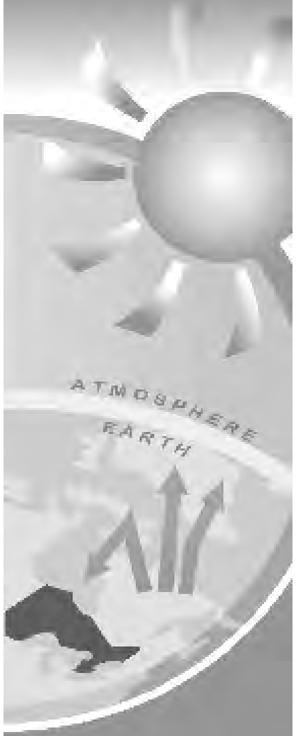
Ministry of Natural Resources

35

CLIMATE
CHANGE
RESEARCH
REPORT
CCRR-35



Responding to
Climate Change
Through Partnership

The Potential Effects of Climate Change on the Growth and Development of Forested Peatlands in the Clay Belt (Ecodistrict 3E-1) of Northeastern Ontario

Ontario

Sustainability in a Changing Climate: An Overview of MNR's Climate Change Strategy (2011-2014)

Climate change will affect all MNR programs and the natural resources for which it has responsibility. This strategy confirms MNR's commitment to the Ontario government's climate change initiatives such as the Go Green Action Plan on Climate Change and outlines research and management program priorities for the 2011-2014 period.

Theme 1: Understand Climate Change

MNR will gather, manage, and share information and knowledge about how ecosystem composition, structure and function – and the people who live and work in them – will be affected by a changing climate. Strategies:

- Communicate internally and externally to build awareness of the known and potential impacts of climate change and mitigation and adaptation options available to Ontarians.
- Monitor and assess ecosystem and resource conditions to manage for climate change in collaboration with other agencies and organizations.
- Undertake and support research designed to improve understanding of climate change, including improved temperature and precipitation projections, ecosystem vulnerability assessments, and improved models of the carbon budget and ecosystem processes in the managed forest, the settled landscapes of southern Ontario, and the forests and wetlands of the Far North.
- Transfer science and understanding to decision-makers to enhance comprehensive planning and management in a rapidly changing climate.

Theme 2: Mitigate Climate Change

MNR will reduce greenhouse gas emissions in support of Ontario's greenhouse gas emission reduction goals. Strategies:

- Continue to reduce emissions from MNR operations though vehicle fleet renewal, converting to other high fuel efficiency/low-emissions equipment, demonstrating leadership in energy-efficient facility development, promoting green building materials and fostering a green organizational culture.
- Facilitate the development of renewable energy by collaborating with other Ministries to promote the value of Ontario's resources as potential green energy sources, making Crown land available for renewable energy development, and working with proponents to ensure that renewable energy developments are consistent with approval requirements and that other Ministry priorities are considered.
- Provide leadership and support to resource users and industries to reduce carbon emissions and increase carbon storage by undertaking afforestation, protecting natural heritage areas, exploring opportunities for forest carbon management to increase carbon uptake, and promoting the increased use of wood products over energy-intensive, non-renewable alternatives.
- Help resource users and partners participate in a carbon offset market, by working with our partners to ensure that a robust trading system is in place based on rules established in Ontario (and potentially in other jurisdictions), continuing to examine the mitigation potential of forest carbon management in Ontario, and participating in the development of protocols and policies for forest and land-based carbon offset credits.

Theme 3: Help Ontarians Adapt

MNR will provide advice and tools and techniques to help Ontarians adapt to climate change. Strategies include:

- Maintain and enhance emergency management capability to protect life and property during extreme events such as flooding, drought, blowdown and wildfire.
- Use scenarios and vulnerability analyses to develop and employ adaptive solutions to known and emerging issues.
- Encourage and support industries, resource users and communities to adapt, by helping to develop understanding and capabilities of partners to adapt their practices and resource use in a changing climate.
- Evaluate and adjust policies and legislation to respond to climate change challenges.

The Potential Effects of Climate Change on the Growth and Development of Forested Peatlands in the Clay Belt (Ecodistrict 3E-1) of Northeastern Ontario

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2013

Science and Information Resources Division • Ontario Ministry of Natural Resources

Library and Archives Canada Cataloguing in Publication Data

Lafleur, Benoit
The potential effects of climate change on the growth and development of forested peatlands in the Clay Belt (ecodistrict 3E-1) of northeastern Ontario [electronic resource] / Benoit Lafleur, Nicole J. Fenton and Yves Bergeron.

(Climate change research report ; CCRR-35)
Electronic monograph in PDF format.
Includes abstract in French.
Issued also in printed form.
Includes bibliographical references.
ISBN 978-1-4606-2958-1

1. Peatland forestry--Environmental aspects--Ontario, Northern--Forecasting--Computer simulation. 2. Forest productivity--Climatic factors--Ontario, Northern--Forecasting--Computer simulation. I. Bergeron, Yves, 1956- II. Fenton, Nicole J., 1975- III. Ontario. Ministry of Natural Resources. Applied Research and Development IV. Title. V. Series: Climate change research report (Online) CCRR-35

SD387 E58 L34 2013 634.909713'1401 C2013-964028-2

Printed in Ontario, Canada

Single copies of this publication
are available from:

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Summary

The objective of this study was to model the development of northeastern Ontario forested peatlands in relation to changing temperatures, precipitation, and natural fire regimes for the period 2011-2100 and explore the effects of paludification or the accumulation of peat on dry mineral soil. Model projections indicated a slight to moderate decrease in forested peatland area by 2100 along with slower rates of paludification. The projected decreases in paludification rates imply greater forest productivity and increased potential for forest harvest. Also expected is a gradual loss of open paludified stands, which could affect the overall carbon balance as well as habitat availability for species associated with open areas. Recommendations for model enhancement and forest management planning are also provided.

Résumé

L'objectif de cette étude était de modéliser le développement des tourbières forestières du nord-est de l'Ontario en fonction des changements de températures, de précipitations et de régime de feux pour la période 2011-2100, et explorer les effets de la paludification ou de l'accumulation de tourbe sur des sols minéraux secs. Les projections du modèle indiquent une diminution légère ou modérée de la surface occupée par les tourbières forestière pour l'horizon 2100, ainsi qu'un taux de paludification plus bas. La diminution projetée du taux de paludification implique une productivité forestière accrue et une augmentation potentielle de la récolte. Ces résultats suggèrent aussi une perte graduelle de peuplements paludifiés ouverts, ce qui pourrait affecter le bilan de carbone régional ainsi que la disponibilité d'habitats pour les espèces associées aux habitats ouverts. Finalement, nous faisons des recommandations afin d'améliorer le modèle ainsi que la planification des aménagements forestiers.

Acknowledgements

This study was made possible by funding from the Climate Change Office, Ontario Ministry of Natural Resources. We thank Rachelle Lalonde for providing forest cover maps, Mélanie Desrochers for producing the projection maps, and Aurélie Terrier for helpful discussion on fire modeling. Thanks to Martin Simard for providing the photograph used on the cover of this report. We thank Paul Gray, Martin Simard, and an anonymous reviewer for commenting on an earlier version of the report. Thanks also to Trudy Vaittinen for report formatting and production support.

