variation is related to hydrology as well as to biological productivity, and to how productivity is balanced by decomposition. Hence, despite lower temperatures, DOC concentrations can be higher in rivers in taiga regions — coniferous forests of high northern latitudes — than in rivers in wet tropical and temperate regions[3].

The principal variable that affects the yield of DOC from catchments in the Northern Hemisphere is the proportion of the catchment that constitutes wetland[4]. Variations between and within sites can largely be explained by hydrological variables. This is illustrated by the substantial increase in DOC concentrations in lakes and streams in Sweden during the 1970s and 1980s, despite a reduction in annual temperatures (and in contrast to the British data[2]). This effect has been explained by the increased precipitation and runoff in these locations[5,6], which are typical of the northern boreal region where a large proportion of global peat carbon is stored.

An increase in DOC concentrations was found in headwater streams in the experimental lakes area in northwestern Ontario, where increased temperatures were accompanied by dryer conditions. However, an increase in temperature of 2 °C in association with decreasing precipitation in this area resulted in a drop in DOC concentration in the lakes (and therefore in rivers downstream of the lakes), because dryer conditions led to longer retention times and thus to increased DOC removal by within-lake processes[7]. Such in-lake processes, which are dominated by microbial and photochemical decomposition, effectively degrade DOC in northern lakes with high concentrations of humic substances[8,9].

These examples show that temperature is not in itself a satisfactory predictor of DOC concentration or of continental export of DOC. Freeman *et al.* discuss DOC export on the basis of concentration and do not consider transport. An increase in concentration does not necessarily result in increased river transport, which is the product of concentration and discharge. The authors claim that the increased DOC concentrations they find in British rivers were not affected by river discharge, even though river discharge can often explain variations in DOC export[10].

The export of organic carbon from land affects freshwater environments as well as coastal areas, and it may also contribute greatly to the vast store of organic carbon in the oceans. It is evident that several interacting factors determine the outcome of climate effects on DOC export, and that correlative experimental studies that base their conclusions on temperature or any other single parameter may be overly simplistic.

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1. Post, W. M., Emanuel, W. R., Zinke, P. J. & Stangenberger, A. G. *Nature* **298,** 156–159 (1982).
2. Freeman, C., Evans, C. D., Monteith, D. T., Reynolds, B. & Fenner, N. *Nature* **412,** 785 (2001).
3. Meybeck, M. *Am. J. Sci.* **282,** 401–451 (1982).
4. Curtis, P. J. in *Aquatic Humic Substances: Ecology and Biogeochemistry* (eds Hessen, D. O. & Tranvik, L. J.) 93–105 (Springer, Berlin, 1998).
5. Forsberg, C. *Hydrobiologia* **229,** 51–58 (1992).
6. Anderson, T., Nilsson, Å. & Jansson, M. *Lect. Notes Earth Sci.* **33,** 243–254 (1991).
7. Schindler, D. W. *et al. Biogeochemistry* **36,** 9–28 (1997).
8. Granéli, W., Lindell, M. & Tranvik, L. J. *Limnol. Oceanogr.* **41,** 698–706 (1996).
9. Molot, L. A. & Dillon, P. J. *Global Biogeochem. Cyc.* **11,** 357–365 (1997).
10. Thurman, E. M. *Organic Geochemistry of Natural Waters* (Nijhoff/Junk, Boston, 1985).

Freeman et al. *reply* — Tranvik and Jansson question our proposed link between temperature and DOC export, on the basis of spatial patterns of DOC concentration, confounding effects of hydrology, and apparently conflicting observations from other regions.

In response, it is first necessary to distinguish factors that control spatial variation between sites from those that determine temporal variation at an individual site. For example, a catchment wetland area is unlikely to change on a decadal timescale. Tranvik and Jansson also comment that DOC is higher in cooler regions, where low decomposition rates allow peat to accumulate. In fact, this spatial relationship between temperature and decomposition is fully consistent with our proposed mechanism for peatlands in the United Kingdom, because rising temperature at an individual site will increase peat decomposition, leading to greater DOC export.

We agree that hydrological changes can significantly affect DOC export. It is useful here to consider DOC export as a two-stage process: DOC is first produced in the soil and is then transported from the soil to the drainage network. The transport stage is controlled by discharge, so hydrology influences short-term fluctuations in riverine DOC export. However, long-term changes in discharge, unless accompanied by changes in DOC production, cannot generate a sustained trend in DOC flux. Flowpath changes may affect DOC supply by altering the proportion that is adsorbed onto mineral horizons, but such changes are probably unimportant in peatlands.

The primary hydrological factor that influences peatland DOC production, and hence long-term trends, may therefore be soil moisture, because greater soil aeration under dryer conditions will increase decomposition (for example, through greater enzymatic activity[1]). This could enhance DOC production over and above the temperature-induced increases that we have observed experimentally. Soil moisture is influenced by both rainfall and temperature and, although temperature has increased in the United Kingdom in recent decades, regional rainfall patterns have been more heterogeneous, with few trends in annual means. In some areas, however, increases in winter/summer rainfall ratios[2] may have contributed to DOC increases by reducing soil moisture in summer, with increased washout in winter.

Tranvik and Jansson note that warmer and dryer conditions in northwestern Ontario led to reduced DOC concentrations, partly through enhanced in-lake removal as a result of longer residence times[3]. Soils in this region are thin, and recently decomposed plant material provides a substantial and relatively labile DOC source[4]. DOC from blanket peats in the United Kingdom is older and more recalcitrant, and input–output data for British upland lakes, which generally have lower residence times, suggest that in-lake removal is minimal[5]. Similar DOC trends at our stream sites also argue against in-lake factors. Furthermore, DOC from peat uplands persists into the lower reaches of UK rivers[6], which is consistent with observations that the riverine DOC that enters the oceans largely comprises old, recalcitrant compounds[7].

We agree that terrestrial organic carbon exports are important for both freshwater and oceanic environments, and that climate change may significantly affect these exports. We contend that increasing temperatures, by raising decomposition rates, will increase peatland DOC export, but recognize that other factors, such as hydrological changes, may also be important. Given the ongoing debate about the direction and magnitude of rainfall projections made by the International Panel on Climate Change, future climatic impacts on DOC export remain uncertain.

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1. Freeman, C., Ostle, N. & Kang, H. *Nature* **409,** 149 (2001).
2. Burt, T. P., Adamson, J. K. & Lane, A. M. J. *Hydrol. Sci. J.* **43,** 775–787 (1998).
3. Schindler, D. W. *et al. Biogeochemistry* **36,** 9–28 (1997).
4. Schiff, S. L. *et al. Biogeochemistry* **36,** 43–65 (1997).
5. Curtis, C. J., Harriman, R., Allott, T. E. H. & Kernan, M. *Environ. Change Res. Centre Res. Rep.* **50** (Univ. College London, 1998).
6. Worrall, F., Burt, T. P. & Shedden, R. *Biogeochemistry* (submitted).
7. Raymond, P. A. & Bauer, J. E. *Nature* **409,** 497–499 (2001).