Hummock Vegetation at the Arctic Tree-line near Churchill, Manitoba

JÖRG TEWS

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Hummocks, small earth or peat mounds, are widely distributed in the arctic and develop as a consequence of biomass accumulation and cryoturbation in the active layer. There is general agreement that the type of vegetation covering peat hummocks may alter the accumulation rate of organic material and thus hummock growth and local carbon sink dynamics. Studies on hummock plant community compositions from the arctic are very scarce. Here, I present results of a case study from the arctic tree-line near Churchill, Manitoba (Canada). Vegetation composition, hummock height and soil moisture content were recorded in 40 peat hummocks located along a tree-line gradient from open forest to tundra. Based on a cluster analysis I found three moss-dominated types of hummock vegetation, according to (1) a *Tomenthypnum nitens* (golden fuzzy fen moss) type on low hummocks, (2) a *Hylocomium splendens* (stair-step moss) type on medium-sized hummocks, and (3) a *Pleurozium schreberi* (red-stemmed feathermoss) type on hummocks higher than 60-70 cm. I found hummock height to increase towards the forest interior with decreasing water content of the upper organic layer on the hummock top. This is indicated by a significant change in vegetation composition towards drought resistant moss species on higher hummocks. Furthermore, species richness decreased with increase in hummock height. Based on evidence from historical tree-line invasion the overall results suggest that hummock height increases due to peat accumulation over the course of time resulting in a typical change in plant community composition.

Key Words: peat hummocks, *Tomenthypnum nitens*, Golden Fuzzy Fen Moss, *Hylocomium splendens*, Stair-step Moss, *Pleurozium schreberi*, Red-stemmed Feathermoss, subarctic, forest-tundra ecotone, Hudson Bay Lowlands, Manitoba.

Hummocks are small, up to 1 m high soil mounds widely distributed in the northern boreal, sub-arctic and arctic permafrost regions (e.g., Lundquist 1969; Mackay 1980). Generally, two types of hummocks can be classified: earth hummocks and peat hummocks. Earth hummocks may develop as a result of frost heave and cryoturbation processes where the organic layer overlies fine-grained frost-susceptible soils (Quinton et al. 2000). In contrast, peat hummocks grow as the result of the accumulation of organic material and where the surface of the uppermost mineral layer inside the hummock is positioned below the surrounding ground level (see Dredge 1992). Both hummock types may be perennially frozen or, as a result of warmer summer climate and lower latitude, completely thawed (Zoltai and Pettapiece 1974; Tarnocai and Zoltai 1978). As a transitional form they may be partially frozen with ice lenses remaining in the hummock core during the summer period.

Even though hummocks are a common landscape feature and hummocky terrain covers a large proportion of Arctic Canada (Tarnocai and Zoltai 1978), scientific studies focusing on the vegetation structure of peat hummocks are very scarce. This lack of empirical data and also the potential role of peat hummocks for the carbon dynamics in the northern hemisphere emphasize the need to investigate the spatial distribution of major hummock plant community types. Besides the prevailing local climate, carbon storage in the arctic is strongly influenced by vegetation composition and succession (see Camill et al. 2001). Thus, in order to appreciate carbon dynamics in the northern hemisphere acknowledge of potential carbon sinks (such as peat hummocks) and their major plant community types are necessary. This enables evaluation of ecological factors which may alter accumulation or decomposition rates of organic material and related carbon dynamics. For example, mosses which often dominate hummock vegetation have the potential to play a key role in modifying decomposition rates and the thermal and hydrological regime of arctic soils (Beringer et al. 2001). Here, I present results of a case study on vegetation composition, succession and physiognomy of 40 peat hummocks located along an arctic tree-line transect from tundra to open forest in the Hudson Bay Lowlands near Churchill, Manitoba (Canada).

