Forest Fire Management Adaptation to Climate Change in the Prairie Provinces

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Executive Summary

The effects of future fire regimes altered by climate change, and fire management in adaptation to climate change were studied in the boreal forest region of the Prairie provinces. Four National Parks were used as study areas. Present (1975-90) and future (2080-2100) fire regimes were simulated in Wood Buffalo National Park, Elk Island National Park, Prince Albert National Park and Riding Mountain National Park using data from the Canadian (CGCM1) and Hadley (HadCM3) Global Climate Models (GCM) in separate simulation scenarios. The long-term effects of the different fire regimes on forests were simulated using a stand-level, boreal fire effects model (BORFIRE) developed for this study. Changes in forest composition and biomass storage due to future altered fire regimes were determined by comparing current and future simulation results. This was used to assess the ecological impact of altered fire regimes on boreal forests, and the future role of these forests as carbon sinks or sources. Additional future simulations were run using adapted fire management strategies to meet the management goals for each National Park. This included increased fire suppression and the use of prescribed fire to meet fire cycle objectives. Future forest composition and biomass storage under current and adapted fire management strategies were also compared to determine the impact of various future fire management options.

Both of the GCM's showed more severe burning conditions under future fire regimes. This includes fires with higher intensity, greater depth of burn, greater total fuel consumption and shorter fire cycles (or higher rates of annual area burned). The Canadian GCM indicated burning conditions more severe than the Hadley GCM. The Canadian GCM results also appeared more reliable when fire weather output was compared to current and historical data.

In the model simulations, the shorter fire cycles of future fire regimes generally favoured aspen and birch because of their post-fire resprouting ability, and jack pine because of its serotinous cones which release stored seed after fire. Shorter fire cycles provided more frequent regeneration opportunity for these species. Because black spruce is an annual seeder and has semi-serotinous cones, regeneration was only minimally influenced by future changes in the fire cycle. However, white spruce stands declined sharply due to shorter

fire cycles, and the spring and summer fire regime of the study areas. This was because white spruce doesn't store seed and seed ripening doesn't occur until late summer or early fall, so there is no opportunity to regenerate when trees are killed by early season fire. For all of the study area Parks, maintaining representation of pure and mixed white spruce ecosystems will be a concern under future fire regimes. The model simulations also showed that a management goal of fire exclusion would effectively lead to the removal of jack pine from the study areas, and cause a sharp decline in aspen and birch stands.

There was a general increase in total biomass storage under the simulated future fire regimes. This was caused by two factors. Shorter fire cycles resulted in a younger age-class distribution so there were less slow-growing, low density old stands, and more fast-growing, high density young stands. The second factor was an increase in aspen, which is faster growing than the other species. Aspen regeneration was favoured by short fire cycles, and aspen seedlings out-competed jack pine and white birch. As well, when white spruce failed to regenerate, mixed stands converted to pure aspen stands. A secondary effect of greater aspen live tree biomass was an increase in forest floor biomass because of increased detrital input. Biomass storage was very low in the fire exclusion simulations.

In Wood Buffalo National Park, simulations of increased future fire suppression assisted in maintaining white spruce ecosystems and older age classes of all species, but it had a minimal impact on representation of other forested ecosystems. Increased fire suppression also increased the long-term total biomass storage in the Park by 83M tonnes.

The simulations showed prescribed burning to be an important component of future fire management in Elk Island National Park, Prince Albert National Park and Riding Mountain National Park. Without prescribed fire, the fire cycle in all three Parks would be too long to maintain current stands of aspen, jack pine and white birch. A range of fire regimes appears necessary to manage different areas in each National Park. Aspen in open or closed stands can be promoted by burning after vernal leaf flush, or its removal can be facilitated by burning prior to leaf flush with short to moderate fire cycles or 25-75 years. The use of short fire cycles may be required to maintain grasslands and shrublands and prevent the encroachment of aspen.

White spruce stands require fires of low intensity, or late season fires and longer fire cycles (100+ years). In Prince Albert National Park and Riding Mountain National Park , the use of prescribed fire on 75-year and 100-year fire cycles to maintain current forest ecosystems resulted in a total biomass storage increase of 10-17M tonnes and 8-12M tonnes, respectively.

Future needs in fire and climate change research includes development of landscape models that simulate physical and ecological fire effects, and analysis of future fire management strategies in the commercial forest zone.

Table of Contents

List of Tables

List of Figures

List of Figures (continued)

Introduction

As a result of climate change in the Canadian boreal forest region, future fire regimes are expected to support a general increase in fire intensity, fire severity (depth of burn) and fire season length (Flannigan and Van Wagner 1991, Wotton and Flannigan 1993, Stocks et al. 1998, Flannigan et al. 2001). From a physical standpoint, that kind of change in the fire regime will have a strong effect on the forest disturbance rate (annual area burned) as well as the amount of carbon released to the atmosphere during fires. Because most of the carbon released by fire is in the form of CO_2 and other greenhouse gases (Radke et al. 1991), it is possible that an increase in forest fire activity due to climate-induced change in fire regime may provide a positive feedback that enhances the rate of climate change (Flannigan et al. 1998). Historically, the Canadian forest was estimated to be a net carbon sink until the 1980's when it became a carbon source due to large fire and insect losses during that decade (Kurz and Apps 1999).

In Canada, stand-replacing crown fires burn about 2 M ha each year (Stocks 1991, Amiro et al. 2001) with typical fire cycles of 75-150 years depending on the local fire regime. Over millenia, tree species have adapted to this environment in different ways through fire survival and regeneration strategy. From an ecological standpoint, a change in the fire regime will favour some species over others and cause a shift in species composition (Weber and Flannigan 1997). This can affect carbon sequestration rates because of different growth rates in tree species. Fuel dynamics also have a feedback effect on fire regime through flammability and fuel load. Current research on fire and climate change has focused on the physical aspects of altered fire regimes and carbon release by fire, but very little has been done to study the ecological impacts of altered fire regimes or the impacts of ecological change on the boreal carbon budget. The purpose of this study was to examine both the physical and ecological effects of future altered fire regimes on boreal tree community dynamics and carbon storage, and to examine the impact of fire management in adaptation to climate change.

The study used a simulation approach to examine the effects of altered fire regimes. To simplify simulations, the study was focused on areas where natural disturbance is the primary force of change so that fire disturbance on the landscape was not confounded by human disturbance factors such as road construction and forest harvesting. The four forested National Parks in the boreal region of the Prairie provinces were used as study areas. This provided a wide geographical and forest type range and allowed for a broad examination of climate change impacts on the boreal forest.

Study Area Description

The four National Parks used as study areas are located across the Prairie provinces (Figure 1). Wood Buffalo National Park is the largest and northernmost study area. It is located in the Hay River and Upper Mackenzie sections of the boreal forest region of Rowe (1972) and is characterized by extensive stands of black spruce (*Picea mariana* (Mill.) B.S.P.) on plateau-like uplands and poorly-drained lowlands, jack pine (*Pinus banksiana* Lamb.) on well-drained uplands, and aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss) in mixed or pure stands (Table 2, Figure 2). Most of the Park is characterized by flat topography and poor drainage which has resulted in a mosaic of muskeg, streams, bogs and forest. Most of Wood Buffalo National Park is located in the Subhumid Mid-Boreal Ecoclimatic Region but the western side of the Park towards the Caribou Mountains is classified as the Subhumid High Boreal Ecoclimatic Region (Ecoregions Working Group 1989). This area is noted for short, warm summers and moderate summer rainfall (Table 1). Fire seasons are of moderate length in comparison to other Canadian regions, but burning conditions are often very high (Simard 1973, Harrington et al. 1983, McAlpine 1991).

Elk Island National Park is the smallest study area (Table 3). Because of its position on the Beaver Hills, it is essentially an island of the Boreal Mixedwood section located within the Boreal Aspen Grove section (Rowe 1972). Over 90% of the forested area of the Park is aspen which grows in pure stands and in mixed stands with white spruce and white birch (*Betula papyrifera* Marsh.) (Table 3, Figure 3). Pockets of lowland black spruce also occur within the Park. The landscape has a rolling topography with numerous small lakes. It is located in the Transitional Grassland Ecoclimatic Region (Ecoregions Working Group 1989) with cool summer temperatures and high summer precipitation amounts (Table 1).

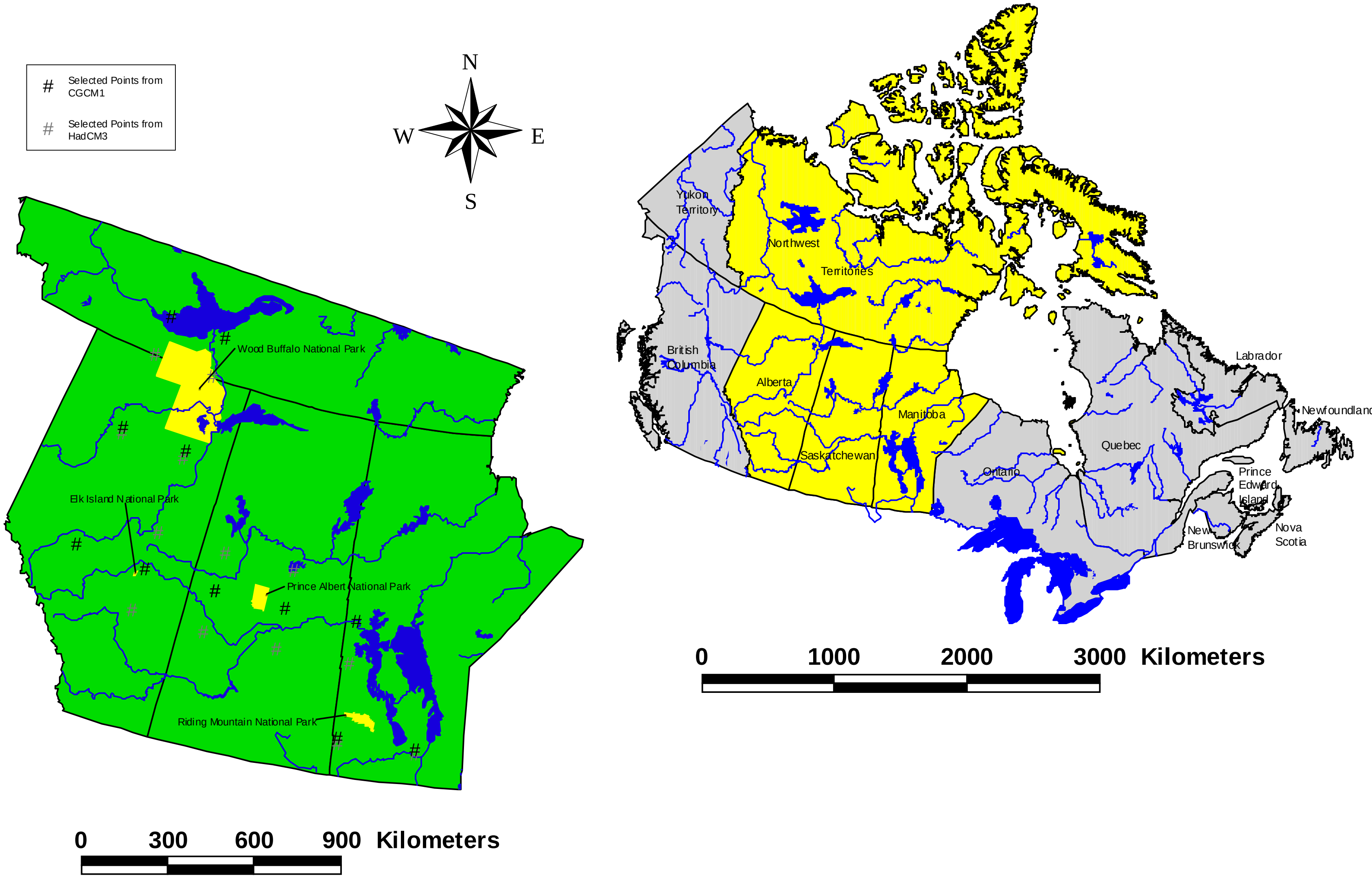


Figure 1. Location of study areas and GCM gridpoints

Table 1. Climate normals for the study areas (Atmospheric Environment Service 1993a, 1993b).

Station	Station Location			Average Temperature (^oC)			Total Precipitation (mm)		
	Latitude	Longitude	Elevation (m)	Annual	January	July	January	July	Annual
Wood Buffalo National Park									
Fort Smith	60°01'N	111°57'W	203	-3.0	-25.4	14.0	19.9	56.8	352.9
Fort Chipewyan	58°46' N	111°07'W	232	-2.1	-24.2	16.4	20.4	63.2	381.4
Elk Island National Park									
Edmonton International Airport	53°18'N	113°35'W	715	2.1	-14.2	16.0	22.9	101.0	465.8
Vegreville	53°29'N	112°02'W	636	1.4	-16.2	16.2	16.6	83.2	402.8
Prince Albert National Park									
Prince Albert Airport	53°13'N	105°41'W	428	0.5	-19.8	17.6	15.4	72.1	405.5
Waskesiu Lake	53°55'N	106°05'W	532	0.3	-18.9	16.3	23.3	79.7	455.7
Riding Mountain National Park									
Wasagaming	50°39'N	99°56'W	626	0.0	-19.7	16.5	18.6	70.9	508.0
Dauphin	51°06'N	100°03'W	304	1.7	-18.0	18.6	19.3	69.3	491.9

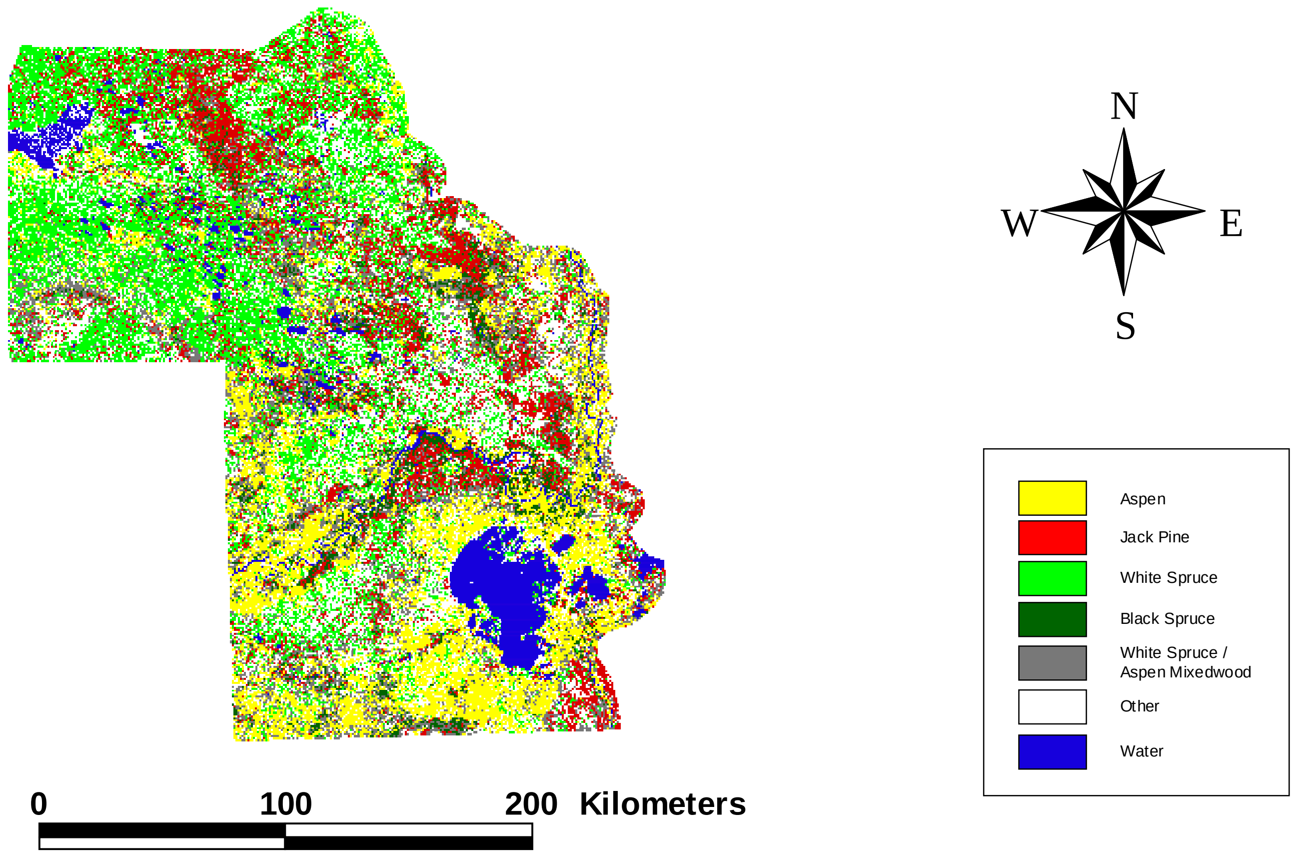


Figure 2. Vegetation Map of Wood Buffalo National Park.

Table 2. Vegetation composition of Wood Buffalo National Park.

a) Park classification.

Stand Type	Area (ha)	Percent of Total
Unclassified	99334	1.96
Water	320005	6.33
Sedge	666901	13.19
Bog Birch/Willow	499187	9.87
Wet Black Spruce	451248	8.93
Dry Black Spruce	736085	14.56
White Spruce	201570	3.99
Jack Pine	694293	13.73
Willow/Shrub/Aspen	807830	15.98
Mixed	546436	10.81
Salt/Mud Flats	32944	0.65
Total	5055833	100

b) Vegetation reclassified for study.

Stand Type	Area (ha)	Percent of Total
Black Spruce	1187333	23.48
Jack Pine	694293	13.73
White Spruce	201570	3.99
White Spruce/Aspen	546436	10.81
Aspen	807830	15.98
Other Forest	499187	9.87
Non Forest	1019850	20.17
Unclassified	99334	1.96
Total	5055833	100

Table 3. Vegetation composition of Elk Island National Park.

Stand Type	Area by Management Zone (ha)						Percent of Total
	Open Aspen Parkland	Closed Aspen Parkland	Lower Boreal Mixedwood	Buffalo Paddock	Exclusion Zones	Total	
Aspen	3800.27	4706.46	2400.01	174.49	149.23	11230.46	59.65
Birch	139.64	80.09	14.07	5.88	1.96	241.64	1.28
Black Spruce	35.08	167.23	113.74	4.54	0	320.59	1.70
Aspen/White Spruce	3.87	14.19	165.92	0	2.13	186.11	0.99
Aspen/Birch	0	207.78	0	0	0	207.78	1.10
Other Forest	22.38	5.55	42.56	0	1.38	71.87	0.38
Non Forest	1951.42	2977.34	1150.16	406.85	84.18	6569.95	34.89
Total	5952.66	8158.64	3886.46	591.76	238.88	18828.4	100
Percent of Total	31.62	43.33	20.64	3.14	1.27	100	

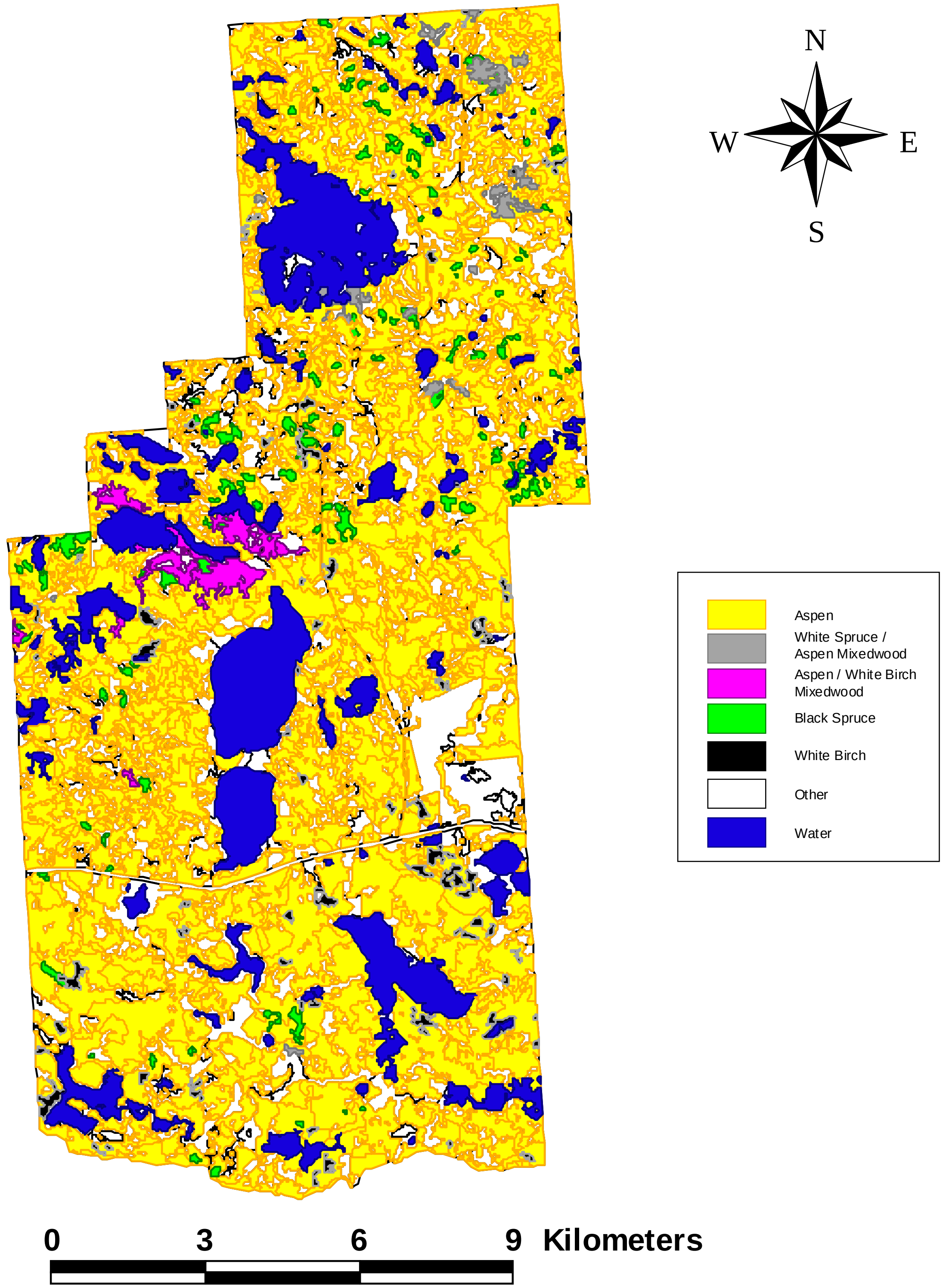


Figure 3. Vegetation Map of Elk Island National Park.

Generally warm and dry spring and fall conditions contribute to a longer overall fire season , but summer burning conditions are usually low due to higher precipitation amounts.

Prince Albert National Park is located entirely in the Boreal Mixedwood section (Rowe 1972). The forest is primarily comprised of aspen, jack pine, black spruce and white spruce. As the name of this forest section implies, about one third of the Park forest occurs as mixedwood stands in various species combinations (Table 4, Figure 4). The landscape has a gently to strongly rolling topography with numerous lakes. The north half of Prince Albert National Park is located in the Subhumid Mid-Boreal Ecoclimatic Region and the south half is in the Subhumid Low Boreal Ecoclimatic Region (Ecoregions Working Group 1989). It has warm summer temperatures and moderate summer rainfall (Table 1), but there is a gradient of slightly warmer and drier conditions to the south end of the Park. The fire season is moderate in length but extreme burning conditions are often reached in the late spring and early summer (Harrington et al. 1983).

Riding Mountain National Park is the most southern and eastern study area. It is located in the extreme southeast extension of Rowe's (1972) Boreal Mixedwood section. The forest is dominated by aspen and white spruce, with smaller components of bur oak (*Quercus macrocarpa* Michx.) forest and other eastern deciduous forest including white elm (*Ulmus americana* L.) and green ash *(Fraxinus pennsylvanica* Marsh.) (Table 5, Figure 5). The Park is noted for the steep Manitoba escarpment, and rolling hills and valleys. Riding Mountain National Park is located in the Subhumid Mid-Boreal Ecoclimatic Region (Ecoregions Working Group 1989) with warm summer temperatures and moderate summer precipitation amounts (Table 1). The fire season of Riding Mountain National Park is very similar to Prince Albert National Park with the highest burning conditions usually occurring in the late spring and early summer, but conditions are often a little more severe (Simared 1973, Harrington et al. 1983).

Table 4. Vegetation composition of Prince Albert National Park.

Stand Type	Area by Management Zone (ha)			Percent of Total
	Fire Exclusion Zone	Fire Management Zone	Total	
Jack Pine	5958.95	18242.47	24201.42	6.12
Aspen	23922.62	70044.92	93967.54	23.76
Black Spruce	8398.87	23814.39	32213.26	8.15
White Spruce	1388.47	3990.06	5378.53	1.36
Jack Pine/Aspen	3909.95	13765.33	17675.28	4.47
Jack Pine/Black Spruce	9523.13	27423.28	36946.41	9.34
Jack Pine/White Spruce	1193.24	2338.32	3531.56	0.89
White Spruce/Aspen	13481.79	45652.86	59134.65	14.95
Other Forest	10455	27022.3	37477.3	9.48
Non Forest	12309.44	72604.27	84913.71	21.47
Total	90541.46	304898.20	395439.66	100
Percent of Total	22.90	77.10	100	

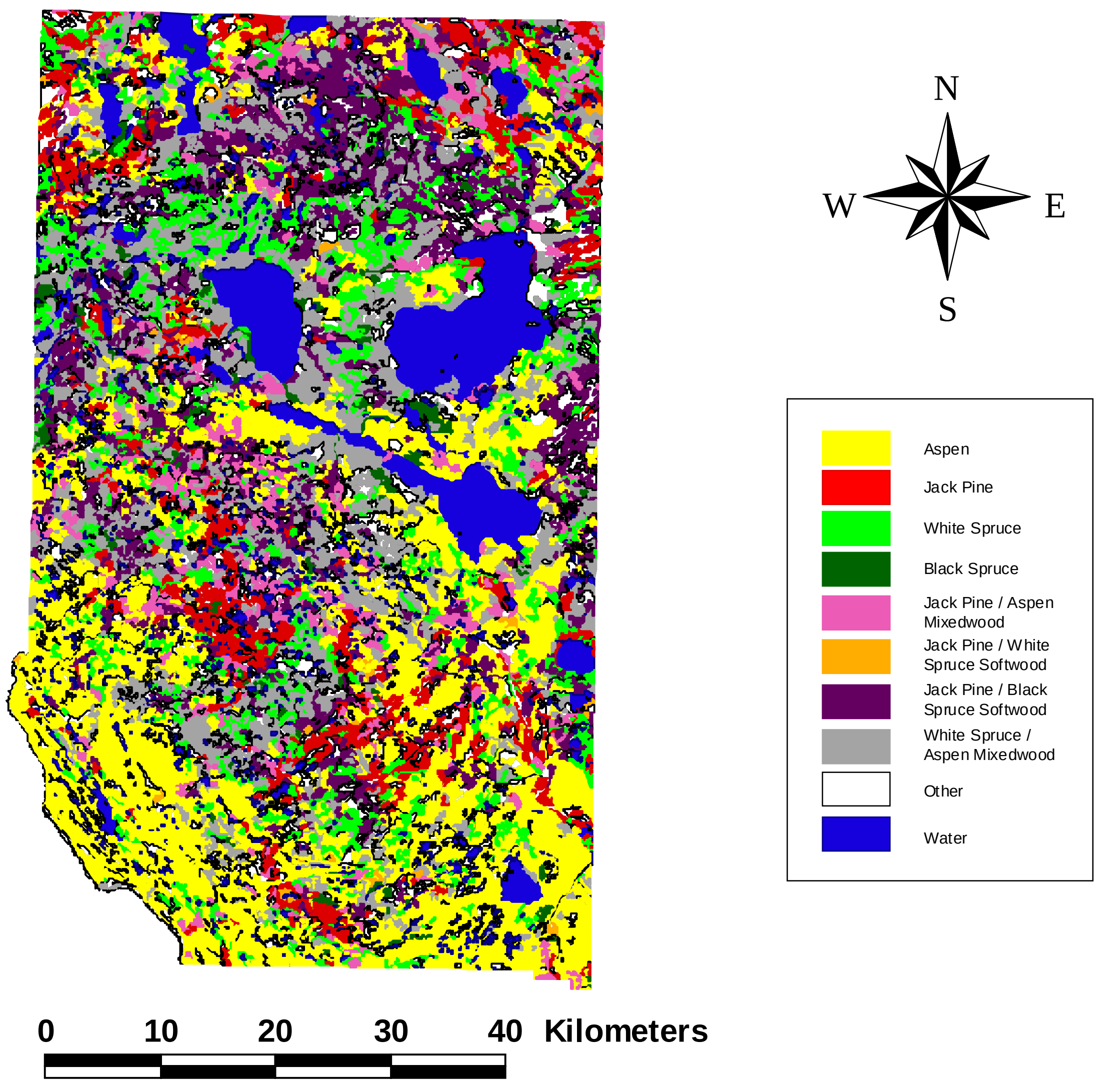


Figure 4. Vegetation Map of Prince Albert National Park

Table 5. Vegetation composition of Riding Mountain National Park.

a) Park classification

Stand Type	Area (ha)	Percent of Total
Shrubland	26074.60	8.45
Regenerating Coniferous Forest	2255.75	0.73
Grassland	2235.28	0.72
Low Shrub Grassland	7659.39	2.48
Deciduous Canopy-Coniferous Subcanopy	37830.77	12.25
Bur Oak Forest	7176.71	2.32
Mixed Canopy (Deciduous-Coniferous) Forest	35465.27	11.49
Aspen Parkland	87365.61	28.30
Closed Canopy Coniferous Forest	17189.55	5.57
Open Canopy Coniferous Forest	19266.55	6.24
Low Canopy Deciduous Forest	4581.55	1.48
Wetland	9118.63	2.95
Eastern Deciduous Forest	38563.82	12.49
Open Water	13941.39	4.52
Other	0.58	0.00
Total	308725.45	100

b) Vegetation reclassified for study.

