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Report on effects of altered soil temperature on the bioavailability of C and N in the riparian zone (Task 4.5)

Background, methods and preliminary results

Hjalmar Laudon and Kevin Bishop

Motivation

Dissolved organic matter (DOM) is a defining feature of streams, rivers and lakes in the boreal region. Most of the DOM export occurs during the spring flood, which in northern Sweden ends a period of close to six months of snow cover. Climate change scenarios for Sweden predict that the largest temperature effect will occur in the northern part of the country and will affect the winter period more than other seasons. How this change in climate will affect the quality and quantity of DOM exported to surface water is presently not well understood.

Objective

The objective of this project is to investigate how snow cover and soil frost regime effect DOM of surface waters with respect to natural conditions and conditions affected by global climate change. The specific goal is to elucidate how winter conditions affect the quality and quantity of DOM in the riparian soil that is available for export to adjacent streams during the transition from winter to spring.

Hypotheses

The timing, extent and duration of snow cover and soil frost in riparian soils are key components that impact the:

1) Concentration and quality of DOM in surface waters during spring flood in the Boreal forest
2) Bioavailability of the DOM exported from the soil during the spring

Background

Close to half of the annual runoff and between 50% and 70% of the dissolved organic carbon (DOC) is exported during snow melt in small streams and rivers in northern Sweden (Laudon et al. 2004a). Besides being the largest component of the ion balance in many Swedish surface waters, DOC is important for complexing and transporting metals, as well as an integral carbon and energy source in aquatic food webs. Stream transport of DOC is also an important component of the carbon cycle affecting the global carbon budget (Hope et al. 1997). In northern Sweden spring flood DOC is of particular interest because many surface waters experience a pH decline of one to two pH units driven primarily by a transient increase in DOC export from the terrestrial to aquatic systems during snow melt (Bishop et al. 2000, Laudon et al. 2005).

The fate of stream DOC will determine its potential impact on downstream environments. After entering the stream network bacterial utilization of DOC constitutes an important control on the DOC concentration. Algesten et al. (2004) has recently estimated that between 30% and 80% of terrestrial-derived DOC is oxidized to CO_2 in streams and lakes in northern Sweden. A large variation in the bacterial utilization of this DOC exists in the region (Sobek et al. 2003). If this variability is an effect of differences in the bioavailability of DOC determined by it terrestrial source or determined by other factors is presently not known.

The annual temperature in northern Sweden is expected to increase by 3 to 5 degrees in 100 years as a result of the burning of fossil fuel (Persson, 2003). This increase is predicted to be more prominent in the northern part of the country and biased towards winter. One important implication of a change in the climate for northern ecosystems will be a change in the timing, extent and duration of the snow cover (Venäläinen et al. 2001). The snow cover not only provides a major fraction of the annual water budget, but also plays a fundamental role in regulating the winter biogeochemistry of soils in the boreal forest (Groffman et al. 2001). Snow cover limits (or even prevents) the development of soil frost by insulating the soil environment during winter (Brooks et al. 1996). A later development of the snow pack, which is a likely effect of a warmer climate, may result in an increased number of freeze-thaw events or even colder soils in some situations because of longer periods during winter when soils are not insulated by snow (Stieglitz et al.2003).

An increased number of freeze-thaw events has been shown to result in increased root mortality (Tierney et al., 2001), improved substrate quality of soil organic matter (Öquist, 2001), elevated nitrate levels in runoff (1980, Mitchell et al., 1996, Fitzhugh et al., 2003) and increased carbon, nitrogen and phosphorus concentrations in soil solution (Fitzhugh et al., 2001). Two recent studies in northern Sweden (Stepanauskas et al. 2000; Eriksson, 2004) have provided initial evidence indicating that lysis of freeze-damaged soil organisms may cause an increase in the nutritional quality of both DOC and dissolved organic nitrogen (DON) during the spring flood. Stepanauskas et al. (2000) calculated that a lysis of only 2-3% of the soil microbial cells in the catchment could support the entire washout of DON observed during the spring flood.