Foreword

This is one in a series of reports to help resource managers evaluate the vulnerability of natural assets to climate change. Given that vulnerability assessment techniques continue to evolve, it is important for resource managers to learn by doing and to pass on knowledge gained to support the Ontario Ministry of Natural Resources and others engaged in adaptive management. Accordingly, the vulnerability assessment reports included in the Climate Change Research Report Series have been prepared using the best available information under the circumstances (e.g., time, financial support, and data availability). Collectively, these assessments can inform decisionmaking, enhance scientific understanding of how natural assets respond to climate change, and help resource management organizations establish research and monitoring needs and priorities.

Cameron Mack

Acting Director, Applied Research and Development Branch

Contents

1.0 Introduction

Edaphic paludification is characterized by peat accumulation on dry mineral soil and eventually results in the accumulation of a thick organic layer and waterlogged conditions (Joosten and Clarke 2002). Paludification is influenced by climatic factors and permanent site features such as surficial deposits and soil texture. During the paludification process, soil temperature and microbial activity decrease as the water table rises, resulting in a slower rate of organic matter decomposition and a concomitant accumulation of organic matter over the mineral soil (Taylor et al. 1987, Payette 2001). As a result of this thickening anoxic organic layer, tree roots are forced out of the warmer, nutrient rich mineral soil and into the cold, nutrient poor organic layer in search of oxygen. The combined effect of the need to increase investment in root development and poor growth conditions in the organic layer results in a significant reduction in forest productivity (Lecomte et al. 2006, Simard et al. 2007). Thus, paludification is detrimental to forest productivity.

The area known as the Clay Belt in northeastern Ontario, Canada supports a large forest resource and an important forest industry. Much of the timber volume allotted to forest companies operating in this area is growing in forested peatlands and forests that are prone to paludification. Climatic projections for northeastern Ontario suggest that temperatures will increase by the end of the century. The average mean temperature in Kapuskasing, Ontario has increased 1.0 ^{o}C since 1938 (Environment Canada 2011) and is projected to increase 3 to 6 °C by 2100 (McKenney et al. 2010). Moreover, precipitation is projected to increase by 10 to 20% in the same period (McKenney et al. 2100). Along with the increased temperatures, evapotranspiration is also expected to increase, and the latter may not be offset by increased precipitation. Therefore, drier soil conditions are anticipated.

Warmer temperatures and changing precipitation and evapotranspiration patterns may contribute to increases in both fire frequency and severity (Flannigan et al. 2005, de Groot et al. 2009, Bergeron et al. 2010, van Bellen et al. 2010). Fire plays an important role in the paludification process because combustion of the organic layer causes the forest stand to *depaludify* (i.e., loss of organic matter and a concomitant decrease in organic layer thickness), which can result in increased in forest productivity (Gignac and Vitt 1994, Lavoie et al. 2005, Lecomte et al. 2005). Together, changes in climate and fire regime will influence the paludification process and affect forest development.

The objective of this study was to explore the potential effects of changing climate and fire regimes on the paludification process in the Clay Belt which lies in the boreal forest.

2.0 Study Area

The Clay Belt Ecodistrict (3E-1) is nested within the Lake Abitibi Ecoregion (3E) and encompasses about 41,287 km^2 (4.2% of the province) (Crins et al. 2009). The Ontario portion of the Clay Belt is delineated in the east by the Ontario-Québec border, by glacial morainal deposits that transition into organic deposits in the north, and by lacustrine deposits in the south and west (Henson et al., in prep.) (Figure 1).

The Clay Belt is located on the Precambrian Shield, which is underlain with granitic and gneissic bedrock, and metavolcanic and metasedimentary rocks of the Precambrian age (Crins et al. 2009). The gently rolling topography is characterized by extensive, poorly drained plains comprised of clayey and loamy soils with smaller pockets of sand and tills (Vincent and Hardy 1977, Lefort et al. 2003). Coniferous forests (35% of the area) and mixed forests (28%) blanket the landscape (Henson et al., in prep.). Black spruce (*Picea mariana*) is the primary species found in low lying areas and on gently sloping uplands while jack pine (*Pinus banksiana*) thrives on well-drained sites. The Gordon Cosens forest management unit was used as the study area because detailed ecosite data that enabled the development of a *paludification index* (ranking of susceptibility of a site to paludification) were available (Figure 2).

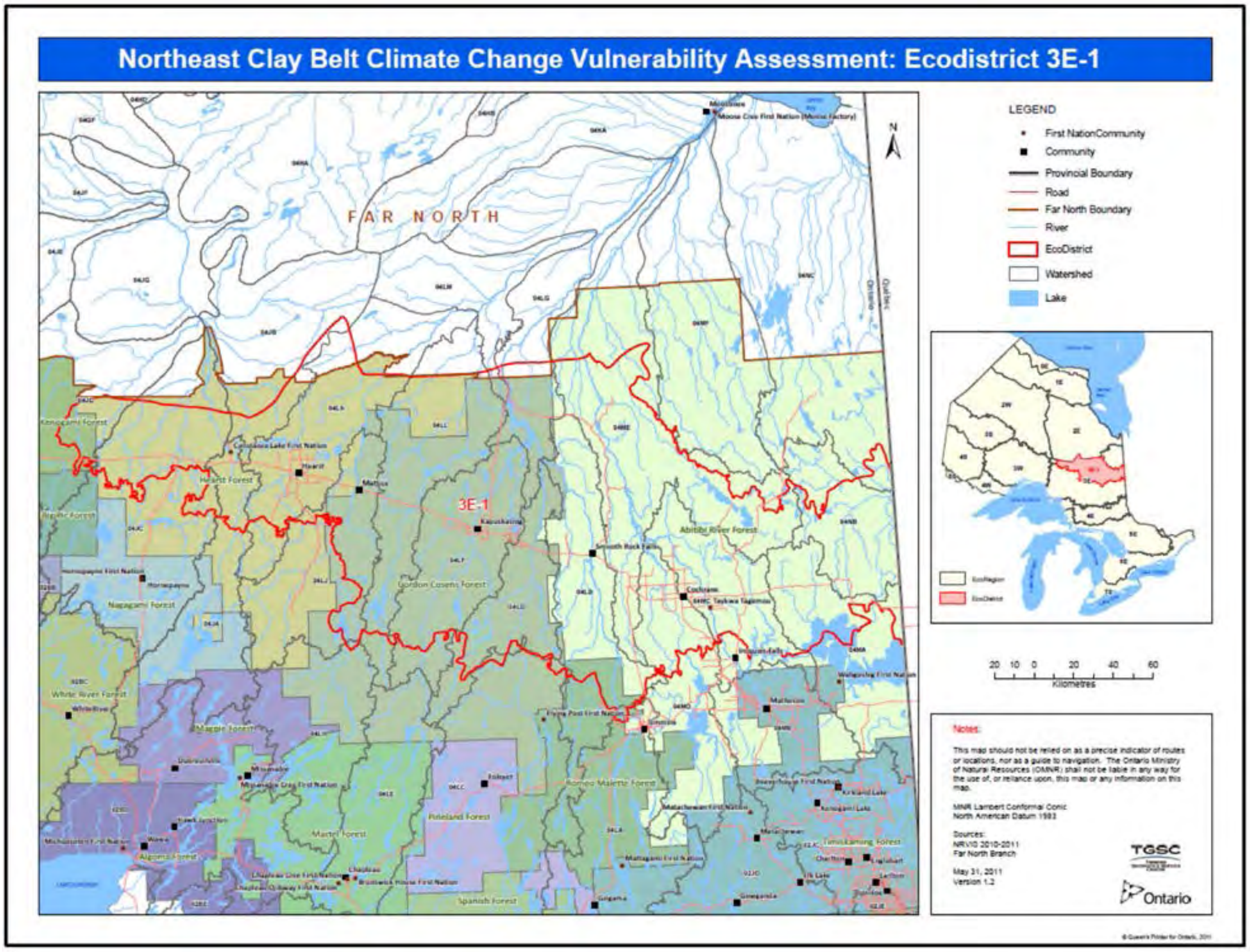

Figure 1. *Location of the Clay Belt (Ecodistrict 3E-1) in Ontario. The Gordon Cosens forest management unit is located in the centre of the ecodistrict.*