Stand Type	Area by Management Zone (ha)					Percent of Total
	Aspen Parkland	Boreal Mixedwood	Eastern Deciduous Forest	Clear Lake	Total	
Aspen	50675.07	28464.17	12132.87	674.88	91946.99	29.78
White Spruce	16190.66	18063.41	4194.12	261.76	38709.95	12.54
White Spruce/Aspen	11680.98	50442.21	8912.51	2259.97	73295.67	23.74
Other Forest	12236.02	22317.65	37155.16	106.30	71815.13	23.26
Non Forest	17682.51	10518.27	757.89	3995.86	32954.53	10.67
Total	108465.24	129805.71	63152.55	7298.77	308722.27	100.00
Percent of Total	35.13	42.05	20.46	2.36	100	

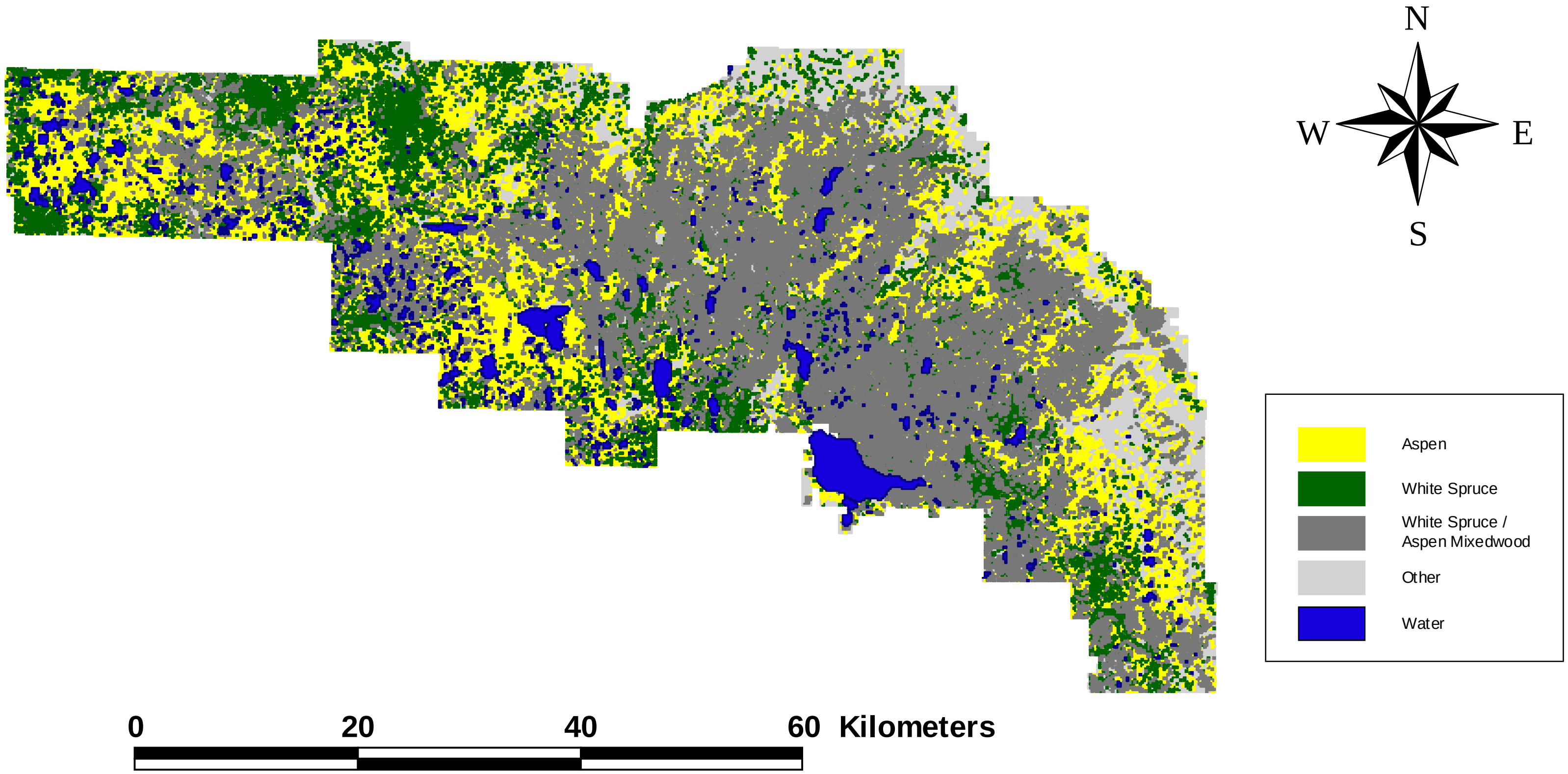


Figure 5. Vegetation Map of Riding Mountain National Park.

Climate and Fire Regime Data

Fire regime is characterised by parameters of fire frequency, fire intensity, fire severity, season of burn, type of fire (crown, surface or ground fire) and fire size (Malanson 1987, Whelan 1995). Comparison of vegetation under present and future fire regimes for the study was based on the first generation coupled GCM of the Canadian Centre for Climate Modeling and Analysis (CGCM1) (Flato et al. 2000) and the climate model of the UK Hadley Centre for Climate Prediction and Research (HadCM3) (Williams et al. 2001). Those models provided values of daily temperature, precipitation, relative humidity, wind speed and growing degree days (GDD, average of maximum and minimum temperatures above 5°C) for the periods 1975-1990 and 2080-2100 for the study locations. The first four parameters were applied to the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) to provide daily estimates of burning conditions. This included the Duff Moisture Code (DMC) which represents the level of dryness of loosely compacted forest floor organic matter and depth of burn; the Buildup Index (BUI) which is an indicator of the total amount of fuel available for combustion and can be used to estimate dead woody fuel consumption; and the Initial Spread Index (ISI) which indicates the rate of fire spread and is used with total fuel consumption to determine fire intensity. These codes were used to simulate the fire severity, fuel consumption and fire intensity characteristics of fire regime. The daily FWI System data used to describe fire regime were summarized to represent the typical range of burning conditions under which most boreal forest fires occur. The data was summarized by average monthly values of DMC and BUI, and average monthly extreme values of ISI for each time period (Table 6). Extreme monthly ISI values were used because development of large, running crown fires that are typical of the boreal forest usually occur when ISI values are very high.

The GDD data was used to estimate important season of burn dates based on leaf-flush for aspen and birch, and green-up of herbaceous understory plants. Aspen leaf-flush occurred in the model at GDD=115 when leaves expanded (Parry et al. 1997) and birch leaf-flush occurred at GDD=155 (estimated from Parry et al. 1997, Burton and Cumming 1995). Green-up of understory vegetation was estimated as the time of full leaf expansion of aspen at GDD=225 (Parry et al. 1997) when forest floor shading is highest in the spring and

Table 6. Summary of monthly FWI System data for study areas. The DMC and BUI represent monthly average (+/- SD) values; the ISI represents monthly extreme values.

a) Wood Buffalo National Park

FWI System Parameter	Month	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
DMC	April	3.6 (1.9)	7.3 (4.6)	13.7 (6.4)	16.7 (9.3)
	May	13.5 (8.7)	29.0 (12.5)	23.7 (10.4)	28.3 (15.4)
	June	31.4 (12.5)	48.4 (17.6)	23.0 (14.5)	24.1 (14.1)
	July	44.0 (15.8)	55.0 (24.2)	16.4 (7.7)	17.8 (8.8)
	August	51.7 (15.9)	59.3 (21.9)	16.5 (7.5)	22.1 (10.8)
	September	38.4 (17.1)	44.8 (19.3)	16.5 (9.0)	20.1 (12.3)
BUI	April	4.6 (2.2)	8.4 (5.0)	14.8 (6.7)	17.6 (9.4)
	May	17.7 (10.7)	34.3 (14.1)	29.9 (10.6)	34.4 (15.6)
	June	42.7 (13.6)	63.0 (19.8)	33.7 (18.0)	35.3 (17.3)
	July	63.6 (20.3)	78.4 (28.9)	27.6 (11.4)	29.8 (13.4)
	August	78.4 (20.5)	89.6 (28.6)	28.8 (12.2)	37.5 (16.7)
	September	63.1 (24.9)	72.6 (27.4)	29.2 (14.7)	34.6 (19.3)
ISI	April	7.4 (2.4)	9.7 (3.9)	3.4 (0.6)	3.5 (0.4)
	May	12.5 (4.7)	13.0 (4.1)	3.2 (0.5)	3.8 (0.4)
	June	13.2 (2.4)	13.4 (3.0)	3.1 (0.7)	3.4 (0.5)
	July	12.9 (3.5)	11.8 (3.6)	2.8 (0.5)	3.1 (0.6)
	August	12.1 (3.2)	14.0 (5.4)	2.6 (0.5)	3.5 (0.6)
	September	12.6 (4.5)	13.7 (5.8)	2.5 (0.6)	3.0 (0.7)

Table 6 (continued). Summary of monthly FWI System data for study areas.

b) Elk Island National Park

FWI System Parameter	Month	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
DMC	April	2.9 (1.8)	7.4 (4.4)	16.4 (7.5)	15.6 (8.2)
	May	5.4 (4.6)	16.4 (8.3)	18.8 (12.6)	18.5 (9.8)
	June	16.7 (8.6)	20.2 (10.1)	12.8 (10.3)	15.7 (10.8)
	July	21.9 (11.7)	23.7 (10.9)	20.5 (15.6)	30.3 (17.8)
	August	29.9 (17.1)	26.5 (12.0)	32.5 (18.3)	49.6 (24.8)
	September	27.2 (17.1)	24.8 (11.7)	33.3 (24.5)	61.7 (34.0)
BUI	April	3.7 (1.9)	8.5 (4.9)	17.2 (7.6)	16.6 (8.2)
	May	7.8 (6.3)	21.1 (10.0)	24.1 (12.5)	24.0 (11.4)
	June	23.6 (11.6)	29.1 (13.6)	19.6 (13.3)	23.7 (14.5)
	July	33.0 (15.7)	36.2 (15.3)	31.6 (20.9)	44.7 (22.7)
	August	46.3 (23.0)	42.6 (16.9)	49.8 (23.4)	73.1 (30.8)
	September	43.9 (24.0)	41.4 (17.8)	51.2 (29.7)	90.1 (41.3)
ISI	April	4.6 (1.5)	7.7 (4.4)	3.7 (0.5)	3.9 (0.5)
	May	9.3 (3.1)	7.5 (2.4)	3.2 (0.6)	3.5 (0.8)
	June	11.2 (3.3)	9.7 (4.8)	2.8 (0.8)	3.5 (0.8)
	July	9.1 (1.8)	8.5 (2.8)	3.4 (1.3)	4.9 (1.3)
	August	8.5 (2.4)	8.5 (2.4)	4.3 (1.3)	5.7 (1.1)
	September	10.7 (4.3)	10.2 (5.0)	3.6 (0.7)	5.6 (1.3)

Table 6 (continued). Summary of monthly FWI System data for study areas.

c) Prince Albert National Park

FWI System Parameter	Month	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
DMC	April	6.3 (3.0)	12.2 (7.9)	11.2 (5.6)	12.6 (6.7)
	May	17.8 (9.6)	28.2 (12.4)	14.9 (8.9)	18.0 (11.9)
	June	31.0 (14.8)	34.0 (15.6)	13.0 (7.8)	15.2 (9.8)
	July	42.4 (23.8)	46.6 (22.7)	13.0 (6.8)	18.2 (10.0)
	August	58.2 (31.7)	59.5 (26.9)	14.5 (6.2)	26.4 (15.7)
	September	53.1 (28.8)	58.6 (25.3)	13.2 (7.7)	26.6 (21.1)
BUI	April	7.5 (3.2)	13.1 (8.1)	12.4 (5.8)	13.6 (7.0)
	May	22.4 (11.2)	34.3 (14.0)	19.7 (9.6)	22.5 (13.3)
	June	42.3 (18.1)	46.8 (18.8)	19.8 (10.3)	22.1 (13.1)
	July	60.8 (29.6)	67.0 (29.1)	21.2 (10.0)	28.1 (13.2)
	August	85.2 (39.7)	87.9 (34.3)	24.7 (9.5)	41.7 (21.7)
	September	82.3 (39.4)	91.0 (32.8)	22.8 (12.1)	42.5 (28.9)
ISI	April	10.8 (3.7)	13.6 (7.9)	3.3 (0.7)	3.7 (0.5)
	May	18.4 (7.0)	15.2 (3.8)	2.9 (0.7)	3.7 (0.6)
	June	20.0 (6.3)	18.0 (10.7)	3.0 (0.5)	3.2 (0.8)
	July	17.3 (4.4)	16.1 (4.3)	2.6 (0.7)	3.9 (1.4)
	August	18.0 (7.9)	15.4 (4.6)	3.0 (0.6)	4.4 (1.3)
	September	20.0 (7.8)	17.3 (7.7)	3.0 (0.5)	4.2 (1.6)

Table 6 (continued). Summary of monthly FWI System data for study areas.

d) Riding Mountain National Park

FWI System Parameter	Month	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
DMC	April	6.7 (4.3)	14.5 (7.9)	10.6 (5.6)	12.6 (7.9)
	May	20.6 (9.3)	31.9 (13.4)	17.9 (9.7)	17.8 (12.5)
	June	32.9 (14.2)	46.4 (23.2)	17.4 (9.0)	17.8 (10.6)
	July	52.0 (20.2)	71.1 (33.8)	18.0 (9.9)	24.8 (14.6)
	August	65.8 (25.5)	90.0 (41.8)	20.5 (12.8)	41.4 (22.8)
	September	65.8 (28.9)	75.7 (44.5)	18.2 (11.9)	37.7 (26.9)
BUI	April	7.7 (4.5)	15.1 (8.1)	11.7 (5.9)	13.2 (8.1)
	May	24.6 (10.4)	36.8 (14.8)	22.6 (10.6)	21.1 (13.4)
	June	43.1 (15.8)	59.1 (25.4)	25.4 (11.9)	24.5 (13.8)
	July	71.0 (23.7)	94.3 (38.2)	28.7 (14.4)	36.5 (18.5)
	August	93.0 (30.4)	123.8 (49.2)	33.5 (17.9)	61.2 (28.4)
	September	97.9 (37.0)	111.7 (53.8)	30.6 (17.9)	58.4 (36.2)
ISI	April	11.1 (5.5)	14.1 (5.3)	3.5 (0.6)	3.8 (0.5)
	May	19.6 (6.2)	19.3 (4.8)	3.4 (0.4)	3.7 (0.6)
	June	22.2 (6.9)	20.4 (10.6)	3.3 (0.5)	3.8 (0.9)
	July	19.6 (6.9)	21.1 (8.1)	3.5 (0.9)	5.4 (1.5)
	August	19.1 (7.3)	23.1 (10.6)	4.0 (1.1)	6.6 (1.6)
	September	27.1 (11.7)	25.6 (13.2)	3.5 (0.6)	5.2 (1.8)

solar drying of understory fuels declines. Leaf-fall was estimated as the time when average daily temperature dropped below 3.5°C. Maximum white spruce seed soundness was found to occur near mid-August in Riding Mountain National Park (Waldron, 1965), and this was used to estimate the time of seed ripening at GDD=1050 for the model. These parameters were used in the model to simulate the season of burn characteristics of fire regime (Table 7).

Fire cycles for 1975-90 were calculated by the annual rate of area burned (as a percent of total area) in each National Park. This was calculated on a monthly basis to provide a monthly fire probability. Harrington and others (1983) studied the correlation of monthly area burned to monthly FWI System values and DMC was found to show the strongest relationship in most cases. For this study, average monthly DMC values for 2080-2100 were used to estimate future monthly area burned. The difference in average monthly DMC values between 1975-90 and 2080-2100 was proportionately reflected in the average monthly area burned.

Fire Effects Model Description

Simulation of the effects of fire regime on vegetation and carbon dynamics was done using a basic ecological model of boreal fire effects (BORFIRE) which was developed for this study. The model quantitatively simulates tree community dynamics (species composition and stand density, average tree height and diameter) and biomass (above- and below-ground, live and dead organic material) using separate submodels. Changes in those two state variables was based on processes of tree mortality, tree recruitment, tree growth, biomass decomposition, and biomass consumption by fire (Figure 6). Fire was the main forcing variable and was included as the third submodel. Tree community dynamics were driven by fire disturbance events which affected recruitment and mortality, and natural thinning due to competition. Biomass component values were the product of species composition and stand density, and dead organic matter accumulation. The model is process-driven using an annual time-step and simulates conditions at the stand level.

Table 7. Julian dates (+/- SD) for key phenological stages used in the BORFIRE model.

Study Area	Simulation Period	CGCM1					HadCM3				
		Green up	Aspen Flush	Birch Flush	Leaf Fall	White Spruce Seed Ripening	Green up	Aspen Flush	Birch Flush	Leaf Fall	White Spruce Seed Ripening
Wood Buffalo National Park	1975-1990	167.1 (4.4)	154.8 (5.3)	159.7 (5.2)	263.9 (6.9)	243.0 (1.0)	160.0 (3.6)	144.0 (3.9)	150.0 (4.4)	258.7 (8.9)	243.0 (1.0)
	2080-2100	145.6 (5.6)	134.5 (5.7)	139.0 (5.6)	273.0 (1.0)	199.4 (1.0)	143.0 (5.0)	129.0 (6.2)	135.0 (5.7)	266.3 (4.3)	202.4 (1.0)
Elk Island National Park	1975-1990	171.8 (5.0)	157.8 (6.2)	163.9 (5.5)	267.0 (5.7)	232.0 (1.0)	158.0 (4.6)	141.0 (5.2)	149.0 (4.8)	262.0 (7.5)	232.0 (1.0)
	2080-2100	144.1 (5.4)	130.7 (6.9)	136.2 (5.9)	273.0 (1.0)	204.3 (1.0)	141.0 (4.7)	126.0 (6.6)	132.0 (6.2)	266.0 (0.7)	200.0 (1.0)
Prince Albert National Park	1975-1990	161.3 (4.8)	148.9 (5.4)	153.4 (5.1)	273.0 (1.0)	243.0 (1.0)	157.2 (3.8)	139.7 (5.8)	146.6 (5.6)	261.6 (6.8)	243.0 (1.0)
	2080-2100	136.3 (5.5)	124.0 (7.2)	129.1 (6.6)	273.0 (1.0)	190.8 (1.0)	140.4 (5.2)	125.6 (6.6)	131.3 (5.9)	267.3 (3.2)	198.7 (1.0)
Riding Mountain National Park	1975-1990	155.2 (5.4)	142.6 (5.9)	147.3 (5.6)	273.0 (1.0)	220.0 (1.0)	146.8 (7.1)	132.6 (8.0)	138.1 (7.0)	264.4 (4.5)	220.0 (1.0)
	2080-2100	132.3 (6.0)	119.6 (7.3)	124.2 (7.4)	273.0 (1.0)	184.4 (1.0)	133.7 (6.5)	121.2 (7.0)	125.9 (6.6)	267.0 (1.0)	189.6 (1.0)

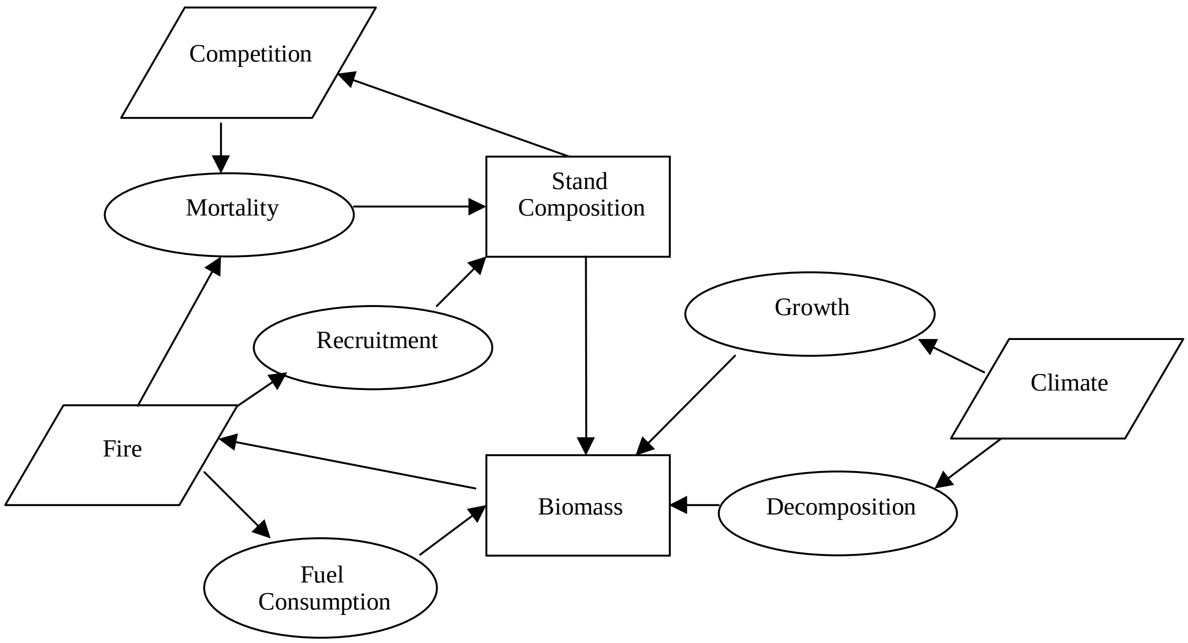


Figure 6. Simplified structure of the BORFIRE model showing state variables (square), processes (ellipse) and driving variables (parallelogram).

Tree Community Submodel

The model simulates the community dynamics of six major boreal tree species: aspen, white spruce, jack pine, black spruce, white birch and balsam fir. Each simulated stand may include any number of species. Stand density (stems/ha, by species) at the end of each time-step was a result of recruitment and mortality to the initial stand density. Recruitment occurred after a fire event as new seedlings for jack pine and black spruce, and as new sprouts for aspen and white birch. White spruce, black spruce and balsam fir recruitment was possible at each time-step if a seed source and growing space was available, and these species were able to regenerate in the understory of aspen or birch. All other species were shade intolerant and could not regenerate under a canopy. For the purposes of this study, all stands were assumed to be fully stocked. Mortality was separated into fire and natural mortality (or thinning). Natural stand thinning followed the fully stocked stand density algorithms of the Alberta Phase III Inventory (Alberta Forest Service 1985) for aspen, white spruce, black spruce, jack pine and mixedwood stands (any conifer/hardwood mix) which were based on Alberta and Saskatchewan forest inventories. Western boreal databases were not available for balsam fir or white birch, so similar data from Ontario was used (Plonski 1974, MacDonald 1991, Payandeh 1991). In the case of non-pure stands, thinning occurred proportionately to stand density by species.

Biomass Submodel

Biomass was separated into live and dead, and above- and below-ground components. Live aboveground tree growth rates followed the Alberta Phase III Inventory and Ontario algorithms. The live below-ground (root) component was calculated as a proportion of aboveground biomass using Kurz et al. (1996). As a result of natural thinning, trees were killed and transferred to the appropriate aboveground and below-ground dead biomass pools. Standing dead stems fell at a rate of 10% annually and they were transferred to surface slash pools of branchwood (10% of tree) and coarse woody debris (CWD, 90% of tree). Respiration of slash branchwood used the maximum decay rate of the fast soil carbon pool (representing a half life of 3-20 years) in the boreal west region of the Carbon Budget Model of the Canadian Forest Service (CBM-CFS, Kurz et al. 1992, Kurz and Apps 1999). The CWD respired at the maximum decay rate of the medium soil carbon pool (half life of 20-100 years) and standing dead stems respired at the medium soil carbon pool minimum decay rate.

Dead below-ground biomass was separated into three pools: a surface litter layer of dead foliage and fine (<1cm) woody material, a duff layer of loosely-compacted surface organic matter, and dead roots. Leaf and needle detritus was an annual input to the forest floor litter layer, and litter was similarly transferred to duff using rates of Keane and others (1989). Through decomposition, branchwood and CWD was transferred from aboveground slash to the duff pool at a rate of 10% and 5% per year, respectively. In each timestep, 10% of dead root biomass and 73.5% of live fine roots (Kurz et al. 1996) were input to the duff layer. Respiration of litter and duff used the rates of fine and medium soil carbon pools for the west boreal region of the CBM-CFS (Kurz et al. 1992) with the maximum rate occurring in the first year after fire and declining to the minimum rate by year 100. Dead root respiration similarly used the medium soil carbon pool rate.

Fire Submodel

Fire is the main driving variable affecting post-fire vegetation response in BORFIRE. The tree community submodel uses the physical characteristics of individual fires (intensity, severity, season of burn) to simulate plant response (tree death, recruitment) based on the fire ecology of each species. Fire frequency was incorporated as time since the last fire, or tree age. In the biomass submodel, fire also affected the physical structure of the stand through loss of biomass during combustion and transfer between pools (e.g., live to dead, aboveground to below-ground).

Fire Ecology and Effects

Because the main purpose of the tree community model was to simulate the ecological effects of altered fire regimes, the interaction of physical fire characteristics and fire ecology was critical. The most important fire ecology traits for each species were summarized (Table 8) and each trait was quantified in the model as it affected tree mortality and recruitment under different fire conditions. Recruitment of aspen, jack pine and black spruce followed the algorithms of Greene and Johnson (1999). To simulate postfire re-

Table 8. Summary of main fire ecology traits for major boreal tree species in the BORFIRE model.

	Jack Pine	Black Spruce	White Spruce	Aspen	White Birch	Balsam Fir
Regeneration Method	canopy-stored seed	canopy-stored seed	seed not stored	root suckers	root collar sprouts	seed not stored
Fire Resistance	moderate	low	low	very low	very low	very low
Seasonal Fire Effect	none	none	self-seeds only after autumn fire	does not re-sprout if burned prior to leaf flush	does not re-sprout if burned prior to leaf flush	none
Reproductive Age (yrs)	20-120	15-200	25-250	5-110	15-110	20-140
Shade Tolerance	intolerant	intolerant	tolerant	intolerant	intolerant	tolerant

sprouting from the root collar in white birch, recruitment was incorporated as a replacement of surviving individual trees. There are no good recruitment models for balsam fir or white spruce, so a basal area approach was used in a very similar fashion to Greene and Johnson (1999). Balsam fir used the same algorithm as black spruce, and white spruce used a simple factor of surviving tree basal area to basal area of a fully stocked pure stand. Long distance seeding of aspen and white birch was considered of minimal importance (see Greene and Johnson 1997, Greene et al. 1999) and was not included in this model. In order for regeneration to occur in the simulated stand, a propagule bank (aspen, jack pine, black spruce, white birch) or a surviving individual (white spruce, balsam fir) was required. Reproductive age and maximum lifespan were used to define the reproductive period for each species (Table 8).

Tree mortality was based on the amount of crown scorch and cambium death during fire using algorithms from Ryan and Reinhardt (1988). Crown scorch height was calculated using Van Wagner's (1973) equation and fire intensity as determined by the Canadian Forest Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) for the vegetation community under specified burning conditions. Crown scorch was estimated from crown scorch height (Peterson 1985). Bark thickness (Kozak and Yang 1981) and fire intensity were used to calculate cambium mortality. For the re-sprouting species (aspen and white birch), season of burn was important to tree mortality and re-sprouting ability as low intensity fires prior to leaf flush have been shown to girdle aspen stems and prevent suckering (Weber 1990). Therefore, the model includes fire intensity and date of leaf-flush in the mortality and recruitment of aspen and white birch. Also, pure deciduous stands in the model do not burn after spring greenup of the understory, but they may burn after autumn leaf-fall when it is possible for the cured herbaceous understory to dry-out quickly with increased solar radiation reaching the forest floor.

Biomass Impacts

Fuel (or biomass) consumption during a fire event was estimated in the model using fuel load and burning condition parameters. Slash consumption as correlated to BUI by McRae (1980) was used to calculate biomass losses in branchwood and CWD pools. Total depth of burn was calculated using forest floor depth and duff moisture content (as estimated by DMC) using the same procedure as FIRESUM (Keane et al. 1989). All biomass in the litter layer was assumed to be lost during combustion. The amount of duff biomass lost was determined using duff fuel load, duff bulk density (97 kg/m^3), litter depth (based on 36 kg/m^3) and total depth of burn.

