more common.

5 Potential Effects of Climate Change on FEHAs

Over the millennia, FEHAs have adapted to the harsh weather of the Alberta prairies. As the climate changes, FEHAs will face conditions that are expected to be much more extreme in intensity and frequency. Predicting how FEHAs will respond to these future extremes is uncertain, but it is possible to explore the broad implications of a changing climate on FEHAs in Alberta.

5.1 Landscape Scale Ecological Changes

FEHAs are currently most abundant in the Dry Mixedgrass Subregion with some occurrence in the Mixedgrass, Foothills Fescue and Northern Fescue Subregions. Historically, the range extended north into the Central Parkland Subregion.

Schneider (2013) examined the expected trajectories of change in Alberta landscapes under varying conditions of a changing climate. Under a "cool" scenario, he predicted that the core range of the FEHA, the Dry Mixedgrass Subregion, is likely to shift north into what is now the Northern Fescue Subregion. Under the "hot scenario" the Grassland Region is likely to replace the Parkland while the current Grassland Region will be largely replaced by plant communities currently found in Wyoming and southern Idaho. Thorpe (2011) concluded that Canadian grasslands are likely to see reduced trees and shrubs, replacement of midgrasses by shortgrasses, an increased proportion of warm-season (C4) grasses relative to cool-season (C3) species. It is difficult to predict the effects of such broad ecological changes on FEHAs in Alberta. Some factors are likely to benefit FEHAs and others may present challenges.

Expansion of grassland area, reduction in shrubs and increased presence of shortgrasses could all be favourable to an increase in FEHA populations within their current range. Increased aridity in southern Alberta may result in reversion of cropland to pasture which should benefit FEHAs. However, trees currently providing nesting substrates are likely to decline in number reducing existing nesting opportunities.

Movement of the grassland northwards and towards the boreal should expand the suitable range of FEHAs in Alberta. However, the historical contraction in the northern limit of FEHA range casts some doubt on whether FEHA will be able to respond to this opportunity. If newly created FEHA habitat is converted to cropland or if fire suppression allows incursion of dense forest, then FEHA may find little new habitat or nesting opportunities. Ecological relationships between

FEHAs and other raptors (Swainson's Hawks, Red-tailed Hawks, Great-horned Owls) may limit FEHA range extension (Schmutz et al. 1980).

Ecosystem changes will likely result in altered prey availability. Drier habitat, shorter grasses, and less cultivation may all favour expansion and increase in RGS populations (Section 3.2.4.) and benefit other potential alternative prey species such as the thirteen-lined ground squirrel *(Ictidomys tridecemlineatus*).

5.2 Threats and Benefits Posed by Extreme Weather

A warming climate is expected to result in greater extremes in the magnitude and frequency of extremely hot days, drought, heavy rainfalls and powerful wind gusts. The potential threats to FEHAs of these extreme events are drought affecting prey species, nestling exposure to heat or cold stress, nest collapse or blowout, and reduction in prey delivery to nestlings.

5.2.1 Disease

Warming temperatures may allow for the introduction of exotic diseases or induce outbreaks of already existing wildlife diseases. However, little is known about disease in FEHAs (Collins and Reynolds 2005). Nemeth et al. (2006) confirmed that FEHAs found dead in the wild have tested positive for West Nile virus, but they suggest that, at least under laboratory conditions, the disease is generally subclinical in raptors. West Nile virus is expected to expand with climate change (Harrigan et al. 2014), but there is little evidence that the disease is currently a major conservation concern for wild raptors.

5.2.2 Asynchrony Between Breeding and Prey Availability

FEHA breeding success depends upon sufficient RGS prey availability during the critical nestling period. Availability is, in turn, dependent upon both RGS population size and date of emergence from hibernation. Schmutz et al. (1980, Fig. 5) showed that peak emergence of RGSs coincided exactly with the FEHA nestling period in 1975 and 1976. Any climate induced changes in the timing of FEHA arrival on the breeding grounds, initiation of breeding or emergence of juvenile ground squirrel could result in an asynchrony negatively affecting FEHA production.

