Letters

ANOTHER LOOK AT THE LITTLE ICE AGE

In a recent issue of *BioScience*, David Schindler presents an apocalyptic view of the future of boreal forests in his article "A Dim View for Boreal Waters and Landscapes" (*BioScience* 47: 157–164). He suggests that climate warming has resulted in increased forest fire activity and reduced lake levels in Ontario's boreal forest and implies that this scenario is applicable to the North America boreal forest.

However, our own research indicates that there is a large regional variation in the response of fire activity and lake levels to climate warming. Contrary to what is portrayed by Schindler for northwestern Ontario, the warming after the end of the Little Ice Age (c. 1850) in Québec's boreal forest has led to a decrease in forest fire activity (Bergeron and Archambault 1993) and an increase in lake water levels (Bégin and Payette 1988, Tardif and Bergeron 1997).

Schindler argues that climatic warming implies an increase in temperature, which in itself may cause an increase in fire activity as well as increased evapotranspiration and lake level decline. However, increased temperature is often associated with an increase in precipitation that often can more than compensate for the effect of increased temperature on the water balance. Our work strongly suggests that decreased forest fire activity and increased lake levels in Québec's boreal forest are related to a more positive water balance since the post–Little Ice Age warming began.

This interpretation has been confirmed by simulations of the Fire Weather Index (FWI) for a doubling of carbon dioxide scenario using a general circulation model (GCM; Bergeron and Flannigan 1995). The FWI integrates weather variables that control fire intensity and spread and is inversely related to the water balance. Simulations showed that except for Central Canada, where the FWI might increase significantly, most of the boreal forest would be characterized by a decreased or unchanged maximum or mean FWI. In a recent study (Flannigan et al. in press), we were able to show that historical frequency of forest fires observed in the Canadian boreal forest was indeed what was predicted by the GCMs. Although we tend to agree with Schindler that boreal forests are threatened, we think that the scientific arguments on climatic warming developed in his article do not properly take into account large regional differences in the climate and in the response of the ecosystem to changes in the climate.

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Response: I am familiar with the fine paleoecological studies of Bergeron and his colleagues and with their conclusions about past climates. They are quite right about past records for climate in the eastern boreal. Indeed, the eastern boreal (Québec and the maritime provinces of Canada) have experienced little of the recent warming and drought seen in central, western, and northwestern areas. In contrast, western and northwestern regions have had more severe climatic warming and greater increases in fire than what I documented for northwestern Ontario. The effects of the recent drought were clearly seen in northern Wisconsin, and well into eastern Ontario. My article could be similarly criticized for other specific regions. For example, the effects of acid rain are important in Québec (Minns et al. 1990, 1992) but will not be seen in western or northwestern boreal regions in the foreseeable future. In brief, not all of the many insults that I described occur in all regions. My point is rather that several stressors do apply to every region, so that I think that the "Dim Future" that I foresee is widespread in the boreal.

That being said, I am somewhat doubtful that increased precipitation may offset the effect of warming on evaporation. Much of the boreal, including Québec, has little water storage capacity because the soils are shallow. A few weeks of warm, dry weather can create extreme fire weather, even under conditions of higher average precipitation. Even the rather slight warming of the 1970s and 1980s greatly increased annual evaporation and decreased

streamflow (Schindler et al. 1996, Schindler 1997). Some climate models predict significant declines in soil moisture under a doubled carbon dioxide scenario for Quebec, although projections are not as extreme as for the central boreal (Manabe and Wetherald 1986).

As Norrman Yan has pointed out to me in a personal letter about my article, I also omitted reference to one insult that is important in eastern boreal waters, invasions of nonnative species. Zebra mussels and the cladoceran *Bythotrephes* are altering the communities of boreal freshwaters, and a host of insect pests are known to predispose boreal forests to fire. These factors could not be accounted for in paleoecological studies and may therefore cause future climatic scenarios for the boreal to be greater than those predicted from models verified with paleoecological data. In summary, we must not focus too narrowly on any other single stressor in a given region: It is the "multiple whammy" that humans are applying to the boreal that is causing its rapid demise worldwide.

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***Correction:** In the article by Wayne M. Getz ("An Introspection on the Art of Modeling in Population Biology," BioScience 48: 540–552), the first two equations on page 547 have typesetting errors: A prime symbol was erroneously added to their denominators.*