A certain amount of the live biomass was also lost during fire to represent fine aerial fuel consumption. In the case of a crown fire, this amount was estimated as the foliage and stem bark components (Ter-Mikaelian and Korzukhin, 1997) for conifers and white birch, and only the foliage for aspen. In non-crowning fires, the model estimates no loss in aspen and a 2% loss of aboveground live biomass in all other tree species to represent bark and lower foliage losses. All live trees that were killed by fire were transferred to the dead standing biomass pool, and all trees that were dead and standing at the time of the fire were transferred to the dead aboveground biomass pools of branchwood and CWD.

Physical Fire Parameters

Fire was simulated as a stochastic event using a Monte Carlo method and the average fire cycle. If a fire event occurred during any annual time-step, the model determined a Julian 'fire date' by randomly selecting a date from a weighted distribution of the historical monthly area burned. The fire date was used to determine the state of hardwood flushing and understory condition (Table 7), and the burning conditions as measured by the FWI System. The model randomly selected the DMC, BUI and ISI values for the fire from a normal distribution of monthly values as calculated for the fire regime database (Table 6).

The DMC was used to calculate forest floor consumption, and BUI was used to calculate aboveground dead biomass consumption. The average fire rate of spread (weighted by species) was calculated with the ISI and tree species data using procedures of the FBP System. Fire intensity was calculated using the average fire rate of spread and fuel consumption during the fire (Byram 1959). Fuel consumption was calculated in several steps using the following FBP System procedures. Foliar moisture content at the time of the fire was calculated using the fire date, latitude, longitude and elevation data. This was combined with live crown base height to determine the critical surface fire intensity for crown fire to occur based on the species composition of the stand. The actual surface fire intensity was determined using the fire rate of spread (from stand composition, age and season of burn) and surface fuel consumption (litter, duff, dead and downed branchwood and CWD). If surface fire intensity was greater than the critical surface fire intensity, then a crown fire occurred and total fire intensity was calculated using rate of fire spread and total fuel consumption (surface fuels plus bark and foliage fuels).

Model Simulations

Each simulation was started with initial conditions of 1,000 seedlings per hectare for each species in the stand, and a standard duff biomass of 80 t/ha. This was to simulate the first year of a stand regenerating after fire. The forest stand types simulated in each Park were determined from the vegetation classifications of Tables 2-5. The vegetation classifications for Wood Buffalo National Park and Riding Mountain National Park were slightly modified for simulation of stand types in this study (Table 2b and 5b). The model used fire regime data in Table 6 to drive species composition and biomass dynamics in the study areas during the 1975-90 and 2080-2100 simulations. Each simulation was run for 400 years to allow the stand dynamics to reach equilibrium under the driving variables. Each simulation scenario was repeated 25 times and averaged. Tree densities during the 400-yr simulation period, and the average tree densities and stand biomass during the final 100-yr period of the simulation were summarized.

The three simulation scenarios that were run for Wood Buffalo National Park reflect the fire management approach used in this large, northern wilderness area. Because much of the Park is remote and poorly accessible, and because it has a relatively short fire cycle, fire management is focused on fire suppression to protect values at risk within the Park, and to prevent fires in the park from spreading onto adjacent provincial and territorial lands. As such, the three scenarios simulated in the study were current fire suppression practices under the current fire regime (1975-1990) and under the future fire regime (2080-2100), and increased fire suppression under the future fire regime. Each simulation scenario was run using the CGCM1 and HadCM3 data sets (a total of six simulation exercises). Increased fire suppression was incorporated as a change in the fire cycle such that the greater fire suppression effort would result in a decrease in the future fire cycle that was equal to half the difference between the current and future fire regimes. Simulations of the current fire regime were based on the actual area burned during 1975-90. A total of 67 fires burned 1.03M ha for a current estimated fire cycle of 78 years. However, the CGCM1 and HadCM3 data produced different future fire regimes so those simulations were based on 56 and 62 years, respectively. As a result, the simulations with increased fire suppression under future fire regimes were also different with the CGCM1 using a 65-year fire cycle, and the HadCM3 using a 69-year fire cycle. For the total area burned in Wood Buffalo National Park during 1975-90, 18% was burned in June, 17% in July, and 64% in August. Data on the seasonal fire date was transformed to a normal distribution of Julian fire date so that when a simulated fire occurred in the model, the fire would happen at a time that was representative of the fire regime. In this case, fires occurred with a normally distributed average Julian fire date of 200 (+/-38.1 days).

In Elk Island National Park, simulations included current fire management practices under current and future fire regimes, and three additional fire management scenarios under the future fire regime. The current fire cycle was 135 years, and the future fire cycle using the CGCM1 data was 57 years, and 119 years using the HadCM3 data. The three future management scenarios were fire cycles of 100 years, 25 years and 15 years as defined in the Ecosystem Conservation Plan, which were applied to the management zones of Elk Island National Park (Figure 7). The current fire regime in Elk Island National Park is driven by prescribed fire. During 1975-90, 2294 ha were burned in 44 fires. Burning was done in either the spring

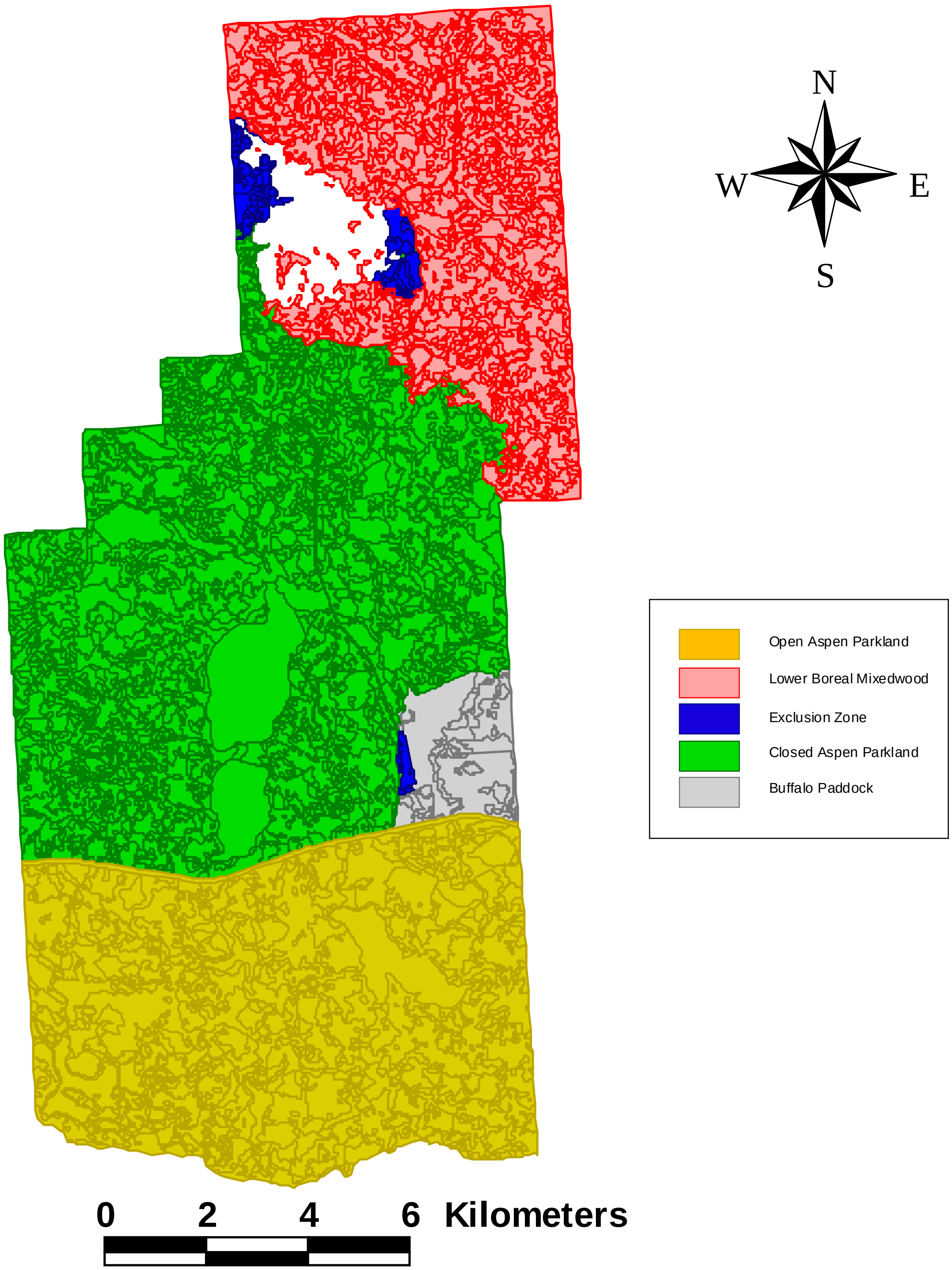


Figure 6. Landscape Management Units in Elk Island National Park

or fall with 51% in April, 28% in May and 20% in October. The model used Julian fire dates of 116 (+/- 15.8) in the spring, and 258 (+/-0.1) in the fall. If a fire occurred in the model, there was an 80% chance of it being a spring fire.

The Fire Management Plan for Prince Albert National Park uses a 75-year fire cycle as a general objective for the forested area of the Park (Weir and Pidwerbeski 1998). Therefore, simulations were run using current and future fire regimes with no change in current fire management, and under future fire regimes with a managed fire cycle of 75 years. This was done for the fire suppression and fire containment units of the Park (Figure 8). Prince Albert National Park had a very low amount of area burned (452 ha in 89 fires) during the 1975-90 study period, resulting in a current fire cycle of 14,286 years. This is essentially fire exclusion. Weir (1996) also estimated the 1945-95 fire cycle in the southern portion of the Park to be 645 years (200-4,270 years, 95% CI) and in the northern portion to be 1,745 years (300-67,380 years, 95% CI). In terms of fire ecology, these long fire cycles are like fire exclusion because none of the boreal tree species has a lifespan longer than half the current fire cycle. In effect, trees must be able to reproduce in the absence of fire. In terms of the fire season, most of the area burned in Prince Albert National Park occurred in the month of June (97%), and only 2% burned in July, producing a normalized Julian fire date of 166 (+/- 5.3) for the model simulations.

Simulation scenarios for Riding Mountain National Park include current fire management under current and future fire regimes, and future fire regimes with managed fire cycles of 100, 50 and 25 years as described for each Fire Management Zone (Figure 9) in the draft Fire Management Plan. During the period 1975-90, a total of 22,760 ha were burned by 52 fires. Riding Mountain National Park has a spring-dominated fire regime with 6% of fires occurring in April, 90% in May, and 3% in June. This was normalized to an average Julian fire date of 136 (+/- 13.4) for all simulations. The current fire cycle was 217 years, and the future 2080-2100 fire cycles were 137 years under CGCM1 and 213 years under HadCM3.

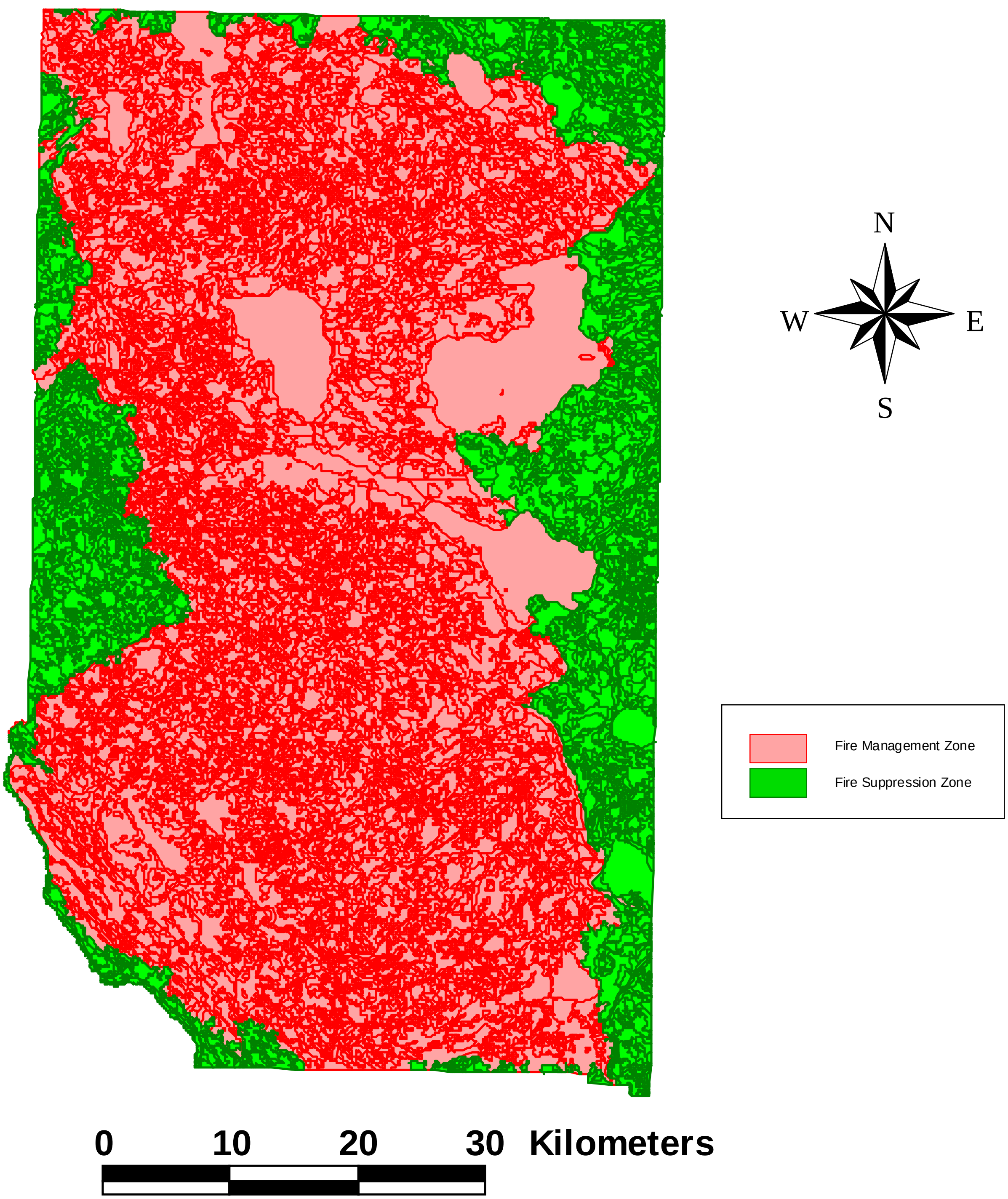


Figure 8. Fire management units in Prince Albert National Park.

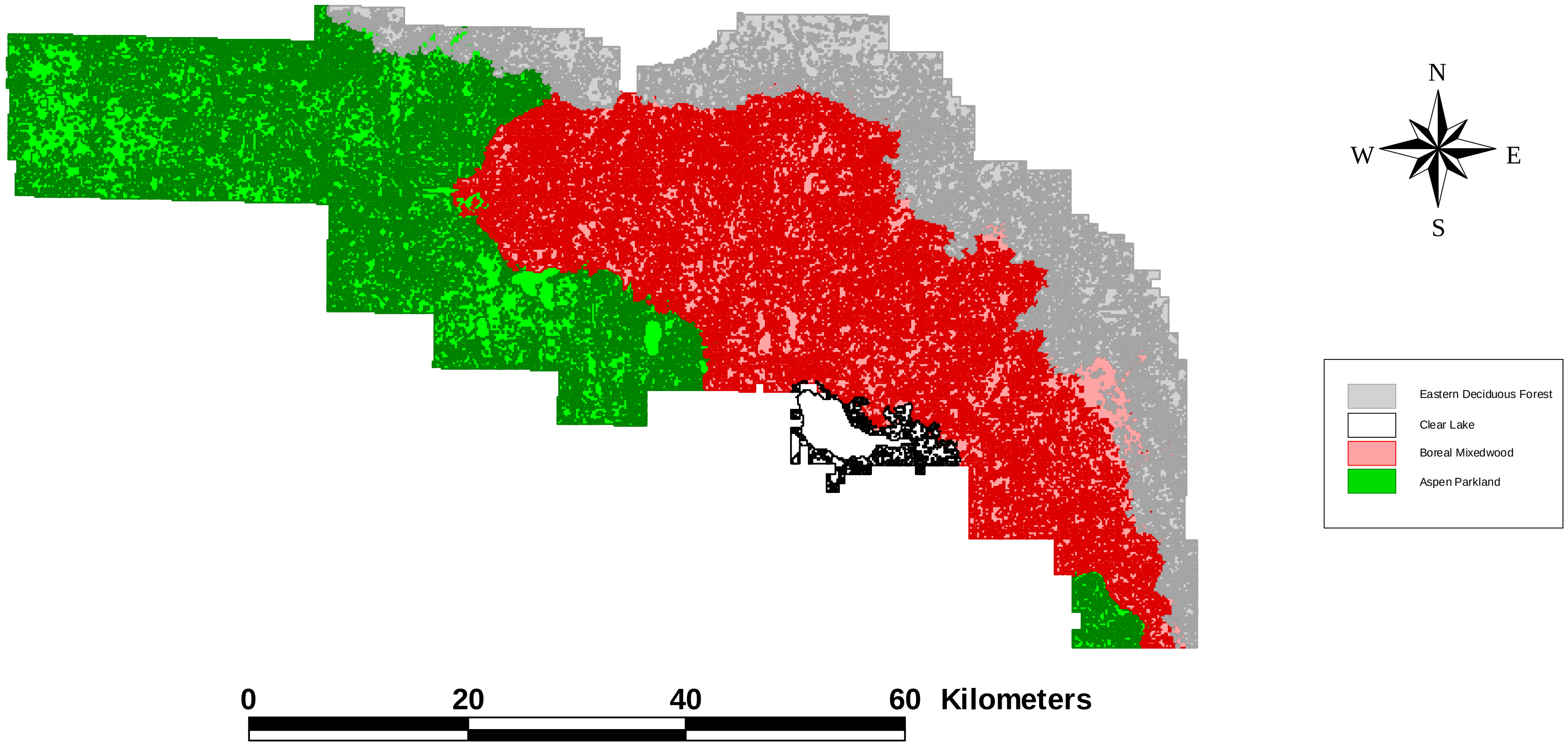


Figure 9. Fire management zones in Riding Mountain National Park.

Study Results

A total of 150 scenarios were run for the study, with each scenario being comprised of twenty-five 400-year simulations. The monthly FWI System values for each Park and fire regime characteristics for each Park scenario were summarized in Table 6 and Table 9, respectively. Stem density for each species in each simulated stand were summarized for current and future fire regimes with no change in fire management strategy (Table 10). Stem densities under different fire management options in the future were summarized in Table 11. The biomass stored in the simulated stands of Tables 10 and 11 were summarized in Tables 12 and 13, respectively. Finally, the total biomass stored in each Park under the different simulation scenarios (Table 14) was calculated using biomass values in Tables 12 and 13, and area values in Tables 2-5.

Fire Regimes

The FWI System values from the CGCM1 data were generally much higher than provided by the HadCM3 (Table 6). The CGCM1 data produced much higher ISI values in all Parks, and higher DMC and BUI values in the summer and fall in all Parks. The HadCM3 data produced higher DMC and BUI values in April in all Parks and May in Wood Buffalo National Park, and in all months in Elk Island National Park. Both scenarios showed that monthly FWI System parameters increased under future fire regimes in all Parks, except for the CGCM1 scenario which showed a slight decrease in future ISI values in Elk Island National Park and Prince Albert National Park, and a slight decrease in DMC and BUI values in Elk Island National Park in the fall.

The fire cycles used to set the Monte Carlo probabilities for each scenario in the model were described under ‘Simulated Fire Cycle’ (Table 9) in terms of years and the average number of fires per 400-year simulation. The actual number of fires (mean , SD) which occurred in the 25 replications of each 400-year simulation scenario were summarized under ‘Model Results’ (Table 9). The results were presented as the total number of fires, and the number of fires >50 kW/m for each 400-year simulation scenario. The current (1975-1990) fire cycles used in the CGCM1 and HadCM3 scenarios were the same within each Park because fire regimes were based on current area burned data. However, future (2080-2100) fire cycles in

Table 9. Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

a) Wood Buffalo National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
Aspen	CGCM1	1975-1990	3.7 (3.1)	4.3 (3.9)	1,198 (2,444)	78	5.1	4.4 (1.4)	2.4 (1.7)
		2080-2100	4.5 (3.6)	5.5 (4.6)	1,351 (2,301)	56	7.1	5.4 (2.0)	3.2 (2.6)
		2080-2100 with suppression	6.0 (4.1)	7.3 (5.1)	1,344 (1,430)	65	6.2	5.0 (1.8)	3.6 (2.6)
	HadCM3	1975-1990	2.4 (1.6)	2.3 (2.2)	322 (312)	78	5.1	4.9 (1.6)	2.9 (1.8)
		2080-2100	2.6 (2.0)	2.7 (2.6)	420 (440)	62	6.5	6.6 (2.4)	4.2 (2.9)
		2080-2100 with suppression	2.3 (1.8)	2.3 (2.3)	347 (349)	69	5.8	5.2 (2.1)	3.3 (2.5)
Jack Pine	CGCM1	1975-1990	2.5 (2.3)	3.3 (3.2)	15,076 (15,980)	78	5.1	4.5 (2.3)	1.7 (1.8)
		2080-2100	5.0 (4.1)	6.6 (5.7)	26,214 (24,330)	56	7.1	6.2 (1.7)	2.6 (1.8)
		2080-2100 with suppression	4.4 (3.9)	5.9 (5.4)	31,000 (34,096)	65	6.2	5.2 (2.3)	2.2 (1.7)
	HadCM3	1975-1990	1.9 (1.6)	2.1 (2.0)	371 (653)	78	5.1	4.2 (2.0)	1.1 (1.5)
		2080-2100	2.8 (3.0)	3.4 (3.8)	1,199 (2,458)	62	6.5	6.1 (2.7)	2.4 (2.4)
		2080-2100 with suppression	2.4 (2.8)	2.8 (3.6)	1,328 (2,071)	69	5.8	6.0 (2.5)	2.6 (2.1)
Black Spruce	CGCM1	1975-1990	2.7 (2.7)	4.2 (4.0)	22,229 (22,863)	78	5.1	4.6 (1.6)	2.7 (1.5)
		2080-2100	2.5 (2.3)	3.8 (3.5)	21,533 (20,188)	56	7.1	5.4 (1.8)	2.8 (1.5)
		2080-2100 with suppression	3.0 (3.8)	4.5 (5.6)	24,841 (34,039)	65	6.2	5.3 (1.5)	3.0 (1.4)
	HadCM3	1975-1990	1.4 (1.7)	2.0 (2.8)	1,506 (2,422)	78	5.1	5.4 (2.0)	3.2 (1.6)
		2080-2100	1.8 (2.4)	2.8 (3.9)	2,599 (3,756)	62	6.5	5.8 (2.1)	2.8 (1.6)
		2080-2100 with suppression	1.4 (1.4)	2.0 (2.3)	1,878 (2,270)	69	5.8	5.8 (2.6)	2.8 (1.7)

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

a) Wood Buffalo National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
White Spruce	CGCM1	1975-1990	2.4 (2.2)	3.7 (3.4)	22,652 (27,542)	78	5.1	4.5 (1.4)	1.1 (0.3)
		2080-2100	2.6 (2.2)	3.8 (3.3)	20,638 (20,307)	56	7.1	5.2 (1.9)	1.6 (0.9)
		2080-2100 with suppression	3.1 (2.8)	4.5 (4.2)	27,510 (32,813)	65	6.2	4.5 (1.4)	1.7 (0.9)
	HadCM3	1975-1990	0.9 (0.6)	0.9 (0.9)	710 (933)	78	5.1	4.4 (1.8)	1.1 (0.3)
		2080-2100	0.8 (1.0)	1.1 (1.7)	1,046 (1,616)	62	6.5	6.2 (2.3)	1.8 (1.0)
		2080-2100 with suppression	1.7 (1.9)	2.3 (3.0)	2,171 (2,919)	69	5.8	4.6 (1.6)	1.8 (1.0)
White Spruce / Aspen Mixedwood	CGCM1	1975-1990	4.3 (2.8)	5.4 (3.8)	9,296 (15,773)	78	5.1	4.8 (1.9)	2.5 (1.7)
		2080-2100	5.3 (3.7)	6.7 (4.8)	9,353 (22,517)	56	7.1	6.8 (2.8)	4.5 (3.3)
		2080-2100 with suppression	6.8 (4.4)	8.7 (5.7)	12,164 (24,892)	65	6.2	5.3 (2.0)	3.5 (2.1)
	HadCM3	1975-1990	2.0 (1.5)	2.0 (2.0)	605 (852)	78	5.1	4.2 (2.7)	2.2 (1.5)
		2080-2100	2.4 (1.9)	2.6 (2.5)	779 (1,233)	62	6.5	6.8 (2.0)	4.2 (2.3)
		2080-2100 with suppression	2.5 (2.0)	2.7 (2.8)	932 (1,510)	69	5.8	5.0 (2.1)	3.1 (1.8)

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).
b) Elk Island National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles: Simulated Fire Cycle: Years	Fire Cycles: Simulated Fire Cycle: Ave. # Fires per 400-yr Simulation	Fire Cycles: Model Results: Ave. # Fires per 400-yr Simulation	Fire Cycles: Model Results: Ave. # of Fires (>50kW/m) per 400-yr Simulation
Aspen	CGCM1	1975-1990	1.6 (0.7)	1.2 (0.8)	303 (242)	135	3.0	3.5 (2.1)	0.8 (0.8)
		2080-2100	1.4 (1.0)	1.2 (1.2)	430 (362)	57	7.0	6.5 (2.4)	1.7 (1.1)
		2080-2100 managed[1]	2.1 (1.8)	2.0 (2.3)	625 (744)	100	4.0	4.2 (1.9)	1.3 (1.3)
		2080-2100 managed[2]	1.3 (1.3)	1.2 (1.6)	358 (308)	25	16.0	14.0 (3.2)	2.0 (1.5)
		2080-2100 managed[3]	0.6 (0.5)	0.6 (0.5)	210 (214)	15	26.7	21.1 (3.4)	2.0 (1.3)
	HadCM3	1975-1990	2.4 (1.6)	2.3 (2.0)	346 (314)	135	3.0	2.8 (1.6)	1.0 (0.7)
		2080-2100	1.4 (1.0)	1.2 (1.2)	430 (362)	119	3.4	3.2 (1.8)	1.3 (1.0)
		2080-2100 managed[1]	3.7 (4.0)	4.1 (5.2)	624 (785)	100	4.0	3.7 (1.9)	1.2 (1.1)
		2080-2100 managed[2]	2.2 (2.5)	2.4 (3.2)	376 (483)	25	16.0	12.8 (3.2)	2.3 (2.2)
		2080-2100 managed[3]	1.7 (1.3)	1.9 (1.8)	298 (274)	15	26.7	19.1 (4.3)	2.0 (1.5)
Black Spruce	CGCM1	1975-1990	1.1 (1.6)	1.7 (2.6)	6,127 (9,784)	135	3.0	3.4 (1.5)	2.7 (1.3)
		2080-2100	0.7 (0.6)	1.3 (1.3)	4,679 (6,097)	57	7.0	6.1 (2.8)	3.4 (1.8)
		2080-2100 managed[1]	0.7 (0.7)	1.3 (1.4)	4,958 (6,858)	100	4.0	4.5 (2.0)	3.0 (1.7)
	HadCM3	1975-1990	1.6 (1.7)	2.5 (3.1)	2,559 (3,430)	135	3.0	2.9 (1.7)	2.3 (1.2)
		2080-2100	1.7 (2.3)	2.5 (3.6)	3,475 (5,464)	119	3.4	3.2 (2.0)	2.1 (1.5)
		2080-2100 managed[1]	1.9 (3.2)	2.6 (4.7)	3,575 (8,074)	100	4.0	3.5 (1.2)	2.7 (1.2)
White Birch	CGCM1	1975-90	1.8 (4.7)	2.5 (6.2)	768 (1,168)	135	3.0	3.6 (1.5)	1.0 (0.8)
		2080-2100	2.0 (2.6)	2.8 (3.4)	888 (1,016)	57	7.0	3.3 (1.9)	1.4 (1.0)
		2080-2100 managed[1]	1.2 (1.5)	1.7 (1.9)	520 (555)	100	4.0	3.8 (1.4)	1.0 (0.7)
		2080-2100 managed[2]	1.4 (1.7)	1.9 (2.2)	711 (787)	25	16.0	15.6 (3.3)	1.7 (0.9)
		2080-2100 managed[3]	0.9 (1.7)	1.3 (2.3)	470 (816)	15	26.7	24.8 (5.8)	1.9 (1.0)
	HadCM3	1975-90	3.4 (4.4)	4.5 (5.8)	703 (862)	135	3.0	3.1 (1.9)	1.0 (0.7)
		2080-2100	2.0 (2.6)	2.8 (3.4)	888 (1,016)	119	3.4	3.3 (1.9)	1.1 (1.1)
		2080-2100 managed[1]	3.1 (3.4)	4.1 (4.4)	667 (686)	100	4.0	4.2 (2.0)	1.3 (1.0)
		2080-2100 managed[2]	1.9 (2.6)	2.7 (3.4)	424 (527)	25	16.0	13.2 (3.7)	1.8 (1.1)
		2080-2100 managed[3]	1.1 (0.9)	1.6 (1.2)	258 (184)	15	26.7	20.5 (4.9)	1.6 (1.0)

