

Nitrogen cycling immediately after fire in an Alberta bog

Drs Melanie A Vile, R Kelman Wieder and Dale H Vitt discuss their research into the nitrogen cycles of peatland bogs and the effects of wildfires in boreal regions of western Canada

Why do your research interests lie in the boreal peatlands of Canada? What uniquely defines this ecosystem?

Peatlands are typically divided into two categories, bogs and fens, with hydrology being the major distinguishing factor. Bogs are ombrotrophic, meaning that the only input of water is via precipitation as rain or snow. Bogs are isolated from groundwater and do not receive runoff from surrounding upland areas. Lateral water flow in bogs is minimal, with the rise and fall of the water table driven by precipitation inputs and evapotranspirational water losses. In contrast, fens receive inputs of water from precipitation, as well as runoff from surrounding upland areas, and can function as either groundwater recharge or discharge areas. Water flows laterally through



Life between fire

Research projects led by biological scientists at **Villanova University** and **Southern Illinois University** seek to develop current knowledge on the biotic and abiotic controls that influence and affect the cycling of carbon and nitrogen in the peatland ecosystems of boreal, continental, Western Canada and their response to climate change

THE STUDY AND UNDERSTANDING of peatland areas in various regions of the world is a core focus for many ecosystem scientists today. Observation of peatlands offers scientists insights into the ecology of vegetation processes and of carbon and nutrient cycles. Characterised by highly dynamic organic activity, peatland areas generally tend to capture carbon through plant photosynthesis at a rate exceeding that through which carbon is lost as a result of plant respiration and the decomposition of dead plant material. The peat itself is constructed of 95 per cent organic matter and accumulates

in deposits that may be several metres thick and which are saturated with water below the water table.

Acknowledging the dependency of peatlands upon water and moisture, research led by Drs Melanie A Vile and R Kelman Wieder at Villanova University, Pennsylvania, and by Dr Dale H Vitt at Southern Illinois University, approaches peatland science in relation to ongoing and future climate change. For these biological scientists, a particular interest lies in the peatlands of continental western Canada, particularly because the climate in this region is one of limited precipitation and

moisture. Indeed, the long hot summers and long cold winters in Alberta, Saskatchewan and Manitoba, where peatlands cover over 365,000 km², receive annual precipitation averaging less than 500 mm. "Peatlands of this region persist at the dry end of the global climatic regime in which peatlands thrive and therefore may be especially sensitive to changes in climate," asserts Wieder.

OVERCOMING KNOWLEDGE GAPS – FIRE AND THE BOG CARBON SINK

Vile, Wieder and Vitt's previous research has identified several significant factors upon which their current research builds. One such discovery is that net carbon accumulation as peat and living vegetation changes according to the period of time since the occurrence of a fire. "These peatlands persist within a context of wildfire, with a fire return interval of about 120 years. Because the living vegetation has been burned or damaged, bogs actually release CO₂ into the atmosphere immediately after fire, as the deep peat deposit decomposes," explains Vile. Significant insights were also gained in understanding the processes of post-fire rejuvenation of the Alberta peatlands: "At about 13 years after fire, as mosses and shrubs become re-established, bogs begin to regain

the upper layers of fen peat, typically draining into streams or lakes.

Could you expand on the conceptual framework your team has constructed for boreal peatland nitrogen cycling?

Recently, we have proposed, and are working towards validating, a new conceptual framework with attendant hypotheses to resolve the paradox of excess nitrogen (N) accumulation in peat in light of both fire and experimentally-augmented N inputs with respect to N cycling in Alberta bogs. Through ²¹⁰Pb-dating of bog peat cores, we have determined that accumulation of N in peat over the past 50 years is up to 20-fold higher than N inputs through atmospheric deposition. Our ongoing work suggests that this excess N accumulation may be derived, in large measure, by biological N₂-fixation, carried out by cyanobacteria living in the *Sphagnum* mosses at the peat surface. We continue to examine the biotic and abiotic factors that affect biological N₂-fixation in boreal bogs and fens, including how this process changes as a function of time since fire.

Drought and wildfires are a likely consequence of a warmer climate in

Canada. What are the repercussions of climate change?

With ongoing climate change, predicted warmer temperatures and decreased summertime precipitation are likely to result in increased frequency and severity of both drought and wildfire across continental western Canada. We have estimated that a decrease in the fire return interval from 120 to 60 years, or an increase in non-winter air temperatures of 2 °C, would convert Alberta's peatlands from a net sink for atmospheric CO₂ to a net source. Although droughts are episodic in nature, the mosses that typically cover the surface of peatlands become water-stressed during drought periods. Because these mosses are a major contributor to the net peatland CO₂ sink, peatlands that are accumulating carbon during wet or moist years can switch to net carbon sources during drought years.