3. Methods

3.1 The Paludification Index

Ecosites provided the spatial context for the study, which are delineated areas of vegetation growing in specific soil conditions and are mapped at scales of 1:10,000 to 1:50,000. At these scales, ecosite characteristics inform forest-level planning and site-specific management prescriptions (Taylor et al. 2000). Permanent (e.g., mode of deposition or surficial deposits and soil texture) and dynamic (e.g., moisture regime and organic matter depth) ecosite variables (Table 1) were used to develop a *paludification index* to rank the susceptibility of each ecosite to paludification. Each variable was classified and ranked (0 - low to 4 - high) by experts to reflect its *paludification power* (Table 1). The paludification index (*PI*) was calculated as:

$$PI = D + M + T + OM + H + O, \qquad \text{[Eq 1]}$$

where *D* = mode of deposition, *M* = moisture regime, *T* = soil texture, *OM* = organic matter depth, *H* = humus form, and *O* = overstorey composition. Stands with a *PI* of 13 were classified as paludified; stands with a *PI* between 8 and 13 were deemed highly susceptible; stands with a *PI* between 7 and 8 were considered moderately susceptible; and stands with a *PI* of 4 to 7 were assigned a low susceptibility ranking. Those stands with a *PI* below 4 were considered not at risk of paludification (Table 2).

Table 1. *Paludification scores for permanent and dynamic ecosite features. Each permanent and dynamic feature is divided into classes, each of which is attributed a score related to its paludification "power": low scores indicate low paludification "power" and high scores indicate high paludification "power". Summing the score of all features generates a paludification index that projects the susceptibility of each ecosite type to paludification.*

Mode of deposition		Moisture regime[1]		Soil texture		Organic layer depth (cm; median value)		Humus form		Overstory species	
Class	Score	Class	Score	Class	Score	Class	Score	Class	Score	Class	Score
Rock	0	0	0	Rock	0	0-9	0	Mull	0	Other spp.	0
Aeolian	1	1	0	Sandy	0	10-19	1	Moder	0	Black spruce	1
Fluviatil	1	2	0	Coarse loam	0	20-29	2	Humic mor	1		
Fluvial till	1	3	0	Medium loam	1	30-39	3	Fibric mor	1		
Clay till	2	4	1	Silty	1	40-120	4	Humic	2		
Lacustrine	2	5	1	Fine loam	1	>120	5	Mesic	2		
Organic	2	6	1	Clay	2			Fibric	2		
		7	2	Organic	2						
		8	2								

[1] Moisture regime: 0 = dry, 8 = saturated.

Table 2. *Paludification index (PI) values in relation to susceptibility to paludification.*

Paludification index[1]	Susceptibility to paludification
< 4	Null
≥ 4 to < 7	Low
≥ 7 to < 8	Medium
≥ 8 to < 13	High
≥ 13	Paludified

[1] Ecosites with PI between 4 and 7 have permanent features that are not conducive to paludification, although their dynamic features suggest paludification is possible given the right conditions (cold and moist climate, absence of fire and successional pathways favouring black spruce). Ecosites with PIs of 7 and 8 represent the threshold between low and high susceptibility to paludification. They have both permanent and dynamic features that are conducive to paludification given the right conditions. Ecosites with PIs between 8 and 13 have permanent and dynamic features that are conducive to and are currently undergoing paludification. They are likely to be paludified given sufficient time. In the base sub-model, the latter do not reach a paludified state because the projection time period was short (100 years) relative to the organic matter accumulation rate.

3.2 The Paludification Model

The model applied in this study comprised a base sub-model, a climate change sub-model, and a fire regime sub-model, each of which is described below:

Base sub-model: The base sub-model variables were programmed to change over time. For example, the organic layer (OL) depth increased with time based on accumulation rates reported by Lecomte et al. (2006) from nearby sites in the proportion of the Clay Belt located in Québec. Lecomte et al. (2006) reported that in the last two centuries the organic matter (OM) accumulation rate has ranged from 10 to 20 cm per 100 years. These authors also demonstrated that OM accumulates at a faster rate when it is >20 cm deep. Soil water content is higher and less variable when OL > 20 cm thick. Lower temperatures and higher water content further reduce OM decomposition rates, and the OM accumulation rate increases. As a result, the base sub-model was adjusted so that stands with a median OL depth of >20 cm accumulated OM at a rate of 20 cm per 100 years, whereas those with a median OL depth of <20 cm accumulated OM at a rate of 10 cm per 100 years. For stands with an initial OL depth of <20 cm, the OM accumulation rate was 20 cm per 100 years as soon as the OM depth reached 20 cm. The fact that Simard et al. (2009) and Drobyshev et al. (2010) observed a significant decline in tree growth in the Clay Belt once OL depth exceeded 20 cm provides evidence to support the 20 cm threshold. Moisture regime was allowed to vary in ecosites where soil texture was finer than medium loam but only if the OL depth was >20 cm. Observations of forested peatlands indicated that drainage was slower when OL depth exceeded 20 cm and that a shift in moisture regime was highly possible. This was factored into the model: for example, for ecosites with a fine loam soil texture and a moisture regime of 4, the model was calibrated to increase the moisture regime to 5 when OL depth reached 20 cm.

Climate change sub-model: According to a model developed by Wu (2012) for ombrotrophic bogs, peat accumulation rate could decrease by up to 70% within the first 100 years as a result of warming temperatures and changing precipitation patterns. Wu (2012) used the temperature and precipitation increases projected by McKenney et al. (2010) for northeastern Ontario (i.e., a 3 °C increase in temperature and a 15% increase in precipitation). Moreover, in a greenhouse study to test the effects of elevated CO_2 on sphagnum growth, Toet et al. (2006) observed a 70% reduction in sphagnum growth rate between the first and third year after the water table was lowered. Therefore, to factor in the potential effects of climate change in this sub-model, OM was allowed to accumulate at a rate 70% slower than that in the base model.

Fire regime sub-model: Climate model-scenario projections were used to inform the fire regime sub-model. Climate projections were derived using the Canadian Global Circulation Model 3.1 (CGCM-3.1) and two scenarios, A2 and B1. The A2 scenario projects a significant increase in the world's human population and in greenhouse gas levels while the B1 scenario projects slower population growth and less dramatic, yet elevated, levels of greenhouse gases in the atmosphere over the 1971-2100 period (Nakićenović et al. 2000). The natural fire regime sub-model was based on a fire cycle of 400 years, which is considered representative of the study area in modern times (Lefort et al. 2003). Furthermore, on the basis of work completed in the James Bay Lowlands, we assumed that 50% of fire ignitions resulted in high severity fires (i.e., fires that left <5 cm of residual organic matter on the mineral soil) (Simard et al. 2007). Because the likelihood of high severity fires depends on the depth of the organic layer, ecosites with an OM depth >120 cm were deemed not likely to burn severely. Finally, in light of the uncertainties about the effect of climate change on fire severity, we modelled three proportions of high severity fires: 25%, 50%, and 75%.

