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Interactions entre les changements et la variabilité climatiques et d'autres contraintes environnementales s'exerçant sur la santé des forêts et des parcours en Amérique du Nord

Résumé

Les forêts et parcours sont importants d'un point de vue social, écologique et économique pour les pays d'Amérique du Nord. Ces écosystèmes fournissent des services comme le bois, le pâturage, des sources d'eau propre, le piégeage du carbone, la beauté des paysages et les habitats de la faune et de la flore sauvages. Cependant, depuis 1850, les concentrations de dioxyde de carbone et d'autres gaz à effet de serre dans l'atmosphère, associées au réchauffement de la planète ont modifié le climat nord-américain et le rythme de ces modifications s'accélère. Les forêts et les parcours ont évolué lentement au cours de milliers d'années et l'impact des changements climatiques rapides sur la santé des écosystèmes et les ressources naturelles est mal connu.

Cependant, nous disposons de suffisamment d'informations pour indiquer l'orientation générale de ces changements, à défaut de pouvoir en définir l'ampleur. Tout porte à croire que la variabilité climatique (soit la variation d'un jour à l'autre ou d'une année à l'autre) va augmenter et entraîner une intensification des épisodes pluvieux, des sécheresses et des vagues de chaleurs. Or, selon toutes vraisemblances, ces changements entraîneront à leur tour une intensification de l'érosion des sols, de la sédimentation au fond des cours d'eau et des incendies en milieu naturel. L'augmentation des pullulations d'insectes et des maladies sera probablement aggravée par effet synergique avec d'autres stress polluants (ozone, pluie acide, etc.).

Les changements climatiques à long terme (soit sur une décennie ou plus), associés à la hausse des températures et au changement de la configuration des précipitations et des fluctuations saisonnières, devraient entraîner des changements au niveau de la composition des écosystèmes, des pêches, de la productivité des habitats sauvages, des forêts et des parcours, ainsi que des débits des cours d'eau. Il se peut qu'en raison de l'ampleur des changements climatiques, certaines zones boisées se transforment en parcours et que des parcours se transforment en chaparral ou en écosystèmes désertiques. Les aménagistes des forêts et des parcours jouent un rôle dans l'atténuation des effets des changements climatiques. Les responsables de la gestion des

Par souci d'économie, le tirage du présent document a été restreint. MM. les délégués et observateurs sont donc invités à ne demander d'exemplaires supplémentaires qu'en cas d'absolue nécessité et à apporter leur exemplaire personnel en séance.
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terres devront également mettre au point des outils et des stratégies d'adaptation, et les appliquer, afin de minimiser les impacts négatifs de la variabilité du climat et des changements climatiques sur ces écosystèmes.

Le présent document traite des interactions entre les changements climatiques et d'autres contraintes environnementales s'exerçant sur la santé des forêts et des parcours en Amérique du Nord.

Introduction

Atmospheric concentrations of carbon dioxide (CO₂) and other greenhouse gases have been increasing since the beginning of the industrial revolution in the 1850s. Since 1860, the average Earth surface temperature has risen over 1°C. Over the next century, increasing gas concentrations could cause the temperature to rise another 2-3° C (IPCC, 2001).

North America experienced one indication of climate change in 1988: that summer was one of the hottest, driest ever recorded. Barges were stranded on the Mississippi River, and forest fires burned millions of acres in the West. In the eastern United States, temperatures were so high that many factory assembly lines had to be shut down. During that same year, the former Soviet Union states and China experienced severe drought, while Africa, India, and Bangladesh witnessed torrential rains and flooding. Since 1988, the planet has continued to warm

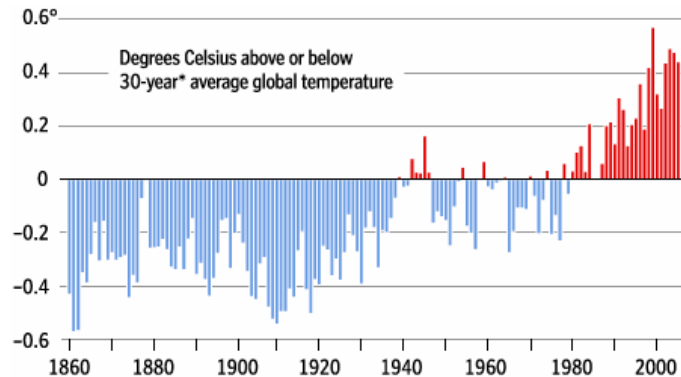


Figure 1. Derivation from global mean temperatures.

(Figure 1) with nine of the ten hottest years ever recorded occurring after 1995 (NCAR).