Mosses, especially *Sphagnum* species, form a nearly complete cover of the peat surface. As non-vascular plants with no roots and no stomates to control CO₂ exchange and water loss from the leaf surfaces, mosses are particularly sensitive to moisture conditions at the top of the peat column. Indeed, the southern limit of peatland distribution in continental western

Canada is determined by the balance between precipitation and evapotranspiration. In a dryer, warmer climate, exacerbated by increased drought frequency and severity, it is likely that peatlands will no longer be able to persist at their current southern limit. As peatlands are displaced to a more northern distribution, the peat deposits without a cover of healthy mosses in all likelihood will return the carbon stored as peat back to the atmosphere as the peat decomposes.

Finally, what have been your main contributions to the biological research of peatlands? What accomplishments are you most proud of?

Collectively, our group has worked on carbon and N cycling in peatlands for over 90 years and we have initiated many transformational concepts, from being the first to map peatlands of Alberta, being the first to document permafrost thaw and the implications this phenomenon for carbon sequestration in peat, to understanding the role of wildfire on carbon cycling and storage from a successional perspective. Our current research is reshaping the traditional view of peatland N cycling, revealing much more important roles of biological N₂-fixation and of the production and utilisation of dissolved organic N by microbes, *Sphagnum* mosses, and vascular plants.

their function as net sinks for atmospheric CO₂," highlights Wieder. "The strength of the CO₂ sink increases as black spruce trees become established, peaking at about 75 years after fire."

These observations enabled the team to refine projections of peatland carbon sinks, as Vile elaborates: "Projections of the carbon sink status of western Canadian peatlands under future climate change need to take into consideration the historical fire regime, as peatlands occur across the landscape as a mosaic of sites with different times since fire, and hence with different but predictable carbon balances"

NITROGEN, FIRE, AND OIL SANDS DEVELOPMENT

Bogs in general have been regarded as nitrogen limited, and as such, adding nitrogen should result in greater plant growth. The Northern Alberta bog region has been identified as an area that has historically low atmospheric inorganic nitrogen deposition (<2 kg/ha/yr) in rain and snow, compared to values as high as 10 kg/ha/yr in eastern Canada or even higher in some parts of Europe.

The research group has begun new studies aimed

at developing a better understanding of the mechanisms by which bogs accumulate nitrogen and how these mechanisms change over post-fire successional development. A key concept is that large measure nitrogen cycling in bogs is controlled by the foundation species of *Sphagnum* mosses that dominate these systems. These *Sphagnum* mosses typically cover 100 per cent of the ground surface, and hence have first access to nitrogen that is deposited as rain or snow, conferring a major role as gatekeepers of new inputs of nitrogen," highlights Wieder. This gatekeeper function is destroyed by fire with the burning or death of the moss cover. New research efforts are based on a novel conceptual framework that links post-fire changes in bog nitrogen cycling to the rejuvenation and successional development of bog vegetation after fire.

Superimposed on the effects of fire is a changing nitrogen deposition regime. With the burgeoning development of the oil sands resource in the Fort McMurray area of northern Alberta, nitrogen inputs to bogs are increasing. Nitrogen emissions from diesel-powered trucks and from oil refining are deposited onto the region's ecosystems in rain and snow. This situation is providing the research team with a unique opportunity to examine how increasing nitrogen inputs in a region with

historically low nitrogen deposition influence bog structure and function.

The researchers hope that the new insights gained through their ongoing research will help to generate better-informed governmental policies and also will enable more scientifically advanced projections into peatland ecology under future climate scenarios.

COLLABORATION IS KEY

The scientists at Villanova University and Southern Illinois University combines expertise in ecosystem ecology, biogeochemistry, bryology and community ecology, and appears to have benefited from the multi-disciplinary collaboration. So far the findings have revealed that biological N₂-fixation may constitute a main source of nitrogen inputs to boreal peatland ecosystems. This is a significant new discovery, as earlier investigations carried out in the peatlands of more nutrient-rich regions had shown inconsequential contributions of N₂-fixation to the peatland nitrogen budget. It may be that as nitrogen inputs to bogs from rain and snow increase, N₂ fixation may be inhibited. This possibility is a key focus of the team's current research.



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PEATLAND GOODS AND SERVICES

Carbon storage is a major service delivered by the world's peatlands. Indeed, if the amount of carbon stored in the form of boreal peat were to be released back to the atmosphere, atmospheric CO₂ concentrations would increase by as much as 50 per cent.

