- High Arctic Wetlands -
Climate Sensitivity and Geomorphology

Christopher J. Ellis
Royal Botanic Garden Edinburgh
Published on-line: 2006

> Developmental Status

- The occurrence of permafrost at high latitudes enables the widespread development of Arctic and Subarctic wetlands [1, 2]; i.e. in low-lying areas, drainage of snow-melt is impeded by perennially frozen ground (Fig. 1).

Figure 1: Polygon-patterned wetland on Bylot Island (with Baffin Island beyond.

- The cold and wet soil conditions in Arctic wetlands acts to slow decomposition, and as organic matter accumulates the permafrost develops upwards into the aggrading sediments. Peat-rich soils associated with such wetlands have contributed a net sink for carbon during the Holocene and are estimated to store > 97 % of the tundra carbon reserve comprising *ca* 180-190 x 10^{15} g of soil-C [3, 4].

- The accretion of sediments is accompanied by the upward growth of 'syngenetic' ice-wedges [5, 6. 7], to form polygon-patterned wetland [1, 2]. The land-forms associated with polygon-patterned wetlands can be divided into three types [8, 9]: low-centre polygons (raised polygonal ridges surrounding a lower, wetter centre), polygon-ponds (raised polygonal ridges surrounding a pool) and high-centre polygons (a raised, domed centre surrounded by a polygonal network of water-filled troughs) – Fig. 2

Figure 2: Polygon-patterned wetlands: low-centre polygons (lower right), and polygon-ponds (centre) coalescing to form thermokarst lakes (upper left).

> Climate Change Consequences

- Human-induced climate change is expected to cause severe warming at high-latitudes [10, 11], prompting concerns that the role of Arctic ecosystems might consequently shift from a store (or sink) to a source of greenhouse gases (CO_2 & CH_4) [12, 13].

- Recent short-term studies have examined the functional response of vegetation and soils to simulated climate change, providing evidence for a pronounced sensitivity of the tundra to expected climatic warming [14, 15, 16, 17].

- However, future change in tundra ecosystems must be interpreted against a background of natural long-term variability. Palaeoenvironmental research points to natural decade- to century-scale change in the Arctic climate during past millennia, driven by variation in solar insolation and volcanic activity [18, 19]. The effect of climate on tundra ecology can therefore be examined by describing the sensitivity of tundra ecosystems to past climatic variability.

- My research has used palaeoecological analyses to ask whether climate sensitivity described by short-term studies may also control tundra wetland development over the long-term (i.e. during the Holocene). The results provide a novel long-term perspective for interpreting and predicting future climatically-controlled change in ecosystem structure and function.

> KEY FINDINGS <

Climatic sensitivity during tundra wetland development [20, 21]

- A series of four cores were collected from separate low-centre polygons within the Qunguliqtut Valley on Bylot Island (73°08' N, 80°00' W), part of the Canadian Arctic Archipelago.

- Radiocarbon-dated sub-fossil moss communities were compared to modern analogue communities sampled from the present-day wetland. Species-responses to soil moisture and pH were used to reconstruct local palaeoenvironments during *ca* 3500 yr of polygon development. Polygon development was characterised by striking temporal variation, comprising periodic wet- and dry-phases.

- Changes in past vegetation and reconstructed soil moisture (wet- and dry phases) were compared to regional palaeoclimatic proxy values, measured as percent melt and delta^{18}O in the ice cores Agassiz-84 and Devon Island 72/73 [22, 23].

- Periodic wet- and dry phases characterising polygon development appear unrelated to past climate over *ca* 50% of the combined stratigraphic records, and are attributable instead to known autogenic geomorphologic mechanisms, i.e. vegetation and periglacial processes controlling ice-wedge growth and polygon topography [20].

- However, during a period incorporating the Little Ice Age (*ca* 305-530 cal. yr BP), reconstructed moisture and vegetation change is pronounced and consistent amongst hydrologically discrete polygons [20, 21]. The estimated magnitude of change in soil moisture between wet- and dry phases is sufficient to imply recurrent shifts in wetland function, controlled principally by autogenic processes, though which may be periodically impacted by pronounced climatic variability.

- *We caution that:*

    1. *Previous research to simulate and describe the effects of climate warming might not have properly accounted for the dynamic role of periglacial geomorphology in regulating the tundra vegetation-soil complex.*
    2. *However, polygon development may have been periodically impacted by the direct or indirect effect of pronounced climate change (i.e. during the Little Ice Age). As a corollary, we suggest that the structure and function of High Arctic peat-forming wetlands may be susceptible to predicted, human-induced climate warming.*

References:

[1] Tarnocai, C. & Zoltai. S.C. (1988) Wetlands of arctic Canada. In National Wetlands Working Group, Canada Committee on Ecological Land Classification*, Wetlands of Canada*: 30-53. Canadian Wildlife Service, Ottawa.

[2] Bliss, L.C. (1997) Arctic ecosystems of North America. In F.E. Wielgolaski (ed.) *Ecosystems of the World, Volume 3. Polar and Alpine Tundra*: 551-683. Elsevier, Amsterdam.

[3] Post, W.M., Emanuel, W.R., Zinke, P.J. & Stangenberger, A.G. (1982) Soil carbon pools and world life zones. *Nature*, 298: 156-159.