Shearer (2014) concluded that earlier initiation of FEHA breeding resulted in larger clutch sizes and more young fledged. However, the rate of prey delivery did not have an effect on breeding success. So, it appears that greater success of earlier nesting pairs cannot be easily attributable to greater prey availability and better food provisioning of the nestlings. This provides little support for concerns about future predator/prey asynchrony.

Satellite telemetry of 9 adult males in 2013 and 2014 suggests that FEHAs are flexible in their spring migration. Dates for leaving the winter range varied from 08 March - 30 March and the number of days on migration varied from 6 – 25. One bird briefly reversed its northward progress when it encountered a spring storm in Nebraska and required 20 days to complete its migration. In 2014, three of the seven birds arrived 10 April or later and all failed to breed while the four birds arriving before that date were successful (Jesse Watson, pers. comm., February 2015). More research is needed on weather effects on migration initiation, migration speed, and arrival date and their effects on breeding success.

Date of hatch in Alberta has not changed in the nearly 40 years between data presented by Schmutz et al. (1980) and that reported by Bayne et al. (2014), although these conclusions were based on different nestling aging techniques (Section 1.5). Despite there being no temporal trend in either spring temperature (Section 2.1.1) or hatch date, there has been no attempt to correlate hatch date and spring conditions for individual years. As noted in Section 2.1.1, spring temperatures vary widely between years.

Gail Michener (pers. comm., December 2014) monitored dates of RGS adult emergence from hibernation and juvenile emergence near Lethbridge between 1987 and 2012. She found that date of emergence from hibernation is strongly influenced by early spring temperatures, with a delay of 1.5 days for each 1.5°C decline in air temperature (pers. comm., December 2014) . The very large between-year differences in spring temperature (Figure 6) can result in differences in RGS emergence dates by as much as 21 days (Michener 1977). However, she found no trend in date of emergence over her 26-year study period (pers. comm., December 2014) which is consistent with lack of an observed trend in spring temperature (Section 2.1.1).

Asynchrony between the phenologies of RGS emergence and FEHA breeding is a potentially significant source of future threat to FEHAs, but major uncertainties remain. We still do not sufficiently understand the effect of climate on FEHA migration initiation, migration speed or arrival dates. The relationship between date of arrival on the breeding grounds and initiation of breeding is uncertain. The effect of a future increases in temperature on RGS emergence and populations size is not known, nor is the ability of FEHAs to adjust their breeding phenology to match that of RGSs.

5.2.3 Exposure

Heavy, prolonged rainfall has been documented as a catastrophic source of nestling mortality in many species (e.g., Fisher et. al., in press, Anctil et al. 2014). Parents are unable to provide continuous brooding and even short periods of exposure are sometimes enough to result in death under wet and windy conditions. Laux et al. (2014) found that nest attendance by FEHA adults increased with both rainfall and wind.

There are no data documenting the extent of storm-related hypothermia in FEHAs. However, Blair (1978) found 2 broods (of 17 nesting attempts) in South Dakota that apparently died of exposure after 10 days of severe thunderstorms and high winds in mid-June 1977. Further evidence comes from video nest surveillance in Alberta before and after an extreme storm event. Cameron Nordell (pers. comm. November 2014) documented that all the young in a nest were alive at 03:10 on 27 June, 2012 when the video camera stopped recording. When video data again became available 22 hr later (00:59, 27 June), the nestlings, estimated to be 28 days old (Cameron Nordell, pers. comm., March 2015), were all dead. This was the most extreme rain/wind event (at Sedalia rainfall = 73.5 mm , wind = 82.1 kph) recorded on the prairies in the period 2007 – 2014 (Table 7). This indicates the scale of wind and rain events that can result in fatal hypothermia in FEHA nestlings that are near fledging.

