BLACK SPRUCE PRODUCTIVITY AND FOLIAR C:N RATIO RESPONSES TO PEATLAND WATER-TABLE LEVEL: A CLIMATE CHANGE STANDPOINT

Tariq Muhammad Munir[1,2,*], Bhupesh Khadka[1], Ghulam Murtaza Jamro[3] and Hameed Ullah[4]

[1]Department of Geography, University of Calgary, 2500 University Dr. NW Calgary, Alberta T2N 1N4, Canada

[2]Department of Geology, St. Mary's University, 14500 Bannister Road SE, Calgary, AB T2X 1Z4, Canada

[3]Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2R3, Canada

[4]Mango Research Institute, Agriculture Farm, Old Shujabad Road, Multan 60500, Punjab, Pakistan

*Corresponding author email: tmmunir@ucalgary.ca

ABSTRACT: In a boreal forested peatland in Alberta, Canada, two sites were compared: 1) undisturbed (control), and 2) 10-year old drained (drained) during 2011-2012 growing seasons (May to October) to (i) investigate water-table (WT) level – black spruce biomass, net primary productivity of tree stand (NPP_{TS}) and foliar C:N ratio relationships, and (ii) examine NPP_{TS} – foliar C:N ratio relationship to verify their WT level control. The overall mean WT levels at the control and drained sites were 37 cm and 80 cm, respectively. Although, the drained site's mean tree biomass (2400 ± 840 g m^{-2}) did not significantly differ from the control site's mean tree biomass (2617 ± 984 g m^{-2}), the drained site's NPP_{TS} (175 ± 36 g m^{-2} yr^{-1}) was significantly higher than the control site's NPP_{TS} (99 ± 34 g m^{-2} yr^{-1}). The years did not significantly differ for biomass or NPP_{TS}. The WT deepening was positively related with NPP_{TS} which in turn was negatively related with foliar C:N ratio. Therefore, we suggest that the lowering of WT in peatlands (dry boreal continental bogs) can significantly increase the tree productivity and foliar C:N ratio with a negative feedback outcome to climate change (by increased atmospheric carbon dioxide uptake rate) or a positive feed back to climate change (by accelerated tree litter decomposition and mineralization rates).

Keywords: biomass, black spruce, foliar nutrient, climate change, peatland, productivity, water table

1. INTRODUCTION

Boreal peatland environments store ~ 550 Peta gram carbon (C; 1Pg = 10^{15} g), approximately 1/3rd of the total soil C pool [1]. These peatlands are expected to be severely sensitive to global climate change [2, 3], and are predominantly roofed by black spruce tree (*Picea mariana* (Mill.) BSP) [4]. In the continental boreal peatlands, the greatest rates of soil C storage are related with the tree stands [5], which are noticeable for their greatest ratios of net primary production (NPP) and decomposition [6] and, a C sequestration rate of 0.1–0.3 Mg C $ha^{-1}yr^{-1}$ [7]. Predicted warming in climate is likely to lower down water-table (WT) level [8] and concentrate soil or plant nutrients [9] in these treed peatlands. While attempts have been made to investigate the C and nutrient cycling, and NPP in peatlands in feedback to potential climate change [e.g., 9, 10, 11], controlled field experimentation to estimate the potential effects of climate change or WT lowering on relationship of tree NPP with its foliar nutrient concentration remains largely unexplored.

Climate change components of warming and altered precipitation pattern have been predicted to lower the WT level in peatlands [12]. The WT lowering is expected to effect NPP of Black spruce that is adapted to shallow root system due to low oxygen availability in the saturated substrate of peatlands [13] characterized by near surface WT level and anaerobic environment. The lowering of WT under a climate change scenario can also result in thickening of oxygenated peat layer or improvement in soil aeration, supportive of increase in rooting depth [13] and NPP of tree stand (NPP_{TS}) [11]. The WT lowering has frequently been reported to increase peat decomposition and mineralization rates [e.g., 14], and enlarge soil available and extractable or foliar total nitrogen (N) pools [e.g., 9]. Whether the increase in productivity is driven by WT lowering or increase in foliar nutrient pools is not studied. We hypothesize that the lowering in WT level will increase the tree NPP and foliar N concentration which will be related with each other.