How a change in the winter conditions will affect DOC and DON in surface waters of the boreal forest region is not well understood. It has, however, recently been demonstrated that the concentration of DOC in streams is strongly controlled by soil solution chemistry in the riparian zone (Bishop et al. 2004; Fig 1). Therefore even a small change in the conditions of the riparian zone could generate changes in both quantity and bioavailability of the DOC exported to the stream during the spring flood.

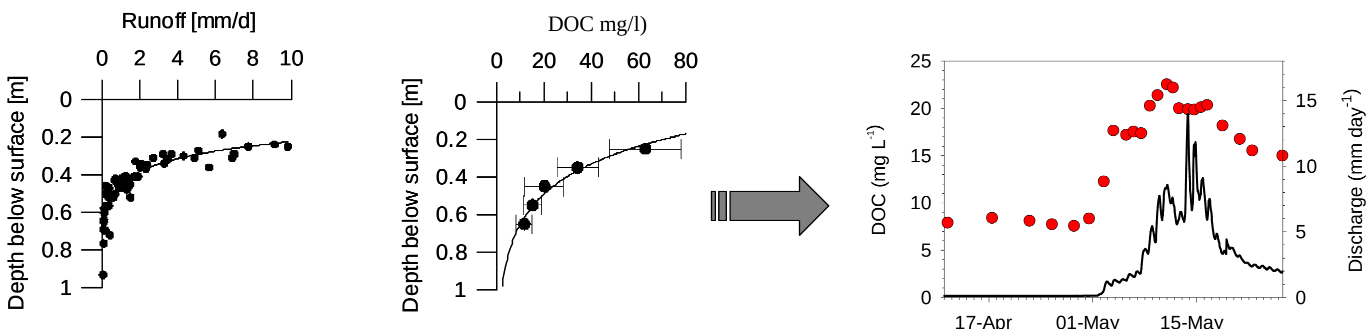

Fig. 1. The relationship between DOC in the riparian soil and runoff DOC. To the left, the correlation between groundwater level and stream runoff. In the center, the relationship between DOC and soil level. To the right, how the hydrology and DOC concentration of the riparian soil is translated into the dramatic concentration increase in the stream observed during the spring flood.

Methods

To test the hypothesis that winter conditions affect the quality and quantity of DOM, we have used a multi-year field scale manipulation experiment with continuous monitoring of soil temperature, soil frost depth and unfrozen soil water content. The field manipulation experiment is located at the Svartberget Research Station 60 km north-west of Umeå and was established in 2002. The experiment includes effect of both biogeochemical transformations and hydrological transport processes. Three soil frost treatments (including unfrozen, deep soil frost and control) with three replicates each (Fig. 2), are used to cover a wide range of possible soil frost depths. This multiyear manipulation is important in order distinguish longer-term effects from the transient conditions often found during the first years after manipulation (Jarvis and Linder, 2000).

The experiment is used to evaluate the effect of different soil frost regimes on the quality and quantity of DOM at five soil depths. Concentration profiles of DOC and DON, C/N ratio, Diode Array Detection (DAD) spectra and low molecular weight (LMW) organic acids are all being measured. Whereas the freeze concentration is expected to result in a conservative increase in measured parameters, lysis of cell structures will decrease the C/N ratio, because of high nitrogen contents of microbial cells (Deluca et al.1992), and increase the concentration of LMW organic acids. Conversely, microbial activity in the soil will decrease the easily degradable LMW organic acids, but also affect the DAD spectra at specific wavelengths (Kalbitz et al, 2003). Soil water samples for bioavailability determination of DOC and bacterial production are also being analysed using leucine incorporation. Furthermore, the dynamics of CO2, CH4 and N2O concentrations at the five soil depths have been measured weekly.