Given their distribution throughout the warm, arid plains of western North America, FEHAs are well-adapted to hot climates. Powers (1981) found mid-day body temperatures of FEHA nestlings to vary from 38.5 – 43.5°C suggesting high physiological tolerance to hyperthermia. Nevertheless, he observed nestlings to show various behavioural indications of stress including shade-seeking which began as early as 5 days post-hatch. Tomback and Murphy (1981) found that FEHA nestlings in Utah had higher and more varied body temperatures when they were underfed. They suggest that the heat stress during periods of malnourishment may explain some cases of nestling mortality. Steenhof et al. (1993) cited instances of thermal stress causing nestling death in southwest Idaho, but no cases were observed during the study itself. Blair (1978) found no nestling deaths from heat prostration in South Dakota and concluded that direct exposure to the sun is not detrimental to FEHAs and may be beneficial by providing additional warmth in the early spring. Nestling shade-seeking behavior has also been observed in Alberta

(Janet Ng, pers. comm., November 2014). Although there is no strong evidence that FEHA nestling mortality occurs from hyperthermia in Alberta, the significance of shade to nest success remains uncertain and should be further investigated.

Blair (1978) noted that FEHAs in South Dakota often locate nests with exposures into the prevailing wind. This is opposite to what would be expected if the intent is to protect nestlings from the wind. Blair (1978) speculated exposure to the wind allows adults and young just learning to fly to become airborne more easily. Extreme wind gusts on the Alberta prairies tend to come from the north and west (Table 4). Steenhof et al. (1993) suggested that wind may offer nestlings protection from heat. Wind is probably only a factor in FEHA nest success when combined with cold rain or when it destroys nests.

Both extreme storm events and extreme heat events are predicted to become more common in Alberta in the coming decades and nestling mortality can be expected to increase. In all cases, extended periods of cold, heat, rain and/or wind are more likely to result in nestling mortality, rather than short-duration, extreme events.

Nestlings are better able to thermoregulate as they get older and are presumably less susceptible to storm death. Of the ten largest single-day storms between 2007 and 2014 at the locations in Figure 7, 67% (47/70) occurred after 15 June while 73% (51/70) of the largest 3-day storms did so. All of the most extreme combined rain/wind events occurred after 15 June (Table 7). This suggests, very provisionally, that most extreme rainstorms occur during the later nestling period when young are better able to withstand exposure to the elements.

5.2.4 Prey Numbers

Several studies have concluded that FEHAS nest density and/or breeding success is related to RGS abundance (Section 1.4). Any factor influencing RGS numbers can be expected to have a profound effect on FEHA populations. Management of RGS populations is likely to be the key to FEHA protection and recovery.

Ecological changes to the grasslands may benefit RGSs. RGSs prefer shorter grasses which will likely become more dominant. As irrigated farming becomes less feasible because of increasing aridity, some croplands are likely to revert to pasture which should favour RGSs (Downey et al. 2006). And, the range of RGSs may expand with the northward expansion of the grassland ecosystem.

Droughts are common on the Alberta prairies and FEHAs are presumably well adapted to them. In fact, drought may benefit FEHAs by increasing RGS numbers. Some authors (Isern 1988; Proulx 2010) assert that RGSs are more abundant in drought years as a result of their preference for short grass (Downey et al. 2006; Proulx 2010). Proulx and MacKenzie (2009) showed that RGS presence dropped significantly when vegetation reached a minimum height of 15 cm. Using playback calls, Downey et al. (2006) found RGSs to be located more in areas with grass height <30 cm. In Montana, grazing by cattle reduced grass height and increase the number of ground squirrel burrows in upland habitat (Bylo et al. 2014).