Therefore, we estimated the black spruce productivity [11] and

C:N ratio across a gradient of WT level in a midlatitude boreal continental bog in Alberta, Canada, and our specific research objectives were (1) to focus on the response of black spruce stand NPP to water-table lowering in a control (undisturbed) and a drained site in a dry Alberta bog [11], (2) to evaluate changes in black spruce foliar C:N ratio with changes in water-table level, and (3) to determine the relationship of water-table level with black spruce stand NPP and foliar C:N ratio in the studied peatland.

2. MATERIAL AND METHODS

2.1 Study Sites, Hydrology and Experimental Design

During the growing seasons (May to October) of 2011 and 2012, we conducted this experiment in a continental treed bog distanced 10 km east of the town of Wandering River, Alberta, Canada. We chose two sites in the continental bog: one undisturbed site hereafter called CONTROL (55°21' N, 112°31' W) and one 10 years old drained site hereafter called DRAINED (55°16′ N, 112°28′ W). The drained site was distanced 9 km away to southwest of the control site. Mean (± SD) WT levels logged at the control and drained places were -56 ± 22 cm and -120 ± 19 cm, respectively (negative value represents below-ground WT level). The creation of these places were detailed by Munir, Xu [15].

As per 30-year (1981-2010) averages taken from Environment Canada, 2014, the average temperature and precipitation for May-October growth period for this area are 11.7 °C and 382 mm, respectively [11]. During 2011-2012 growing seasons the control site mean air temperature and precipitation (measured using a meteorological station installed at the study sites) were 13.23 °C, 14.11 °C and 283 mm, 268 mm, respectively [11].

This Wandering River continental bog was classified (using hydrophytic indicators) as "forested low-shrub bog" [16]. In 2011, the control site was observed to be dominantly covered by *Sphagnum* mosses (e.g., *Sphagnum fuscum and Sphagnum magellanicum*) with sporadic shrubs (mostly *Rhododendron groenlandicum*) compared to the drained site which had a dominant coverage of shrubs and some lichens [15]. Black spruce ((*Picea mariana* (Mill.) B.S.P.) constituted more than 99% of the total tree stand composed of 25767 stems ha^{-1} divided into 37.4% taller (> 137.5 cm up to the height of 770 cm) and 61.6% short (< 137.5 cm height) trees [11]. The tree coverage had a mean canopy height of 169 cm, estimated coverage of 43% and basal area of 74 m^2 ha^{-1} [15]. Only less than 1% of the total tree coverage was constituted by tamarack (*Larix laricina* (Du Roi) K. Koch). This characterization was applies to entire bog encompassing control and drained sites as described by Munir, Xu [15]

Within each of the two treed bog sites, we randomly selected three quadrats each of 10 m × 10 m. At each quadrat, we divided the tree stand into tall (> 137.5 cm height) and short (< 137.5 cm height) trees for total biomass and, incremental biomass or productivity estimates.

2.2 Tree biomass and productivity

In 2011, within each quadrat, we measured height, diameter at breast height (DBH) and basal diameter of all tall and short trees. These parameters were used in generating allometric equations (explained later) to calculate tall and short tree biomasses (g m^{-2}) separately. Tall tree biomass was added to short tree biomass to calculate total black spruce stand biomass within each quadrat. We used an allometric equation from Grigal and Kernik [17] to determine tall trees biomass. For estimation of the short trees biomass, we clipped 20 short trees closest to the forest floor and hauled to Wetland Ecohydrology Lab., University of Calgary. These trees were then oven dried at 80 °C for 48 hrs. We measured dry biomass and height of each short tree, performed exponential regression, and generated an allometric equation (Table 1). This study calculated above-ground tree biomass for 2012 by using the 2011 above-ground tree biomass and productivity values and generating a regression equation (y = 344.81 + 12.36x). We calculated NPP_{TS} (g m^{-2} yr^{-1}) by modifying equations from Szumigalski and Bayley [18] and Thormann and Bayley [19] as:

$$NPP_{TS} = IB_{AG} + IB_{BG} + L_{TREE} \quad (1)$$

where IB_{AG}, IB_{BG} and L_{TREE} denote above-ground incremental biomass, below-ground incremental biomass and tree litter, respectively. All quantities are in g m^{-2} yr^{-1}. Based on tree ring widths and using Dandroscan technique [20] Munir, Perkins [11] quantified IB_{AG} of tall trees for 2011 and 2012, and by regressing leader length against height following Mullin, Morgenstern [21], they also estimated IB_{AG} of short trees for 2011 and 2012. They did not estimate IB_{BG} of tall or short trees, and used allometric equations from Szumigalski and Bayley [18] (22.2% of IB_{AG}). The L_{TREE} was also not estimated, and an allometric equation (17% of IB_{AG}) from Li, Kurz [22] was used.

2.3 Foliar Sampling and Analyses

In 2012, the tree foliage samples were collected from the branches in the upper one-third of the crown and composited for each quadrat (*n* = 3) at each site (*n* = 2) following Choi et al. (2007). The samples were placed in paper bags and oven dried at 60 °C for 48 hrs. Dried materials were ground to powder form and stored in small envelopes in a 40 °C drying oven until analysis. Plant tissue carbon (C) and N concentration (% of dry weight) were determined by combustion in a pure oxygen environment using a Perkin Elmer model 2400 series II CNH analyser (Chemical Instrument Facility, University of Calgary).

Table 1. Regression equations used to estimate total biomass, incremental biomass or productivity of above- or below-ground part of *Picea mariana* during 2011-2012 growing seasons (May-October). All equations follow general linear format: *y = a + bx*, where *y* (biomass) is dependent variable, *x* is independent variable and, *a* and *b* are *y*-intercept and slope, respectively [a].

Site	Year	Tree Height	*y* (Biomass)	*a*	*b*	*x*	*n*	r^2	Reference
All	All	Tall	Total	0.153	2.25	Log DBH	NA	NA	[17]
Control									
	2011	Tall	Incremental	0.013	0.01	Ring Width	9	0.5	[11]
	2012	Tall	Incremental	0.009	0.01	Ring Width	9	0.6	[11]
Drained									
	2011	Tall	Incremental	0.142	0.002	Ring Width	9	0.3	[11]
	2012	Tall	Incremental	0.124	0.003	Ring Width	9	0.9	[11]
All	All	Short	Total	0.009	2.21	Log Height	20	0.9	[11]
Control									
	2011	Short	Incremental	1.17	0.01	Leader Length	9	0.6	[11]
	2012	Short	Incremental	0.132	0.02	Leader Length	9	0.7	[11]
Drained									
	2011	Short	Incremental	-0.97	0.06	Leader Length	9	0.7	[11]
	2012	Short	Incremental	-1.59	0.05	Leader Length	9	0.8	[11]
All	All	All	Root Total or Incremental Biomass = 0.222 * Above-ground Biomass						[22]
All	All	All	Tree Litter = 0.17*Above-ground Incremental Biomass						[18]

[a] DBH is breast height (137 cm from forest floor) diameter; ring width and leader length are in cm; biomass is in grams; *n* = tree sample size; r^2 = regression coefficient; short trees are < 137 cm and tall trees are > 137 cm high above the forest floor.

2.4 Statistical analysis

SPSS 24.0 package (SPSS, Illinois, USA) was used for all statistical analyses. To estimate treatment or fixed effects (WT level: control and drained) on each of the response variables (tree biomass, productivity and C:N ratio), we used separate linear mixed-effects models. Year was taken as repeated measure within the same model because we measured the same quadrats in each growing season of years 2011 and 2012. For this repeated measure mixed-effects model analysis, we observed compound symmetry covariance stricture. At each quadrat and during each year, a mean value of each of biomass, productivity or C:N ratio was used for all statistical analyses. The data sets so obtained were then subjected to Levene's test and Kolmogorov-Smirnov test to test the equality of error and normality of distribution, respectively. A significance level of 95% ($p < 0.05$) was used for ANOVAs used for analyses. We report Goodness of fit as r^2 value.