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

b) Elk Island National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
White Birch Aspen Hardwood	CGCM1	1975-90	1.6 (1.1)	1.6 (1.5)	380 (276)	135	3.0	2.5 (1.7)	0.8 (0.9)
		2080-2100	1.7 (1.9)	1.7 (2.4)	515 (489)	57	7.0	6.4 (2.8)	1.3 (1.0)
		2080-2100 managed[1]	1.4 (0.8)	1.2 (0.9)	683 (873)	100	4.0	4.6 (1.8)	1.2 (0.6)
		2080-2100 managed[2]	1.4 (1.4)	1.4 (1.6)	421 (362)	25	16.0	14.4 (3.2)	1.8 (1.4)
		2080-2100 managed[3]	0.9 (1.1)	1.0 (1.3)	348 (249)	15	26.7	22.8 (4.1)	1.4 (0.8)
	HadCM3	1975-90	2.2 (3.0)	2.1 (4.0)	308 (604)	135	3.0	2.6 (1.9)	0.8 (0.8)
		2080-2100	1.7 (1.9)	1.7 (2.4)	515 (489)	119	3.4	2.8 (1.7)	1.0 (1.0)
		2080-2100 managed[1]	3.0 (3.7)	3.5 (4.8)	540 (714)	100	4.0	3.7 (1.7)	1.3 (1.1)
		2080-2100 managed[2]	2.4 (2.9)	2.8 (3.8)	432 (565)	25	16.0	13.0 (3.5)	2.4 (1.6)
		2080-2100 managed[3]	2.2 (2.7)	2.7 (3.6)	407 (544)	15	26.7	19.1 (4.4)	3.2 (2.3)
Aspen / White Spruce Mixedwood	CGCM1	1975-90	1.7 (2.0)	1.7 (2.7)	4,287 (8,271)	135	3.0	2.9 (1.6)	1.2 (0.6)
		2080-2100	1.3 (1.0)	1.3 (1.4)	2,518 (4,636)	57	7.0	6.2 (2.5)	1.6 (0.8)
		2080-2100 managed[1]	1.2 (0.7)	1.3 (1.0)	3,164 (3,795)	100	4.0	3.8 (2.3)	1.0 (0.5)
	HadCM3	1975-90	2.0 (1.5)	2.2 (2.5)	1,668 (2,579)	135	3.0	2.6 (1.5)	1.1 (0.5)
		2080-2100	1.3 (1.0)	1.3 (1.4)	2,518 (4,636)	119	3.4	2.9 (1.4)	1.2 (0.6)
		2080-2100 managed[1]	3.7 (4.7)	4.5 (6.6)	6,137 (13,923)	100	4.0	3.0 (1.8)	1.6 (0.8)

[1] Fire management based on 100-year fire cycle
[2] Fire management based on 25-year fire cycle
[3] Fire management based on 15-year fire cycle

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

c) Prince Albert National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
Aspen	CGCM1	1975-1990	-[2]	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12987	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	4.4 (3.0)	5.2 (3.8)	774 (564)	75	5.33	5.1 (1.8)	4.0 (2.5)
	HadCM3	1975-1990	-	-	-	14286	0.03	0 (0.2)	0 (0)
		2080-2100	4.0 (3.3)	4.4 (3.8)	666 (572)	12500	0.03	0.1 (0.4)	0.1 (0.3)
		2080-2100 managed[1]	1.5 (0.9)	1.3 (1.1)	188 (170)	75	5.33	5.3 (2.5)	2.8 (2.3)
Jack Pine	CGCM1	1975-1990	-	-	-	14286	0.03	0 (0.2)	0 (0)
		2080-2100	-	-	-	12987	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	4.7 (4.5)	6.4 (6.2)	47,028 (68,576)	75	5.33	5.0 (2.5)	3.0 (2.2)
	HadCM3	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12500	0.03	0 (0.2)	0 (0.2)
		2080-2100 managed[1]	1.1 (1.8)	1.2 (2.2)	407 (348)	75	5.33	5.6 (2.7)	1.0 (1.6)
White Spruce	CGCM1	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12987	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	2.0 (2.5)	3.2 (3.9)	34,567 (49,263)	75	5.33	4.0 (1.7)	1.0 (0)
	HadCM3	1975-1990	4.3 (-)	7.9 (-)	96,340 (-)	14286	0.03	0 (0.2)	0 (0.2)
		2080-2100	0.9 (0.8)	0.6 (0.5)	256 (65)	12500	0.03	0.1 (0.3)	0.1 (0.3)
		2080-2100 managed[1]	0.8 (0.6)	0.8 (1.1)	779 (1,202)	75	5.33	4.5 (1.7)	1.0 (0.2)
Black Spruce	CGCM1	1975-1990	-	-	-	14286	0.03	0.1 (0.3)	0.1 (0.3)
		2080-2100	1.5 (-)	2.1 (-)	28,987 (-)	12987	0.03	0 (0.2)	0 (0.2)
		2080-2100 managed[1]	2.2 (2.7)	3.4 (4.0)	29,542 (36,628)	75	5.33		
	HadCM3	1975-1990	8.7 (-)	13.7 (-)	157,577 (-)	14286	0.03	0 (0.2)	0 (0.2)
		2080-2100	-	-	-	12500	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	0.9 (1.0)	1.1 (1.6)	967 (1,289)	75	5.33	5.6 (1.8)	2.8 (1.4)

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).
c) Prince Albert National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m²)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
Jack Pine / Black Spruce Mixedwood	CGCM1	1975-1990	0.4 (0.1)	0.2 (0.1)	110 (49)	14286	0.03	4.8 (2.3)	2.0 (1.3)
		2080-2100	5.4 (-)	7.3 (-)	46,752 (-)	12987	0.03	0 (0.2)	0 (0.2)
		2080-2100 managed[1]	2.3 (2.1)	3.2 (2.9)	25,984 (27,254)	75	5.33	5.6 (1.7)	3.1 (1.7)
	HadCM3	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12500	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	1.0 (0.8)	1.0 (1.1)	622 (643)	75	5.33	4.4 (2.5)	2.5 (1.7)
Jack Pine / White Spruce Mixedwood	CGCM1	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	3.0 (-)	5.2 (-)	4,675 (-)	12987	0.03	0 (0.2)	0 (0.2)
		2080-2100 managed[1]	2.3 (2.1)	3.2 (2.9)	25,984 (27,254)	75	5.33	4.8 (2.1)	2.8 (1.7)
	HadCM3	1975-1990	1.4 (-)	2.6 (-)	23,511 (-)	14286	0.03	0 (0.2)	0 (0.2)
		2080-2100	0.5 (-)	0.26 (-)	242 (-)	12500	0.03	0 (0.2)	0 (0.2)
		2080-2100 managed[1]	1.4 (1.5)	1.3 (1.9)	506 (752)	75	5.33	5.5 (3.0)	2.6 (2.2)
Jack Pine / Aspen Mixedwood	CGCM1	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12987	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	4.7 (3.2)	5.6 (4.0)	2,624 (5,149)	75	5.33	4.6 (1.7)	3.6 (2.0)
	HadCM3	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	-	-	-	12500	0.03	0 (0.2)	0 (0.)
		2080-2100 managed[1]	1.8 (1.4)	1.7 (1.8)	274 (273)	75	5.33	6.1 (2.3)	4.0 (2.7)
White Spruce / Aspen Mixedwood	CGCM1	1975-1990	1.4 (-)	0.9 (-)	681 (-)	14286	0.03	0 (0.2)	0 (0.2)
		2080-2100	-	-	-	12987	0.03	0 (0)	0 (0)
		2080-2100 managed[1]	4.4 (3.4)	5.6 (4.5)	16,436 (49,046)	75	5.33	4.5 (2.5)	3.0 (2.8)
	HadCM3	1975-1990	-	-	-	14286	0.03	0 (0)	0 (0)
		2080-2100	1.2 (-)	0.8 (-)	478 (-)	12500	0.03	0.1 (0.3)	0 (0.2)
		2080-2100 managed[1]	1.6 (1.2)	1.5 (1.6)	339 (489)	75	5.33	5.8 (2.3)	4.2 (2.2)

[1] Fire management based on a 75-year fire cycle.
[2] No fires.

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

d) Riding Mountain National Park

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles: Simulated Fire Cycle: Years	Fire Cycles: Simulated Fire Cycle: Ave. # Fires per 400-yr Simulation	Fire Cycles: Model Results: Ave. # Fires per 400-yr Simulation	Fire Cycles: Model Results: Ave. # of Fires (>50kW/m) per 400-yr Simulation
Aspen	CGCM1	1975-1990	1.9 (1.2)	1.9 (1.5)	3,269 (3,170)	217	1.8	1.6 (1.3)	0.7 (0.7)
		2080-2100	4.6 (3.9)	5.2 (5.0)	5,423 (8,167)	137	2.9	2.6 (1.4)	1.7 (1.5)
		2080-2100 managed[1]	4.3 (3.1)	5.1 (3.9)	3,274 (5,943)	100	4.0	3.4 (2.0)	2.0 (1.8)
		2080-2100 managed[2]	3.1 (2.3)	3.7 (3.0)	2,020 (3,776)	50	8.0	7.4 (2.5)	3.9 (3.0)
		2080-2100 managed[3]	2.4 (2.1)	2.9 (2.8)	2,202 (3,420)	25	16.0	10.0 (3.9)	3.8 (3.7)
	HadCM3	1975-1990	2.0 (1.2)	1.7 (1.4)	233 (178)	217	1.8	1.5 (1.0)	0.5 (0.7)
		2080-2100	3.1 (2.8)	3.3 (3.4)	450 (464)	213	1.9	1.6 (1.1)	0.4 (0.7)
		2080-2100 managed[1]	2.4 (1.5)	2.3 (2.0)	380 (333)	100	4.0	3.0 (1.6)	1.5 (1.6)
		2080-2100 managed[2]	1.8 (1.5)	1.8 (2.0)	291 (307)	50	8.0	7.2 (3.1)	3.6 (2.8)
		2080-2100 managed[3]	1.6 (1.4)	1.6 (1.8)	259 (275)	25	16.0	15.0 (3.2)	6.3 (3.0)
White Spruce	CGCM1	1975-1990	1.4 (1.7)	2.8 (2.9)	26,240 (27,606)	217	1.8	1.9 (1.2)	0.8 (0.4)
		2080-2100	2.4 (1.9)	4.2 (3.2)	38,563 (31,649)	137	2.9	3.1 (1.3)	1.0 (0.2)
		2080-2100 managed[1]	1.9 (1.8)	3.3 (2.8)	33,679 (37,201)	100	4.0	3.6 (1.6)	1.0 (0)
		2080-2100 managed[2]	1.5 (1.4)	2.3 (2.1)	16,620 (17,033)	50	8.0	5.2 (2.1)	1.0 (0)
		2080-2100 managed[3]	1.4 (1.1)	2.0 (1.6)	18,098 (18,603)	25	16.0	9.0 (2.4)	1.0 (0)
	HadCM3	1975-1990	1.3 (0.7)	1.3 (1.7)	1,217 (1,599)	217	1.8	1.7 (1.5)	0.6 (0.5)
		2080-2100	1.7 (1.6)	2.0 (2.5)	2,004 (2,465)	213	1.9	1.7 (1.2)	0.8 (0.4)
		2080-2100 managed[1]	1.1 (0.9)	1.3 (1.6)	1,467 (2,216)	100	4.0	3.8 (1.8)	1.0 (0.4)
		2080-2100 managed[2]	0.7 (0.4)	0.8 (0.7)	851 (861)	50	8.0	7.2 (2.8)	1.0 (0.2)
		2080-2100 managed[3]	0.8 (0.7)	1.0 (1.1)	962 (1,222)	25	16.0	12.6 (2.9)	1.0 (0.2)

Table 9 (continued). Summary of average (+/- SD) head fire intensity, fuel consumption and depth of burn for fires >50kW/m, and fire cycles in the 400-year simulations (see text for fire cycle details).

d) Riding Mountain National Park (continued)

Stand Type	Model Scenario		Depth of Burn (cm)	Fuel Consumption (kg/m^2)	Head Fire Intensity (kW/m)	Fire Cycles			
						Simulated Fire Cycle		Model Results	
						Years	Ave. # Fires per 400-yr Simulation	Ave. # Fires per 400-yr Simulation	Ave. # of Fires (>50kW/m) per 400-yr Simulation
White Spruce / Aspen Mixedwood	CGCM1	1975-1990	2.2 (2.9)	3.1 (3.9)	26,317 (27,314)	217	1.8	1.8 (1.1)	1.0 (0.4)
		2080-2100	4.4 (2.8)	5.8 (3.7)	22,550 (23,778)	137	2.9	2.7 (1.4)	1.8 (1.5)
		2080-2100 managed[1]	3.6 (3.1)	4.6 (3.9)	13,820 (21,174)	100	4.0	3.8 (2.0)	2.0 (1.6)
		2080-2100 managed[2]	3.0 (2.7)	3.6 (3.5)	5,707 (10,552)	50	8.0	7.2 (2.3)	3.4 (2.1)
		2080-2100 managed[3]	1.9 (1.6)	2.3 (2.1)	4,008 (6,377)	25	16.0	10.8 (3.6)	4.0 (3.9)
	HadCM3	1975-1990	1.7 (1.0)	1.5 (1.1)	717 (859)	217	1.8	1.7 (1.1)	1.1 (0.8)
		2080-2100	1.8 (2.2)	1.8 (3.2)	1,150 (3,018)	213	1.9	1.6 (1.2)	1.2 (0.9)
		2080-2100 managed[1]	1.9 (1.6)	1.8 (2.1)	680 (1,126)	100	4.0	4.4 (2.1)	2.5 (2.0)
		2080-2100 managed[2]	2.0 (1.7)	2.3 (2.4)	591 (875)	50	8.0	8.3 (2.4)	4.2 (3.1)
		2080-2100 managed[3]	1.7 (1.3)	1.8 (1.8)	416 (681)	25	16.0	14.4 (3.9)	4.7 (3.6)

[1] Fire management based on a 100-year fire cycle
[2] Fire management based on a 50-year fire cycle
[3] Fire management based on a 25-year fire cycle

Table 10. Comparison of average number of stems per hectare in forest stands during the final 100 years of the 400-year simulations under current and future fire regimes with no change in fire management strategy.

a) Wood Buffalo National Park

Stand Type	Species	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
Aspen	Aw	230	454	810	1090
Jack Pine	Pj	310	714	265	563
Black Spruce	Sb	2665	1842	5298	2072
White Spruce	Sw	6	25	0	0
WhiteSpruce/Aspen Mixedwood	Sw	0	17	23	5
	Aw	112	694	356	1251

b) Elk Island National Park

Stand Type	Species	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
Aspen	Aw	0	5	12	72
Birch	Bw	0	33	6	105
Black Spruce	Sb	4873	4277	4361	5513
White Spruce/Aspen Mixedwood	Sw	130	0	62	61
	Aw	38	0	0	0
Aspen/Birch Mixedwood	Aw	0	35	0	0
	Bw	0	0	0	0

c) Prince Albert National Park

Stand Type	Species	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
Aspen	Aw	0	0	0	0
Jack pine	Pj	0	0	0	0
Black Spruce	Sb	4455	4632	4434	4455
White Spruce	Sw	683	683	658	628
Jack Pine/Aspen Mixedwood	Pj	0	0	0	0
	Aw	0	0	0	0
Jack Pine/Black Spruce Mixedwood	Pj	0	0	0	0
	Sb	4588	4479	4441	4441
Jack Pine/White Spruce Mixedwood	Pj	0	0	0	0
	Sw	683	655	655	678
White Spruce/Aspen Mixedwood	Sw	653	680	680	653
	Aw	0	0	0	0

d) Riding Mountain National Park

Stand Type	Species	CGCM1		HadCM3	
		1975-1990	2080-2100	1975-1990	2080-2100
Aspen	Aw	0	520	27	19
White Spruce	Sw	129	34	246	159
White Spruce/Aspen Mixedwood	Sw	73	35	119	125
	Aw	0	293	85	96

Table 11. Comparison of average number of stems per hectare in forest stands during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

a) Wood Buffalo National Park

Stand Type	Species	CGCM1		HadCM3	
		Current Fire Management	Increased Suppression	Current Fire Management	Increased Suppression
Aspen	Aw	454	594	1090	1067
Jack Pine	Pj	714	462	563	737
Black Spruce	Sb	1842	1429	2072	2588
White Spruce	Sw	25	12	0	76
WhiteSpruce/Aspen Mixedwood	Sw	17	0	5	33
	Aw	694	717	1251	621

b) Elk Island National Park

Stand Type	Species	CGCM1				HadCM3			
		Current Fire Management	Managed 100-Year Cycle	Managed 25-Year Cycle	Managed 15-Year Cycle	Current Fire Management	Managed 100-Year Cycle	Managed 25-Year Cycle	Managed 15-Year Cycle
Aspen	Aw	5	24	0	0	72	52	99	0
Birch	Bw	33	0.1	0	0	105	59	2	0
Black Spruce	Sb	4277	3532			5513	5202		
White Spruce/Aspen Mixedwood	Sw	0	95			61	78		
	Aw	0	0			0	0		
Aspen/Birch Mixedwood	Aw	35	0	0	0	0	0	0.3	0
	Bw	0	0	0	0	0	0	0	0

Table 11 (continued). Comparison of average stem numbers in forest stands during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

c) Prince Albert National Park

Stand Type	Species	CGCM1		HadCM3	
		Current Fire Management	Managed 75 Year Cycle	Current Fire Management	Managed 75-Year Cycle
Aspen	Aw	0	1389	0	800
Jack pine	Pj	0	1019	0	45
Black Spruce	Sb	4632	1671	4455	3992
White Spruce	Sw	683	29	628	0
Jack Pine/Aspen Mixedwood	Pj	0	0	0	0
	Aw	0	856	0	1313
Jack Pine/Black Spruce Mixedwood	Pj	0	235	0	138
	Sb	4479	180	4441	2276
Jack Pine/White Spruce Mixedwood	Pj	0	405	0	432
	Sw	655	0	678	2
White Spruce/Aspen Mixedwood	Sw	680	15	653	0
	Aw	0	752	0	1571

d) Riding Mountain National Park

Stand Type	Species	CGCM1				HadCM3			
		Current Fire Management	Managed 100-Year Cycle	Managed 50-Year Cycle	Managed 25-Year Cycle	Current Fire Management	Managed 100-Year Cycle	Managed 50-Year Cycle	Managed 25-Year Cycle
Aspen	Aw	520	378	452	159	19	338	753	949
White Spruce	Sw	34	6	23	0	159	30	0	0
White Spruce/Aspen Mixedwood	Sw	35	0	0	0	125	6	0	0
	Aw	293	132	203	289	96	495	718	448

Table 12. Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under current and future fire regimes with no change in fire management strategy.

a) Wood Buffalo National Park

Stand Type	Species	Simulation Period	CGCM1							HadCM3						
			Dead Wood	Forest Floor	Trees				Total	Dead Wood	Forest Floor	Trees				Total
					Aw	Pj	Sb	Sw				Aw	Pj	Sb	Sw	
Aspen	Aw	1975-1990	4.14	42.37	40.60				87.10	11.37	97.52	102.51				211.40
		2080-2100	6.44	48.93	41.17				96.55	11.43	95.30	88.89				195.62
Jack Pine	Pj	1975-1990	9.14	51.80		10.87			71.82	10.31	83.58		21.14			115.03
		2080-2100	12.87	49.99		15.91			78.78	14.66	86.28		28.59			129.54
Black Spruce	Sb	1975-1990	13.42	58.80			19.36		91.58	28.76	126.60			34.65		190.01
		2080-2100	11.20	48.64			17.19		77.03	16.51	78.34			27.09		121.94
White Spruce	Sw	1975-1990	1.99	8.66				2.79	13.43	0.00	1.22				0	1.22
		2080-2100	1.31	5.97				1.89	1.22	0.00	0.69				0.76	1.45
White Spruce/Aspen Mixedwood	Sw/Aw	1975-1990	4.72	43.05	42.78			0.00	90.54	11.77	83.22	63.80			8.26	167.06
		2080-2100	8.62	56.52	51.15			1.71	117.99	15.78	117.64	110.26			1.47	245.15

b) Elk Island National Park

Stand Type	Species	Simulation Period	CGCM1							HadCM3						
			Dead Wood	Forest Floor	Trees				Total	Dead Wood	Forest Floor	Trees				Total
					Aw	Bw	Sb	Sw				Aw	Bw	Sb	Sw	
Aspen	Aw	1975-1990	0.40	4.73	2.24				7.37	1.33	13.69	18.22				33.25
		2080-2100	0.93	9.05	9.38				19.35	1.31	28.06	56.64				86.01
Birch	Bw	1975-1990	0.01	11.01		0.42			11.43	1.00	25.82		14.02			40.84
		2080-2100	1.21	38.12		23.92			63.26	1.66	43.15		18.52			63.34
Black Spruce	Sb	1975-1990	31.18	180.08			75.12		286.38	34.08	171.79			68.89		274.76
		2080-2100	20.65	98.32			34.14		153.10	32.52	171.65			69.75		273.92
White Spruce /Aspen Mixedwood	Sw/Aw	1975-1990	3.83	43.38	16.42			25.87	89.50	5.05	25.75	0.08			4.65	35.52
		2080-2100	0.05	2.84	0.12			0.11	3.12	2.46	23.46	3.33			11.30	40.55
Aspen/Birch Mixedwood	Aw/Bw	1975-1990	0.09	2.70	1.40	0.45			4.64	0.58	9.12	6.59	0			16.29
		2080-2100	1.08	9.97	11.08	0.35			22.48	0.30	8.40	8.04	0			16.75

Table 12 (continued). Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under current and future fire regimes with no change in fire management strategy.

c) Prince Albert National Park

Stand Type	Species	Simulation Period	CGCM1 Dead Wood	CGCM1 Forest Floor	CGCM1 Trees Aw	CGCM1 Trees Pj	CGCM1 Trees Sb	CGCM1 Trees Sw	CGCM1 Total	HadCM3 Dead Wood	HadCM3 Forest Floor	HadCM3 Trees Aw	HadCM3 Trees Pj	HadCM3 Trees Sb	HadCM3 Trees Sw	HadCM3 Total
Aspen	Aw	1975-1990	0	0.37	0				0.37	0	0.37	0				0.37
		2080-2100	0	0.37	0				0.37	0.05	3.63	2.53				6.21
Jack pine	Pj	1975-1990	0.00	12.28		0			12.28	0.00	12.28		0			12.28
		2080-2100	0.00	12.28		0			12.28	0.00	12.29		0			12.29
Black Spruce	Sb	1975-1990	26.80	214.21			143.35		384.36	27.49	213.60			142.05		383.14
		2080-2100	27.06	215.58			141.26		383.91	26.80	214.21			143.35		384.36
White Spruce	Sw	1975-1990	49.55	203.21				80.87	333.62	49.23	201.35				78.92	329.50
		2080-2100	49.55	203.21				80.87	333.62	45.59	188.13				74.33	308.05
Jack Pine/Aspen Mixedwood	Pj/Aw	1975-1990	0	0.98	0	0			0.98	0	0.98	0	0			0.98
		2080-2100	0	0.98	0	0			0.98	0	0.98	0	0			0.98
Jack Pine/Black Spruce Mixedwood	Pj/Sb	1975-1990	22.46	198.89		0	142.51		363.86	22.35	199.08		0	143.21		364.63
		2080-2100	21.88	195.78		0	141.52		359.17	22.35	199.08		0	143.21		364.63
Jack Pine/White Spruce Mixedwood	Pj/Sw	1975-1990	49.39	201.48		0		80.87	331.73	47.42	195.87		0		77.63	320.93
		2080-2100	47.41	193.89		0		77.63	318.93	49.53	201.47		0		80.68	331.67
White Spruce/Aspen Mixedwood	Sw/Aw	1975-1990	45.00	177.76	0			76.72	299.49	46.42	181.33	0			79.91	307.67
		2080-2100	46.42	181.33	0			79.83	307.59	44.60	175.72	0			76.72	297.03

d) Riding Mountain National Park

Stand Type	Species	Simulation Period	CGCM1 Dead Wood	CGCM1 Forest Floor	CGCM1 Trees Aw	CGCM1 Trees Sw	CGCM1 Total	HadCM3 Dead Wood	HadCM3 Forest Floor	HadCM3 Trees Aw	HadCM3 Trees Sw	HadCM3 Total
Aspen	Aw	1975-1990	0.22	5.20	4.76		10.18	1.02	17.10	21.81		39.93
		2080-2100	7.01	67.21	104.55		178.77	1.78	24.16	32.10		58.05
White Spruce	Sw	1975-1990	11.02	52.12		15.89	79.03	19.00	87.17		29.16	135.33
		2080-2100	4.80	24.84		6.02	35.65	16.42	71.11		22.54	110.07
White Spruce/Aspen Mixedwood	Sw/Aw	1975-1990	9.03	38.12	0.00	13.52	60.67	12.38	67.12	28.38	15.54	123.43
		2080-2100	10.99	69.82	45.80	6.65	133.26	13.37	80.64	47.92	15.62	157.55

Table 13. Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

a) Wood Buffalo National Park

Stand Type	Species	Fire Management Strategy	CGCM1							HadCM3						
			Dead Wood	Forest Floor	Trees				Total	Dead Wood	Forest Floor	Trees				Total
					Aw	Pj	Sb	Sw				Aw	Pj	Sb	Sw	
Aspen	Aw	current [1]	6.44	48.93	41.17				96.55	11.43	95.30	88.89				195.62
		suppression [2]	8.56	86.02	86.96				181.54	15.85	113.48	117.94				247.27
Jack Pine	Pj	current	12.87	49.99		15.91			78.78	14.66	86.28		28.59			129.54
		suppression	8.63	39.73		9.01			57.37	18.00	104.48		42.39			164.87
Black Spruce	Sb	current	11.20	48.64			17.19		77.03	16.51	78.34			27.09		121.94
		suppression	11.91	50.08			21.43		83.42	17.89	85.80			24.67		128.36
White Spruce	Sw	current	1.31	5.97				1.89	9.17	0.00	0.69				0.76	1.45
		suppression	1.98	6.62				2.95	11.55	9.86	37.70				10.58	58.14
White Spruce/Aspen Mixedwood	Sw/Aw	current	8.62	56.52	51.15			1.71	117.99	15.78	117.64	110.26			1.47	245.15
		suppression	8.13	62.93	69.03			0.00	140.09	10.83	79.91	62.93			2.21	155.88

[1] Current level of fire suppression.
[2] Increased fire suppression.