Detailed analysis failed to detect any statistically significant relationships between the Palmer Drought Severity Index (Figure 10) and either ground squirrel numbers or the various measures of FEHA breeding success cited in Schmutz et al. (2008) and Houston and Zazelenchuk (2005). However, the data are sparse and there are clearly multiple factors at play. For example, Proulx (2012) found the major rainfall event on 20 – 27 May 2010 (Table 1) killed approximately 30% of a RGS population in southwestern Saskatchewan.

As Schmutz (Alberta Ferruginous Hawk Recovery Team 2009) points out, ground squirrels use the least energy from fat reserves during hibernation when the burrow temperature is near zero. However, they cannot lower their temperatures below that of the burrow suggesting that energy reserves might be depleted in warm winters leading to increased mortality and reduced population size. There are no data supporting this hypothesis (Gail Michener, pers. comm., November 2014), but it should be further investigated.

A major impediment to better understanding what drives RGS population size is the lack of consistent, high-quality and spatially extensive surveys such as were briefly implemented by the Alberta Conservation Association (Downey et al. 2006). The summaries of RGS numbers provided by Schmutz et al. (2008), and in related publications, provides tantalizing glimpse of RGS population trends, but more detailed information is needed.

5.2.5 Hunting Success

Bad weather may limit reduce the ability of FEHAs to hunt or may reduce the availability of prey. Laux et al. (2014, Fig. 2) found that prey delivery rates to FEHA nestlings declined with increasing rainfall. Deliveries stopped entirely at rainfall events of ≥3mm/hr. Long-lasting rainstorms may therefore threaten nestling survival. Goos (2014) concluded that the home range of male FEHAs increases with increasing daily rainfall. She speculated that this might result from ground squirrels retreating underground in bad weather (Michener and Koeppl 1985) leading to reduced prey deliveries and the need to expend more energy in searching widely.

5.2.6 Nest Integrity

Several papers point to the threat posed by nest collapse in FEHAs (e.g. De Smet and Conrad 1992; Schmutz and Hungle 1989) and other species (Reese 1970; Martínez et al. 2013). Laux et al. (2014) found that rate of nest material delivery increased before storms and with decreasing barometric pressure suggesting that FEHAs may be able to predict coming storms and shore up the nest in anticipation of potential damage.

Schmutz et al. (2008) recorded 11 of 881 (1.2%) completed nests as collapsing in study areas near Hanna, Alberta and Kindersley-Alsask, Saskatchewan. Schmutz has recently updated these values to 2.4% of 1101 nests collapsing (Ryan Fisher, pers. comm., January 2015).

Recent data suggest that nest collapse may be an even more significant source of population limitation. Bayne et al. (2014) report on a study undertaken from 2010 – 2013 in which 1017 nesting attempts were made at 687 sites. Nest failures were seen in 360 cases (35%). Of these, 81 (23%) of nests were damaged by wind and/or rain. Only about 15% of damaged nests (ca. 12) were seen to fledge young. Consequently, weather-related nest damage accounted for about 69 nest failures or ca. 19% of all nest failures and about 7% of nesting attempts. This is similar to the 6% (63/1104) of Swainson's Hawk nests that blew down near Hanna between 1975 and 1996 (Schmutz et al. 2001). Examination of Bayne et al.'s Figure 23 indicates that approximately 9% of tree nests (n = 804) and only about 3% of nests on artificial platforms (n = 213) were destroyed by weather. These data suggest that weather-related nest failures currently depress population recruitment by somewhere in the range of 7%.

Steenhof et al. (1993) and Schmutz et al. (1984) found that FEHAs prefer artificial structures (transmission towers, utility poles, artificial platforms) over cliffs, shrubs and trees. Nest success is significantly higher on artificial structures than on natural substrates (Schmutz et al. 1984; Steenhof et al. 1993).