Methods

Study area

The study site is situated at the open forest tree-line near Twin Lakes, a flat-topped glacial kame deposit approximately 25 km southeast of the town of Churchill (Figure 1). The open forest vegetation is composed of a mix of Tamarack (*Larix laricina* [Du Roi] K. Kock) and White Spruce (*Picea glauca* [Moench] Voss) with interspersed Black Spruce (*Picea mariana* [Mill.] Britt Sterns & Pogg). The present tree line north of Twin Lakes is extended into a wet sedge fen

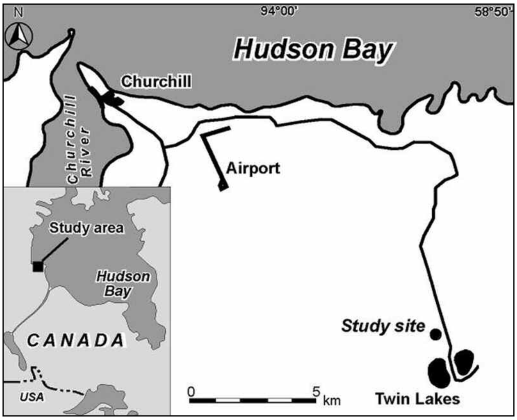

FIGURE 1: Location of the study site in the Hudson Bay Lowlands near Churchill in northeastern Manitoba (Canada).

predominated by *Carex aquatilis* (Water Sedge) and *Carex limosa* (Mud Sedge). The current position of the tree-line has moved up to 150 m towards the open sedge fen within the last 70 years (see Scott et al. 1987). Here, the current tree-line is composed of *L. laricina* which established during the latest forest invasion. Whereas young *L. laricina* tree-line stands are characterized by small hummocks, the open forest interior towards Twin Lakes is dominated by mature *P. glauca* trees on typically hummocky terrain with large hummocks and inter-hummock, water-filled troughs. The nomenclature for plants follows after Porsild and Cody (1980).

Sample design

During July 1999 I established a 250 m transect from the open sedge fen towards the forest interior. I sampled each hummock (total 40) that occurred within a 5 m wide corridor along the transect line. For each hummock I measured its height from the top to the base. Vegetation composition was studied by using a frame placed on top of each hummock. The frame size 0.5 * 0.5 m was small enough to cover the tops of the smallest hummocks. For larger hummocks I chose homogeneous parts of the vegetation on the hummock top. Vascular plant cover within the sampling frame was then estimated for each plant species separately using the decimal Londo-scale (Londo 1984). Within each frame soil samples were taken from the upper organic layer (5 cm – 20 cm depth) during one sampling day and then water content gravimetrically determined (samples were 24h oven-dried at 95°).

Statistical analysis

To group species datasets Mulva's minimal variance clustering technique using van der Maarel's coefficient was used (Wildi and Orlóci 1996). Simple linear regression was used to examine the relationship between hummock height as an independent variable and water content, species richness, and similarity of species composition (species turnover rate) as the dependent variables. For the species turnover rate between sample *i* and *j* hummocks were ranked by height and *ß* defined according to:

$$\beta = \frac{l+g}{i+j} \qquad \text{eqn 1,}$$

where l is the number of species that disappeared between sample i and j and g the number of new species.

Results

Hummocks are a dominant micro-topographical feature at the open forest tree-line. For the transect area I found a mean density of 320 hummocks ha^{-1}. However, density was significantly higher in mature *P. glauca* stands towards the open forest. The majority of hummocks were predominately covered by either one of the moss species *Tomenthypnum nitens* (Golden Fuzzy Fen Moss), *Hylocomium splendens* (Stair-step Moss) or *Pleurozium schreber* (Red-stemmed Feathermoss) whereas herbaceous plants where less frequent. This was confirmed by a resemblance matrix of a cluster analysis for 40 sample plots (Figure 2). The *Tomenthypnum nitens*-group was mainly composed of *Polygonum viviparum* (Alpine Bistort), *Equisetum variegatum* (Variegated Scouring-rush), *Andromeda polifolia* (Dwarf Bog-rosemary), and *Carex aquatilis* (Water Sedge), indicating somewhat wet conditions (see Table 1). In contrast, hummocks with *Hylocomium splendens* had a more or less Dwarf Shrub dominated cover with species such as *Vaccinium vitis-idaea* (Lingonberry), *Ledum groenlandicum* (Common Labrador Tea), and the lichen *Cladina rangiferina* (Grey Reindeer Lichen). The third major group was dominated by *Pleurozium schreberi* associated with *Betula glandulosa* (Dwarf Birch) and the grass *Calamagrostis canadensis* (Blue Joint), indicating somewhat dry conditions.