Table 13 (continued). Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

b) Elk Island National Park

Stand Type	Species	Fire Management Strategy	CGCM1							HadCM3						
			Dead Wood	Forest Floor	Trees				Total	Dead Wood	Forest Floor	Trees				Total
					Aw	Bw	Sb	Sw				Aw	Bw	Sb	Sw	
Aspen	Aw	current	0.93	9.05	9.38				19.35	1.31	28.06	56.64				86.01
		100-yr cycle	0.48	12.89	9.86				23.23	1.04	8.54	12.80				22.38
		25-yr cycle	0	0.05	0				0.05	0.91	5.46	3.94				10.31
		15-yr cycle	0	0.00	0.02				0.02	0.00	0.03	0.89				0.92
White Birch	Bw	current	1.21	38.12		23.92			63.26	1.66	43.15		18.52			63.34
		100-yr cycle	0.88	39.86		10.38			51.12	1.58	27.86		9.54			38.98
		25-yr cycle	0	1.19		0			1.19	0.01	1.54		0.37			1.92
		15-yr cycle	0.00	0.19		0.78			0.97	0.00	0.17		0			0.17
Black spruce	Sb	current	20.65	98.32			34.14		153.10	32.52	171.65			69.75		273.92
		100-yr cycle	21.46	111.74			36.58		169.78	35.09	172.13			60.08		267.30
		25-yr cycle														
		15-yr cycle														
White spruce/Aspen Mixedwood	Sw/Aw	current	0.05	2.84	0.12			0.11	3.12	2.46	23.46	3.33			11.30	40.55
		100-yr cycle	9.44	38.57	0.			14.6	62.61	7.89	49.44	8.67			14.7	80.70
		25-yr cycle														
		15-yr cycle														
Aspen / White Birch Mixedwood	Aw/Bw	current	1.08	9.97	11.08	0.35			22.48	0.30	8.40	8.04	0			16.75
		100-yr cycle	0.24	7.75	4.75	0.31			13.05	0.91	8.59	4.88	0			14.38
		25-yr cycle	0	0.11	0	0			0.11	0.08	1.38	0.29	0.15			1.90
		15-yr cycle	0	0.004	0	0			0.00	0	0.002	1.09	0.19			1.28

Table 13 (continued). Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

c) Prince Albert National Park

Stand Type	Species	Fire Management Strategy	CGCM1							HadCM3						
			Dead Wood	Forest Floor	Trees				Total	Dead Wood	Forest Floor	Trees				Total
					Aw	Pj	Sb	Sw				Aw	Pj	Sb	Sw	
Aspen	Aw	current	0	0.37	0				0.37	0.05	3.63	2.53				6.21
		75-yr cycle	16.58	139.61	160.65				316.84	11.27	118.97	149.68				279.92
Jack pine	Pj	current	0.00	12.28		0			12.28	0.00	12.29		0			12.29
		75-yr cycle	21.63	103.02		33.86			158.51	2.88	26.84		4.39			34.11
Black Spruce	Sb	current	27.06	215.58			141.26		383.91	26.80	214.21			143.35		384.36
		75-yr cycle	16.62	94.76			51.53		162.91	27	131.8			52.99		211.79
White Spruce	Sw	current	49.55	203.21				80.87	333.62	45.59	188.13				74.33	308.05
		75-yr cycle	3.83	17.61				4.78	26.22	0.001	1.86				0	1.86
Jack Pine/Aspen Mixedwood	Pj/Aw	current	0	0.98	0	0			0.98	0	0.98	0	0			0.98
		75-yr cycle	14.64	131.89	175.04	0			321.57	16.76	140.17	147	0.41			304.34
Jack Pine/Black Spruce Mixedwood	Pj/Sb	current	21.88	195.78		0	141.52		359.17	22.35	199.08		0	143.21		364.63
		75-yr cycle	7.64	44.13		10.59	2.48		64.84	15.18	97.78		9.37	31.64		153.97
Jack Pine/White Spruce Mixedwood	Pj/Sw	current	47.41	193.89		0		77.63	318.93	49.53	201.47		0		80.68	331.67
		75-yr cycle	15.20	84.41		19		0.00	118.61	19.29	133.91		25.86		1.77	180.83
White Spruce/Aspen Mixedwood	Sw/Aw	current	46.42	181.33	0			79.83	307.59	44.60	175.72	0			76.72	297.03
		75-yr cycle	9.65	76.31	65.77			2.83	154.56	16.90	150.00	151.26			0	318.16

Table 13 (continued). Comparison of average forest stand biomass (t/ha) during the final 100 years of the 400-year simulations under future (2080-2100) fire regimes, and current and adapted fire management strategies.

d) Riding Mountain National Park

Stand Type	Species	Fire Management Strategy	CGCM1					HadCM3				
			Dead Wood	Forest Floor	Trees		Total	Dead Wood	Forest Floor	Trees		Total
					Aw	Sw				Aw	Sw	
Aspen	Aw	current	7.01	67.21	104.55		178.77	1.78	24.16	32.10		58.05
		100-yr cycle	5.94	52.17	54.38		112.49	5.23	58.71	73.88		137.82
		50-yr cycle	5.16	32.54	24.35		62.05	8.10	69.72	49.45		127.27
		25-yr cycle	0.99	6.54	1.66		9.19	8.11	54.54	30.63		93.28
White Spruce	Sw	current	4.80	24.84		6.02	35.65	16.42	71.11		22.54	110.07
		100-yr cycle	1.98	9.10		2.79	13.87	29.78	5.76		0.03	35.57
		50-yr cycle	2.09	8.04		3.05	13.18	0.00	0.64		0.23	0.87
		25-yr cycle	0	0.035		0	0.04	0	0.5		0	0.50
White Spruce/Aspen Mixedwood	Sw/Aw	current	10.99	69.82	45.80	6.65	133.26	13.37	80.64	47.92	15.62	157.55
		100-yr cycle	4.31	51.38	71.5	0	127.19	8.52	78.62	69.38	2.75	159.27
		50-yr cycle	3.9	31.33	30.82	0	66.05	7.03	62.29	57.69	0	127.01
		25-yr cycle	1.44	9.99	3.41	0	14.84	3.97	27.75	13.98	0	45.70

Table 14. Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).

a) Wood Buffalo National Park

		CGCM1			HadCM3	
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	78	56[1]	65[2]	78	62[1]	69[2]
Dead Wood (tonnes)	28,599,439	32,411,872	31,889,543	56,917,394	47,644,081	54,448,149
Forest Floor (tonnes)	165,272,280	164,076,648	192,257,045	332,844,538	294,326,785	317,350,342
Trees (tonnes)						
Aspen	56,172,418	61,208,983	107,969,374	117,670,759	132,057,082	129,662,688
Jack Pine	7,547,595	11,048,098	6,255,580	14,675,596	19,852,472	29,431,080
Black Spruce	22,990,296	20,410,914	25,444,546	41,143,055	32,167,140	29,291,505
White Spruce	561,509	1,313,633	594,632	4,515,830	956,134	3,340,234
Trees Total (tonnes)	87,271,817	93,981,629	140,264,132	178,005,240	185,032,829	191,725,507
Total (tonnes)	281,143,535	290,470,149	364,410,719	567,767,172	527,003,695	563,523,998

[1] Future fire regime, no change in fire management.
[2] Future fire regime, increased fire suppression.

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).

b) Elk Island National Park

Open Aspen Parkland

	CGCM1					HadCM3				
Fire Regime	1975-1990	2080-2100				1975-1990	2080-2100			
Fire Cycle (years)	135	57[1]	15[2]	25[3]	100[4]	135	119[1]	15[2]	25[3]	100[4]
Dead Wood (tonnes)	2,647	4,431	0	0	2,736	6,411	6,355	0	3,460	5,434
Forest Floor (tonnes)	25,986	43,169	38	356	58,621	61,773	118,780	138	20,965	42,574
Trees (tonnes)										
Aspen	8,558	35,629	76	0	37,471	69,249	215,248	3,382	14,973	48,677
White Birch	58	3,341	109	0	1,449	1,957	2,587	0	52	1,332
Black Spruce	2,635	1,197	0	0	1,283	2,417	2,447	0	0	2,108
White Spruce	100	0	0	0	57	18	44	0	0	57
Trees Total (tonnes)	11,352	40,168	185	0	40,260	73,641	220,326	3,382	15,025	52,174
Total (tonnes)	39,986	87,768	223	356	101,617	141,825	345,460	3,520	39,449	100,182

Closed Aspen Parkland

	CGCM1					HadCM3				
Fire Regime	1975-1990	2080-2100				1975-1990	2080-2100			
Fire Cycle (years)	135	57[1]	15[2]	25[3]	100[4]	135	119[1]	15[2]	25[3]	100[4]
Dead Wood (tonnes)	7,193	8,156	0	0	6,102	12,233	11,825	0	4,300	11,190
Forest Floor (tonnes)	54,421	64,193	16	353	84,703	97,508	166,311	155	26,107	73,696
Trees (tonnes)										
Aspen	11,044	46,428	94	0	47,393	87,132	268,278	4,415	18,604	61,380
White Birch	127	1,988	62	0	896	1,123	1,484	39	61	764
Black Spruce	12,562	5,709	0	0	6,117	11,520	11,665	0	0	10,047
White Spruce	367	2	0	0	207	66	160	0	0	209
Trees Total (tonnes)	24,100	54,126	157	0	54,613	99,840	281,586	4,455	18,665	72,400
Total (tonnes)	85,714	126,475	173	353	145,418	209,582	459,723	4,610	49,072	157,286

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).

b) Elk Island National Park continued.

Lower Boreal Mixedwood

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	135	57[1]	100[4]	135	119[1]	100[4]
Dead Wood (tonnes)	5,153	4,607	5,172	7,922	7,270	7,819
Forest Floor (tonnes)	39,181	33,908	50,606	57,042	91,373	48,670
Trees (tonnes)						
Aspen	8,089	22,521	23,665	43,749	136,486	32,160
White Birch	6	337	146	197	261	134
Black Spruce	8,544	3,883	4,161	7,835	7,934	6,833
White Spruce	4,292	18	2,422	771	1,875	2,439
Trees Total (tonnes)	20,931	26,759	30,394	52,552	146,556	41,567
Total (tonnes)	65,265	65,273	86,172	117,516	245,199	98,055

Exclusion Zone

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	135	57[1]	100[4]	135	119[1]	100[4]
Dead Wood (tonnes)	69	141	93	211	204	175
Forest Floor (tonnes)	819	1,431	2,084	2,149	4,322	1,434
Trees (tonnes)						
Aspen	369	1,399	1,471	2,719	8,459	1,929
White Birch	1	47	20	27	36	19
Black Spruce	0	0	0	0	0	0
White Spruce	55	0	31	10	24	31
Trees Total (tonnes)	56	47	51	37	60	50
Total (tonnes)	1,312	3,019	3,700	5,117	13,045	3,588

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).

b) Elk Island National Park continued.

Buffalo Paddock

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	135	57[1]	100[4]	135	119[1]	100[4]
Dead Wood (tonnes)	212	263	186	393	386	350
Forest Floor (tonnes)	1,707	2,249	2,991	3,321	5,929	2,435
Trees (tonnes)						
Aspen	390	1,636	1,720	3,180	9,883	2,233
White Birch	2	141	61	82	109	56
Black Spruce	341	155	166	313	317	273
White Spruce	0	0	0	0	0	0
Trees Total (tonnes)	734	1,932	1,948	3,575	10,308	2,562
Total (tonnes)	2,653	4,444	5,125	7,289	16,623	5,348

[1] Future fire regime, no change in fire management.
[2] Future fire regime, managed 15 year fire cycle.
[3] Future fire regime, managed 25 year fire cycle.
[4] Future fire regime, managed 100 year fire cycle.

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).
c) Prince Albert National Park
Fire Management Zone

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	14,286	14,286[1]	75[2]	14,286	12,500[1]	75[2]
Dead Wood (tonnes)	3,621,934	3,672,383	2,854,137	3,694,099	3,588,346	2,948,569
Forest Floor (tonnes)	20,216,090	20,308,640	20,692,073	20,349,219	20,296,148	23,741,018
Trees (tonnes)						
Aspen	0	0	16,664,788	0	177,360	19,413,279
Jack Pine	0	0	952,531	0	0	403,153
Black Spruce	7,321,976	7,244,969	1,295,165	7,310,116	7,341,075	2,129,597
White Spruce	4,014,150	4,148,750	148,270	4,144,657	3,987,661	4,139
Trees Total (tonnes)	11,336,125	11,393,719	19,060,754	11,454,774	11,506,096	21,950,168
Total (tonnes)	35,174,150	35,374,742	42,606,965	35,498,092	35,390,591	48,639,755

Fire Exclusion Zone

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	14,286	14,286[1]	75[2]	14,286	12,500[1]	75[2]
Dead Wood (tonnes)	1,173,453	1,186,889	948,671	1,194,488	1,162,779	974,492
Forest Floor (tonnes)	6,698,105	6,719,067	6,839,512	6,733,654	6,729,395	7,776,851
Trees (tonnes)						
Aspen	0	0	5,414,264	0	60,574	6,194,756
Jack Pine	0	0	325,292	0	0	147,852
Black Spruce	2,561,151	2,534,140	456,411	2,556,865	2,567,784	746,368
White Spruce	1,243,069	1,281,194	44,790	1,279,577	1,233,782	2,112
Trees Total (tonnes)	3,804,220	3,815,334	6,240,757	3,836,442	3,862,140	7,091,088
Total (tonnes)	11,675,778	11,721,290	14,028,940	11,764,583	11,754,315	15,842,431

[1] Future fire regime, no change in fire management.
[2] Future fire regime, managed 75 year fire cycle.

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).
d) Riding Mountain National Park

Aspen Parkland

	CGCM1					HadCM3				
Fire Regime	1975-1990	2080-2100				1975-1990	2080-2100			
Fire Cycle (years)	217	137[1]	25[2]	50[3]	100[4]	217	213[1]	25[2]	50[3]	100[4]
Dead Wood (tonnes)	294,978	561,289	66,989	340,877	383,412	504,004	512,296	457,348	492,585	846,710
Forest Floor (tonnes)	1,552,501	4,623,483	448,674	2,145,103	3,391,219	3,061,894	3,317,841	3,096,057	4,271,031	3,986,746
Trees (tonnes)										
Aspen	241,466	5,833,062	123,953	1,593,944	3,590,897	1,436,856	2,186,528	1,715,475	3,179,754	4,554,295
White Spruce	415,145	175,174	0	49,382	45,172	653,603	547,308	0	3,724	32,608
Trees Total (tonnes)	656,612	6,008,236	123,953	1,643,326	3,636,069	2,090,458	2,733,836	1,715,475	3,183,478	4,586,904
Total (tonnes)	2,504,091	11,193,008	639,616	4,129,305	7,410,699	5,656,356	6,563,973	5,268,880	7,947,094	9,420,360

Eastern Deciduous

	CGCM1				HadCM3			
Fire Regime	1975-1990	2080-2100			1975-1990	2080-2100		
Fire Cycle (years)	217	137[1]	50[3]	100[4]	217	213[1]	50[3]	100[4]
Dead Wood (tonnes)	135,945	203,114	107,384	119,975	213,828	219,516	160,931	282,158
Forest Floor (tonnes)	652,679	1,541,844	712,577	1,134,523	1,223,604	1,352,815	1,404,132	1,440,636
Trees (tonnes)								
Aspen	57,816	1,676,680	570,119	1,297,030	517,616	816,586	1,114,133	1,514,726
White Spruce	196,666	88,164	14,622	13,376	278,302	247,243	1,103	24,653
Trees Total (tonnes)	254,482	1,764,844	584,741	1,310,406	795,917	1,063,828	1,115,236	1,539,380
Total (tonnes)	1,043,106	3,509,802	1,404,702	2,564,903	2,233,350	2,636,159	2,680,299	3,262,174

Table 14 (continued). Summary of total Park biomass (tonnes) under different model scenarios (summarized by Park management units if applicable).

d) Riding Mountain National Park
Boreal Mixedwood

	CGCM1				HadCM3			
Fire Regime	1975-1990	2080-2100			1975-1990	2080-2100		
Fire Cycle (years)	217	137[1]	50[3]	100[4]	217	213[1]	50[3]	100[4]
Dead Wood (tonnes)	660,649	840,502	381,352	422,249	996,814	1,021,887	585,169	1,116,564
Forest Floor (tonnes)	3,012,314	5,883,338	2,651,808	4,241,074	5,447,179	6,040,051	5,138,128	5,740,943
Trees (tonnes)								
Aspen	135,655	5,286,157	2,247,731	5,154,500	2,052,641	3,331,002	4,317,564	5,602,613
White Spruce	968,986	444,399	55,093	50,397	1,310,670	1,194,930	4,155	139,258
Trees Total (tonnes)	1,104,641	5,730,556	2,302,825	5,204,896	3,363,312	4,525,932	4,321,719	5,741,871
Total (tonnes)	4,777,604	12,454,396	5,335,985	9,868,219	9,807,305	11,587,869	10,045,015	12,599,378

Clear Lake

	CGCM1			HadCM3		
Fire Regime	1975-1990	2080-2100		1975-1990	2080-2100	
Fire Cycle (years)	217	137[1]	100[4]	217	213[1]	100[4]
Dead Wood (tonnes)	23,433	30,821	14,268	33,644	35,724	30,580
Forest Floor (tonnes)	103,303	209,641	153,708	186,055	217,168	218,809
Trees (tonnes)						
Aspen	3,217	174,064	198,288	78,869	129,965	206,657
White Spruce	34,715	16,615	730	42,758	41,198	6,223
Trees Total (tonnes)	37,932	190,679	199,018	121,628	171,163	212,880
Total (tonnes)	164,668	431,141	366,993	341,327	424,055	462,268

[1] Future fire regime, no change in fire management.
[2] Future fire regime, managed 25-year fire cycle.
[3] Future fire regime, managed 50-year fire cycle.
[4] Future fire regime, managed 100-year fire cycle.

each Park were different for the two GCM scenarios because they were calculated as a function of the difference between current and future DMC values, and the two GCM's produced different values. In general, the CGCM1 data produced greater increases in future DMC, so fire cycles were shorter.

The generally higher DMC, BUI and ISI values of the CGCM1 simulation scenarios resulted in greater depths of burn, fuel consumption and fire intensities (Table 9). The only exception to this was Elk Island National Park where these three fire regime characteristics were quite similar between the CGCM1 and HadCM3 simulations. For both GCM scenarios in all Parks, there was a large number of fires with a head fire intensity <50 kW/m (see model results of Table 9). These fires are non-lethal to trees (including regeneration) in the model. The simulation results also show that fire intensities were highly variable (Table 9), indicating fire regimes were a mix of low intensity surface fires and high intensity crown fires.

Species Composition and Stand Biomass

Wood Buffalo National Park

Average stem density of aspen stands increased under future fire regimes (compared to the current 1975-90 fire regime) in Wood Buffalo National Park, although the HadCM3 data produced much higher values (Table 10a, Figure 10a). Higher HadCM3 stem densities were partially the result of a slightly higher fire occurrence rate (Table 9a) which was an artifact of the random ignition process in the model. This caused a greater aspen suckering rate. In combination with this, the lower head fire intensity values of the HadCM3 scenario (Table 9a) caused a lower aspen mortality rate, also promoting higher stem densities. Increased fire suppression in the future resulted in higher stem densities (compared to the future fire regime with no change in fire management) in the CGCM1 simulations and very little change in stem density in the HadCM3 simulations. There are several reasons for this result. Because of stochastic fire simulation in the model, the 16% increase in fire suppression (as measured by future fire cycle lengths with current suppression and with increased fire suppression levels) in the CGCM1 scenario was ineffective in increasing the fire cycle which actually decreased 10%. This indicates that the random nature of fire occurrence had a greater influence on fire cycle length than the increase in fire suppression. In the HadCM3 simulations, an 11% increase in fire suppression resulted in a fire cycle length increase of 15%. However, the average stem density under future fire regimes and current fire suppression levels was already at a very high level (Table 11a; 1090 stems/ha), indicating that stand density was being limited by competition rather than by any fire influence. Therefore, a 15% change in fire cycle length due to fire suppression had a minimal effect on stem density.

Average aspen stand biomass increased under future fire regimes of the CGCM1 scenario (Table 12a) because of the large percentage increase in stem density. The HadCM3 simulations showed a slight decrease in future stand biomass because there was a lower percentage increase in stem density, but the shorter fire cycle length also caused a lower average stand age. This resulted in a lower average biomass per tree, and the overall average stand biomass decreased because the effect of decreased average tree biomass was greater than the effect of increased average stem density.

Figure 10. Average number of mature stems per hectare in Wood Buffalo National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with increased fire suppression. Model results are for (a) aspen, (b) jack pine, (c) black spruce, and (d) white spruce using climate outputs from CGCM1 and HadCM3 Global Circulation Models.

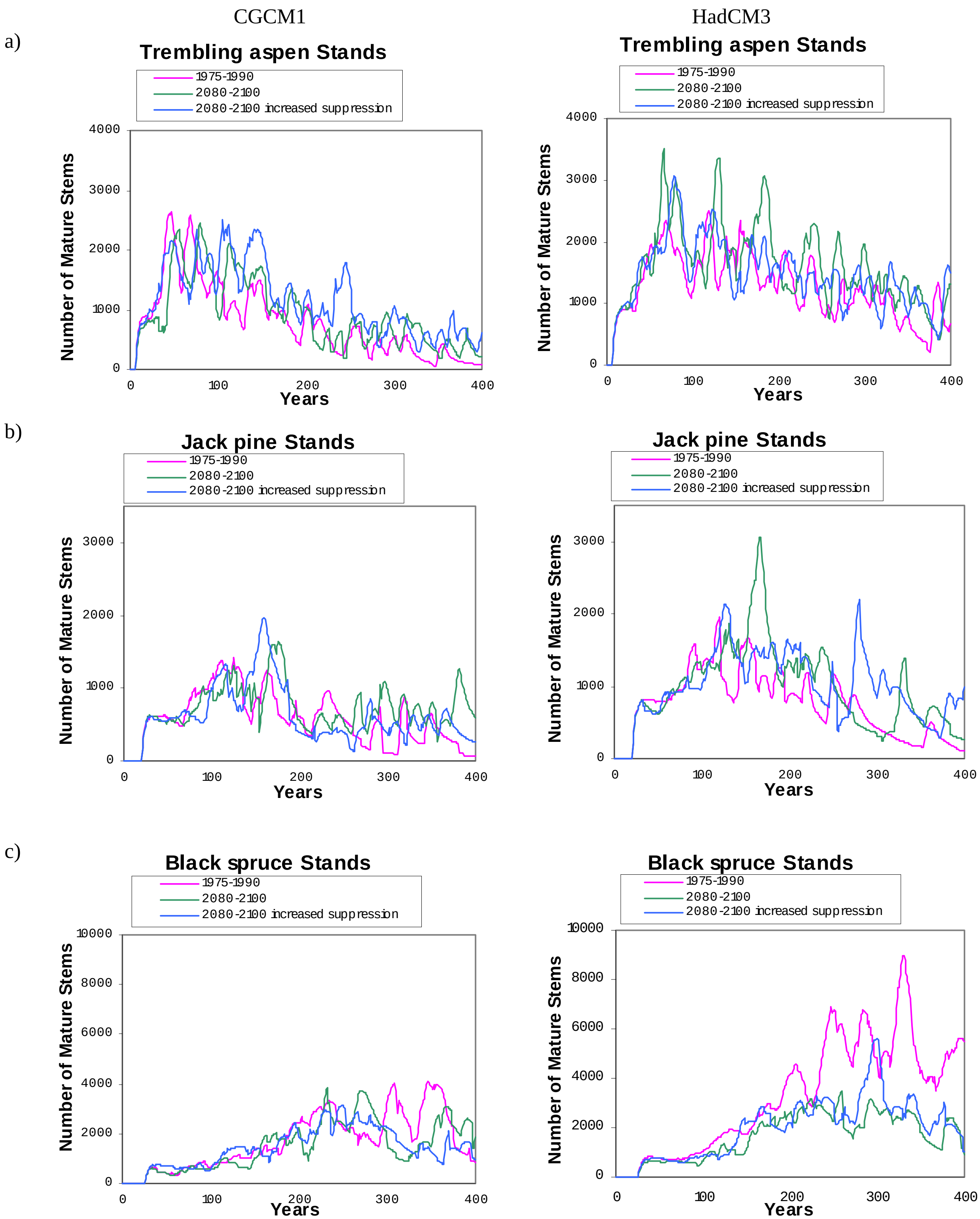
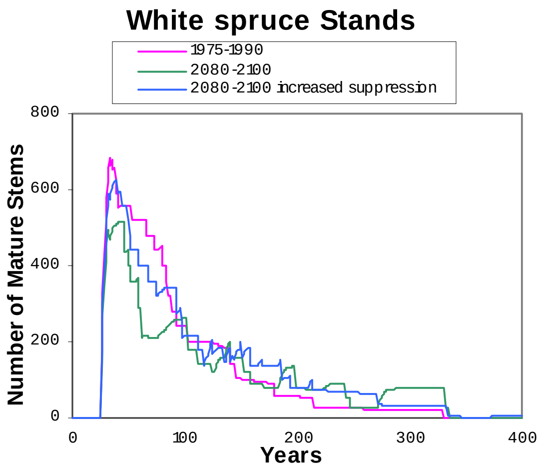
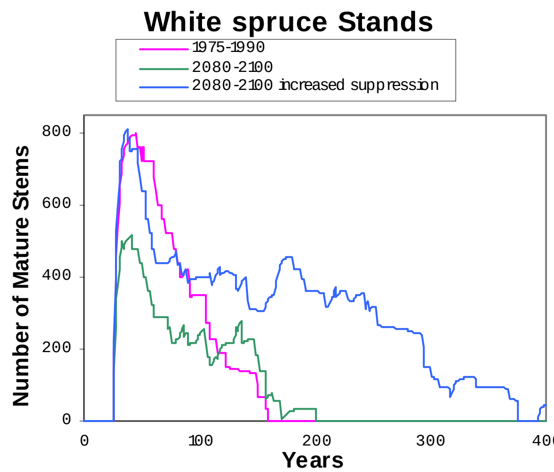


Figure 10 (continued). Average number of mature stems per hectare in Wood Buffalo National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with increased fire suppression. Model results are for (a) aspen, (b) jack pine, (c) black spruce, and (d) white spruce using climate outputs from CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

d)





Under future fire suppression in the CGCM1 scenario, aspen stand biomass almost doubled because of the large increase in stem density (Table 13a). The HadCM3 scenario also showed an increase in stand biomass, but since stem density remained essentially unchanged, this increase was caused by an increased fire cycle length causing an older average stand age and a greater average biomass per tree.

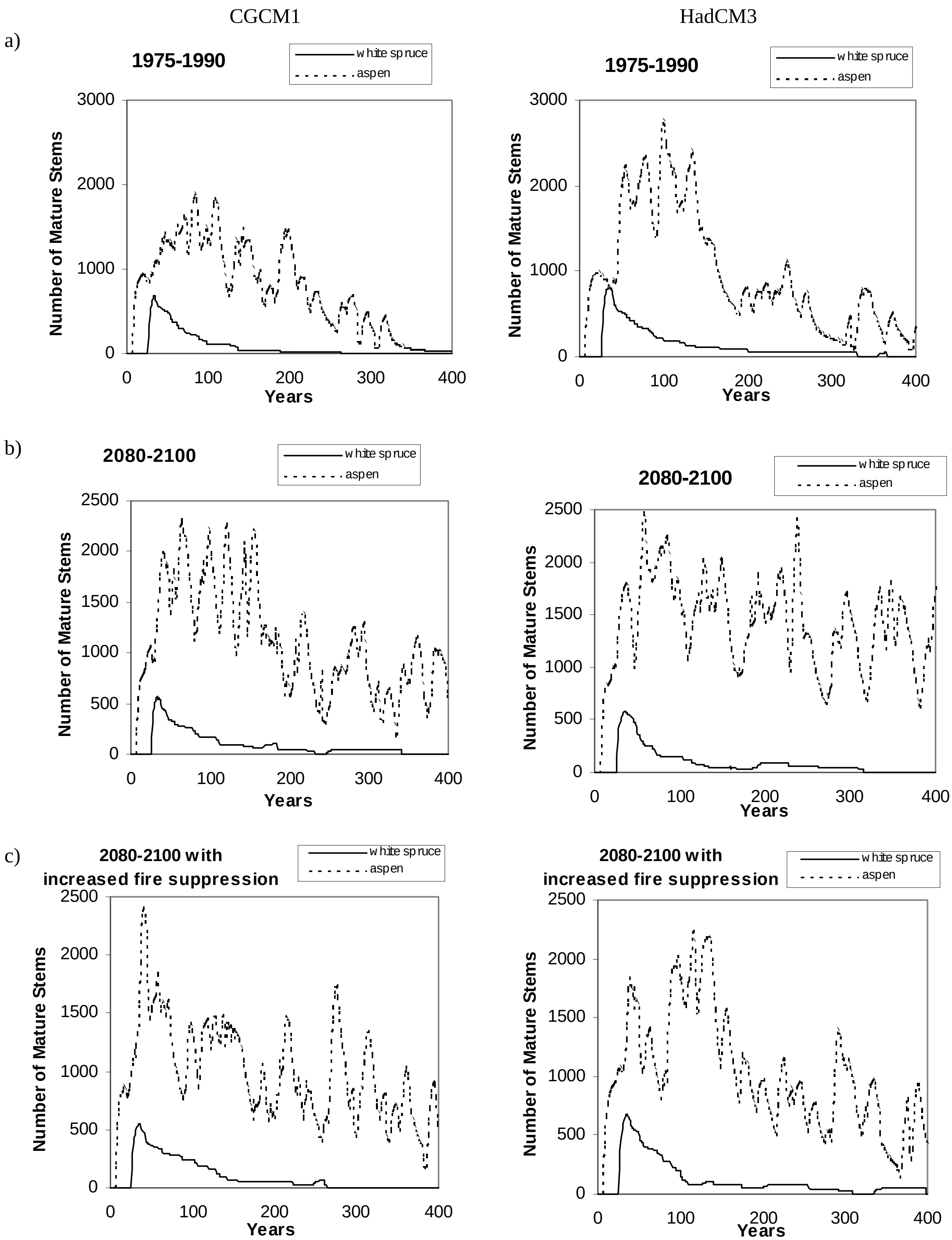
Stem density in jack pine stands under future fire regimes were twice as high as densities under current fire regimes in both GCM scenarios (Table 10a, Figure 10b). This was because the shorter fire cycles of future fire regimes provided greater opportunity for regeneration. Increasing fire suppression in the future resulted in longer fire cycles in the CGCM1 scenario and a decreased jack pine stem density (Table 11a). The HadCM3 scenario resulted in an increased stem density because of a slight increase in the frequency of cone-opening fires >50 kW/m (Table 9a) despite increased fire suppression. This was another effect of the random selection process for fire occurrence. Jack pine stands showed a 10-14% increase in biomass under future fire regimes (Table 12a). Most of the increase occurred in standing live trees although there was also and increase in dead wood biomass. Forest floor biomass slightly decreased in the CGCM1 simulation and slightly increased in the HadCM3 run. Increased fire suppression under future fire regimes resulted in a decrease of biomass using the CGCM1 data and an increase in the HadCM3 simulation Table (13a). The latter resulted from an anomalous decrease in fire cycle length due to the random selection process for fire starts.