Janet Ng (pers. comm., December 2014) determined that 31% of 170 tree nests were in cottonwoods (*Populus deltoides*), 24% in trembling aspen (*Populus tremuloides*), 15% in Manitoba maple (*Acer negundo*), with 31% making up other or unknown species. She found nest collapse in only 6% of nests in cottonwoods and 8% of nests in Manitoba maple whereas 13% of nests in trembling aspens blew out. The sample sizes for other tree species were small, but suggest that nests in willows are especially susceptible to collapse with 8 of 14 (22%) falling down. Brandy Downie (pers. comm. March 2015) reports nest collapse in a willow for two consecutive years in an area with few suitable nesting locations. Installation of an ANP resulted in successful nesting thereafter.

Ng (pers. comm., December 2014) also recorded the relative location in the tree that nests were built. Of 156 nests, 51% were built near the trunk, 28% on an extending branch, and 15% at the apex of the tree. Nests on a branch or near the trunk were quite secure from collapse (2% and 6% respectively), but 25% of those located on tree-tops were blown down.

Ng (pers. comm., December 2014) found that nest collapse is significantly more likely in smaller trees and those with more dead wood. The mean diameter at breast height (DBH) of trees showing nest collapse was 25.11 cm (SD= 6.59) while it was 38.36 cm (SD = 19.69) for trees with intact nests. The proportion of the tree determined to be dead was 0.35 (SD= 0.37) for trees in which the nest collapsed and 0.20 (SD = 0.24) in trees with intact nests.

Although there are no data on tree species availability, Ng's data suggest that cottonwoods are preferred for nesting and, together with Manitoba maple, provide the most secure nesting opportunities, particularly when the trees are large and healthy. The data also suggest that nests in cottonwoods and Manitoba maples are more likely to blow-out than those in artificial nest platforms (6-8% vs 3% respectively).

5.3 Species Distribution Modelling

Species distribution modeling correlates current range with a suite of conditions currently experienced by the species and predicts where these conditions will exist in the future. Sohl (2014) undertook species distribution modeling of FEHAs in the US incorporating not only climatic conditions but also land use and land cover parameters. This analysis suggests that the species range will have shrunk in the US by more than 20% in 2075 relative to 2001. The projected decline is largely a result of the study being truncated at the Canadian border and distribution being lost mostly in the southern part of the US range. The paper concludes that predicted distributions based on future climate alone estimate unrealistically large range changes. Models that incorporate predicted future land use and land cover tend to show smaller distribution changes because land use is more heterogeneous at local scales than is climate.