3. RESULTS

3.1 Microclimate and Hydrology of Sites

The growing seasons' (May-October) of 2011 and 2012 had warmer average temperatures by 1.37 °C and 1.39 °C, respectively, and had greater precipitation by 43 mm in 2011 and lesser precipitation by 78 mm in 2012 than the 30-year (1981-2010) regional averages measured at Athabasca, Alberta, Canada [11]. After twelve years (in 2012) of WT lowering at drained site and recent atmospheric warming and drying, the WT levels were lowered at control by 6 cm and at drained site by 5 cm (Fig. 1), respectively.

3.2 Tree Biomass, Productivity and C:N Ratio

Although, the mean (± SD) total above- and below-ground tree biomass was higher at control (2617 ± 981 g m^{-2}) compared to one at the drained site (2400 ± 840 g m^{-2}), the difference was non-significant (Repeated Measure one-way ANOVA, $F_{1, 11}$ = 0.67, p = 0.450; Fig. 2A). Conversely, the mean tree growth during 2011-2012 (incremental above-ground biomass + below-ground biomass + tree litter) at drained site (175 ± 46 g m^{-2}) was significantly greater (Repeated Measure one-way ANOVA, $F_{1, 11}$ = 86.78, p < 0.001; Fig. 2B) than that at the control site (106 ± 37 g m-2). We determined the below-ground biomass (tree roots) by using the equation given by Li, Kurz [22], and that turned out to be higher at control (475 g m^{-2}) and lesser at drained site (435 g m^{-2}). Surprisingly the tree root productivity was lesser at control (8 g m^{-2} and 7 g m^{-2}) compared to those at the drained site (15 g m^{-2} and 13 g m^{-2}) in 2011 and 2012, respectively [11].

The tree productivity was driven by WT lowering, and was found to be related to WT level (Fig. 3A; $F_{1, 23}$ = 108.72, p < 0.001, r^2 = 0.85). The WT level related tree productivity was in turn related to its foliar C:N ratio (Fig. 3B; $F_{1, 19}$ = 6.50, p < 0.038, r^2 = 0.58) which was lower at drained (61 ± 11) and higher at the control site (82 ± 14).

4. DISCUSSION

This study is based on C balance and productivity field investigations [11, 15, 23] in a subhumid, continental treed bog. They quantified black spruce productivity for two years' (2011-2012) growth seasons (May-October), and found it positively related with the deepening of WT level. We advanced their research by quantifying changes in black spruce foliar C:N ratio in response to changes in WT level, and investigating the relationship of black spruce NPP with its foliar C:N ratio, in the studied peatland.