Black spruce stands declined sharply in stem density under future fire regimes (Table 10a, Figure 10c). However, all of the CGCM1 scenarios resulted in head fire intensities that were at least an order of magnitude greater than the HadCM3 scenarios (Table 9a). This accounts for the much higher stem densities in the HadCM3 simulations because of lower tree mortality rates. Increased fire suppression in the future caused a decrease in stem density in the CGCM1 scenario, and an increase in stem density in the HadCM3 scenario (Table 11a). This is because tree mortality trends followed head fire intensity trends, and the CGCM1 scenario produced a 15% increase in head fire intensity versus a 28% decrease in the HadCM3 scenario. Under future fire regimes, stand biomass in black spruce decreased 16% in the CGCM1 scenario, and 36% in the HadCM3 scenario (Table 12a). There was a greater decrease in the HadCM3 simulations because of greater increases in fuel consumption and depth of burn rates (Table 9a). Increased fire suppression under future fire regimes only resulted in a 5-8% increase in stand biomass (Table 13a).

Stem density of white spruce stands was very low for all simulations (Table 10a, Figure 10d), although increased fire suppression under future fire regimes produced slightly higher values in the HadCM3 scenario (Table 11a). This was due to the low head fire intensities (Table 9a) and reduced tree mortality in the HadCM3 simulations. White spruce stand biomass followed the same trends as stem density in all scenarios (Table 12a and 13a).

In all mixedwood stand simulations, average white spruce stem densities were very low (<35 stems/ha) (Table 10a and 11a, Figure 11). The aspen component of mixedwood stands showed increased stem densities of 4-6 times under future fire regimes (Table 10a, Figure 11) due to shorter fire cycles causing greater suckering opportunity. Under future fire regimes with increased fire suppression, the HadCM3 scenario showed a sharp decrease in aspen stem density. This was because increased fire suppression increased fire cycle length and reduced the opportunity for suckering regeneration.

Figure 11. Average number of mature aspen and white spruce stems per hectare in mixedwood stands of Wood Buffalo National Park under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with increased fire suppression (c). Model results are based on climate outputs from CGCM1 and HadCM3 Global Circulation Models.



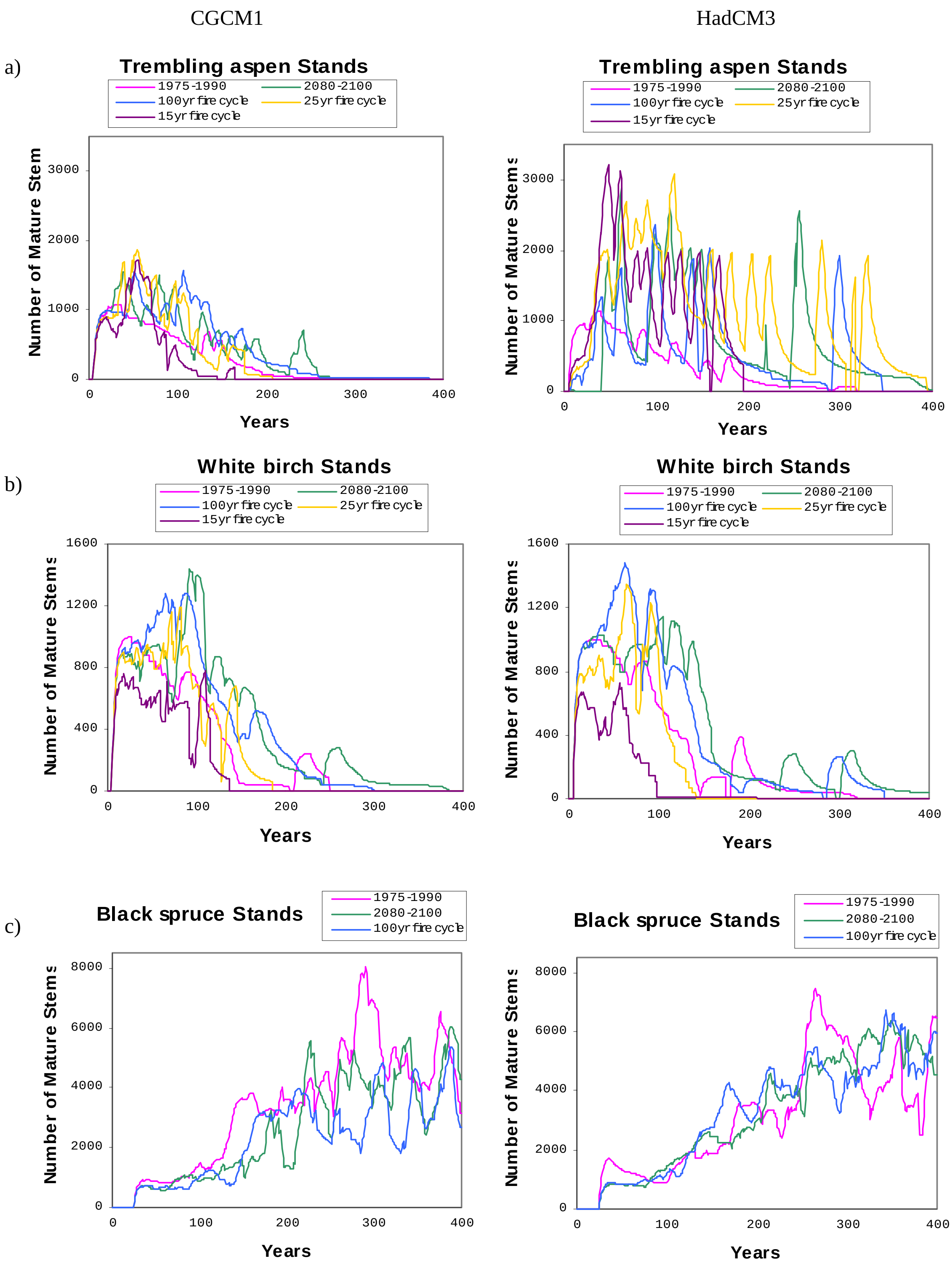
the head fire intensity values of the HadCM3 simulations were very low so tree mortality was a minimal influence on stem density. Average stand biomass of aspen and white spruce followed the trends in stem density values for all simulations (Table 12a and 13a).

Elk Island National Park

The average stem density of aspen stands was very low in all simulations. The current (1975-90) fire regime with a 135-year was too long to support healthy aspen stands with strong post-fire suckering ability (Table 10b, Figure 12a). Future fire regimes had shorter fire cycles (Table 9b) but stem density was still very low in both GCM scenarios (Table 11b). This was due to the prescribed burn nature of fire management used in the model simulations where almost all fire in Elk Island National Park occurred as spring prescribed fire, and occasionally as fall fire. Spring aspen flushing occurred earlier in the HadCM3 scenarios, so there was a greater chance of spring prescribed fires occurring after aspen leaf flush. This timing was critical to aspen re-sprouting because burning before leaf flush girdled the tree and prevented suckering, but burning after leaf flush scorched leaves and induced root suckering. The average Julian fire date of (116 +/-15.8) was much earlier than the aspen leaf flushing date (Table 7) so post-fire suckering opportunity was very low. However, the HadCM3 scenarios had earlier flushing dates, particularly in the 2080-2100 period, so suckering and stem densities were slightly higher.

Aspen stand simulations under future fire regimes and management scenarios of 100-year, 25-year and 15-year fire cycles also showed low stem densities, with the lowest values occurring at the shortest fire cycles (Table 11b). This was because shorter fire cycles increased the rate at which pre-flush fires occurred, preventing any real opportunity to produce root suckers. Trends in stand biomass values followed stem densities for current and future fire regimes (Table 12b) and for future fire management scenarios (Table 13b). The only exception was the 25-year fire cycle in the HadCM3 scenario which showed a lower biomass value despite the higher stem density. This was because the average stand age was very low (<25 years) so there was low biomass per tree.

Figure 12. Average number of mature stems per hectare in Elk Island National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years for all species, and 25-years and 15-years for aspen and white birch. Model results are for (a) aspen, (b) white birch, and (c) black spruce using climate outputs from CGCM1 and HadCM3 Global Circulation Models.



The birch stand results paralleled the aspen results in every way (Table 10b, 11b, 12b, and 13b; Figure 12b). This was because basal re-sprouting of birch in the model used the same seasonal pattern as aspen with respect to timing of spring fire and leaf flush, and the effect on re-sprouting. The only difference is that birch had a slightly later leaf flush date than aspen (Table 7) but this showed little effect in the results.

In contrast to aspen and birch, black spruce stand simulations produced very high stem densities (Table 10b and 11b, Figure 12c). The future CGCM1 scenarios produced slightly lower stem densities because of higher fire intensities (Table 9b) resulting in greater stem mortality and lower total stand biomass values. The HadCM3 scenarios showed very little change in biomass of black spruce stands under the present, future and future managed fire regimes (Tables 12b and 13b) because there was only a small change in fire cycle length (135, 119, and 100 years, respectively).

Average stem densities for white spruce/aspen mixedwoods was very low for both species in all model simulations (Table 10b and 11b, Figure 13). The spring fire regime prevents white spruce from producing a viable seed crop during the year of burn, so regeneration could only occur as an understory invader between fire events. Therefore, longer fire cycles produced higher average white spruce stem densities. The aspen component did equally poor because of the spring fire regime (previously described). As a result, aspen stem numbers were too low to maintain themselves in virtually all simulation scenarios. Stand biomass trends (Table 12b and 13b) followed the same pattern as stem density trends.

Simulation of the aspen/birch hardwood stands showed neither species to be self-sustaining under any of the fire regimes, including the three management scenarios (Table 10b and 11b, Figure 14). The only exception to this was a very low aspen component under future fire regimes in the CGCM1 scenario, but the stem density was too low to be considered a vigorous, self-sustaining stand. Stand biomass trends (Table 12b and 13b) paralleled stem density. These results were a direct result of the inability of aspen and birch to successfully re-sprout under long fire cycles, or under spring burning regimes.

Figure 13. Average number of mature stems per hectare in Elk Island National Park mixedwood forest stands under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 100-years (c). Model results were generated using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

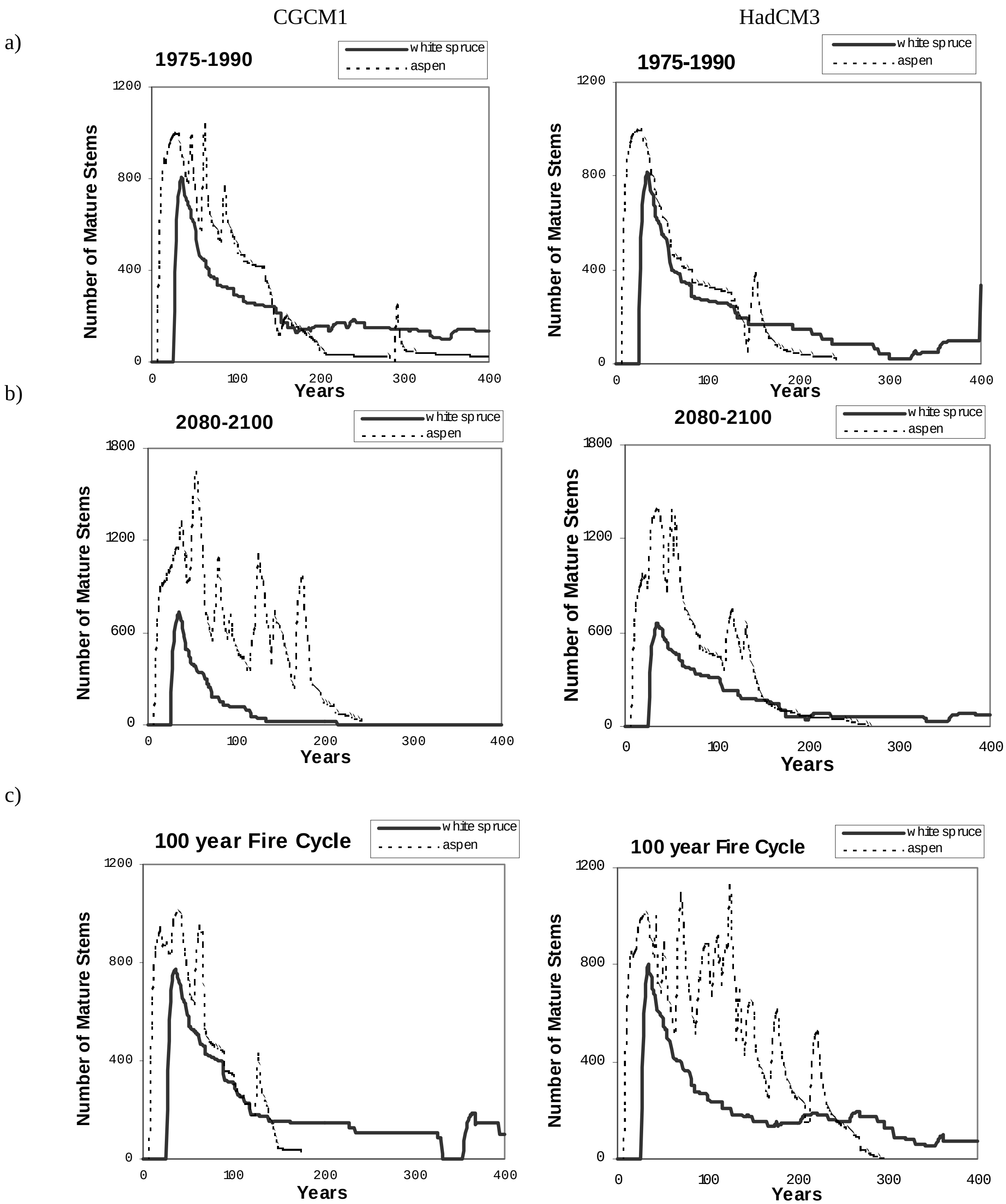


Figure 14. Average number of mature stems per hectare in Elk Island National Park hardwood forest stands under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years (c), 25-years (d) and 15-years (e). Model results were generated using climate outputs from CGCM1 and HadCM3 Global Circulation Models.

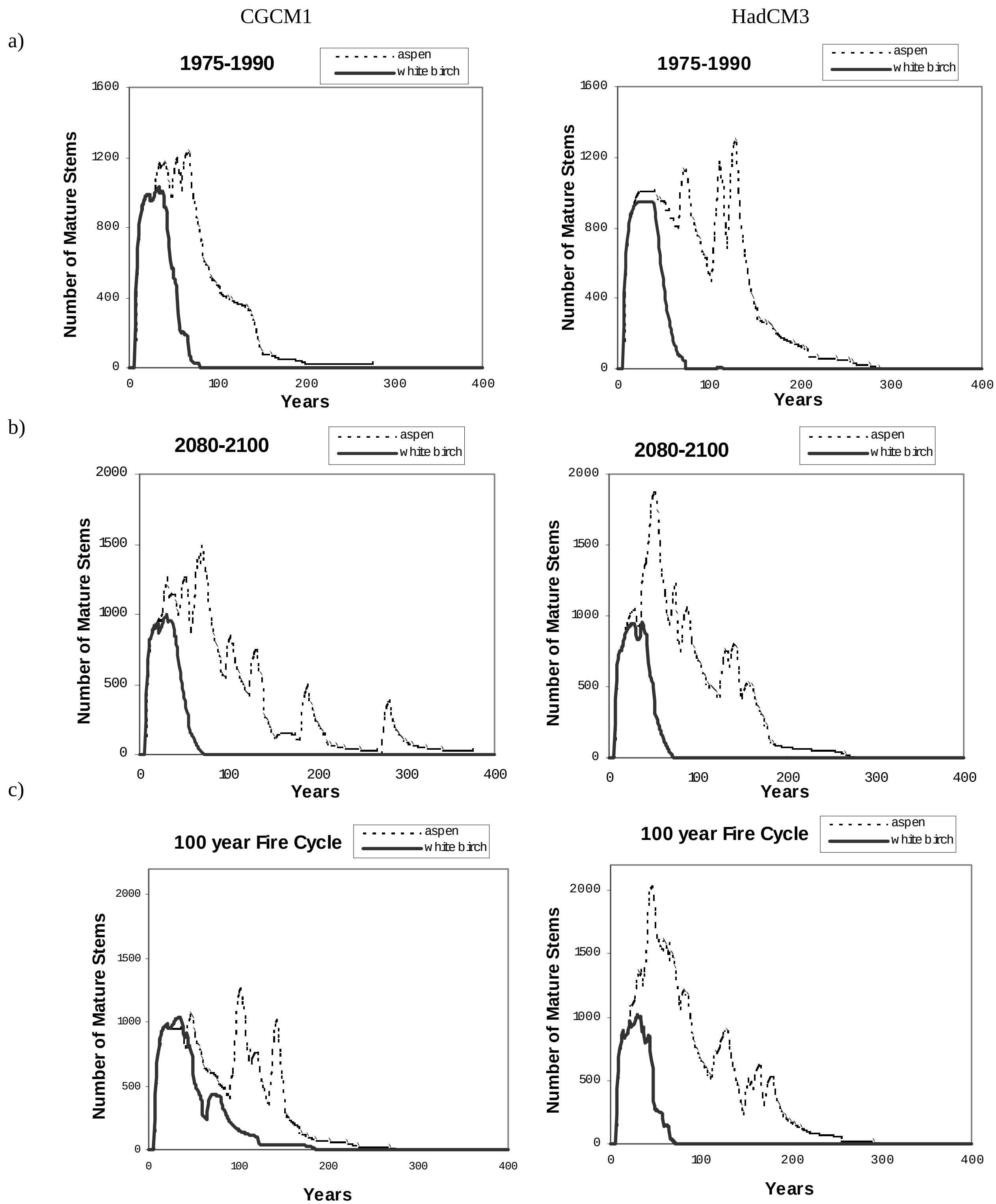
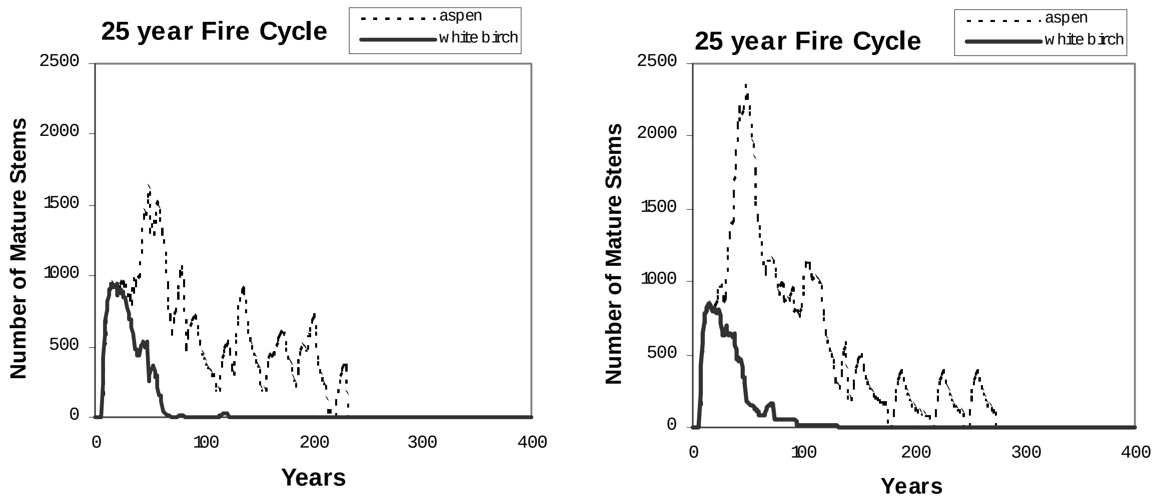


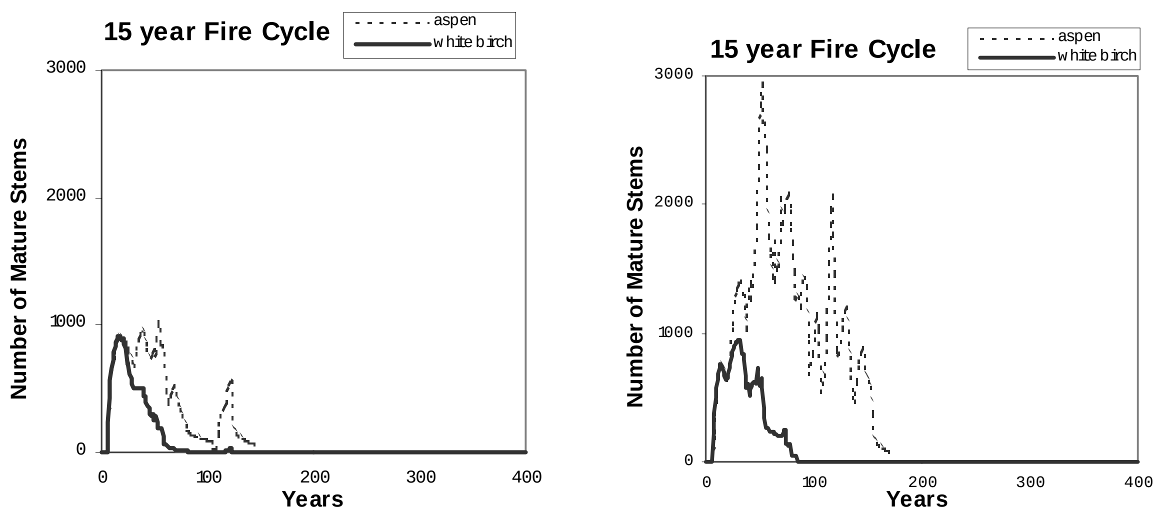
Figure 14 (continued). Average number of mature stems per hectare in Elk Island National Park hardwood forest stands under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years (c), 25-years (d) and 15-years (e). Model results were generated using climate outputs from CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

d)



e)



Prince Albert National Park

The current and future fire regimes with no change in fire management in Prince Albert National Park were essentially fire exclusion simulations. Aspen and jack pine stands were not self-sustaining under those conditions because they require disturbance to maintain vigorous regenerating stands (Table 10c, Figure 15a and 15b). If there was no fire to stimulate suckering in aspen or to open the serotinous cones of jack pine, the stand eventually declined as trees approach their maximum lifespan. However, black spruce and white spruce successfully regenerated in the absence of fire (Table 10c, Figure 15c and 15d). This was because both species produce good seed crops at least every 2-5 years and it was possible for seedlings to become established in new openings as trees died when the stand approached its maximum lifespan. In the model, this was simulated as a 'pulse' of new stems that occurred after the maximum lifespan had been reached (Figure 15c and 15d). Biomass storage in aspen and jack pine stands were extremely low because trees could not regenerate, but the high density stands of black spruce and white spruce had very high biomass levels (Table 12c).

Under a future managed fire cycle of 75 years (Table 11c), aspen and jack pine stands had much higher stem densities. However, the HadCM3 scenario produced much lower head fire intensities than the CGCM1 scenario (Table 9c). This resulted in very few fires >50 kW/m in the HadCM3 future (2080-2100) managed fire scenario for jack pine, causing low stem density. Black spruce stem density was still very high under the managed 75-year fire cycle because it has semi-serotinous cones. Stem density appeared to decrease under the future managed fire cycle, but this was strictly an artifact of averaging the final 100 years of the 400-yr simulation period. As shown in Figure 15c, there was a large 'pulse' of black spruce regeneration in the last 100 years which occurred under current and future fire regimes, but not under the future managed 75-year fire cycle. Averaging the 'pulse' period overestimated the average stem density for current and future fire regimes, and made it appear as if stem densities decreased under the future managed 75-year fire cycle. White spruce is a fire-avoiding species and any increase in fire occurrence will cause a decrease in average stem density. This was reflected in the future managed 75-year fire cycle scenario (Table 11c).

Figure 15. Average number of mature stems per hectare in Prince Albert National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years. Model results are for (a) aspen, (b) jack pine, (c) black spruce, and (d) white spruce using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

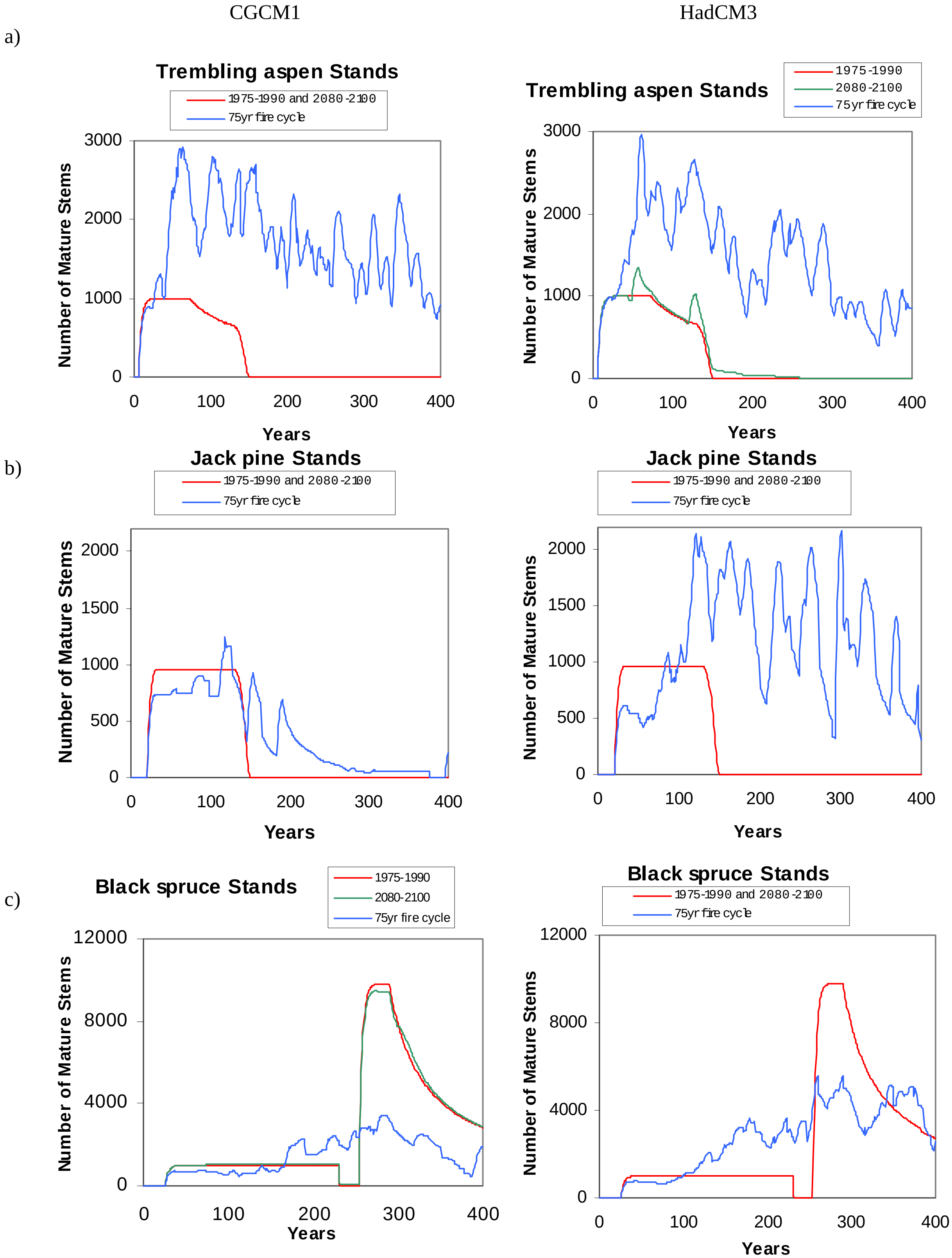
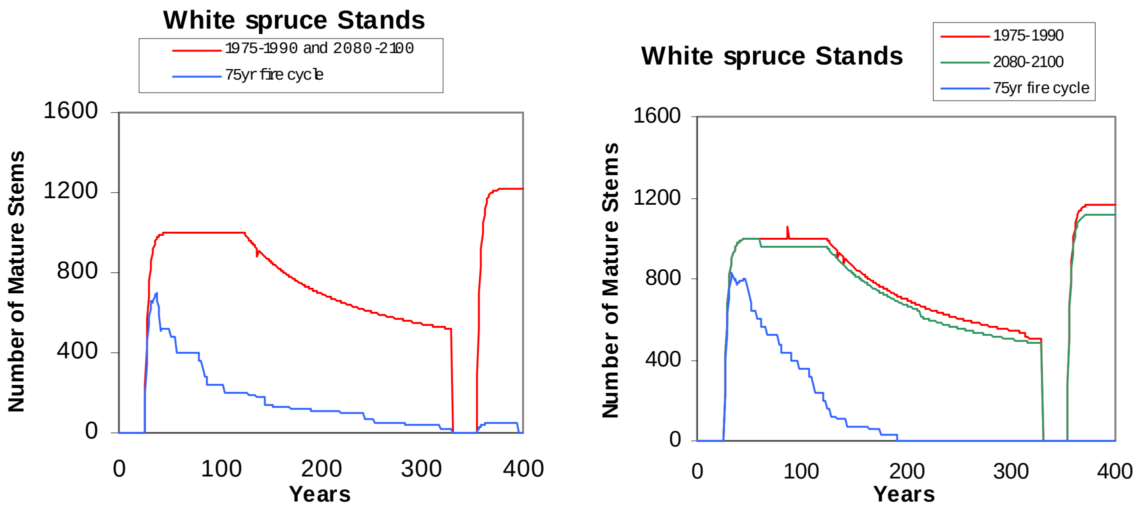


Figure 15 (continued). Average number of mature stems per hectare in Prince Albert National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years. Model results are for (a) aspen, (b) jack pine, (c) black spruce, and (d) white spruce using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

d)



The future managed fire cycle resulted in much greater biomass storage in aspen and jack pine stands, a reduction in black spruce stands, and a large reduction in white spruce biomass storage (Table 13c).