Summary of Threats and Benefits to FEHAs Posed by Climate Change

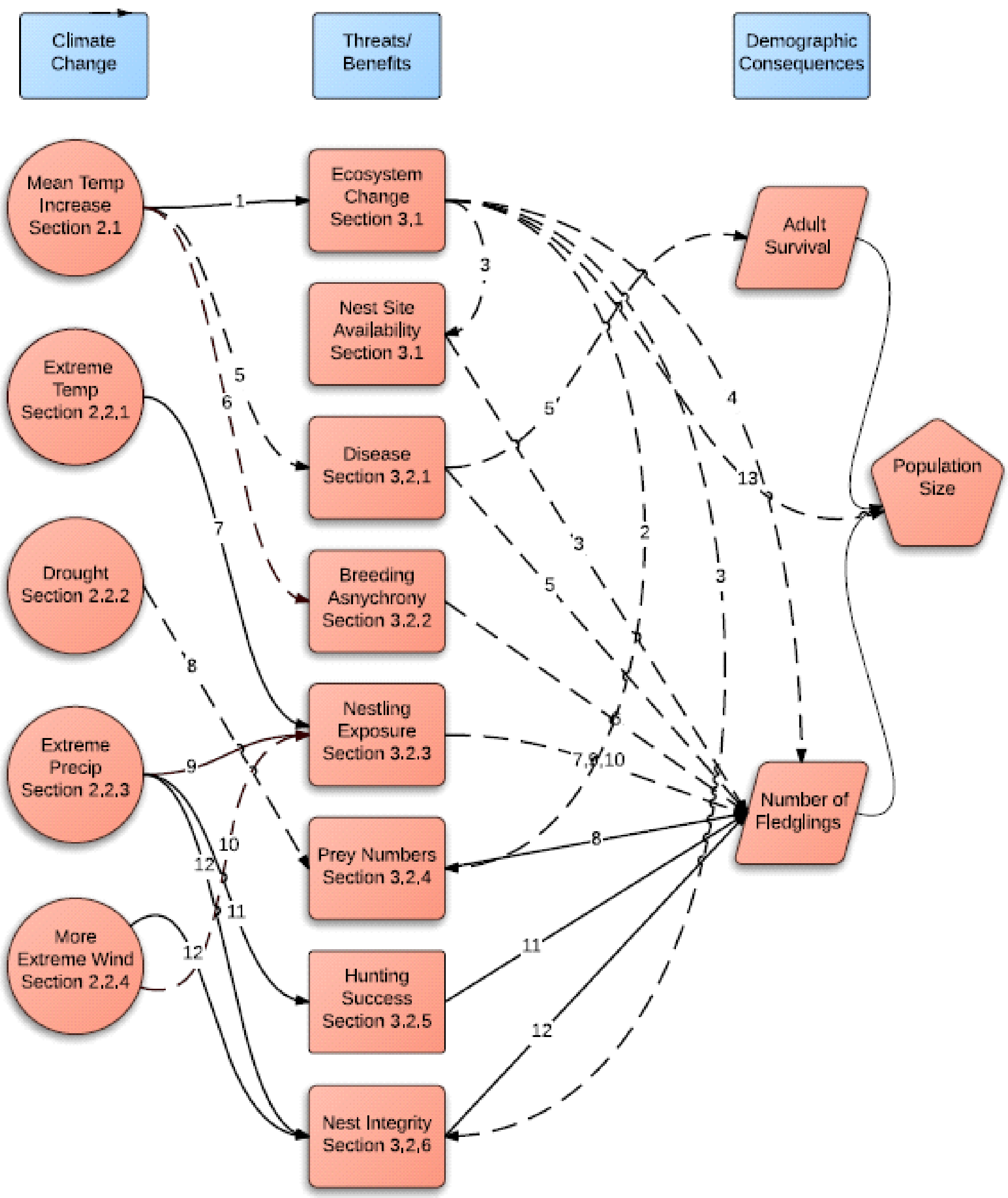
- The nature and extent of grasslands will change with warming temperatures. This may both threaten and benefit FEHAs in largely unpredictable manners.
- Increased temperatures may increase incidence of disease. However, there is little to suggest that this is a significant threat.
- RGSs emerge earlier in warmer springs. The nesting chronology of FEHAs appears to be tuned to RGS emergence and it is not known if there is sufficient temporal plasticity in FEHAs to respond.
- Nestlings in Alberta seek shade indicating heat stress, but there is little evidence that it is a significant source of nestling mortality.
- Exposure to wind and rain has been observed to be a source of nestling mortality, although there is no evidence that it is a significant source of nestling mortality.
- Drought conditions may increase RGS populations and therefore FEHA reproductive success. However, detailed analysis found no significant linkage between drought and ground squirrel numbers or measures of FEHA breeding success.
- Heavy rain events reduce rates of prey delivery, but it is unknown whether this influences nestling mortality.
- Approximately 9% of tree nests and 3% of nests on ANPs are lost to nest collapse as result of wind and/or heavy precipitation. Cottonwoods and Manitoba maples provide the most secure natural nesting substrate and willows the least.

6 Management Actions

6.1 Conceptual Model Linking Climate Change to FEHA Populations

The components of climate change, the threats and benefits these incur on FEHAs and the demographic consequences are summarized in a conceptual model (Figure 17) as recommended by Cross et al. (2012).

Figure 17. Conceptual diagram depicting causal linkages between climate change and FEHA population size. The dashed lines indicate uncertain linkages.