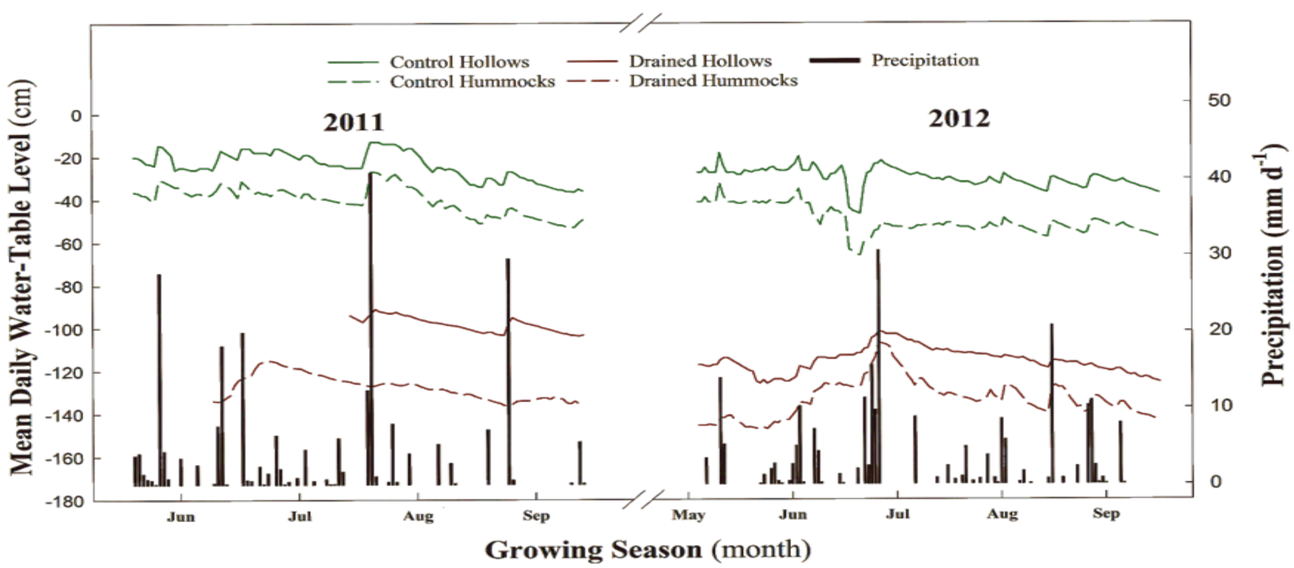

Figure 1. Mean daily precipitation at all sites and mean daily water-table level at hummock-hollow microtopography during 2011-2012 growing seasons (May-October).

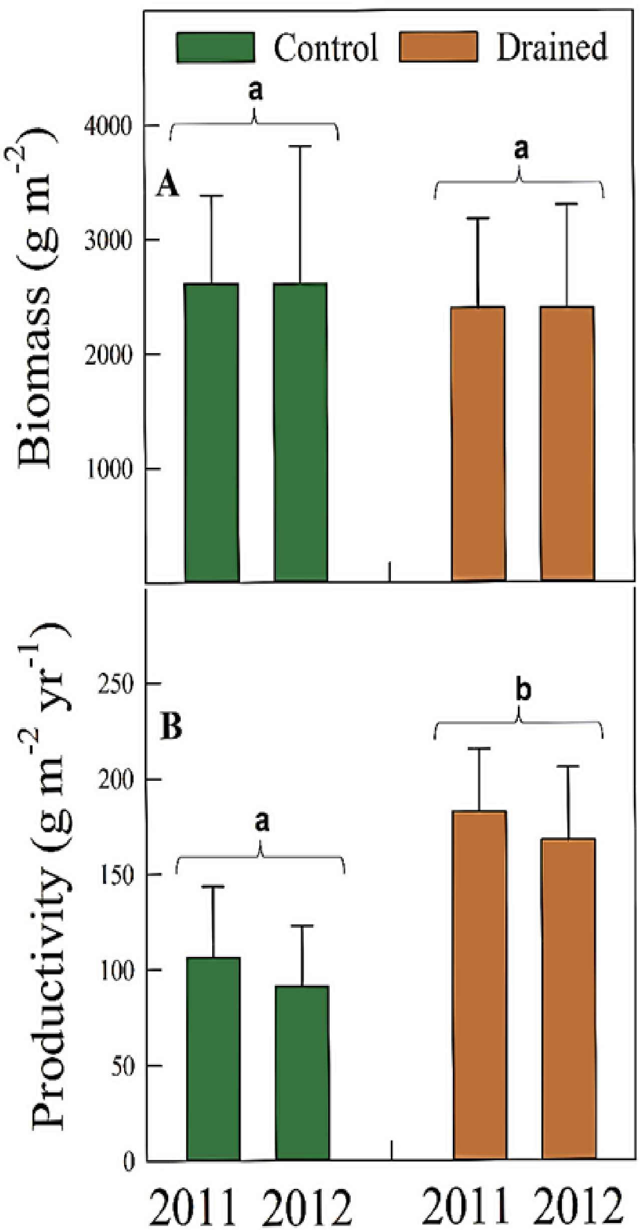

Figure 2. Tree biomass (g m^{-2}; A) and productivity (g m^{-2} yr^{-1}; B) did not significantly differ between years or sites except the drained site productivity significantly differed (Repeated Measure ANOVAs: Biomass, $F_{1, 11} = 0.67$, $p = 0.450$; Productivity, $F_{1, 11} = 86.78$, $p < 0.001$). Each error bar indicates ± SD of the mean ($n = 6$). Sites differ significantly at $P < 0.05$ when they differ in assigned letter.