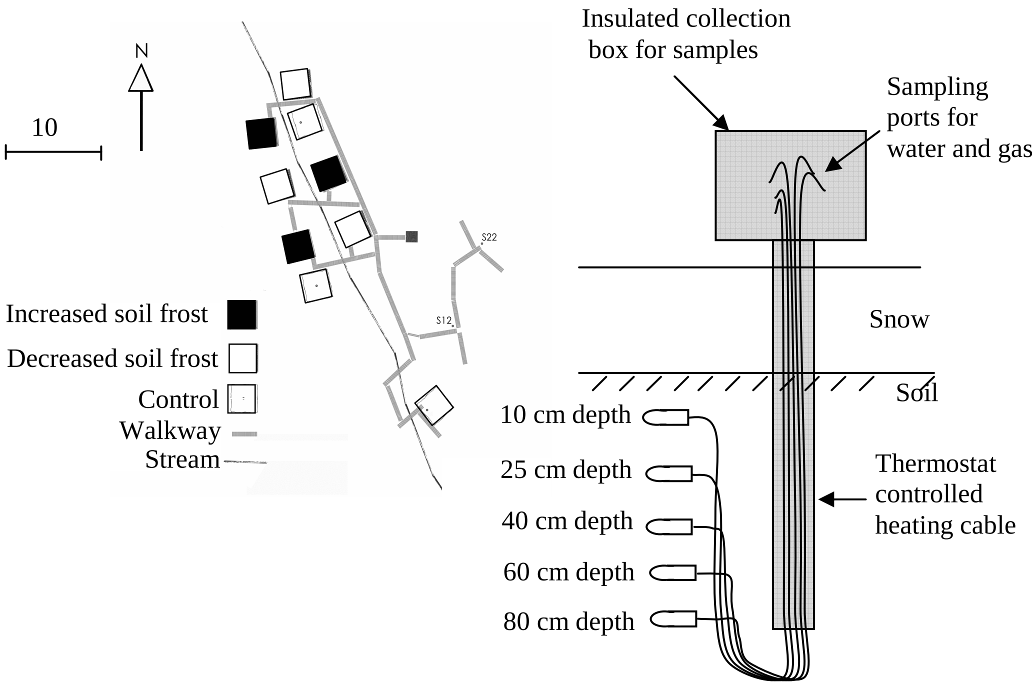

Figure 2. Schematic figure of the soil frost experiment. To the left is a map of the plot locations in relation to the stream. To the right is a description of the below ground sampling. At depths of 10, 25, 40, 60 and 80 cm below soil surface water samples can be collected during the entire winter and spring. This is made possible by the thermostat controlled heating system which prevents water from freezing when water collected from the lysimeters passes frozen soil horizons. Soil temperature and unfrozen water content (using TDR) are continuously monitored at all depths. Gas sampling probes at each depth are also installed for weekly measurements of CO_2, CH_4, and N_2O.

Preliminary results

The field scale manipulation experiment of soil frost with continuous monitoring of soil temperature, soil frost depth, unfrozen soil water content and soil water chemistry has revealed interesting and unanticipated results. Soil frost has been manipulated by insulation to prevent below-ground freezing and by delaying snow accumulation by three months to increase soil frost. The insulation and snow removal has demonstrated to be an effective way of controlling below soil temperature. One finding during the manipulation, which is within the range of natural variation of soil frost depths in the area, has been that it is not only winter temperature that is affected. Soil temperatures well into July are affected by the thermal conditions during winter (Figure 3). This temperature effect on the below-ground environment also gave a clear chemical effect (figure 4). The concentration of DOC in the previously frozen soil layers was clearly elevated compared to the unfrozen reference plots.