Summarized below are the linkages between climate change, threats/benefits and demographic consequences along with the recommended adaptive actions for each. More detail can be found in the referenced document sections. The certainty rankings represent the opinion of the authors.

Table 8. Summary of the conceptual diagram in Figure 19 indicating, for each linkage, the potential effects of climate change on FEHAs, the section of the report in which the effect is discussed, the degree of certainty regarding the linkage, and proposed management actions.

Linkage	Description	Section	Assessment	Certainty	Management Actions
1	Mean Temperature Increase -> Ecosystem Change	3.1	Increasing temperature will change the ecological structure of the grassland and expand it	High	None
2	Ecosystem Change -> Change in Prey Numbers	3.1 and 3.2.4	Shift to shortgrass prairie and expansion of the grassland may benefit RGSs	Medium	1. Regular population monitoring of RGS population size. 2. Explore influences of climate on RGS, population size, especially effects of drought, on habitat and spring conditions on overwinter mortality.
3	Ecosystem Change -> Nest Integrity and Availability	3.1	Changes in number and species of trees may affect nest integrity and availability	Low	1. Monitor nest tree availability on current and potential FEHA range.
4	Ecosystem Change -> Number of Fledglings	3.1	Changes in numbers of suitable nest trees could directly affect number of nests	Low	1.Continue with 5-year population survey. 2. Systematically search for new sites within current range and at the northern edge of range. 3. Enhance natural nesting opportunities by planting, tending and protecting nest trees.
5	Mean Temperature Increase -> Disease -> Nestling and Adult Mortality	3.2.1	Increasing temperature may increase incidence of disease and mortality.	Low	1. Screen dead or rehabbed FEHAs for disease.
6	Mean Temperature Increase -> Breeding Asynchrony -> Number of Fledglings	3.2.2	Increasing spring temperatures are likely to result in earlier emergence of RGSs. However, it is not known if FEHAs can respond by altering the timing of breeding	Effect of temperature on ground squirrel emergence and numbers—Medium; Ability of FEHA to change breeding chronology—Low.	1. Monitor timing of RGS emergence from hibernation. 2. Monitor FEHA hatch date 3. Investigate relationships between FEHA migration and breeding phenology, spring weather and RGS emergence.
7	Extreme Temperature -> Nestling Exposure ->Number of Fledglings	3.2.3	High temperatures stress nestlings, but it is not known if this causes mortality	High temperature stress—High; Effect on nest success-- Low	1.Determine if providing protection from sun affects nest success.
8	Drought -> Prey Numbers -> Number of Fledglings	3.2.4	Increased drought may increase number of RGSs which could increase nest success.	Effect of drought—Low; Effect of prey numbers on nest success—High	1. Regular population monitoring of RGS population size. 2. Explore influences of drought on RGS population size. 3. Monitor FEHA nest success and productivity.
9	Extreme Precipitation -> Nestling Exposure ->Number of Fledglings	3.2.3	Extreme rainfall definitely causes nestling mortality through exposure, but the population consequences are not clear	Rainfall stress on nestlings—High; Effect on nest success-- Low	1..Determine if providing protection from rain affects nest success.
10	Extreme Wind -> Nestling Exposure -> Number of Fledglings	3.2.3	Extreme wind can cause nestling mortality through exposure, particularly in concert with heavy rainfall. But, the population consequences are not clear.	Wind stress on nestlings—Low; Effect on nest success-- Low	1. Determine if providing protection from wind affects nest success.
11	Extreme Precipitation -> Hunting Success -> Number of Fledglings	3.3.5	Prey delivery declines during heavy rain events, but the consequences to nestling survival are not known.	Effect of rain on prey delivery—High; Effect on nest success-- Low	1. Investigate effects of supplementary feeding on nestling survival.
12	Extreme Precipitation and Wind -> Nest Integrity -> Number of Fledglings	3.2.6.	Nest collapse caused by wind and heavy rain is a significant source of nestling FEHA mortality in Alberta.	Effect of wind and rain on nest collapse—High; Effect on nest success-- High	1. Monitor rates of nest collapse. 2. Secure existing nests from blow down. 4. Provide artificial nest platform following design in Magaj (2011). 5. Enhance natural nesting opportunities in tree species providingteh the most security from severe weather.
13	Ecosystem Change -> Population Size	3.1	Expansion of the grassland may increase the range size of FEHAs	Low	1. Systematically search for new sites within current range and at the northern edge of range. 2. Undertake Species distribution modeling to better understand the extent of future suitable range.