The interaction of climate with other forms of environmental stress (e.g., fire, insects, air pollution) is of particular concern (Aber et al., 2001). Ecosystems may be able to withstand individual stresses, but multiple, co-occurring stresses could seriously impact forest and rangeland health and sustainability. In this paper, we will examine the impact of the interactions of climate change and other environmental stress on North American forests and rangelands.

Climate change and climate variability

For the purposes of this paper we define climate change as a long-term progression to a different climate regime through the accretion of small changes. In contrast, climate variability is the daily to inter-annual fluctuation in weather which has always been part of the climate record, but the amplification of which has increased over the past century.

Although there is debate regarding the proportion of climate change that can be attributed to natural variability and cycles, there is an overwhelming consensus that human atmospheric inputs of CO₂ and other gases are increasing global surface air temperatures (Figure 1). These increases in air temperature are projected to continue well into the next century, as predicted by recent general circulation models (GCM). The Hadley Centre's Second Generation Coupled Ocean-Atmosphere GCM, version 2 (HadCM2Sul), predicts an approximate increase of 3.0°C in mean global annual air temperature by 2100 (Climate Impacts LINK Project, 1999).

We have seen increases in variability resulting in weather changes that range from local to continental scales. Precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high-latitudes of the Northern Hemisphere continents, and rainfall has increased by

0.2 to 0.3% per decade over tropical (10°N to 10°S) land areas. Rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade (Holland, 1997).

Across the mid- and high-latitudes of the Northern Hemisphere and over the latter half of the 20th century, there has been a 4% increase in the frequency of heavy precipitation events across the US. Increases in heavy precipitation events can arise from a number of causes, including changes in atmospheric moisture and increased atmospheric convectivity that lead to increased thunderstorm activity and large-scale storms (Emanuel, 2005).

In total, these alterations in climate variability and change have begun to alter North American forests and rangelands. These changes will continue and will likely accelerate in the coming years and decades (IPCC, 2002).

Interactions between climate change and other environmental stresses

Climate change is not the only environmental stress impacting forests and rangelands. Insects and disease, wildfire, ozone, and acid rain are additional stresses that can impact ecosystem health and sustainability. Climate change is likely to interact with each of these stresses as global warming continues.

The impacts of these disturbances are highly variable over time and space. Some disturbances, such as hurricanes and ice storms, may be infrequent (i.e., one major event every few years) but have extreme (i.e., near-complete ecosystem destruction) impacts on large areas of forest (e.g., more than 1,000 km²). Other disturbances such as windstorms may be more frequent (i.e., hundreds per year), but individually affect a smaller area (e.g., less than 100 km²). North American forests and rangelands are increasingly seeing more frequent and severe disturbances such as wildfires and insect outbreaks.

Although much has been learned about the impacts of individual disturbances on forest structure and function, there is little research on the interactions of climate and disturbance (Dale et al., 2000). From our current understanding, some disturbances will very likely increase in severity (e.g., insect and pathogen outbreaks), shift in geographic region (e.g., ice storms), or shift in frequency (e.g., major hurricanes). The combination of climate change and variability will now be examined in conjunction with other environmental stresses

Climate change and ozone interactions on ecosystem stress

Expanding urbanization in North America means that more of our landscape can be considered urban forests. Data suggest that atmospheric CO₂ concentrations in many of our cities are significantly above those in rural areas. Concentrations of ground-level ozone (O₃), have also been increasing recently in most Canadian cities (16% since 1990) (Stats. Can., 2005), meaning that urban forests are already experiencing levels of these gasses predicted for the future. The increased smog days have negatively impacted the already declining urban forest in the larger cities.

Long-range transport of ozone precursors (such as nitrous oxides) and its formation downwind lead to the exposure of large tracts of North American forests to toxic levels of the gas. Effects of this exposure can worsen effects of drought and winter thaw on trees by decreasing their root to shoot growth ratio, and also reduce root energy resources and water use efficiency. This could increase the severity and incidence of large scale tree decline (Cox and Zhu, 2003) and drought interaction (McLaughlin and Percy, 1999). The toxic effects of ozone exposure also offset the

positive gains in productivity due to increased atmospheric CO₂ (Karnosky et al., 1999). In combination, higher temperatures and increased O₃ will further stress forests, thus leaving these ecosystems more vulnerable to secondary pathogens such as insects.

Climate and wildfire interactions on ecosystem stress

Higher temperatures in western North America from March through August coupled with earlier snowmelt are extending the wildfire season and increasing the intensity of wildfires (Westerling et al., 2006; Running, 2006). Westerling et al. (2006) illustrates the correlation between warming temperatures and the occurrence of large wildfires (Figure 2).