In this project we hypothesize that the timing, extent and duration of soil frost has a key control on the concentration and bioavailability of DOM that are exported from the riparian soil to surface waters during spring flood. The most important control on DOM is through freeze-out processes, lysis of cell structures and by limiting the soil microbial activity during winter. While freeze-out processes are believed to mainly control the concentration of DOM in soil solution below the expanding ice during freezing, lysis of cell structures may release highly bioavailable organic compounds of low molecular weight and low C/N ratio (Stepanauskas et al. 2000). The thermal conditions of the soil ecosystem also influence soil organic matter decomposition rate and microbial water availability (Schimel et al. 2004). Temperatures below freezing are unfavourable for heterotrophic microbial activity. This may result in undecomposed organic material of high substrate quality that will subsequently be decomposed during unfrozen conditions. Furthermore, the timing and extension of soil frost determines the hydrological pathways during the early phase of snow melt (Laudon et al, 2004b) and thereby the sequence of soil environments traversed by melt water and DOC on its way to the stream. Whether the increase in DOC in the recently thawed soil layers is due to freeze out processes, lysis of cells or a retardation of microbial activity will be further investigated in the coming months of the project.

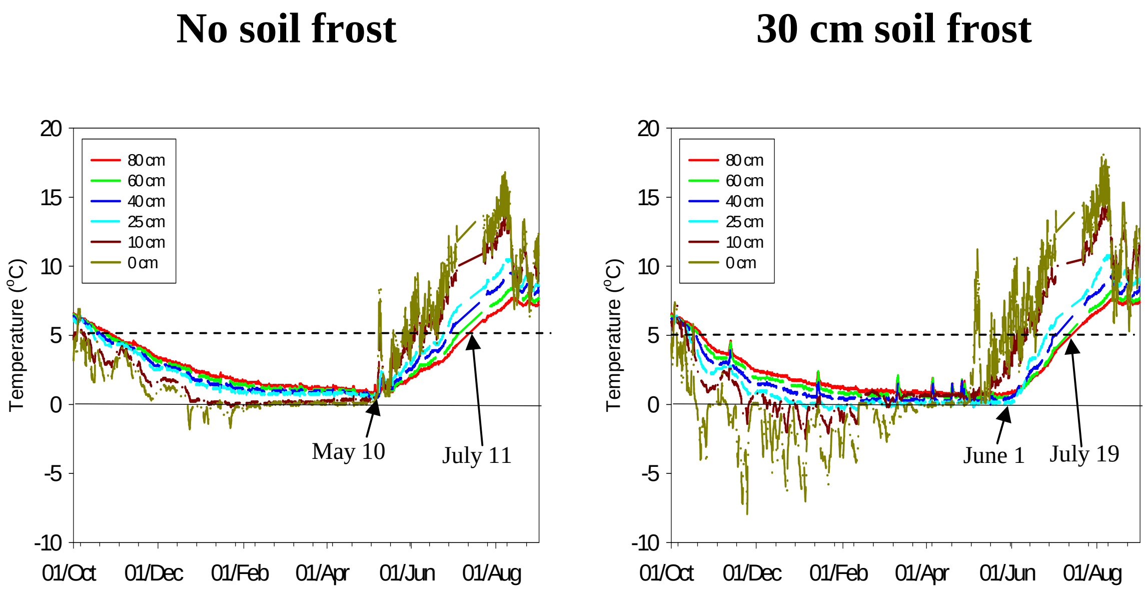

Figure 3. Below-ground temperature in the soil frost manipulations. Note that the soil temperature is delayed well into July in the deep soil frost treatment (right pane).