Moreover, peatlands store huge quantities of water, essentially functioning like reservoirs. Even in western Canada where the precipitation is low, the peatlands hold nearly 1,000 km³ of water, three times more than the annual discharge of Canada's largest river, the McKenzie River.

Furthermore, peatland areas are home to a variety of plant, insect, bird and mammal species, which in turn provide special value for Aboriginal populations, as Vile expounds: "They traditionally use peatlands for hunting, trapping, berry picking, and collection of medicinal plants; peatlands are integral to their cultural and personal wellbeing".

It has recently come to light that considerable financial significance is associated with peatlands and peatland science. The monetary value, for instance, of the 102,559 km² area containing over 21,000 km² of peatland in southeastern Manitoba is estimated to be between \$97 and \$294 million (CAD) per year, plus an additional \$0.5 to \$196 million per year for carbon sequestration alone. Thus, new insights into the ecology of the peatlands offer important knowledge of how such valuable areas can be protected and maintained.

PEATLANDS AND GLOBAL CHANGE

Changing precipitation, temperatures, and nitrogen deposition, all components of global change, may have significant consequences for boreal peatlands. Indeed, the research team has projected that an increase in growing season temperature of only 2°C or a shortening of the fire return interval from 120 to 60 years would be sufficient to switch Alberta peatlands from net sinks to net sources of CO₂. Both a warming and an increase in fire frequency and extent are predicted for boreal continental Canada.

In addition, significantly increased nitrogen deposition may result in changes in peatland vegetation in the long term, specifically with vascular plants achieving an increased abundance over *Sphagnum* mosses. "This could have profound implications for peatland carbon storage, threatening the important carbon sink



RESEARCH TECHNICIANS CARA ALBRIGHT, JAMES QUINN AND KIM SCOTT

ecosystem service that peatlands represent across the globe," suggests Wieder.

Moreover, in peatlands, as in most terrestrial ecosystems, nitrogen is the nutrient that most often limits plant growth and its associated uptake of atmospheric CO₂. Vile and Wieder state that: "Several models incorporate, and subsequently link, the nitrogen and carbon cycles into climate projections because ultimately, the quantity of biologically available nitrogen has been shown to significantly affect both the pace and magnitude of carbon uptake, and hence the severity of climate change". The linkages between the nitrogen and carbon cycles must be understood as researchers seek to project peatland responses to the many facets of global change.

THE FUTURE AND VALUE OF PEATLANDS

The overall results of the team's research indicate that the peatlands of boreal, continental Canada are not as stable as once thought. Instead, it has been revealed that these vast dynamic peatlands exist between periods of fire that return approximately every 120 years. Yet, it is important to note that fire does not occur simultaneously across the peatlands, instead there is a mosaic effect whereby sites with different times-since-fire periods witness a functional evolution: "Net sources of atmospheric CO₂ eventually shift to net CO₂ sinks over time," asserts Wieder. However, the research team has shown that these peatlands, thriving in an environment of limited moisture and under exceptionally low background nitrogen deposition, may respond to the various components of global change in ways that are likely to compromise their important carbon sink function.

The work of Wieder, Vile, and Vitt will play a critical role in protecting and managing peatlands in Alberta and may lead to greater understanding of how these vast carbon-rich ecosystems will respond to global change worldwide.

INTELLIGENCE

NITROGEN CYCLING IMMEDIATELY AFTER FIRE IN AN ALBERTA BOG

OBJECTIVES

- To obtain a better understanding of the structure and function of boreal peatlands
- To investigate the biotic and abiotic controls on the cycling of carbon and nitrogen and how boreal peatlands may be affected by ongoing climate change, wildfire, and elevated nitrogen and sulphur deposition from oil sands development in northern Alberta

KEY COLLABORATORS

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KEL WIEDER is a Professor of Biology at Villanova University, Pennsylvania. Current research focuses on the biogeochemistry of boreal peatlands, focusing on carbon and nitrogen cycling in light of ongoing climate change and in response to natural and anthropogenic disturbance.

MELANIE VILE is a Research Assistant Professor at Villanova University. As an ecosystem ecologist, her research focuses broadly on biogeochemical interactions between microbes and their chemical environment, and how these interactions affect ecosystem functioning.

DALE H VITT is Professor Emeritus of Plant Biology, University Outstanding Scholar, and the former Chair of the Department of Plant Biology at Southern Illinois University Carbondale. He is an ecologist, specialising in bryophytes, plants that contribute to or dominate many ecosystems globally.