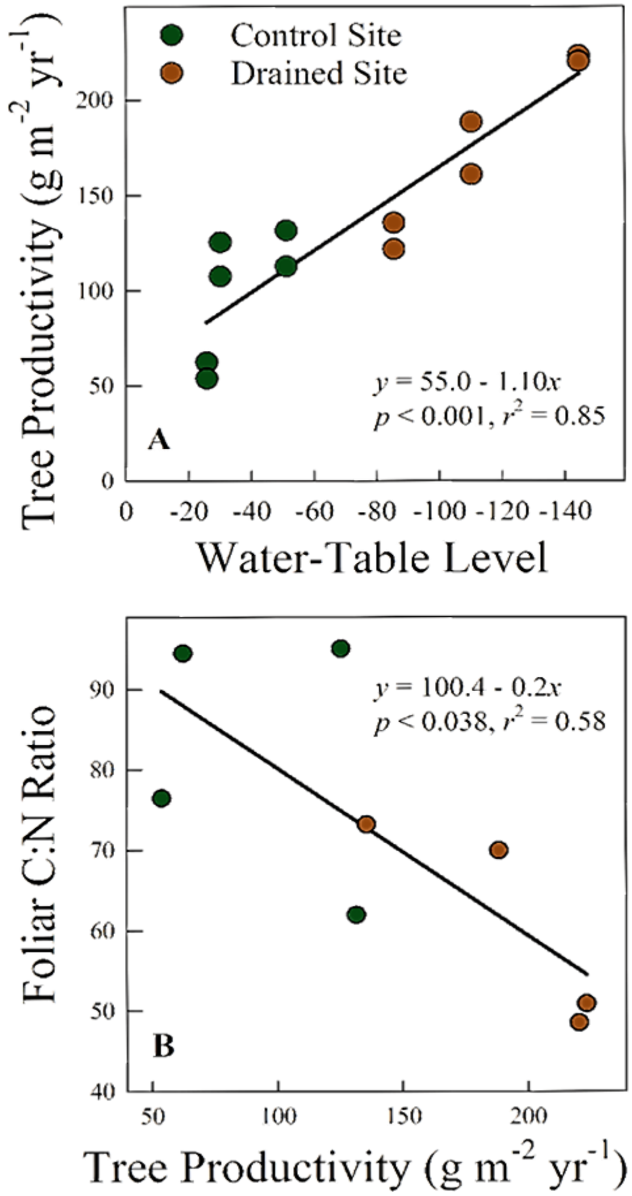

Figure 3: A). Relationship between water-table level and tree productivity (ANOVA, $F_{1, 23} = 108.72$, $p < 0.001$). Each point is a mean water-table level and tree productivity at one quadrat for one growing season in one year; B). Relationship between tree productivity and its foliar C:N ratio (ANOVA, $F_{1, 19} = 6.50$, $p = 0.038$). Only two foliar samples were collected for C:N analysis from each site in one year. Each point is a mean tree productivity and foliar C:N ratio at one quadrat for one growing season in one year.

4.1 Water-table – Biomass, NPP and C:N Ratio Relationships

This study uses the WT levels at the two peatland sites and black spruce biomass and productivity values reported by Munir, Perkins [11] except, they did not include the tree root biomass in the total tree biomass calculation compared to inclusion of the tree root biomass in the total tree biomass calculation by this study. The mean above-ground tree biomass data (2031 ± 379 g m^{-2}) reported by Munir, Perkins [11] were supported by the above-ground tree biomass data (2177 ± 2260 g m^{-2}) given by Moore, Bubier [10] for across 16 bogs in northern boreal forest. We observed no significant difference in the biomass across the gradient of decreasing WT level due our control site had an average below-ground WT level of 36 cm which supported the tree stand with denser but smaller diameter trees compared to the 80 cm deeper drained site. No significant differences between years were found for biomass or NPP$_{TS}$ values, although a mild reduction in NPP$_{TS}$ in 2012 was observed across sites. The reduction may be due to the overall drier and warmer conditions which also mildly lowered the WT across all sites during 2012 growing season (May to October).