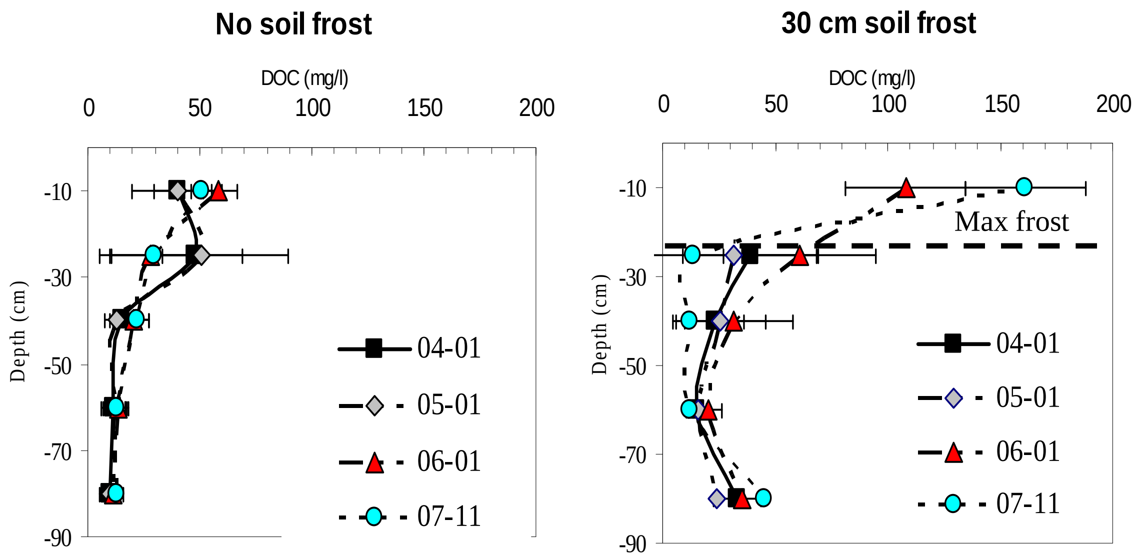

Figure 4. Concentration profiles of DOC in the soil during winter, spring and early summer at five soil depths in plots without and with deep soil frost.

Summary, implications and work in progress

The preliminary results from this study show dramatic effects of soil frost on the concentration of DOC. Most climate scenarios indicate that warming will be greatest in northern latitudes and especially strong during the winter months. Paradoxically, in high latitude regions a climate change towards warmer conditions will not necessarily lead to warmer soil temperatures in the spring. Instead a shift leading to snow covering the ground for shorter durations could even result in an increase in soil freezing in northern forests. Although this merely is speculations, the importance of winter conditions and soil frost needs to be better understood in order to predict future effects on water quality. If soil conditions under a changing climate are changing towards higher DOM concentrations in the riparian soil this will in turn affect the receiving stream ecosystems. In this project a number of questions remain. At present data is being analyzed to answer questions on how DON is affected by the soil frost conditions. We are also investigating a number of quality aspects of DOM in the soil environment including its bioavailability and how they are affected by winter temperature conditions.

Cited References

Algesten, G. Sobek, S., Bergstrom, A. K., Agren, A., Tranvik, L. J. and Jansson, M., 2004. Role of lakes for organic carbon cycling in the boreal zone. Global Change Biology, 10(1): 141-147.

Bishop, H., Seibert, J., Köhler, S and Laudon, H. 2004. Resolving the Double Paradox of rapidly mobilized old water with highly variable responses in runoff chemistry. Hydrol. Proc. 18:185-189.

Bishop, K., Laudon, H., and Köhler, S. 2000. Separating the natural and anthropogenic components of spring flood pH decline: A method for areas that are not chronically acidified. Water Resour. Res. 31: 1873-1889.

Brooks, P.D., Williams, M.W., and Schmidt, S.K., 1996. Microbial activity under alpine snowpacks, Niwot Ridge, Colorado. Biogeochem. 32, 93-113.

Deluca, T.H., Keeney, D.R. and McCarty, G.W. 1992. Effect of freeze-thaw events on mineralization of soil nitrogen. Biol. Fertil. Soils 14:116-120.

Fitzhugh, R. D., Likens, G.E., Driscoll, C.T., Mitchell, M.J., Groffman, P.M., Fahey, T.J., and Hardy, J.P. 2003. Role of soil freezing events in interannual patterns of stream chemistry at the Hubbard Brook experimental forest, New Hampshire. Environ Sci Technol. 37, 1575-1580.