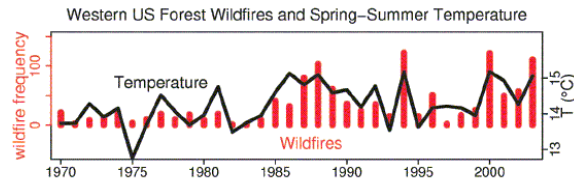


Figure 2. Annual frequency of large (> 400 ha) western U.S. forest wildfires (bars) and mean March through August temperature for the western US.

Running (2006) suggested that the trends in larger fires correlate well with reduced moisture availability in forest areas. Flannigan et al. (2005) have projected between 74 and 118% increases in wildfire burn areas in Canada. Also, the 1998 record air temperature year corresponded to the a record year for wildfires in Mexico.

Land managers have done an excellent job of suppressing wildfires since the 1950's. The recent increase in wildfires has been blamed on the accumulated increase of wildfire fuel loads over this time period. However, considering the correlations presented between temperature, snow melt and available moisture, and fire activity, it is likely that climate, more specifically changing climate variability, may play a larger role than previously thought in western fire issues.

Westerling et al. (2006) concluded that

“land use history is an important risk factor in specific forest types (e.g., some ponderosa pine and mixed conifer forests), but that broad-scale increases in wildfire frequency across the western United States has been driven primarily by sensitivity of fire regimes to recent changes in climate over a relatively large area. The overall importance of climate in wildfire activity underscores the urgency of ecological restoration and fuels management to reduce wildfire hazards to human communities and to mitigate ecological impacts of climate change in forests that have undergone substantial alterations due to past land uses. At the same time, however, large increases in wildfire driven by increased temperatures and earlier spring snowmelts in forests where land use history had little impact on fire risks indicate that ecological restoration and fuels management alone will not be sufficient to reverse current wildfire trends.”

The amount of funding to battle wildfires has doubled in the past decade and now represents 40% of the total USDA Forest Service budget. Managers need to work with researchers regarding current and future impacts of climate change on forest and rangelands to avoid unexpected costs and ecosystem consequences.

Winter warming and forest mortality interactions on ecosystem stress

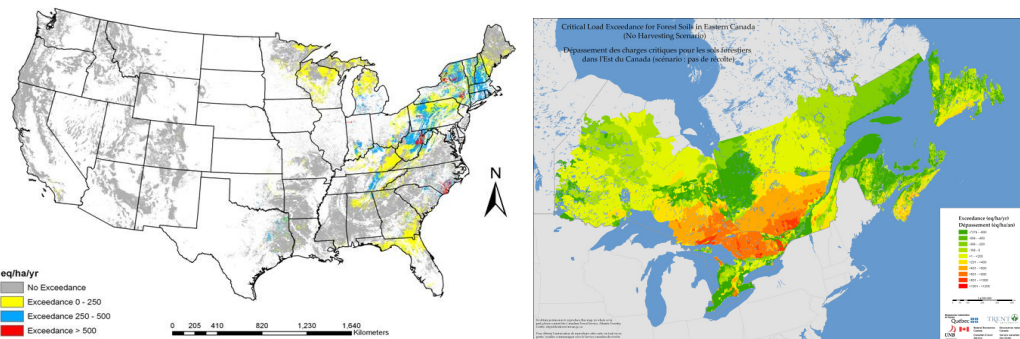
Warmer winters are likely across northern latitudes as global temperatures increase, with increased maximum temperatures, inter-annual variation, and longer, more intense winter thaws. The number of damaging winter thaws in the northern forests has increased since 1930 (Bourque

The potential for additional MPB range expansion appears likely. Cold temperatures at the upper elevations of the Rocky Mountains have historically posed a barrier to the MPB (Logan et al., 2003). Since the mid-1990s, a series of mild winters greatly increased MPB populations, and in 2002 the MPB established a population on the east side of the Rockies at an elevation of 874 m. The MPB is now only 50 to 100 km from the nearest jack pine (*Pinus banksiana*) stands, which could potentially be a host species for the beetles (Carroll, 2003; Logan and Powell, 2005). If the MPB were to become established in the jack pine forest, there would be a contiguous host species across all of Canada (approximately 400 million ha), and down the eastern U.S. as far as Texas (Logan and Powell, 2005). If MPB were to move into eastern North America, forest carbon loss could easily exceed a Petagram (i.e., 100 million metric tons). To put this into perspective, this amount of wood loss is equal to 2159 times the weight of the doomed cruise ship *Titanic*!