In contrast to the biomass, the mean NPP_{TS} value at our drained site (175 ± 36 g m^{-2} yr^{-1}) was significantly greater than that at our control site (99 ± 35 g m^{-2} yr^{-1}). The increasing productivity with deepening of WT has been reported and attributed to thicker oxic peat which might have increased the availability of nutrients to tree roots [13, 24]. The increasing nutrient availability with deepening of WT has also been reported by peatland WT level – nutrient relationship studies [e.g., 9, 25], however, this investigation found a significant link between the productivity and foliar C:N ratio which strongly evidences that the increases in tree productivity and its foliar C:N ratio were actually driven by the impact of WT lowering.

4.2 NPP – foliar C:N ratio relationship

The NPP_{TS} and foliar C:N ratio significantly increased with deepening of WT. We found that the NPP_{TS} was related with foliar C:N ratio, evidencing that the changes in NPP_{TS} and foliar C:N ratio were WT level driven. Therefore, we suggest that the lowering of WT in peatlands (dry boreal continental bogs) can significantly increase the tree productivity and foliar C:N ratio which can result in a negative feedback to climate change (by increased atmospheric carbon dioxide uptake rate) or a positive feed back to climate change (by accelerated tree litter decomposition and mineralization rates).

CONCLUSION

In a boreal continental treed bog, the water-table lowering (simulating climate change) increased black spruce stand's biomass and productivity, and decreased foliar C:N ratio. The increasing productivity was related with decreasing foliar C:N ratio, verifying that water-table level was the leading driver of NPP_{TS} and foliar C:N ratio. Therefore, in the event of climate change and subsequent water-table lowering, increased productivity and decreased C:N ratio can give an important feedback to climate change.

ACKNOWLEDGEMENTS

This research project was funded by the University of Calgary and Alberta Tech Futures while SunGro Hort. Ltd. permitted access to their peatland sites. We appreciate Dr. Fung for statistical analysis back up, Dr. B. Xu, C. Campbell, J. Branham, M. Keith, S. V. Stavel, and H. Yeung for field and M. Bird for lab. help. Comments from two anonymous referees, Dr. M. Jamshed and editor Muhammad Azam Sheikh helped greatly to improve this manuscript.

5. REFERENCES

[1]. Yu, Z., Loisel, J., Brosseau, D. P., Beilman, D. W., and Hunt, S. J., "Global peatland dynamics since the Last Glacial Maximum". *Geophysical Research Letters*. **37**(13): 1-28(2010).

[2]. Tarnocai, C., Canadell, J., Schuur, E., Kuhry, P., Mazhitova, G., and Zimov, S., "Soil organic carbon pools in the northern circumpolar permafrost region". *Global Biogeochemical Cycles*. **23**(GB2023): 1-11(2009).

[3]. Vitt, D. H., Wieder, R. K., Scott, K. D., and Faller, S., "Decomposition and peat accumulation in rich fens of boreal Alberta, Canada". *Ecosystems*. **12**(3): 360-373(2009).

[4]. Turetsky, M., "Current disturbance and the diminishing peatland carbon sink". *Geophysical Research Letters*. **29**(11): 2002).

[5]. Maclean, D. A., "Vulnerability of fir-spruce stands during uncontrolled spruce budworm outbreaks: a review and discussion". *The Forestry Chronicle*. **56**(5): 213-221(1980).

[6]. Clymo, R., Turunen, J., and Tolonen, K., "Carbon accumulation in peatland". *Oikos*. **81**(2): 368-388(1998).