The species groups that were revealed by the cluster analysis showed significant affiliation in terms of transect position and respective hummock height. The *Tomenthypnum nitens*-group was mainly found on low hummocks (see Table 1) located near the tree-line (Figure 3a). Here, the organic layer on hummock tops was mostly saturated (Figure 3b), typical for the hydrological situation near the sedge fen. Hummocks with *Hylocomium splendens* had medium-sized heights and an intermediate transect position, whereas *Pleurozium schreberi*-hummocks with heights above 60 cm where predominately found in the open forest interior.

Overall, there was an increase in hummock height towards the open forest (Figure 3a, $R^2 = 0.57$). Increase in height had a significant negative effect on organic layer water content (Figure 3b, $R^2 = 0.46$). In terms of patterns of plant species richness, species number decreased with increase in hummock height (Figure 3c, $R^2 = 0.42$; see also Table 1). Total number of plant species found, including mosses and lichens, was 45, and 8.1 species per sample plot on average. Moreover, intermediate hummock heights were indicated

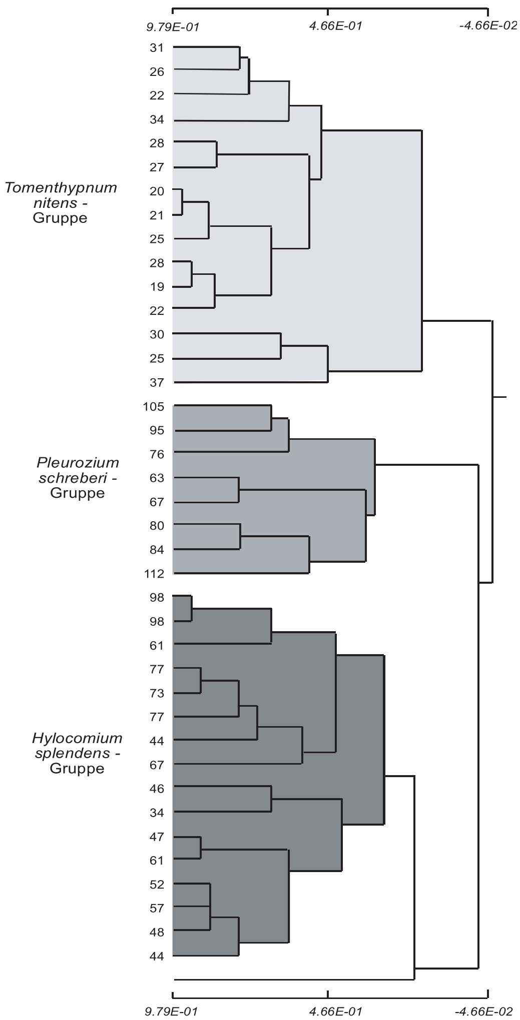

FIGURE 2: Cluster analysis of 40 hummock vegetation samples. Three moss-dominated plant community types are distinctive according to the occurrence of *Tomenthypnum nitens*, *Hylocomium splendens* and *Pleurozium schreberi*. Numbers for each sample indicate respective hummock height given in cm.

by a relatively high species turnover rate when plots were ranked by height (Figure 3d), i.e., species composition showed a higher variation than vegetation of either low or high hummocks.

Discussion

The results of this field study from the arctic tree-line near Churchill indicate a significant relationship between hummock height and the position along the tree-line gradient on one hand, and hummock height and water content, vegetation type, species richness, and species turnover on the other hand. Increasing hummock height towards the forest interior seemed to reduce moisture availability for mosses on the hummock tops and facilitate the establishment of species-poorer communities with drought-resistant vascular plants. Interestingly, *Tomenthypnum nitens, Hylocomium splendens* and *Pleurozium schreberi* are ubiquitous moss species with a wide ecological distribution (Nicholson and Gignac 1995). However in this study they showed distinct distribution patterns in relation to hummock height and soil water availability within a relatively small area.