6.2 Summary of Management Actions

The following management actions are summarized and consolidated from Table 8. Effective recovery of FEHAs will require a range of interventions. However, only those measures with a clear link to weather and climate change are included here.

Because so little is known about the potential effects of climate change on FEHAs, a majority of the proposed actions entail research and monitoring designed to fill the information gaps. The only practical, on-the-ground, immediate management actions specifically designed to curb the effects of weather on FEHAs are to provide more protection from nest blow down through securing existing nests and providing ANPs following established protocols.

Higher Priority activities are shown in red text, Medium Priority actions in blue and Lower Priority approaches in green. Priority ranking represents the opinion of the authors.

Richardson's Ground Squirrels

1. Regular population monitoring of RGS population size using a robust technique such as that described by Downey et al. (2006).
    a. Linkages 2, 8
    b. Higher Priority
2. Explore influences of climate on RGS population size, especially effects of drought, on habitat and spring conditions on overwinter mortality.
    a. Linkages 2, 8
    b. Medium Priority
3. Monitor timing of RGS emergence from hibernation.
    a. Linkage 6
    b. Medium Priority

Breeding Asynchrony

1. Investigate relationships between FEHA migration and breeding phenology, spring weather and RGS emergence.
    a. Linkage 6
    b. Medium Priority

Artificial Nest Platforms (ANPs)

1. Provide ANPs at strategic locations.
    a. Linkages 7, 9, 10
    b. Higher Priority
2. Investigate methods for construction modifications to designs provided by Migaj et al. (2011) to provide shelter from wind, sun and rain.
    a. Linkage 9, 10
    b. Lower Priority
3. Develop methods to increase nest integrity of ANPs and continue regular upkeep and maintenance on existing ANPs.
    a. Linkage 12
    b. Lower Priority

Natural Nests

1. Secure existing nests from blow down.
    a. Linkage 12
    b. Higher Priority
2. Enhance natural nesting opportunities by planting, tending and protecting nest trees. Cottonwoods and Manitoba maples provide the most secure nesting opportunities. Trees species and locations should be ecologically suitable.
    a. Linkage 12
    b. Medium Priority
3. Monitor nest tree availability on current and potential FEHA range.
    a. Linkage 3
    b. Lower Priority

Exposure to Extreme Weather

1. Determine if providing protection from wind, sun and rain affects nest success.
    a. Linkage 7, 9, 10
    b. Medium Priority
2. Monitor rates of nest collapse.
    a. Linkage 12
    b. Medium Priority

FEHA Population Productivity, Size, and Distribution

1. Continue with 5-year population survey.
    a. Linkage 4
    b. Higher Priority
2. Monitor FEHA hatch date.
    a. Linkage 4
    b. Higher Priority
3. Monitor FEHA nest success and productivity.
    a. Linkages 7, 8, 9, 10
    b. Higher Priority
4. Systematically search for new sites within current range and at the northern edge of range.
    a. Linkages 4, 13
    b. Medium Priority
5. Investigate effects of supplementary feeding on nestling survival.
    a. Linkage 11
    b. Lower Priority
6. Undertake species distribution modelling to better understand the extent of future suitable range.
    a. Linkage 13
    b. Lower Priority

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