[4] Oechel, W.C. & Vourtilis, G.L. (1994) The effects of climate change on land-atmosphere feedbacks in arctic tundra regions. *Trends in Ecology and Evolution*, 9: 324-329.

[5] Harry, D.G. & Gozdzik, J.S. (1988) Ice wedges: growth, thaw transformation, and palaeoenvironmental significance. *Journal of Quaternary Science*, 3: 39-55.

[6] Mackay, J. R. 1990. Some observations on the growth and deformation of epigenetic, syngenetic and anti-syngenetic ice wedges. *Permafrost and Periglacial Processes*, 1: 15-29.

[7] Mackay, J.R.(2000) Thermally induced movements in ice-wedge polygons, western Arctic coast: a long-term stucy. *Géographie physique et Quaternaire*, 54: 41-68.

[8] Péwé, T. R. Ice-wedges in Alaska: classification, distribution and climate significance. *Proceedings, International Conference on Permafrost*: 76-81. National Academy of Sciences-National Research Council, Washington, U.S.A.

[9] Billings, W.D., & Peterson. K.M. (1980) Vegetational change and ice-wedge polygons through the thaw-lake cycle in Arctic Alaska. *Arctic and Alpine Research*, 12: 413-432.

[10] Mitchell, F.F.B., Manabe, S., Tokioka, T. & Meleshoko, V. (1990) Equilibrium climate change. In J.T. Houghton, G.J. Jenkins, and J.J. Ephraums (eds) *Climate Change, the IPCC Scientific Assessment*: 131-172. Cambridge University Press, Cambridge.

[11] Maxwell, B. (1992) Arctic climate: potential for change under global warming. In F.S. Chapin, R.L. Jefferies, J.F. Reynolds, G.R. Shaver & J. Svoboda (eds) *Arctic Ecosystems in a Changing Climate: an Ecophysiological Perspective*: 11-34. Academic Press, San Diego.

[12] Shaver, G.R., Billings, W.D., Chapin, F.S., Giblin, A.E., Nadelhoffer, K.J., Oechel, W.C. & Rastetter, E.B. (1992) Global change and the carbon balance of arctic ecosystems. *Bioscience*, 42: 433-441.

[13] Chapin, F.S., McFadden, J.P. & Hobbie S.E. (1997) The role of arctic vegetation in ecosystem and global processes. In S. J. Woodin & M. Marquiss (eds) *Ecology of Arctic Environments. British Ecological Society Special Publication No. 13*: 97-112. Blackwell Science, Oxford.

[14] Chapin, F.S., Shaver, G.R., Giblin, A.E., Nadelhoffer, K.J. & Laundre J.A. (1995) Responses of arctic tundra to experimental and observed changes in climate. *Ecology*, 76: 694-711.

[15] Chapin, F.S., & Shaver, G.R. (1996) Physiological and growth responses of arctic plants to a field experiment simulating climate change. *Ecology*, 77: 822-840.

[16] Robinson, C.H., Wookey, P.A., Lee, J.A., Callaghan, T.V. & Press, M.C. (1998) Plant community responses to simulated environmental change at a high arctic polar semi-desert. *Ecology*, 79: 856-866.

[17] Arft, A.M., Walker, M.D., Gurevitch, J., Alatalo, J.M., Bret-Harte, M.S., Dale, M., Diemer, M., Gugerli, F., Henry, G.H.R., Jones, M.H., Hollister, R.D., Jónsdóttir, I.S., Laine, K., Lévesque, E., Marion, G.M., Molau, U., Mølgaard, P., Nordenhäll, U., Raszhivin, V., Robinson, C.H., Starr, G., Stenström, A., Totland, Ø., Turner, P.L., Walker, L.J., Webber, P.J., Welker, J.M. & Wookey P.A. (1999) Responses of tundra plants to experimental warming: meta-analysis of the international tundra experiment. *Ecological Monographs*, 69: 491-511.

[18] Overpeck, J., Hughen, K., Hardy, D., Bradley, R., Case, R., Douglas, M., Finney, B., Gajewski, K., Jacoby, G., Jennings, A., Lamoureux, S., Lasca, A., MacDonald, G., Moore, J., Retelle, M., Smith, S., Wolfe, A. & Zielinski. G. (1997) Arctic environmental change of the last four centuries. *Science*, 278: 1251-1256.

[19] Mann, M.E., Bradley, R.S. & Hughes, M.K. (1998) Global-scale temperature patterns and climate forcing over the past six centuries. *Nature*, 392: 779-787.

[20] Ellis, C.J. & Rochefort, L. (2004) Century-scale development of High Arctic polygon-patterned tundra wetland, Bylot Island (73 ^{o}N). *Ecology*, 85: 963-978.

[21] Ellis, C.J. & Rochefort, L. (2006) Long-term sensitivity of a High Arctic wetland to Holocene climate change. *Journal of Ecology*, 94: 441-454.

[22] Paterson, W.S.B., Koerner, R.M., Fisher, D., Johnson, S.J., Clausen, H.B., Dansgaard, W., Bucher, P. & Oeschger., H. (1977) An oxygen-isotope climatic record from the Devon Island ice cap, arctic Canada. *Nature*, 266: 508-511.

[23] Koerner, R.M. & Fisher D.A. (1990) A record of Holocene summer climate from a Canadian high-arctic ice core. *Nature*, 343: 630-631.