The plant community composition of peat hummocks described here are the first inventory of hummock vegetation in the Hudson Bay Lowlands, the largest contiguous wetland in North America (Boudreau and Rouse 1995). Other published studies are concerned with the Mackenzie delta region where earth hummock physiology and plant species composition is completely different. Thus, they are difficult to compare (see e.g., Zoltai and Pettapiece 1974). It is unclear whether peat hummocks accumulate organic material and increase in size regardless of the local environment or whether this is driven by the micro-topography such as the establishment of trees. However, the local tree-line extension near Twin Lakes suggests that once young trees establish on formerly open tundra, peat hummocks may develop where shading and increased moisture from trapped snow coincide with feather moss establishment (Scott and Hansell 2002). Moreover, the occurrence of rotten tree stumps in the subsoil of the former centre of large, degraded hummocks (J. Tews personal observation) may support the latter hypothesis and is additional evidence that these hummock are formed by organic matter accumulation, not by cryogenic processes as is the case with earth hummocks.

Based on this study I hypothesize that hummock plant community composition at the tree-line near Twin Lakes is changing in the course of hummock growth. This is important as accumulation rates of peat (and thus carbon dynamics) are strongly influenced by local vegetation succession (Camill et al. 2001). Bello and D'Souza (2000) found that with increase in hummock height, accumulation rates of organic material decrease. For an average height of 20 cm they estimated an accumulation rate of 20 g m^{-2} $year^{-1}$, for 60 cm hummock height only 5 g m^{-2} $year^{-1}$. These results largely confirm growth rates found for *Tomenthypnum nitens* and *Hylocomium splendens* (see Busby et al. 1978). In general, decomposition rates increase with decreasing water saturation during the short summer period. However, due to this rather small array of data, current available data may not support proper estimates of community-specific accumulation rates necessarty to model large-scale spatial and temporal carbon dynamics in the arctic. Thus, based on the knowledge of the predominant types of hummock plant communities, more studies on community-specific accumulation rates are needed.

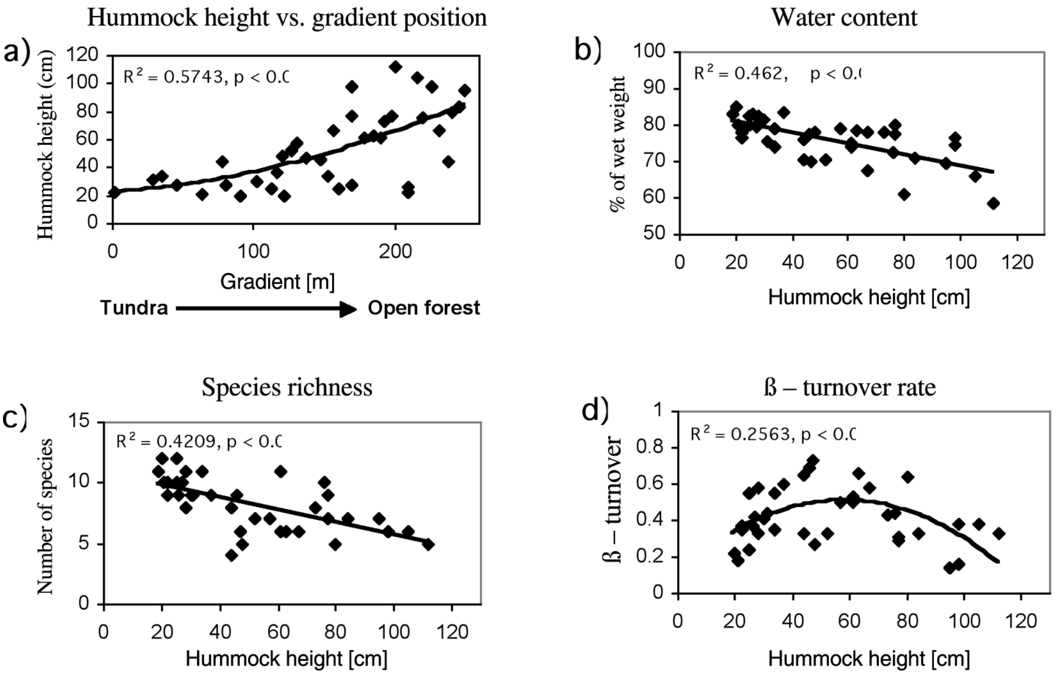

FIGURE 3: Simple regression analysis for: (3a) hummock height vs. gradient position along the tree-line from open tundra to forest; (3b) water content of upper humus layer on hummock top vs. hummock height; (3c) total number of plant species vs. hummock height; (3d) species turnover rate vs. hummock height.