To explore the potential effects of increased temperatures and changing precipitation patterns on forest peatland development, the three sub-models were run in the following sequence: (1) base sub-model, (2) base sub-model + climate change sub-model, and (3) base sub-model + climate change sub-model + fire regime sub-model.

4.0 Results

Based on Ontario forest mapping data from 2004 (LaLonde, pers. comm.), about 42% of the Gordon Cosens Forest was paludified. Results from the base sub-model (without the climate change sub-model) for 2004 indicate that only 5% of the area had no chance of paludification and 53% of the area had a low to medium chance of paludification (Table 3, Figure 2).

Table 3. *Susceptibility of Gordon Cosens forest stands to paludification for the period 2011-2100 with and without projected climate change.*

Ecosite[1]	% of area[2]	Without climate change			With climate change		
		2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
1	1.6	N	N	N	N	N	N
2	0.7	N	N	N	N	N	N
3	2.9	N	N	N	N	N	N
4	0.9	L	L	L	L	L	L
5	2.6	L	L	L	L	L	L
6	18.6	L	L	L	L	L	L
7	4.2	L	L	L	L	L	L
8	8.2	M	H	H	M	M	M
9	11.7	M	M	H	M	M	M
10	6.5	M	H	H	M	M	M
11	24.6	P	P	P	P	P	P
12	9.2	P	P	P	P	P	P
13	5.3	P	P	P	P	P	P
14	3.0	P	P	P	P	P	P
Paludification susceptibility		Percent area of all ecosites					
Null (N)		5.2	5.2	5.2	5.2	5.2	5.2
Low (L)		26.3	26.3	26.3	26.3	26.3	26.3
Medium (M)		26.4	14.7	0.0	26.4	26.4	26.4
High (H)		0.0[3]	11.7	26.4	0.0	0.0	0.0
Paludified (P)		42.1	42.1	42.1[4]	42.1	42.1	42.1

[1] Ecosites are as described by Taylor et al. (2000).

[2] Based on the 2004 forest resource inventory.

[3] An artifact of the paludification scoring process.

[4] Paludification is a slow process relative to the 100-year projection.

As paludification is a relatively slow process, no changes in the susceptibility of stands to paludification were projected for the 2041-2070 period relative to current conditions (Table 3, Figure 3). For the 2071-2100 period, however, 100% of the stands classified as *medium* in 2011-2041 and 2041-2070 time periods were projected to be highly vulnerable to paludification (Table 3, Figures 4 and 5) while the proportion of stands classified as *null* and *low* did not change. Therefore, in the absence of climate change almost 70% of the Gordon Cosens Forest could be paludified (42%) or highly susceptible (26%) to paludification by the end of the century.

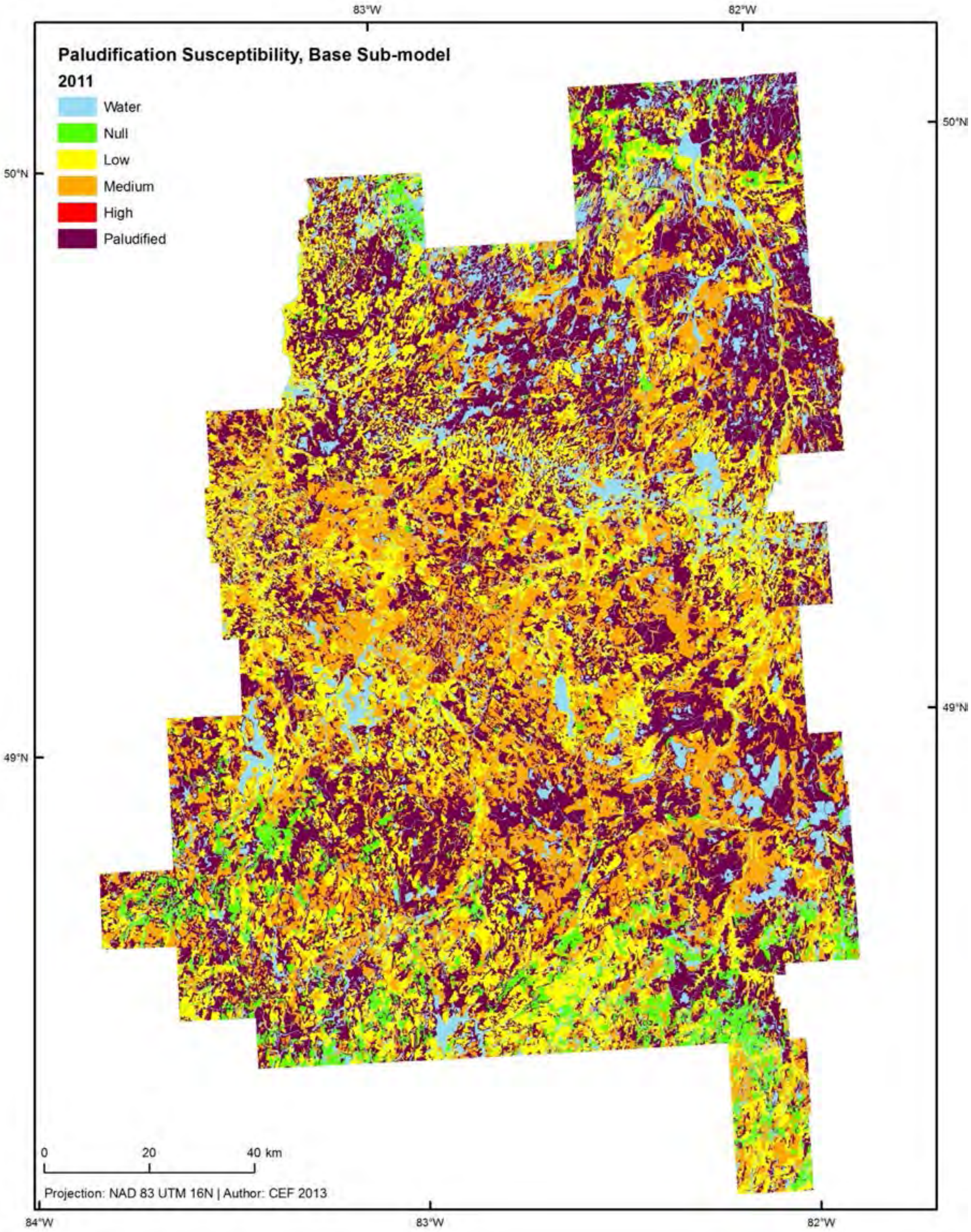

Figure 2. *Current (2011) susceptibility of the Gordon Cosens Forest to paludification.*