Fitzhugh, R.D., Driscoll, C.T., Groffman, P.M., Tierney, G.L., Fahey, T.J., and Hardy, J.P., 2001. Effects of soil freezing disturbance on soil solution nitrogen, phosphorus, and carbon chemistry in a northern hardwood ecosystem. Biogeochem. 56, 215-238.

Eriksson, T. 2004. Variations in bioavailability of dissolved organic matter during a spring flood episode in northern Sweden. MSc. thesis Dept Forest Ecology, SLU, Stencilserie No 98.

Groffman, P.M., Driscoll, C.T., Fahey, T.J., Hardy, J.P., Fitzhugh, R.D., and Tierney, G.L., 2001. Colder soils in a warmer world: A snow manipulation study in a northern hardwood forest ecosystem. Biogeochem. 56, 135-150.

Hope, D., Billett, M.F. and Cresser, M.S., 1997. Exports of organic carbon in two river systems in NE Scotland. Journal of Hydrology, 193(1-4): 61-82.

Jarvis, P. and Linder, S., 2000. Botany - Constraints to growth of boreal forests. Nature, 405: 904-905.

Kalbitz, K., Schmerwitz, J., Schwesig, D. and Matzner, E., 2003. Biodegradation of soil-derived dissolved organic matter as related to its properties. Geoderma, 113(3-4): 273-291.

Laudon, H., Köhler, S., and Buffam, I. 2004a. Seasonal dependence of DOC export in five Boreal catchments in northern Sweden. Aquatic Sci. In press.

Laudon, H., Köhler, S., Seibert, J. and Bishop, H. 2004b. Hydrological flow paths during the spring flood: Congruence between hydrometric measurements and oxygen-18 in snow melt, soil water, and runoff, Water Resour. Res. 40, W03102, doi:10.1029/2003WR.

Mitchell, M.J., Driscoll, C.T., Kahl, J.S., Likens, G.E., Murdoch, P.S., and Pardo, L.H., 1996. Climatic control of nitrate loss from forested watersheds in the northeast United States. Environ Sci Technol. 30, 2609-2612.

Nordgren, A., 1992. A method for determining microbially available-N and available-P in an organic soil. Biology and fertility of soils, 13(4): 195-199.

Öquist, M. 2001. Northern Peatland carbon biogeochemistry: The influence of vascular plants and edaphic factors on carbon dioxide and methane exchange. Linköping University, Linköping.

Persson, G. (red), 2003. Klimatmodellering och klimatscenarier ur SWECLIMs perspective SMHI reports No. 102, SMHI, SE-601 76 Norrköping, Sweden. 101p.

Schimel, J.P., Bilbrough, C. and Welker, J.A., 2004. Increased snow depth affects microbial activity and nitrogen mineralization in two Arctic tundra communities. Soil Biology & Biochem., 36: 217-227.

Sobek, S., Algesten, G., Bergstrom, A.K., Jansson, M. and Tranvik, L.J., 2003. The catchment and climate regulation of pCO(2) in boreal lakes. Global Change Biology, 9(4): 630-641.

Stepanauskas, R., Laudon, H. and Jorgensen, N.O.G., 2000. High DON bioavailability in boreal streams during a spring flood. Limnology and Oceanography, 45(6): 1298-1307.

Stiegliz, M. Dery, S.J. Romanovsky, V. E. and Osterkamp, T.E. 2003. The role of snow cover in the warming of arctic permafrost. Geophys. Res. Let., 30, 541-544.

Tierney, G.L., Fahey, T.J., Groffman, P.M., Hardy, J.P., Fitzhugh, R.D., and Driscoll, C.T., 2001. Soil freezing alters fine root dynamics in a northern hardwood forest. Biogeochem. 56, 175-190.

Venäläinen, A., H. Tuomenvirta, M. Heikinheimo, S. Kellomaki, H. Peltola, H. Strandman, and H. Vaisanen, 2001. Impact of climate change on soil frost under snow cover in a forested landscape. Clim. Res. 17: 63-72.