Another current environmental issue makes the matter even more complex: global climate change. On average, climate change in the arctic may yield more precipitation and warmer summers (see Sonesson 2002). Based on these assumptions, there is general agreement that global climate change will alter decomposition rates and carbon storage (e.g., Gorham 1997; Earle et al. 2003). Dormann and Woodin (2002) pointed out that the driver of future change in arctic vegetation is likely to be increased nutrient availability, aris-

Table 1: Typical species composition of hummocks at the arctic tree-line near Churchill, Manitoba. The table shows 27 characteristic hummock samples out of a total of 40 samples (13 samples with less significant community affiliation are not shown). Three moss-dominated plant community types are evident according to *Tomenthypnum nitens*, *Hylocomium splendens* and *Pleurozium schreberi*.

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Hummock height	21	19	26	28	34	31	25	20	25	37	22	22	27	98	47	98	73	77	61	105	95	76	112	77	84	67	80
# of species	10	11	9	11	11	9	12	12	10	9	10	9	10	6	6	6	8	7	6	7	7	10	5	9	7	6	5
Tomenthypnum nitens	9	10	10	10	9	8	10	9	8	1	10	9	9														
Polygonum viviparum	.1	.2	.4	.2	.4	.4	.4	.2	.4	.2																	
Equisetum variegatum	.4	.4	.2	.4	.4		.2	.4	.1		.4	.2	.4														
Scirpus caespitosus	.2				3			.4			.4																
Carex aquatilis	1	.4	.2	.4			1	1				.4	1														
Andromeda polifolia	2	.1		.2			1	1			.2	1	.4														
Platanthera obtusata				.1						.1																	
Oxyccocus microcarpus			1	.4				.1					.4														
Rubus acaulis	.2				1	.4	.4		.1	.1			.4														
Pedicularis lapponica		.2						.2																			
Salix reticulata		.2			1						.2		2														
Aulacomnium palustre	1						.4	1	2	9		.4	1														
Hylocomium splendens														9	6	10	8	8	6	2	1	6	1	8	1		
Vaccinium vitis-idaea														3		2	3	2	.2	.4	2	.4	7	2	1	.4	
Ledum groenlandicum														8		6				5	4	4		.2			
Ledum decumbens														1		2					2	1			3		1
Cladina rangiferina															4		.1	.4	2		.4	1	2	1	6	2	2
Pleurozium schreberi																				8	7	4	5	1	3	9	6
Betula glandulosa																				2							
Calamagrostis canadensis																					.2				.1		

ing for example from temperature-induced increases in mineralization. In particular, the response of plant growth to rising CO_2 levels appears to depend on nutrient availability (Heijmans et al. 2002). In the arctic vegetation nitrogen is tightly controlled by the moss layer (e.g., Li and Vitt 1997; Sommerkorn et al. 1999). Moreover, mosses such as *Pleurozium schreberi* have been reported to be able to fix nitrogen in symbiosis with a cyanobacterium (i.e. *Nostoc* sp.) (Deluca et al. 2002). Thus, increase in average summer temperatures due to climate change and the resulting increase in mineralization rates may potentially decrease local carbon storage with severe consequences for the global carbon cycle. However, scientific research is far from establishing realistic future scenarios. For example, in the context of our study, it was recently shown that individual bryophyte species displayed contrasting responses to changes in the nutrient supply and that they should not be grouped as a single functional type (Gordon et al. 2001). From this it is evident that further detailed hummock vegetation studies are needed, particularly in the arctic where the impact of climate change is likely to be most effective.

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Literature Cited

Bello, R., and **A. D'Souza**. 2000. Half-century carbon accumulation rates in a Churchill, Manitoba Sedge Fen. In: Circumpolar Ecosystems IV, Churchill Northern Studies Centre, page 16.

Beringer, J., A. H. Lynch, F. S. Chapin, M. Mack, and **G. B. Bonan**. 2001. The representation of arctic soils in the land surface model: The importance of mosses. Journal of Climate 14: 3324-3335.

Boudreau, L. D., and **W. R. Rouse**.1995: The role of individual terrain units in the water balance of wetland tundra. Climate Research 5: 31-47.

Busby, J. R., L. C. Bliss, and **C. D. Hamilton**.1978. Microclimate control of growth rates and habitats of the boreal forest mosses *Thomenthypnum nitens* and *Hylocomium plendens*. Ecological Monographs 48: 95-110.