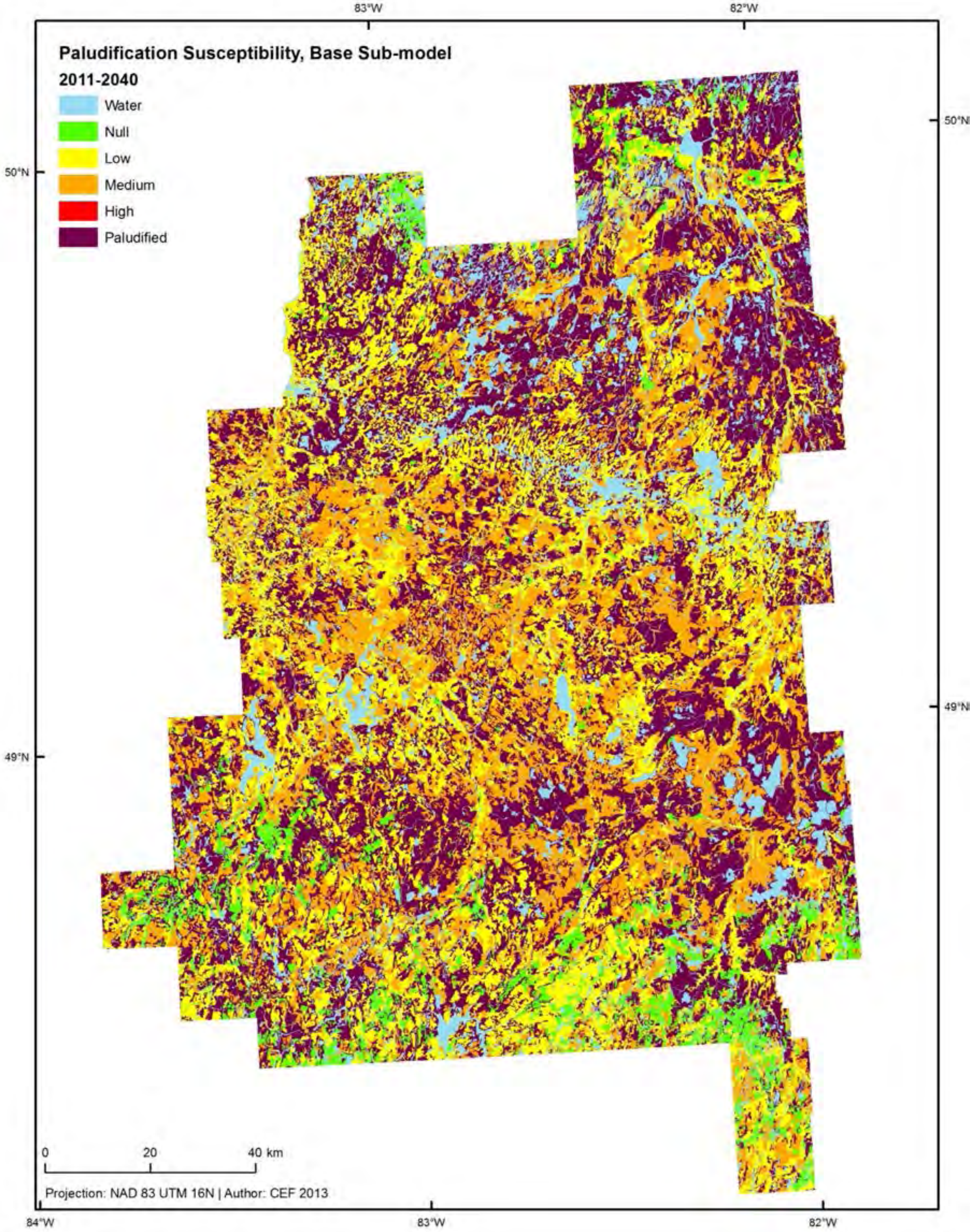

Figure 3. *Base sub-model projection of the susceptibility of the Gordon Cosens Forest to paludification for 2011-2040.*

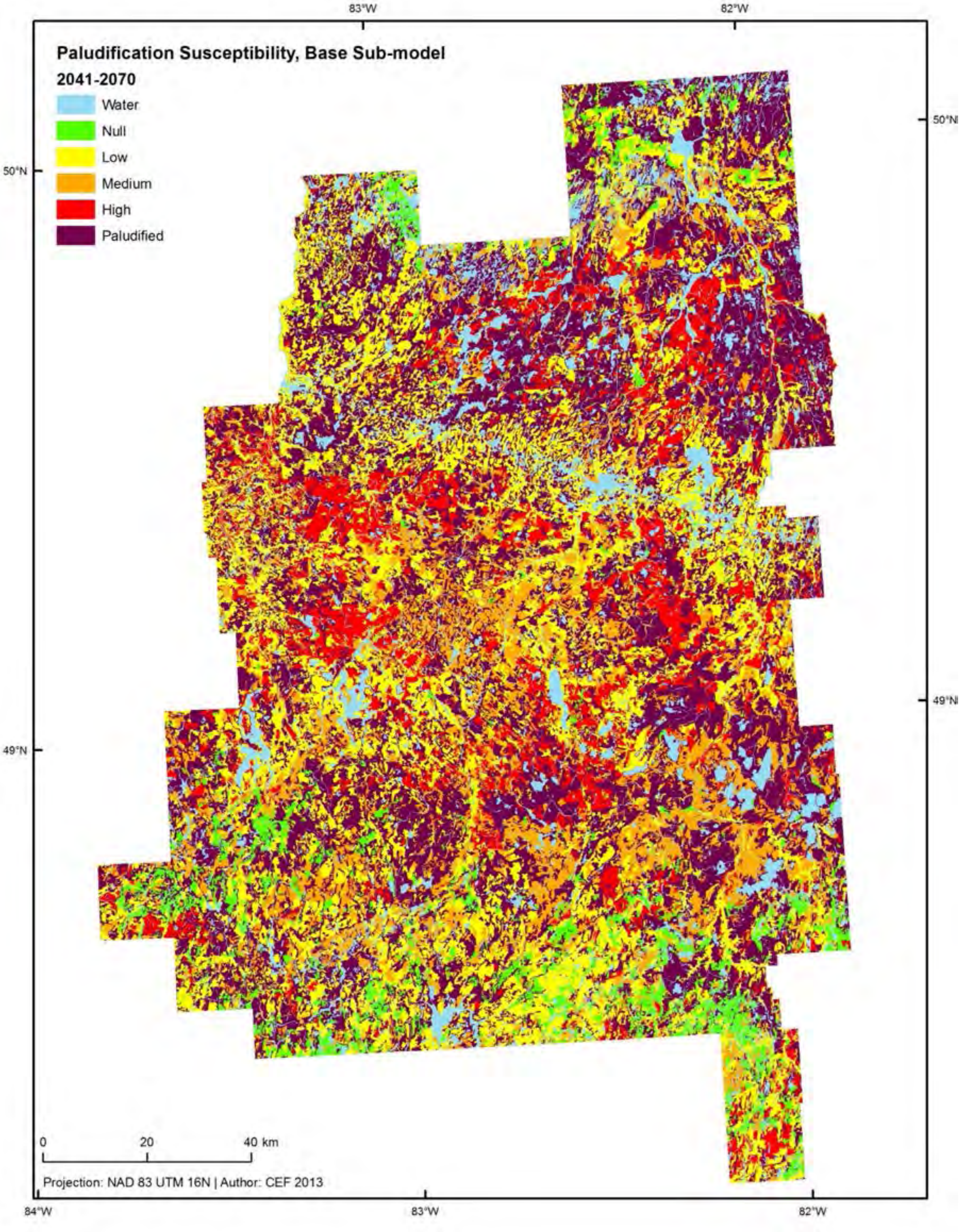

Figure 4. *Base sub-model projection of the susceptibility of the Gordon Cosens Forest to paludification for 2041-2070.*