The four mixed stand simulations showed results that largely paralleled the simulation results of individual species (Table 10c and 11c; Figures 16, 17, 18 and 19). In other words, combining species in mixed stands had no effect on how individual species responded to the fire regime and management scenarios, although there were two exceptions to this. The first was the aspen/jack pine mixedwood stand simulation under the managed 75-year fire cycle which showed aspen out-competing jack pine such that the jack pine component was not self-sustaining (Figure 16c). The second was the jack pine/black spruce softwood stand simulation which showed higher jack pine densities in the CGCM1 scenario with more frequent fire and higher fire intensities, and higher density black spruce densities in the HadCM3 scenario with less frequent fire and low fire intensities (Table 9c and Table 11c). Biomass storage trends in mixed stands followed the stand density trends (Table 12c and 13c). and in jack pine/white spruce stands.

Figure 16. Average number of mature stems per hectare in Prince Albert National Park mixed forest stands of jack pine and aspen under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years (c). Model outputs were generated using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

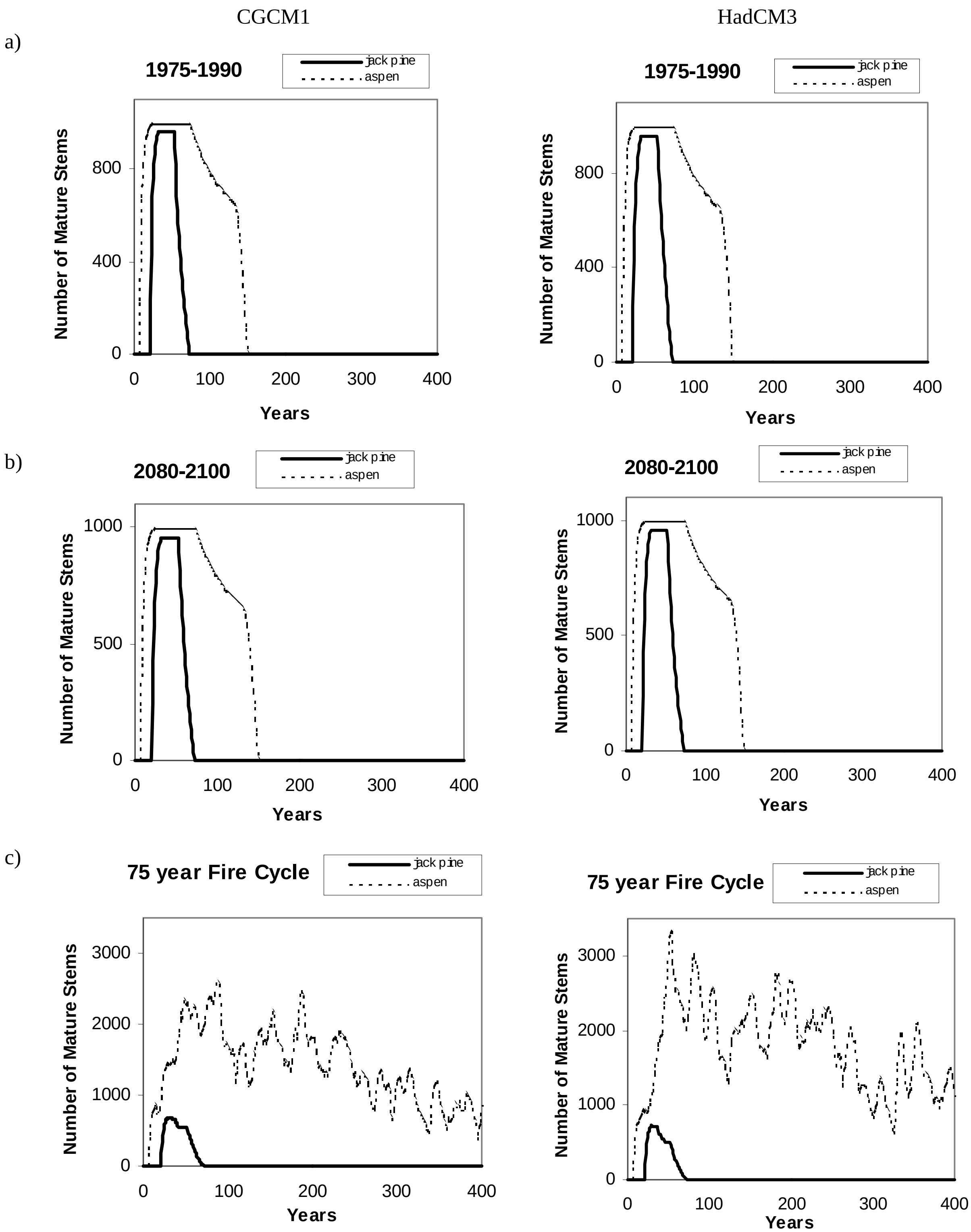
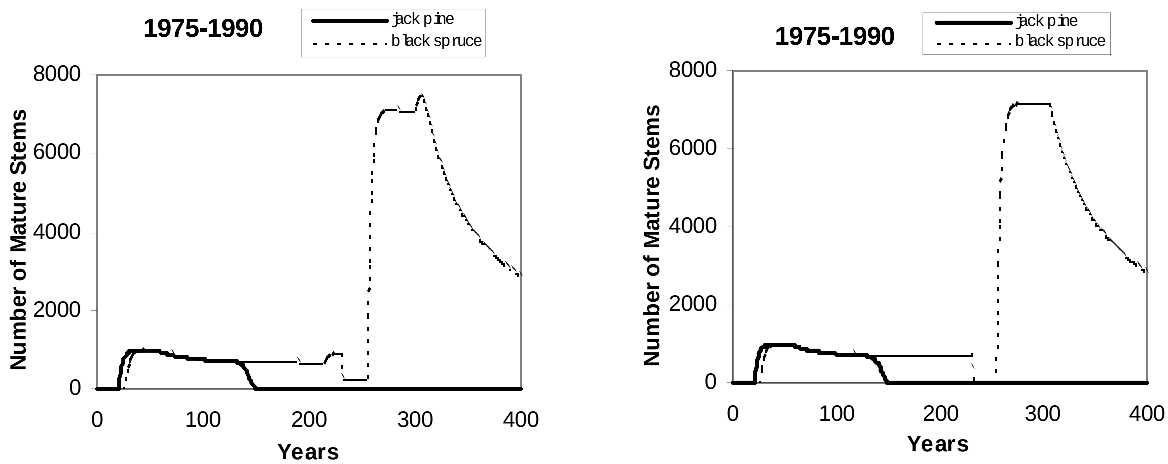


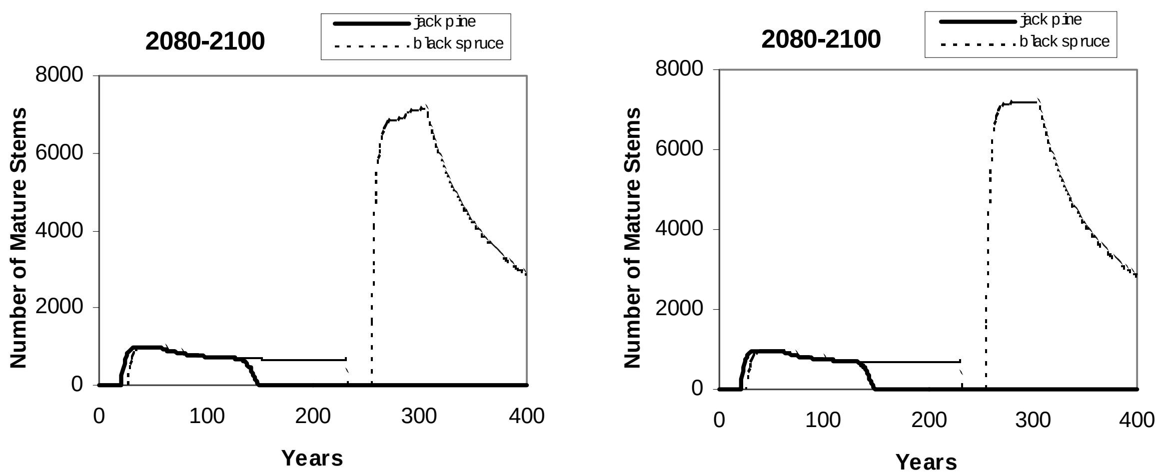
Figure 17. Average number of mature stems per hectare in Prince Albert National Park mixed softwood stands of jack pine and black spruce under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years (c). Model results were generated using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

a)



b)



c)

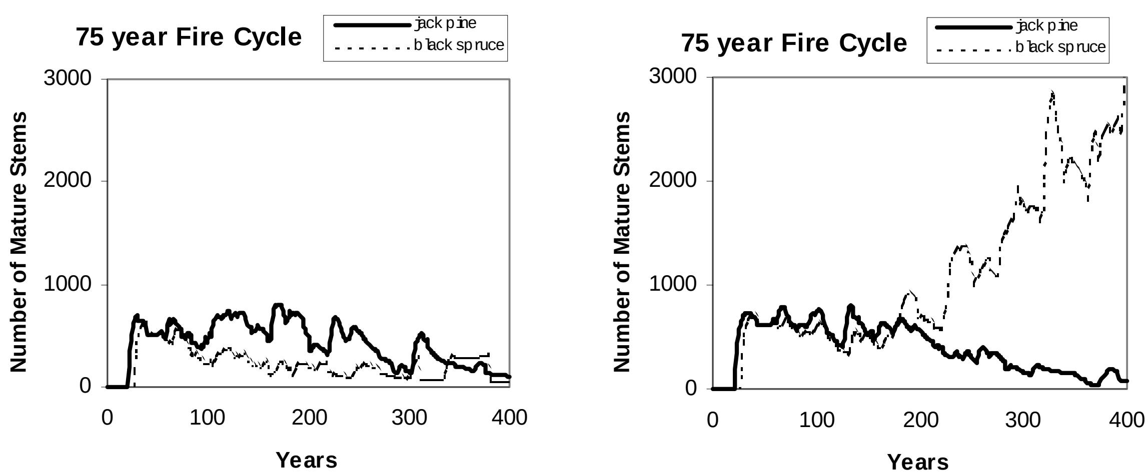


Figure 18. Average number of mature stems per hectare in Prince Albert National Park mixed softwood stands of jack pine and white spruce under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years (c). Model results were generated using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

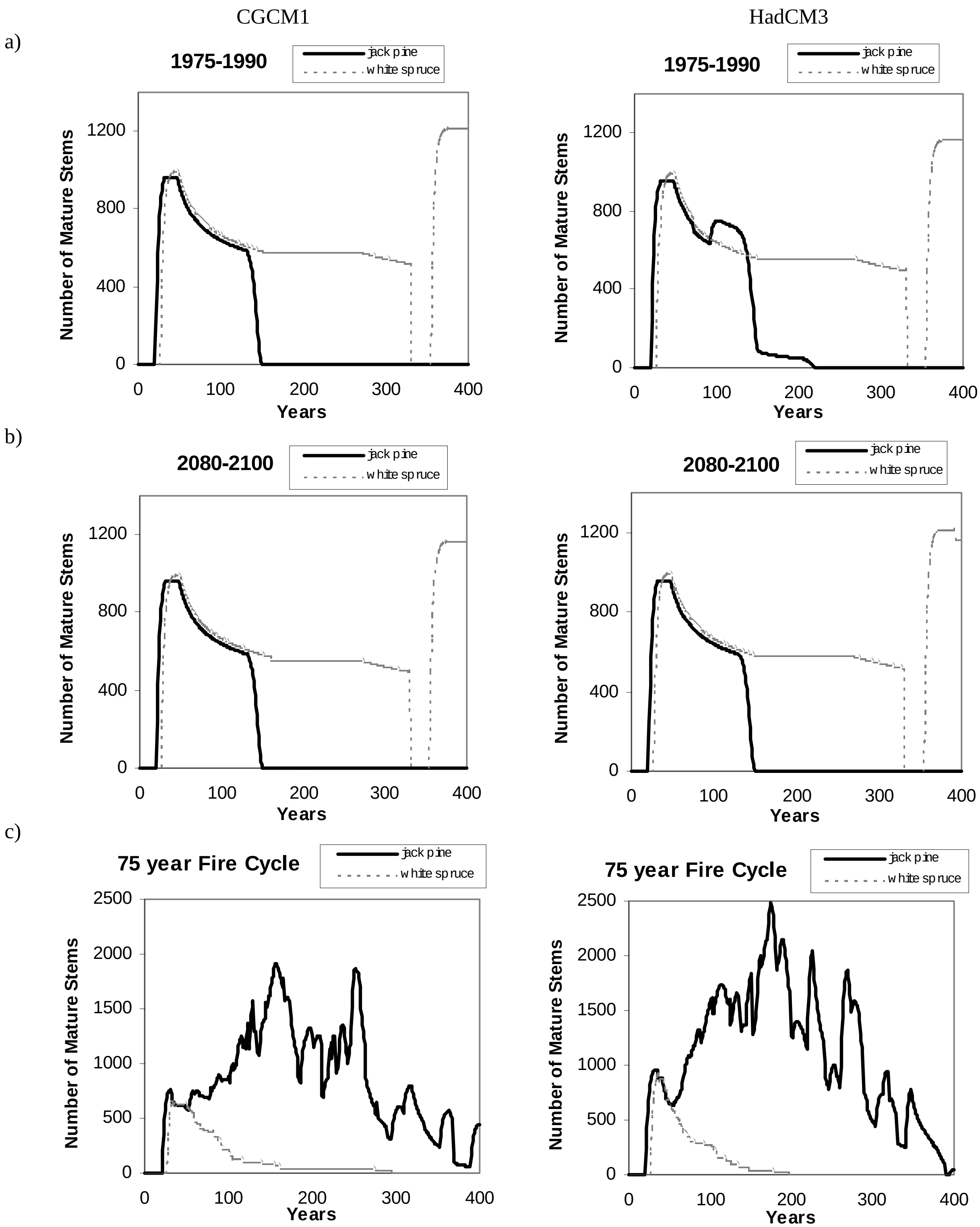
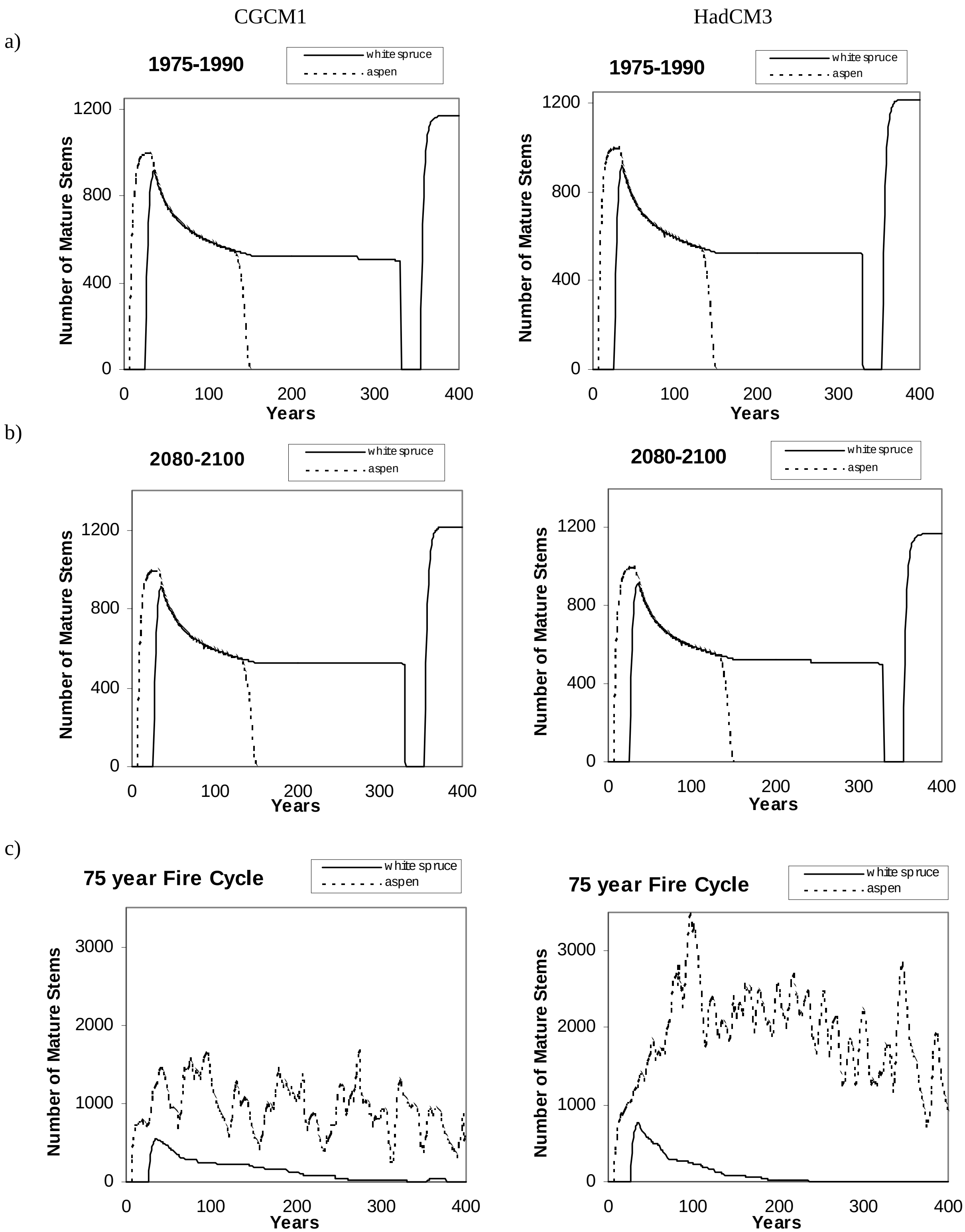


Figure 19. Average number of mature stems per hectare in Prince Albert National Park mixed softwood stands of jack pine and white spruce under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with a managed fire cycle of 75 years (c). Model results were generated using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.



The two GCM scenarios showed opposite trends in biomass storage in white spruce/aspen stands under the managed 75-year fire cycle. This was due to the higher aspen stem densities in the HadCM3 scenario.
In summary, the future managed 75-year fire cycle increased biomass storage in jack pine/aspen stands, and decreased biomass storage in jack pine/black spruce stands,

Riding Mountain National Park

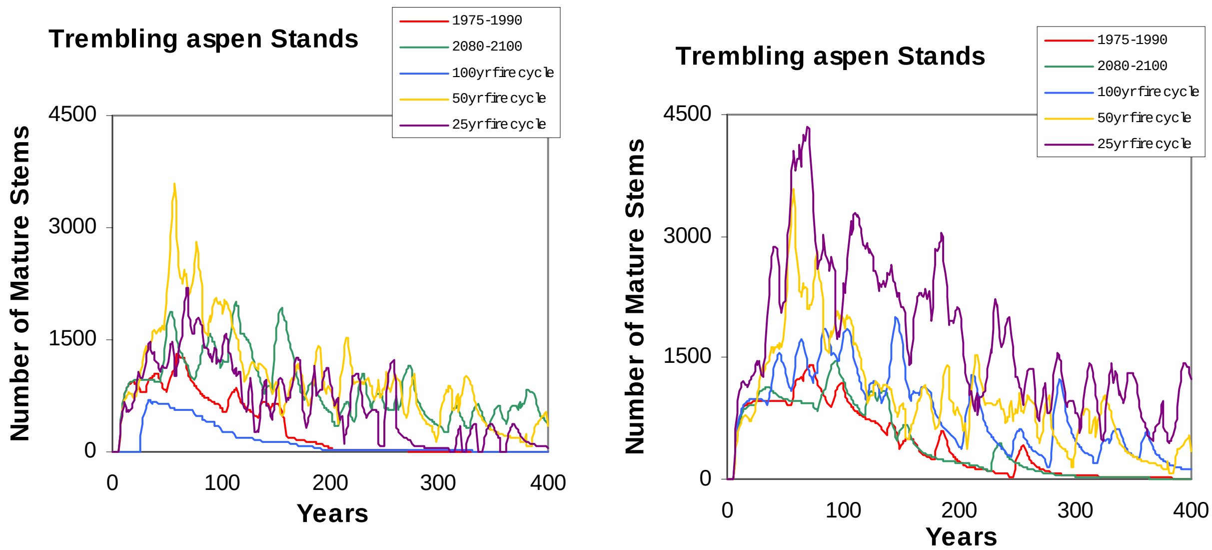
The long current (1975-90) fire cycles in Riding Mountain National Park resulted in conditions that did not promote post-fire suckering in aspen stands, causing low stem densities (Table 11d, Figure 20a). The future fire cycle under the HadCM3 scenarios changed little, but the CGCM1 data produced a much shorter future fire cycle which caused an increase in aspen stem density (Table 10d). Higher stem densities were generally maintained by the shorter managed fire cycles under future conditions with the highest aspen stem density was achieved under the shortest HadCM3 fire cycle (Table 11d). In general, stem density increased with shorter fire cycles of fires >50 kW/m for both GCM scenarios. Aspen leaf flush occurred earlier in the HadCM3 scenarios (Table 7) which promoted aspen suckering and higher stem densities in those simulations due to the prescribed spring fire regime of Riding Mountain National Park. Biomass storage trends in aspen stands followed stem density at longer fire cycles under present and future unmanaged scenarios (Table 12d) but decreased sharply with shorter fire cycles of managed scenarios (Table 13d). The managed fire cycles had higher biomass storage under the HadCM3 scenarios, and this was caused by lower fuel consumption during fires and higher stem densities (Table 9d).

Because of the spring fire regime in Riding Mountain National Park, it was not possible for white spruce to regenerate after any of the fires in the simulations because there was no ripened viable seed after fire. As a result, only stands which did not burn were able to regenerate. This was reflected in the stem density graphs (Figure 20b) which showed unburned stands regenerating when they reached the end of their lifespan at 300 years (plus 25 years for senescence). After a stand burned, biomass no longer accumulated because there were no live trees. The remaining post-fire biomass decomposed and the probability of a second high intensity fire decreased with time. As a result, the white spruce simulation scenarios produced a very low number of fires >50 kW/m (Table 9d).

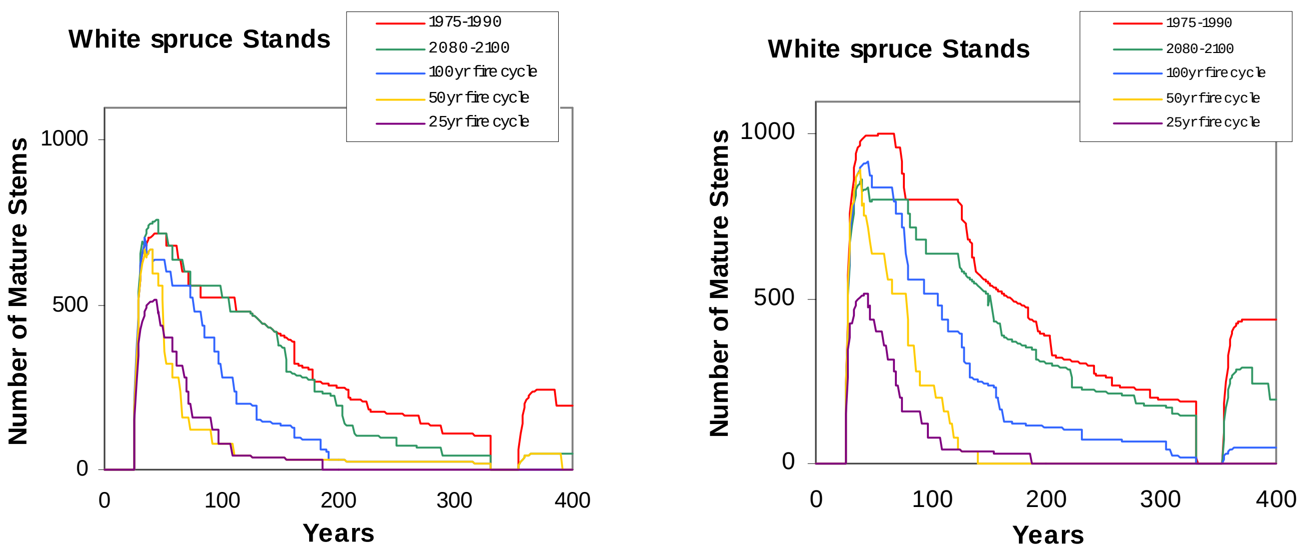
Figure 20. Average number of mature stems per hectare in Riding Mountain National Park forest stands under 1975-90 and 2080-2100 fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years, 50-years and 25-years. Model results are for aspen (a) and white spruce (b) using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

a)



b)



Typically, there was one high intensity fire in each scenario which killed the stand, followed by many fires <50kW/m. In effect, the white spruce scenarios at Riding Mountain National Park reflected the probability of a stand-ending fire under different fire cycles.

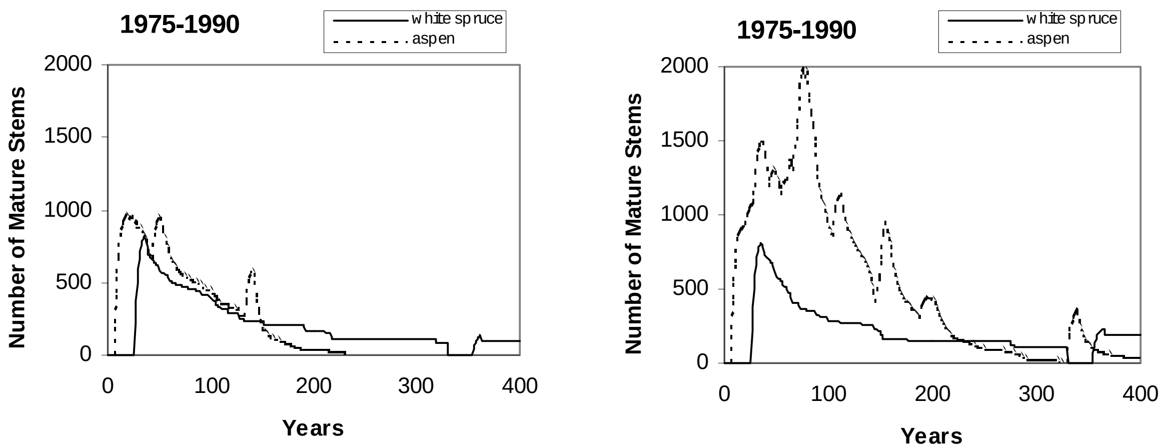
In general, white spruce stands were of high density under the long fire cycles of the present and future fire regimes, although the HadCM3 scenarios produced higher stem densities (Table 10d). This was due to much lower fire intensities (Table 9d) causing minimal tree mortality. White spruce stem density was much lower under the shorter future fire cycles and stands were generally not self-sustaining (Table 11d). Biomass storage trends were identical to stem density trends (Table 12d and 13d).

The white spruce-aspen mixedwood stands responded to the different fire regimes in a similar way to the individual stands of those species. White spruce density was highest and aspen density was lowest at the longest fire cycles (Table 10d, Figure 21). As fire cycles became shorter, aspen was favoured over white spruce (Table 11d). Stand biomass increased when the current long fire cycle of 217 years was shortened to about 100 years (Table 12d) because of the increase in stem density of fast-growing aspen. However, stand biomass decreased at shorter managed fire cycles (Table 13d). Even though aspen density continued to increase at shorter fire cycles, the average biomass per stem decreased because the average stand age decreased as well.