[7]. Harden, J., Trumbore, S. E., Stocks, B., Hirsch, A., Gower, S. T., O'neill, K., and Kasischke, E., "The role of fire in the boreal carbon budget". *Global Change Biology*. **6**(S1): 174-184(2000).

[8]. Stocker, T. F., *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. 2014: Cambridge University Press.

[9]. Macrae, M. L., Devito, K. J., Strack, M., and Waddington, J. M., "Effect of water table drawdown on peatland nutrient dynamics: implications for climate change". *Biogeochemistry*. **112**(1-3): 661-676(2013).

[10]. Moore, T. R., Bubier, J. L., Frolking, S. E., Lafleur, P. M., and Roulet, N. T., "Plant biomass and production and CO_2 exchange in an ombrotrophic bog". *Journal of Ecology*. **90**(1): 25-36(2002).

[11]. Munir, T. M., Perkins, M., Kaing, E., and Strack, M., "Carbon dioxide flux and net primary production of a boreal treed bog: Responses to warming and water-table-lowering simulations of climate change". *Biogeosciences*. **12**(4): 1091-1111(2015).

[12]. Roulet, N., Moore, T., Bubier, J., and Lafleur, P., "Northern fens: methane flux and climatic change". *Tellus B*. **44**(2): 100-105(1992).

[13]. Lieffers, V. J. and Rothwell, R. L., "Rooting of peatland black spruce and tamarack in relation to depth of water-table". *Canadian Journal of Botany-Revue Canadienne De Botanique*. **65**(5): 817-821(1987).

[14]. Laiho, R., "Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels". *Soil Biology and Biochemistry*. **38**(8): 2011-2024(2006).

[15]. Munir, T. M., Xu, B., Perkins, M., and Strack, M., "Responses of carbon dioxide flux and plant biomass to water table drawdown in a treed peatland in northern Alberta: a climate change perspective". *Biogeosciences*. **11**(3): 807-820(2014).

[16]. Riley, J. L., *Flora of the Hudson Bay Lowland and its postglacial origins*. 2003: NRC Research Press.

[17]. Grigal, D. and Kernik, L., "Generality of black spruce biomass estimation equations". *Canadian Journal of Forest Research*. **14**(3): 468-470(1984).

[18]. Szumigalski, A. R. and Bayley, S. E., "Net above-ground primary production along a bog-rich fen gradient in central Alberta, Canada". *Wetlands*. **16**(4): 467-476(1996).

[19]. Thormann, M. N. and Bayley, S. E., "Above-ground net primary production along a bog-fen-marsh gradient in southern boreal Alberta, Canada". *Ecoscience*. **4**(3): 374-384(1997).

[20]. Varem-Sanders, T. M. L. and Campbell, I. D., "DendroScan: a tree-ring width and density measurement system. Canadian Forest Service, Northern Forestry Centre, Edmonton, Alta. Spec. Rep. 10". 1996).

[21]. Mullin, T., Morgenstern, E., Park, Y., and Fowler, D., "Genetic parameters from a clonally replicated test of black spruce (Picea mariana)". *Canadian Journal of Forest Research*. **22**(1): 24-36(1992).

[22]. Li, Z., Kurz, W. A., Apps, M. J., and Beukema, S. J., "Belowground biomass dynamics in the carbon budget model of the Canadian forest sector: Recent improvements and implications for the estimation of NPP and NEP". *Canadian Journal of Forest Research*. **33**(1): 126-136(2003).

[23]. Munir, T. and Strack, M., "Methane flux influenced by experimental water table drawdown and soil warming in a dry boreal continental bog". *Ecosystems*. **17**: 1271-1285(2014).

[24]. Paavilainen, E. and Päivänen, J., *Peatland forestry: ecology and principles*. Vol. 111. 1995: Springer Science & Business Media.

[25]. Wood, M. E., Macrae, M. L., Strack, M., Price, J. S., Osko, T. J., and Petrone, R. M., "Spatial variation in nutrient dynamics among five different peatland types in the Alberta oil sands region". *Ecohydrology*. **9**(4): 688-699(2016).