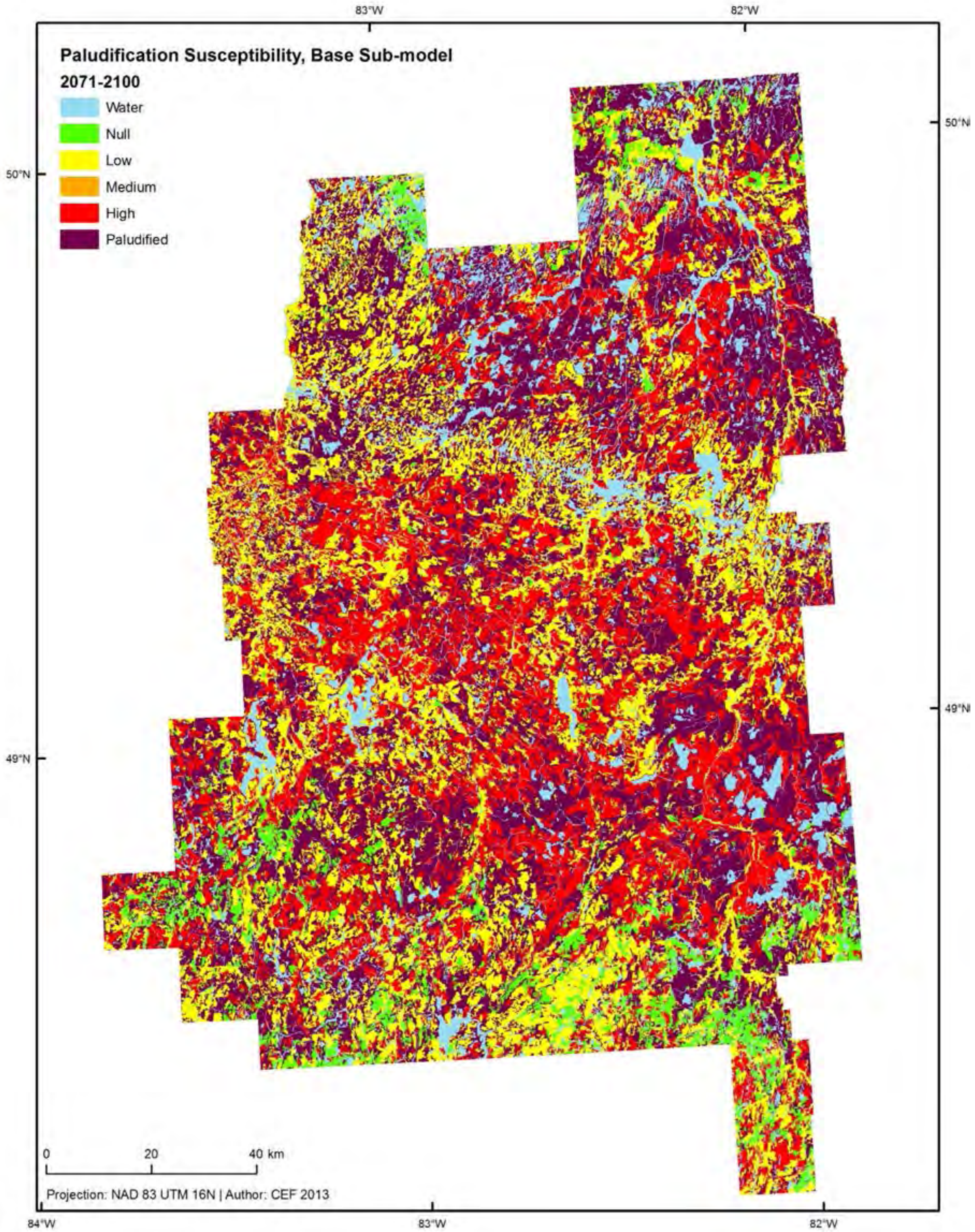

Figure 5. *Base sub-model projection of the susceptibility of the Gordon Cosens Forest to paludification for 2071-2100.*

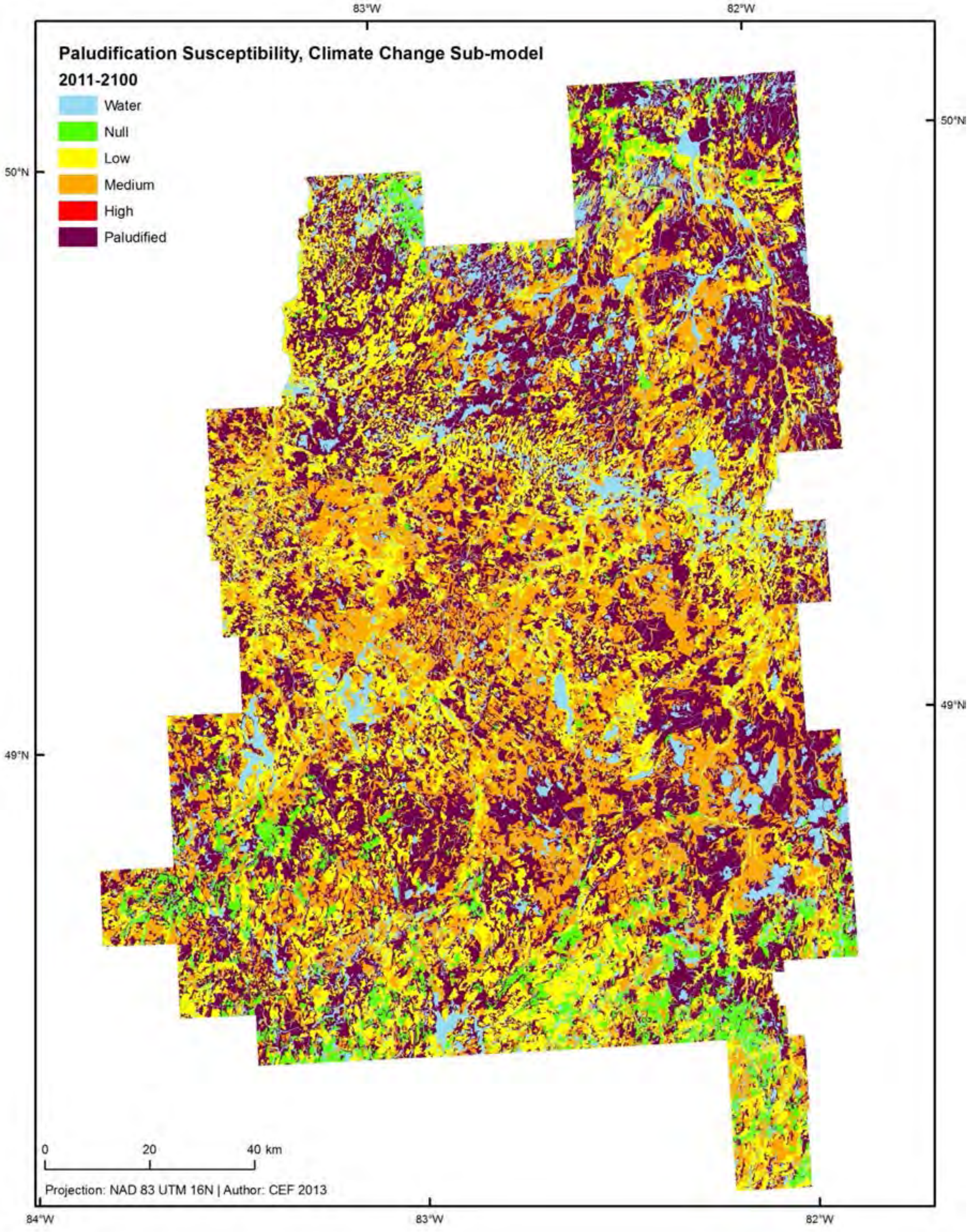

Figure 6. *Projected effects of climate change on the susceptibility of the Gordon Cosens Forest to paludification for the period 2011-2100.*

Projections from the climate change sub-model indicate no change in the susceptibility of stands to paludification relative to current conditions (Table 3, Figure 6). A slight decrease in paludified area was projected using the fire sub-model regardless of the proportion of stands subjected to high severity fires (Figure 7). Yet, the relative decrease in paludified area was lower when only 25% of the stands were burned by fires of high severity and was relatively higher when 75% of the stands were burned by high severity fires. Therefore, climate change-induced fire patterns will potentially retard the paludification process throughout the remainder of the century.