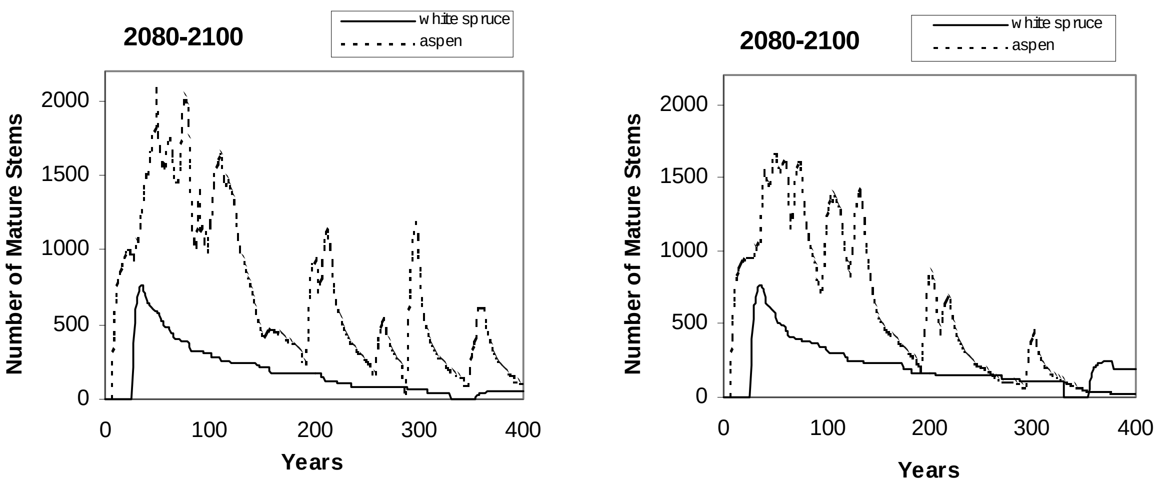
Figure 21. Average number of mature stems per hectare in Riding Mountain National Park mixedwood stands of aspen and white spruce under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years (c), 50-years (d) and 25-years (e). Model results were obtained using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

CGCM1 HadCM3

a)



b)



c)

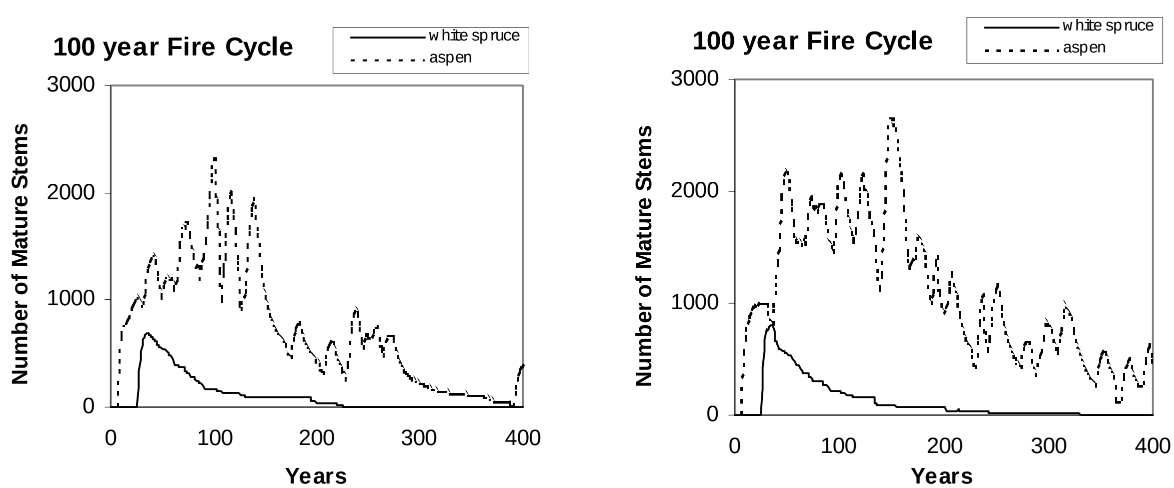
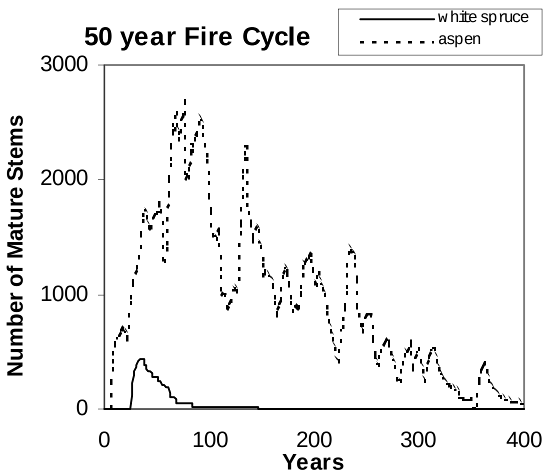
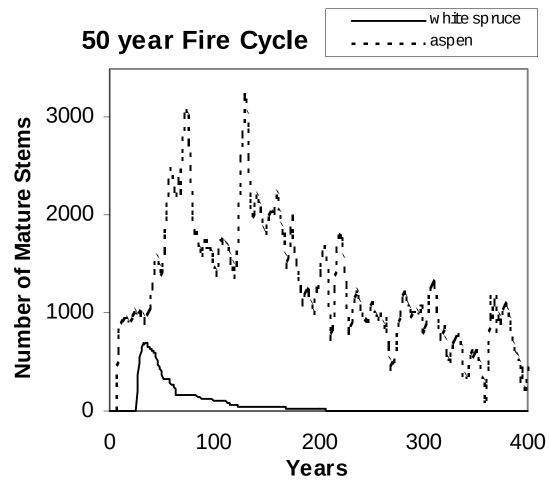


Figure 21 (continued). Average number of mature stems per hectare in Riding Mountain National Park mixedwood stands of aspen and white spruce under 1975-90 (a) and 2080-2100 (b) fire regimes with no change in fire management, and under 2080-2100 fire regime with managed fire cycles of 100-years (c), 50-years (d) and 25-years (e). Model results were obtained using climate outputs from the CGCM1 and HadCM3 Global Circulation Models.

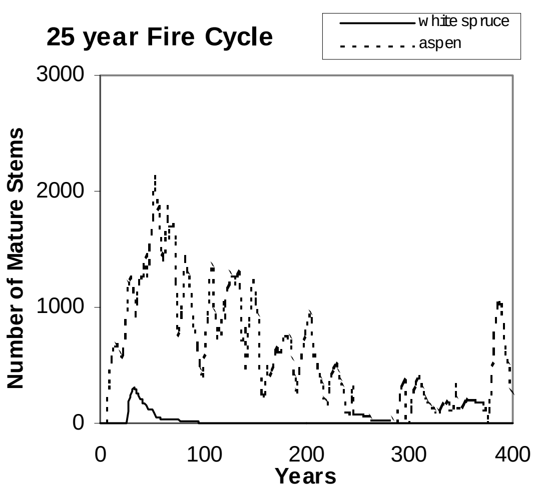
CGCM1 HadCM3

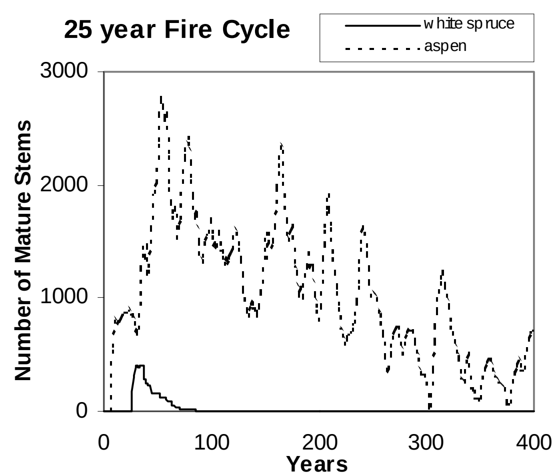
d)





e)





Total Biomass Summaries

Wood Buffalo National Park

Results from the two GCM's produced different biomass storage trends in Wood Buffalo National Park (Table 14a). The CGCM1 simulations showed an increase in total Park biomass storage of 83M tonnes over current biomass levels under future fire regimes and increased suppression. A slight increase of 9M tonnes occurred because aspen and jack pine were favoured by shorter future fire cycles. Increasing future fire suppression produced another increase of 74M tonnes in biomass storage, with about half of this due to increased aspen biomass and the other half due to increased forest floor storage.

This result occurred because each tree species has an optimum fire cycle for carbon storage under particular growing conditions which is determined by the change in stand density and average stem biomass with fire cycle. In this particular case, increased future fire suppression resulted in an average fire cycle of 65 years which was closer to the optimum biomass storage fire cycle for aspen than the future fire cycle of 56 years that would occur with no change in fire management. The significant increase in forest floor biomass storage with increased future fire suppression was due to two factors: an increase in forest floor detrital input due to higher density stands, and a reduction in the number of fires burning forest floor biomass.

The HadCM3 scenarios produced very different results for Wood Buffalo National Park. Biomass levels were almost double the values from the CGCM1 scenarios, and this was due to the much lower fire intensities, depths of burn and fuel consumption of HadCM3 scenarios. In contrast to the CGCM1 results, the HadCM3 simulations also showed a decreasing trend in biomass storage under future fire and management regimes. This is because the HadCM3 simulations indicated a much greater decrease (12%) in forest floor biomass storage due to increased fire occurrence. In contrast, the CGCM1 scenario only decreased 1% because it had a greater increase in forest floor detrital input due to a greater proportional increase in stand density. The HadCM3 scenario indicated that fire suppression increased future total biomass storage, but the overall biomass storage was still below current levels.

Elk Island National Park

Over 90% of the forest in Elk Island National Park is comprised of aspen, so the biomass dynamics under the different scenarios are closely related to aspen. Biomass storage summaries for the different fire regime and management scenarios are presented by land management unit in Table 14b. The two GCM's produced very similar biomass storage trends for Elk Island National Park, although the HadCM3 data produced higher biomass values. This was attributed to the higher aspen stem densities under the HadCM3 simulations which caused higher tree biomass values as well as higher forest floor biomass levels because of greater detrital input to the forest floor. Even though the HadCM3 biomass values appear much greater, it should be noted that with the exception of black spruce, the biomass storage rates (Table 12b and 13b) were low for all Elk Island National Park scenarios. Therefore, the difference in biomass storage values between the two GCM scenarios may appear large when viewed on its own, but the difference isn't so great when compared to the much higher biomass storage rates of other Parks. Similarly, changes in total biomass storage under the different scenarios were also very low (<0.6M tonnes) in comparison to the other Parks.

All land management unit scenarios (except one noted below) showed an increase in biomass storage under future fire regimes with no change in fire management. This was because the current fire cycle of 135 years was not short enough to support self-sustaining aspen stands. The future fire cycle of 119 years in the HadCM3 scenarios provided more opportunity for regeneration after fire. As well, the aspen leaf-flushing date was earlier in the HadCM3 scenarios which meant more fires occurred after flushing, and this contributed to greater regeneration rates. The CGCM1 scenarios had a future fire cycle of 57 years which also increased the opportunity for post-fire regeneration, but the later aspen spring flushing date meant many fires occurred prior to leaf flush. This would girdle trees and prevent regeneration. Therefore, the overall increase in aspen biomass was not as great in the CGCM1 scenarios. Managing the fire cycle for 15 or 25 years in all of these land management units greatly reduced storage in all biomass pools.

The only exception to these results was in the lower boreal mixedwood land management unit where the current fire cycle of 135 years supported the greatest biomass storage in the CGCM1. In that case, there was a larger component of black and white spruce which are both favoured by longer fire cycles. Since all future fire regime and management scenarios had much shorter fire cycles, the overall biomass storage in this land management unit decreased. This did not occur in the HadCM3 scenarios for the lower boreal mixedwood because the future fire regime supported a longer fire cycle of 119 years (versus 57 years in the CGCM1 scenario) which promoted aspen and had less of a negative effect on black and white spruce. Biomass storage decreased with managed fire cycles of 100, 25 and 15 years under both GCM scenarios.

Prince Albert National Park

Data from both of the GCM's resulted in similar biomass levels and trends for all scenarios (Table 14c). The simulation results clearly showed that total biomass storage was much greater under a managed fire cycle similar to the natural fire regime (eg, a 75-year fire cycle) than by managing for fire exclusion. Although the actual current fire cycle of Prince Albert National Park is shorter than simulated, it is still comparatively long (Weir 1996). Based on the range of fire cycles simulated in the other Parks, a reduction in the current actual fire cycle length of Prince Albert National Park under future fire regimes can be expected to increase total Park biomass storage by 10-17M tonnes primarily because of an increase in aspen stem densities. Aspen accounts for about 40% of the forest composition in the Park, so any change in aspen biomass will have a large impact on overall biomass storage.

The HadCM3 scenarios produced slightly higher biomass levels. This was due to greater forest floor and dead wood biomass storage which resulted from very low fire intensities, depths of burn, and fuel consumption (in comparison to the CGCM1 scenarios). The HadCM3 simulations also showed slightly higher tree biomass which increased detrital input to the forest floor and dead wood biomass pools.

Riding Mountain National Park

The simulation scenarios for all fire management zones in Riding Mountain National Park showed increased biomass storage under the future fire regime (Table 14d). This was due to a shorter future fire cycle which increased aspen biomass, and increased forest floor biomass as a result of greater detrital input from aspen. The CGCM1 results were much higher because the simulated future fire cycle was lower at 137 years. The HadCM3 future fire cycle of 213 years was only marginally shorter than the current fire cycle of 217 years, so the increase in biomass storage was very small.

Under the future managed fire cycles, biomass storage decreased with shorter fire cycles in the CGCM1 scenarios. The HadCM3 scenario showed a biomass storage increase under the 100-year managed fire cycle (in comparison to the unmanaged future fire regime) because of the large decrease in fire cycle length (100 vs. 213 years). The HadCM3 managed fire scenarios were higher in total biomass than the CGCM1 scenarios due to lower fuel consumption. The CGCM1 scenario estimates an increase in total Park biomass storage of about 12M tonnes under a future managed fire cycle of 100 years, whereas the HadCM3 scenario estimated an increase of about 8M tonnes. The HadCM3 scenario estimated a smaller future biomass storage increase because of higher estimates for current biomass storage values.

Discussion

Future Fire Regimes and Impacts

The two GCM scenarios used in this study were consistent in showing an increasing fire danger trend in future fire regimes which is in agreement with other climate change and fire studies (Flannigan et al. 2000, Li et al. 2000, Kafka et al. 2001). The future mean monthly values of DMC and BUI, and extreme monthly values of ISI increased for virtually every month in all four study area Parks. The only exceptions occurred in the CGCM1 scenario which showed a slight decrease in future extreme ISI values in Elk Island National Park and Prince Albert National Park, and a slight decrease in average fall DMC and BUI values in Elk Island National Park. The direct impacts of future altered fire regimes were fires with greater depths of burn, greater consumption of aboveground and below-ground fuels, and higher fire intensities. Elk Island National Park was an exception to some of the results because the fire regime was based primarily on an early spring prescribed burn program. The DMC and BUI values at that time of year were generally very low, so future depth of burn and fuel consumption showed little change from current values.

Although both GCM's showed increases in future fire intensity, the CGCM1 model produced much higher values and greater future increases in fire intensity than the HadCM3 model. In general, the North American boreal forest fire regime is one of relatively infrequent (75-125 years), very large, high intensity crown fires (Stocks 1991, Weber and Flannigan 1997, Amiro et al. 2001). This is a reflection of both the climate and the extensive range of crown fire-producing coniferous fuel types. The HadCM3 results do not reflect the high intensity fire regime of the boreal forest in west-central Canada. This was due to the exceptionally low ISI values estimated by the HadCM3 model which caused low rates of fire spread and subsequently, low fire intensity. Examination of the HadCM3 FWI System results indicate that low wind speeds are causing the low ISI estimates. The 1975-90 monthly extreme ISI values from the CGCM1 and HadCM3 scenarios were lower than historical (1953-80) data for the study areas (Harrington et al. 1983), but the latter were exceptionally low. Therefore, the CGCM1 results are expected to be more indicative of future fire intensities. Overall, the 1975-90 average monthly DMC and BUI values from the CGCM1 scenario were higher than the historical data, and the HadCM3 were lower, so the results from both scenarios can be viewed as a probable range of depth of burn and fuel consumption.

The future altered fire regimes also had a substantial impact on forest stand composition and biomass. All simulation scenarios for all Parks showed shorter fire cycles in the future. This favoured aspen, jack pine and white birch which regenerate quickly after fire. There was less of an impact on black spruce which is well-adapted to either long or relatively short (30-50 year) fire cycles. The only declining species under future fire regimes was white spruce which is poorly fire-adapted and is most successful under long fire regimes. Mixed stands showed a greater component of aspen and jack pine under future fire regimes, and less of white spruce. In some cases, mixed stands became pure stands of aspen or jack pine, and white spruce was removed from other stands.

Shorter future fire cycles also caused a decrease in average stand age. For tree species with a shorter (<150 years) lifespan, this shifted the average stand age away from the slow-growing older age-classes towards the younger, fast-growing age-classes. Average stand densities also increased with shorter fire cycles because of the reduced time for competitive thinning. As a result of faster growing trees and higher stand densities, the total amount of biomass stored in many future forest stands increased substantially. This was found to happen in stands of jack pine and white birch, but the effect was most noticeable in aspen which has very high growth rates relative to other boreal tree species.

Aspen accounts for the largest proportion of total forested area in each of the four National Parks in the study. Therefore, future fire regimes with shorter fire cycles caused an increase in total biomass storage in each National Park. The only exception to this was the HadCM3 scenario for Wood Buffalo National Park which showed an increase in tree biomass storage, but a larger decrease in forest floor and dead wood biomass due to greater fire losses from more frequent fire. In the CGCM1 scenario for Wood Buffalo National Park, there was a greater increase in tree biomass which increased detrital input to the forest floor and reduced the overall biomass losses in the forest floor and dead wood biomass pools.

The model simulations indicate that an increase in fire suppression may not necessarily result in a reduction of area burned due to the random nature of fire occurrence and burning conditions. For instance, in the case of fire regime simulations with fire cycles longer than 100 years, the probability of fire is so low that even one or two fires above the average in a 400-year simulation can dramatically change the fire regime and area burned. Of course, this effect is not present in fire regimes with short fire cycles where fire is so frequent that an increase of one or two fires in 400 years is not very influential. However, the study results do indicate that an increase in fire suppression will generally result in a decrease in area burned.

Options for Future Fire Management Adaptation

Each of the four National Park used in the study is in a unique fire management situation, so their options to adapt to future climate change conditions are varied. However, they all share the common mandate of maintaining ecological integrity within each Park. Measures of ecological integrity in National Parks include net primary productivity, population dynamics, species diversity, and succession (Woodley 1993). In terms of forest fire management, this means managing for a fire regime that maintains those measures within the natural range of variability. Measuring the ecological success of fire management is difficult, but the impact of fire on forest composition, stand density, age class distribution, forest floor and dead woody debris serves as a starting point because those factors affect the structure, function and biodiversity of forest ecosystems. Lastly, biomass storage also has a larger environmental impact in terms of climate change because it can serve as either a source or sink of atmospheric carbon. Changes in forest characteristics under future fire regimes, and the impacts of different fire management options in the future, including current fire management strategy (status quo) are summarized for each of the four National Park study areas.

Wood Buffalo National Park

Future changes in the fire regime of Wood Buffalo National Park due to climate change will not cause the loss of any boreal tree species, but it will result in a decrease of white spruce representation in the Park which currently accounts for about 4% of the forest area. White spruce/aspen mixedwood stands will also shift towards greater aspen content and some stands will convert to pure aspen stands. White spruce in pure and mixedwood ecosystems are obviously important to Park biodiversity, so it would be beneficial to adapt future fire management for increased protection of white spruce areas. The model simulations also indicate that white spruce stands were more prevalent under increased fire suppression. Aspen stands will increase in area, and all other forest stand types will remain well-represented under the future fire regime, so there is no need to adapt fire management for those species.

In the future, all forest stand types will show a shift towards a younger age-class distribution. This will reduce the biodiversity represented by older stands in the Park, but the impact could be minimized by increased fire suppression. The CGCM1 scenario indicated that the biggest impact of increased future fire suppression was a significant increase in biomass storage of 83M tonnes. This was due primarily to the fire cycle shifting closer to the age of maximum growth in aspen, which also increased forest floor biomass through increased detrital input. On the other hand, the HadCM3 scenario showed a decreasing amount of biomass storage under future fire regimes.

There appears to be two reasons for this difference between the two GCM's. Firstly, the fire cycle for maximum biomass storage (the highest value in the balance of growth vs. decomposition and fire losses) in the Park appears to be about 66 years, as estimated from simulation results. In the HadCM3 scenario, increasing fire suppression shifted the future fire cycle from 62 years to 69 years, which made it only marginally closer to the fire cycle for maximum biomass storage. On the other hand, the CGCM1 scenario shifted the future fire cycle from 56 to 65 years which was a larger shift towards the fire cycle for maximum biomass storage. It should be recognized that the length of this cycle is primarily dependent on three factors: rate of growth, decomposition rates, and fire effects. Temperature, moisture regime and site quality affect the net rates of growth and decomposition of live and dead biomass. Fire effects are species and site specific, and are dependent on stochastic fire events and physical fire parameters. Therefore, the exact fire cycle length for maximum biomass storage varies between stands (and Parks) because it depends on species composition, location, site characteristics and fire regime.

The second factor affecting biomass storage was the relative amount of dead biomass stored under the two GCM scenarios, as the HadCM3 scenarios stored much more dead biomass than the CGCM1 scenario. Each forest stand has a maximum dead biomass carrying capacity that is attained when the detrital input equals decomposition, and that limit is reached when dead biomass accumulates to a certain level. The HadCM3 scenarios were much closer to the maximum dead biomass storage capacity, so there was less potential to increase biomass storage in that scenario. High dead biomass levels in the HadCM3 scenarios were primarily caused by high detrital input due to high live biomass levels. Lower surface fuel consumption, lower depth of burn and much lower fire intensities which reduced crown fuel consumption also contributed to high dead biomass levels.

Live tree biomass (which is driving the higher dead biomass levels through detritus) in the HadCM3 scenario for 1975-90 were in the range of 115-210 t/ha. These values appear fairly high compared to other boreal estimates of 65 t/ha (Kurz and Apps 1999), 56-108 t/ha (Bonnor 1985) and 30-170 t/ha (others cited in Bonan 1990). The CGCM1 live tree biomass of 71-91 t/ha (for 1975-90) is more in line with published data. Therefore, the CGCM1 biomass results appear more realistic than those from the HadCM3 scenarios, including the potential to increase long-term future biomass storage by 83M tonnes.

Elk Island National Park

Fire management in Elk Island National Park is a unique situation in that the fire regime is almost exclusively the result of prescribed fire, and that prescribed burning is usually done in the spring with a small amount of burning being done in the fall. As well, over 90% of the forested area of the Park is dominated by one tree species (aspen), so maintaining the other mixed species ecosystems in the Park is important.

The two GCM scenarios produced very different future fire regimes for Elk Island National Park, as reflected in the FWI System values. It should be noted that this was the only Park in the study where the HadCM3 scenarios produced higher FWI System values than the CGCM1 scenarios, so there clearly is some dichotomy in the GCM's for this borderline region between prairie and aspen parkland. Although the two GCM scenarios show very different future fire cycles of 57 years and 119 years, they were estimated by future change in DMC values and don't necessarily reflect the fully managed prescribed burn nature of the Park fire regime. However, we can still view the relative impacts of prescribed fire being applied at the simulated fire cycles under future burning conditions.

Because aspen and white birch are species which have a seasonal re-sprouting response to fire, the seasonal aspect of prescribed burning is an important consideration to fire management. In the future, if prescribed burns are done at the same time period in spring and earlier leaf-flushing occurs under future climate, then there is greater potential for re-sprouting of aspen and white birch due to post-flush leaf scorch. For the open aspen parkland units, continuing with early pre-flush spring burns would promote open vegetation. In the closed aspen parkland units, shifting more towards later post-flush burns would promote re-sprouting of aspen and white birch. It should also be noted that some re-sprouting may also occur after a pre-flush burn due to solar heating of the soil which can stimulate root suckering in aspen and birch (Maini and Horton 1966, Steneker 1974, Backéus 1985, de Groot and Wein 1999). Shortening the prescribed fire cycle to 25-

years or 15-years will accelerate the rate at which average stand densities of aspen or white spruce increase or decrease, depending on whether the seasonal timing promotes suckering or not. An important point to note is that fire is required to stimulate suckering and to maintain the current representation of aspen and birch stands in the Park. The prescribed fire program will continue to be necessary in the future to ensure these forest ecosystems are healthy and self-sustaining.

White spruce is another species which is affected by the seasonal prescribed burn program. White spruce can only reproduce after fire if a tree survives, or if the fire occurs after seed ripening in August. Spring and fall fires in mixed aspen and white spruce stands are usually not very intense, so it is possible for white spruce trees to survive those fires. However, the low branching habit of white spruce makes it easier for a ground fire to climb into the canopy of the tree and kill it. Therefore, in order to protect the small amount of this mixed ecosystem in the Park, it is preferable to burn these stands in the fall. Burning in fall will still promote aspen re-sprouting, so the stand will remain mixed. Longer prescribed fire cycles (e.g., 100 years) would be better to maintain white spruce, but a fire cycle longer than 150 years would be too long to maintain a healthy aspen component to the stand. Fall burning should also only be done in years of good seed crop production in white spruce. The few pockets of black spruce stands in the Park can be maintained under any fire cycle greater than 50 years, and there is no seasonal impact of fire on this species.

Fire management in the Park can be used to manipulate the fire cycle towards the point of maximum biomass storage in aspen stands, but the Park is not large enough to make a significant impact on a national or regional scale. As well, managing to meet biomass goals would be in conflict with goals of maintaining other significant ecosystems in the Park (such as grasslands and open aspen forest) which require short fire cycles.

Prince Albert National Park

The current long fire cycles in Prince Albert National Park are clearly not a future fire management option. Maintaining those fire cycles would be ecologically undesirable because of the loss of jack pine, aspen and white birch ecosystems in the Park. A managed future fire cycle of 75 years will maintain a balanced representation of forest types in the Park, and the use of prescribed fire will be required to achieve that goal. Under a 75-year fire cycle, white spruce and mixed white spruce-aspen ecosystems (representing 1% and 15% of the Park, respectively) should be managed for fire more intensively than other stands. This includes the use of suppression and prescribed fire to ensure white spruce areas are burned by low intensity spring fires to promote tree survival, or after seed ripening (late summer and fall) in years of good seed crop production. Longer fire cycles are more beneficial to white spruce, so white spruce-aspen stands should be burned on a 75-125 year cycle to promote both species. Pure white spruce stands should have longer fire cycles of 150+ years. In the grasslands area of the Park, a shorter fire cycle may be required to prevent encroachment by aspen through early spring (pre-flush) burning.

The two GCM scenarios produced very similar biomass results in Prince Albert National Park. Based on the simulation results, Prince Albert National Park has the potential to increase biomass storage by about 10-17M tonnes under the future managed fire cycle of 75 years.

Riding Mountain National Park

Results from both of the GCM's indicate an increasing trend in future fire regimes of Riding Mountain National Park. This will favour aspen and reduce white spruce in the Park. These effects are greater under the CGCM1 scenario because of the shorter future fire cycle estimated by that model. Total biomass storage will also increase under the future fire regime. Managing the fire cycle for 100 years will decrease white spruce stem densities and biomass in the Park, but aspen densities and biomass will remain high. There is potential to increase overall Park biomass storage by 8-12M tonnes over current levels under a 100-year fire cycle. Shorter managed fire cycles of 50 and 25-years will cause an increase in aspen densities and a decrease in white spruce densities, and the biomass of both species will drop sharply. Short fire cycles of 50 and 25-years will also reduce the amount of area represented by older age-classes. However, a short fire cycle does have a place in overall vegetation management in the Park. In certain areas, it can be used to thin or remove aspen stands by using early spring (pre-flush) fires to maintain other open vegetation types like grasslands or shrub-grasslands. In this way, aspen that is encroaching on grasslands or shrublands can be pushed back to maintain the limited amount of those other important ecosystems in the Park.

To maintain a representative amount of white spruce ecosystems in the Park, longer fire cycles of 150+ years are required in pure white spruce stands, and 75-125 years in white spruce-aspen mixedwood stands. Another problem for white spruce maintenance is that fires historically occurred in the spring and regeneration is difficult under this regime because of tree mortality. Therefore, a future managed fire cycle for these ecosystems should be based on a late summer or fall burning regime in years of good seed crop production, unless spring burns can be done with low fire intensity.

Conclusions

Current fire management practices in Wood Buffalo National Park could be adapted to future fire regimes by increasing fire suppression to maintain representation of white spruce ecosystems and older age-classes of all ecosystems in the Park. There is also potential to significantly increase biomass storage in Wood Buffalo National Park through increased fire suppression.

The prescribed burn program in Elk Island National Park will continue to be critical to the ecological integrity of the Park in the future. Burning in closed aspen parkland should be conducted later in the spring after leaf-flush in aspen and white birch stands to promote suckering. The open aspen parkland units should be burned in the early spring period before deciduous leaf-flush to reduce suckering. To maintain white spruce in mixed ecosystems with aspen, these stands should have longer prescribed fire cycles of 100-125 years, and burning should be done in the fall, and only in years with good white spruce seed crops.

Prince Albert National Park will continue to require a prescribed burn program in the future to meet its managed 75-year fire cycle. To maintain white spruce representation in the Park, longer fire cycles of 75-125 years in mixed stands of white spruce and aspen, and 150+ years in pure white spruce stands are recommended. Late seasonal burning in years of good white spruce seed crop production are also necessary in those stands. A significant increase in future biomass storage is also expected under the 75-year managed fire cycle.

Similar to the other study area Parks, future fire management in Riding Mountain National Park will require a range of fire regimes to maintain the variety of ecosystems presently in the Park. White spruce ecosystems can be maintained under longer future fire cycles of 150+ years in pure stands, and 75-125 years in mixedwood stands with aspen. Late season burning in years of good seed crop production would also benefit white spruce ecosystems. There is potential for significant increase in biomass storage through managed fire cycles of 100 years. Shorter fire cycles of 25-50 years and early spring burning can be used to maintain open grassland and shrubland vegetation types by removing encroaching aspen.

The results of this study indicate the impacts of future fire regimes and fire management in National Parks where there is minimal human disturbance. There is a need to do similar analyses of future fire management strategies in the commercial forest where forest harvesting, or fuel manipulation, is another interacting factor. This would require spatial modeling and analysis of different fire management options, different harvesting patterns and silvicultural strategies, and changing fire regimes. To do this kind of research, there is a need to incorporate the dynamics of physical and ecological fire effects in current landscape disturbance models. The SEMLAND model (Li 2000) is an example of a landscape disturbance model currently being adapted to simulate fire effects dynamics.

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