Camill, P., J. A. Lynch, J. S. Clark, J. B. Adams, and **B. Jordan**. 2001. Changes in biomass, aboveground net primary production, and peat accumulation following permafrost thaw in the boreal peatlands of Manitoba, Canada. Ecosystems 4: 461-478.

Deluca, T. H., O. Zackrisson, M. C. Nilsson, and **A. Sellstedt**. 2002. Quantifying nitrogen-fixation in feather moss carpets of boreal forests. Nature 419: 917-920.

Dorman, C. F., and **S. L. Woodin**. 2002. Climate change in the Arctic: using plant functional types in a meta-analysis of field experiments. Functional Ecology 16: 4-17.

Dredge, L. A. 1992. Field guide to the Churchill Region, Manitoba. Geological Survey of Canada, Miscellaneous Report 53.

Earle, L. R., B. G. Warner, and **R. Aravena**. 2003. Rapid development of an unusual peat-accumulating ecosystem in the Chilean Altiplano. Quaternary Research 59: 2-11.

Gordon, C., J. M. Wynn, and **S. J. Woodin**. 2001. Impacts of increased nitrogen supply on high Arctic heath: the importance of bryophytes and phosphorus availability. New Phytologist 149: 461-471.

Gorham, E. 1997. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications 1: 182-195.

Heijmans, M. M. P. D., H. Klees, W. de Visser, and **F. Berendse**. 2002. Response of a Sphagnum bog plant community to elevated CO2 and N supply. Plant Ecology 162: 123-134.

Li, Y. H., and **D. H. Vitt**. 1997. Patterns of retention and utilization of aerially deposited nitrogen in boreal peatlands. Ecoscience 4: 106-116.

Londo, G. 1984. The decimal scale for releves of permanent quadrats. Pages 45-49 *in* Sampling methods and taxon analysis in vegetation science – Handbook of Vegetation Science 4. *Edited by* R. Knapp. Junk, The Hague, Netherlands.

Lundquist, J. 1969. Earth and ice mounds: a terminological discussion. Pages 203-215 *in* The Periglacial Environment. *Edited by* T. L. Pewe. Montreal. Quebec.

Mackay, J. R. 1980. The origin of hummocks, Western Arctic Coast, Canada. Canadian Journal of Earth Science 17: 996-1006.

Nicholson, B. J., and **L. D. Gignac**. 1995. Ecotope dimensions of peatland bryophyte indicator species along gradients in the Mackenzie River Basin, Canada. Bryologist 98: 437-451.

Porsild, A. E., and **W. J. Cody**. 1980. Vascular plants of Continental Northwest Territories, Canada. National Museum of Natural Sciences, Ottawa.

Quinton, W. L., D. M. Gray, and **P. Marsh**. 2000. Subsurface drainage from hummock-covered hillslopes in the Arctic tundra. Journal of Hydrology 237: 113-125.

Scott, P. A., R. I. C. Hansell, and **D. C. F. Fayle**.1987. Establishment of white spruce population and responses to climatic change at the tree-line, Churchill, Manitoba, Canada. Arctic and Alpine Research 19: 45-51.

Scott, P. A., and **R. I. C. Hansell**. 2002. Development of white spruce islands in the shrub zone of the forest-tundra. Arctic 55: 238-246.

Sommerkorn, M., M. Bolter, and **L. Kappen**.1999. Carbon dioxide fluxes of soils and mosses in wet tundra of Taimyr Peninsula, Siberia: controlling factors and contribution to net system fluxes. Polar Research 18: 253-260.

Sonesson, M., B. A. Carlsson, T. V. Callaghan, S. Halling, L. O. Bjorn, M. Bertgren, and **U. Johanson**. 2002. Growth of two peat-forming mosses in subarctic mires: species interactions and effects of simulated climate change. Oikos 99: 151-160.

Tarnocai, C., and **S. C. Zoltai**.1978. Earth hummocks of the Canadian arctic and subarctic. Arctic and Alpine Research 10: 581-594.

Wildi, O., and **L. Orlóci**.1996. Numerical Exploration of Community Patterns. SPB Academic Publishing, The Hague, 171 pages

Zoltai, S. C., and **W. W. Pettapiece**. 1974. Tree distribution on perennially frozen earth hummocks. Arctic and Alpine Research 6: 403-411.

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