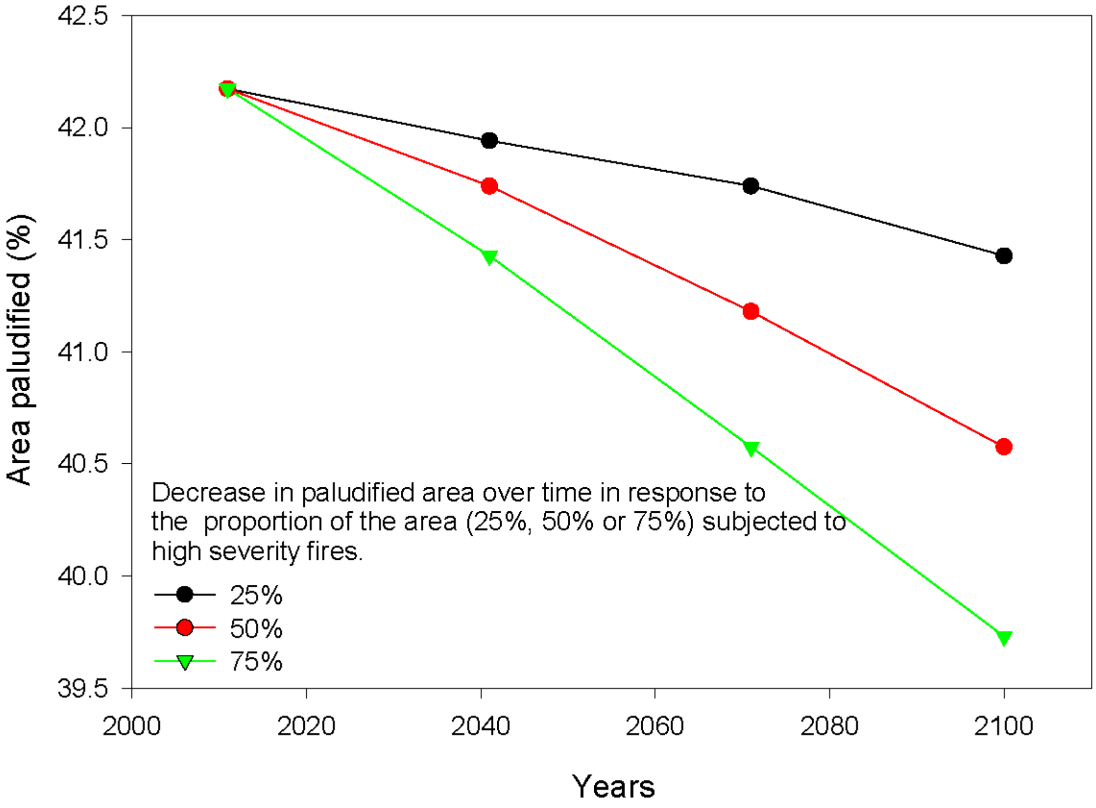

Figure 7. *Projected effects of changes in climate and fire severity on the susceptibility of the Gordon Cosens Forest to paludification for the period 2011-2100. (Note that the y-axis range was selected to illustrate the differences in paludified area relative to fire severity).*

5.0 Discussion

As expected, projections from the base sub-model indicated that slow but noticeable changes would occur in the rate of paludification. By the end of the century, in the absence of fire, about 70% of the Gordon Cosens Forest in northeastern Ontario's Clay Belt may be highly susceptible to paludification (26%) or already paludified (42%). This change results from increased organic layer depth and concomitant changes in soil moisture regimes. Stands expected to be most susceptible to paludification (those in ES 8 to ES 10) were growing on lacustrine surficial deposits or clay till with fine-textured soil (clay to coarse loam), a moisture regime of 5 to 6 (i.e., moist to very moist), organic matter median depth of 20 cm, and an overstorey of black spruce or trembling aspen. Because of site features, forested stands in ES 1 to ES 7 are not projected to be at risk of paludification this century. Despite its simplicity, the base sub-model captures changes in vulnerability of forested ecosystems to paludification over time.

Although increased precipitation and a resulting higher water table would lead to increased rates of organic matter accumulation by decreasing the decomposition rate, increased temperatures will increase evapotranspiration and leave less moisture in the system (Soja et al. 2007, Wu 2012). A decrease in moisture availability will, in turn, lower the water table, thicken the oxic layer, and increase substrate temperature. These changes will decrease the organic matter accumulation rate and increase the organic matter decomposition rate, which together will stabilize the organic layer depth during the 21st century. Based on the climate model-scenarios used in this study (e.g., CGCM3-A2), an increase in the proportion of severe fires is likely, at least in the western portion of the ecodistrict where water balance projections suggest a potentially significant decrease in soil moisture by 2100 (MacRitchie and Turnbull 2012). Reduced soil moisture may result in more high severity fires because severity is linked to the amount of moisture in the upper layers of the soil (Miyanishi and Johnson 2002, Greene et al. 2007, Shetler et al. 2008). However, the slow rate of paludification associated with this model results in a slight decrease in paludified area regardless of the proportion of high severity fires, suggesting either that the rate of organic matter accumulation in the model is too conservative, or that the existing highly paludified landscape is not completely in balance with the current climate and fire regime (Payette 2001).

6.0 Recommendations

Our recommendations relate to model improvements that would increase the accuracy of future paludification assessments of forests in northeastern Ontario and how results of this kind of study might inform forest management planning.

Enhance the model - Enhance the mechanistic model to include sensitivity analysis capabilities. In addition, an enhanced model could include the effects of climate change on fire frequency or the spatially integrated mean fire interval. Fire frequency is projected to increase for most of Canada by 2100, and by as much as 150% in some ecoregions under some scenarios (Wotton et al. 2010). For the Clay Belt, Bergeron et al. (2010) projected that the mean fire interval would be reduced from the current 400 years to a mean of 222 years (95% confidence interval 169 to 313 years). While Bergeron et al. (2010) stress that this is within the range of natural variation for the Clay Belt region, it still represents an increase in the frequency of fires and would affect the proportion of forested peatlands across the landscape.

Monitor paludification - Monitor the paludification process to inform development of future forest management plans, particularly when forest harvest patterns emulate a range of fire severities (Lafleur et al. 2010, Renard 2010).