Also, between 2002 and 2003 a drought and bark beetle infestation induced regional-scale die-off of pinon pine (*Pinus edulis*) across 12,000 km² of southwestern North America. This example highlights the potential for such sub-continental die-offs to be more severe and extensive in future global-change-type drought under warmer conditions (Breshears et al., 2005).

Climate and air pollution interactions on ecosystem stress

Since the passage of the US 1990 Clean Air Act Amendments, sulfur (S) deposition has been significantly reduced across much of North America, but little progress has been made in reducing nitrogen (N) emissions or deposition. Concern regarding the impacts of continued S and N (commonly termed “acid”) deposition on forest health prompted the development of critical acid loads assessments for forest soils. A critical acid load (CAL) is a quantitative estimate of exposure to one or more pollutants above which harmful effects on sensitive elements of the environment occur. A pollutant load in excess of CAL is termed exceedance.



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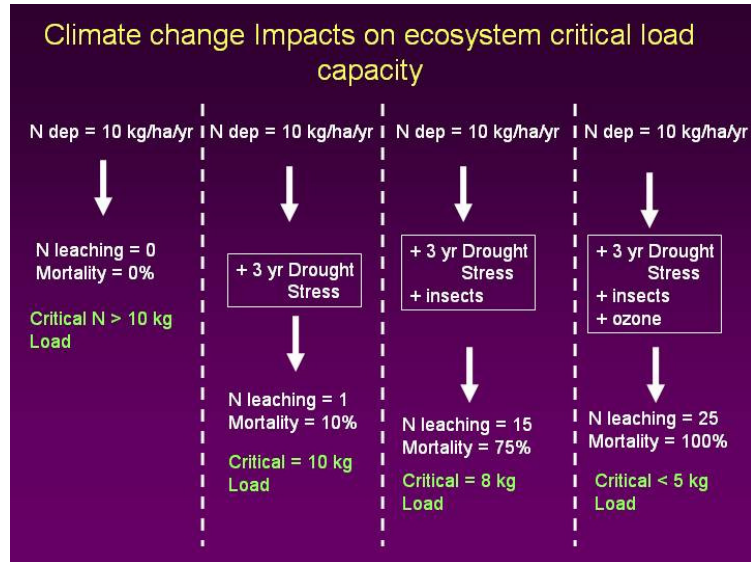
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Figure 4. Exceedance of critical loads in the United States (a) and eastern Canada (b) based on the average 1994–1998 atmospheric total S+N depositions (from Ouimet et al., 2005; McNulty et al., in review).

Over 50% of the mapped areas between Ontario and the Atlantic Provinces were in exceedance of the CAL, with highest exceedances in southern Ontario and Quebec and the southern Maritimes (Figure 4b, Ouimet et al., 2005). Approximately 3% of US forest soils are in exceedance of their CAL by more than 250 eg ha⁻¹ yr⁻¹ (McNulty et al., in review). The CAL estimates and steady-state exceedance values for S+N deposition did not include the effects of forest fire or forest harvesting, which could have considerable impacts on critical loads.

Although these results are interesting, model predictions do not account for the synergistic impacts of climate change and other environmental stress on an ecosystem's critical load capacity. Drought, insects, disease, and ozone can all occur individually or simultaneously as additional ecosystem stress. The combined impacts of these stresses can greatly impact an ecosystem's response to climate change and variability (Figure 5).

Figure 5. The impact of multiple stresses on soil CAL



For example, the interactions of drought, ozone, and insect stresses could reduce a soil's critical acid load by more than half. Land managers need to consider the interactions of climate and other stresses as CAL limits are set. Also, CAL limits will need to be reevaluated as the atmosphere continues to warm and interactions between climate change and other ecosystem stress continue to shift.

Conclusions

Carbon dioxide remains in the atmosphere for up to a century after it is released. Therefore, it will be many decades before even the most aggressive greenhouse gas mitigation strategies reverse global warming. During this time, the forests and rangelands of North America will be subjected to more intense and often new combinations of environmental stress. The rate of climate change will be much faster than the thousands of years required for trees and grasses to adapt to change conditions. Forest and rangeland managers will need to intervene through the application of existing (e.g., controlled burns, forest thinning, insect control) and new management activities. Good progress is being made by scientists in understanding the complex interactions between climate change and other ecosystem stresses. However, little research is currently occurring on mitigation strategies for coping with expected interactive stress. Significant increases in adaptation studies are now required to prevent unforeseen and potentially catastrophic ecosystem disturbances caused by a changing climate.

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