7.0 References

Bergeron, Y., D. Cyr, M.P. Girardin and C. Carcaillet. 2010. Will climate change drive 21st century burn rates in Canadian boreal forest outside of its natural variability: Collating global climate model experiments with sedimentary charcoal data. Int. J. Wildl. Fire 19: 1127-1139.

Crins, W.J., P.A. Gray, P.W.C. Uhlig and M.C. Wester. 2009. The ecosystems of Ontario, Part 1: Ecozones and ecoregions. Ont. Min. Nat. Resour., Peterborough ON. Sci. Inf. Br., TER IMA TR-01. 71p.

de Groot, W.J., J.M. Pritchard and T.J. Lynham. 2009. Forest floor fuel consumption and carbon emissions in Canadian boreal forest fires. Can. J. For. Res. 39: 367-382.

Drobyshev, I., M. Simard, Y. Bergeron and A. Hofgaard. 2010. Does soil organic layer thickness affect climate-growth relationships in the black spruce boreal ecosystem? Ecosystems 13: 556-574.

Environment Canada. 2011. National climate data and information archive: Climate data online. Environment Canada, Ottawa, ON. Online: http://climate.weatheroffice.ec.gc.ca/climateData/canada_e.html.

Flannigan, M., K.A. Logan, B. Amiro, W. Skinner and B.J. Stocks. 2005. Future area burned in Canada. Clim. Change 72: 1-16.

Gignac, L.D. and D.H. Vitt. 1994. Responses of northern peatlands to climate change: Effects on bryophytes. J. Hattori Botan. Lab. 75: 119-132.

Greene, D.F., S.E. Macdonald, S. Haeussler, S. Domenicano, J. Noël, K. Jayen, I. Charron, S. Gauthier, S. Hunt, E.T. Gielau, Y. Bergeron and L. Swift. 2007. The reduction of organic-layer depth by wildfire in the North American boreal forest and its effect on tree recruitment by seed. Can. J. For. Res. 37: 1012-1023.

Henson, B., M.C. Wester, W.J. Crins, P.W.C. Uhlig, and P.A. Gray. In preparation. The ecosystems of Ontario, Part II: Ecodistricts. Ont. Min. Nat. Resour., Peterborough, ON. Sci. Res. Br.

Joosten, H. and D. Clarke. 2002. Wise use of mires and peatlands – Background and principles including a framework for decision-making. Intern. Mire Conserv. Group and Intern. Peat Soc., Jyväskylä, Finland. 303p.

Lafleur, B., N.J. Fenton, D. Paré, M. Simard and Y. Bergeron. 2010. Contrasting effects of season and method of harvest on soil properties and the growth of black spruce regeneration in the boreal forested peatlands of eastern Canada. Silva Fenn. 45: 799-813.

Lavoie, M., D. Paré and Y. Bergeron. 2005. Impact of global change and forest management on carbon sequestration on northern forested peatlands. Environ. Rev. 13: 199-240.

Lecomte, N., M. Simard, Y. Bergeron, A. Larouche, H. Asnong and P.J.H. Richard. 2005. Effects of fire severity and initial tree composition on understorey vegetation dynamics in a boreal landscape inferred from chronosequence and paleoecological data. J. Veg. Sci. 16: 665-674.

Lecomte, N., M. Simard, N. Fenton and Y. Bergeron. 2006. Fire severity and long-term ecosystem biomass dynamics in coniferous boreal forests of eastern Canada. Ecosystems 9: 1215-1230.

Lefort, P., S. Gauthier and Y. Bergeron. 2003. The influence of fire weather and land use on the fire activity of the Lake Abitibi area, eastern Canada. For. Sci. 49: 509-521.

MacRitchie, S. and B. Turnbull. 2012. Water balance results. Presentation at Clay Belt Vulnerability Assessment and Adaptation Options Workshop. January 25-26, 2012. Ont. Min. Nat. Resour., Timmins, ON.

McKenney, D.W., J.H. Pedlar, K. Lawrence, P.A. Gray, S.J. Colombo and W.J. Crins. 2010. Current and projected future climatic conditions for ecoregions and selected natural heritage areas in Ontario. Ont. Min. Nat. Res., Appl. Res. Develop. Br., Sault Ste. Marie, ON. Clim. Change Res. Rep. CCRR-16. 42p.

Miyanishi, K. and E.A. Johnson. 2002. Process and patterns of duff consumption in the mixedwood boreal forest. Can. J. For. Res. 32: 1285-1295.

Nakićenović, N. (and 27 others). 2000. Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, New York, NY. 599 p.

Payette, S. 2001. Les principaux types de tourbières. Pp 39-89 in S. Payette and L. Rochefort (eds.). Écologie des tourbières du Québec-Labrador. Les Presses de l'Université Laval, Québec, QC.

Renard, S. 2010. Impact du brûlage dirigé comme préparation de terrain pour contrer l'entourbement et favoriser la croissance de l'épinette noire dans les pessières à mousses paludifiées de la ceinture d'argile. Master's thesis. Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, QC.

Shetler, G., M.R. Turetsky, E. Kane and E. Kasischke. 2008. Sphagnum mosses limit total carbon consumption during fire in Alaskan black spruce forests. Can. J. For. Res. 38: 2328-2336.

Simard, M., N. Lecomte, Y. Bergeron, P.Y. Bernier and D. Paré. 2007. Forest productivity decline caused by successional paludification of boreal soils. Ecol. Appl. 17: 1619–1637.

Simard, M., P.Y. Bernier, Y. Bergeron, D. Paré and L. Guérine. 2009. Paludification dynamics in the boreal forest of the James Bay Lowlands: Effect of time since fire and topography. Can. J. For. Res. 39: 546-552.

Soja, A.J., N.M. Tchebakova, N.H.F. French, M.D. Flannigan, H.H. Shugart, B.J. Stocks, A.I. Sukhinin, E.I. Parfenova, F.S. Chapin III and P.W. Stackhouse. 2007. Climate-induced boreal forest change: Predictions versus current observations. Global Planet. Change 56: 274-296.

Taylor, K.C., R.W. Arnup, B.G. Merchant, W.J. Parton and J. Nieppola. 2000. A field guide to forest ecosystems of northeastern Ontario, 2nd edition. Ont. Min. Nat. Resour., Northeast Sci. Info. South Porcupine, ON.

Taylor, S.J., T.J. Carleton and P. Adams. 1987. Understory vegetation change in a *Picea mariana* chronosequence. Vegetatio 73: 63–72.

Toet, S., J.H.C. Cornelissen, R. Aerts, R.S.P. van Logtestijn, M. de Beus and R. Stoevelaar. 2006. Moss response to elevated CO_2 and variation in hydrology in a temperate lowland peatland. Plant Ecol. 182: 27-40.

van Bellen, S., M. Garneau and Y. Bergeron. 2010. Impact of climate change on forest fire severity and and consequences for carbon stocks in boreal forest stands of Quebec, Canada: A synthesis. Fire Ecol. 6: 16-44.

Vincent, J. and L. Hardy. 1977. L'évolution et l'extinction des lacs glaciaires Barlow et Ojibway en territoire québécois. Géographie Physique et Quaternaire 31: 357-372.

Wotton, B.M., C.A. Nock and M.D. Flannigan. 2010. Forest fire occurrence and climate change in Canada. Int. J. Wildl. Fire 19: 253-271.

Wu, J. 2012. Response of peatland development and carbon cycling to climate change: a dynamic system modeling approach. Environ. Earth Sci. 65: 141-151.

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