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A 100-year conservation experiment: Impacts on forest carbon stocks and fluxes

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ABSTRACT

Forest conservation is an important climate change mitigation strategy. National parks in Canada's Rocky and Purcell Mountains offer a rare opportunity to evaluate the impacts of a century of conservation on forest carbon (C) stocks and fluxes. We studied forest ecosystem C dynamics of three national parks in the Rocky and Purcell Mountains of British Columbia – Yoho, Kootenay, and Glacier National Parks – over the period 1970–2008 using the CBM-CFS3 inventory-based forest C budget model. We hypothesized that parks and protected areas would contain higher forest C density and have lower CO_2 uptake rates compared to their surrounding reference areas because of the exclusion of timber harvesting and resulting predominance of older, slower growing forest stands. Results for Glacier National Park relative to its reference area were consistent with our hypothesis. Forests in Kootenay National Park were substantially younger than those in its reference area despite the exclusion of harvesting because natural disturbances affected large areas within the park over the past century. Site productivity in Kootenay National Park was also generally higher in the park than in its reference area. Consequently, Kootenay National Park had both higher C density and higher CO_2 uptake than its reference area. Yoho National Park forests were similar in age to reference area forests and more productive, and therefore had both higher C stocks and greater CO_2 uptake. C density was higher in all 3 parks compared to their surrounding areas, and parks with younger forests than reference areas had higher CO_2 uptake. The results of this study indicate that forest conservation in protected areas such as national parks can preserve existing C stocks where natural disturbances are rare. Where natural disturbances are an important part of the forest ecology, conservation may or may not contribute to climate change mitigation because of the risk of C loss in the event of wildfire or insect-caused tree mortality. Anticipated increases in natural disturbance resulting from global warming may further reduce the climate change mitigation potential of forest conservation in disturbance-prone ecosystems. We show that managing for the ecological integrity of landscapes can also have carbon mitigation co-benefits.

1. Introduction

Establishment of Canada's national park system began over one hundred and twenty-five years ago. Several national parks were established in the Rocky Mountains and nearby Purcell Mountains between 1885 and 1920. The development of trans-continental rail lines brought these landscapes to the attention of the Canadian public, and law makers soon protected them from resource extraction activities that were rapidly expanding throughout the Canadian West. National parks are dedicated to the people of Canada for their education and enjoyment so they will be left unimpaired for future generations. As mandated by the Canada National Parks Act in 2001, maintenance of ecological integrity[1] has become the first priority of the Parks Canada Agency (Woodley, 2009).

The contribution of these parks to wildlife conservation and biodiversity protection has been intensively studied by conservation biologists. The largely intact nature of the ecosystems conserved by the collection of Canadian and US protected areas in what is termed the Yellowstone to Yukon corridor make these parks important components of continental conservation

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[1] Canada National Parks Act defines ecological integrity as "a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes".

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strategies seeking to maintain all the original top predators and key species for the region while addressing issues of landscape and habitat connectivity and climate change adaptation.

More recently, the potential contribution of these parks to climate change mitigation has become a question of policy and management interest. Protected areas are recognized worldwide as being important components of climate change mitigation and adaptation strategies because of their governance structures, permanence, and management effectiveness (Dudley et al., 2010). In developing countries, protected areas can play an important role in reducing carbon (C) emissions by reducing deforestation, i.e. the conversion of forest to non-forest land uses (Soares-Filho et al., 2010). In developed countries, where deforestation rates are generally lower, the effectiveness of conservation as a strategy for reducing C emissions or increasing C sinks is debated because the alternative to conservation is typically forest management rather than deforestation. Forests in Canada are generally not threatened by deforestation because they are predominantly on public land that is allocated for forestry and governed by legislation and codes of practice to promote sustainable forest management. It is not clear how forest C dynamics differ between forests managed for sustainable timber harvest versus those protected for conservation, particularly when both are subject to natural disturbance, as is the case in boreal forest ecosystems (Kurz and Apps, 1999; Bond-Lamberty et al., 2007; Kurz et al., 2008a,b). Some forest ecosystems lose C when converted from natural to managed disturbance regimes (Kurz et al., 1998; Trofymow et al., 2008) while others may not (Ter-Mikaelian et al., 2008).

Canadian temperate and boreal forests have been recognized as important regions of C storage (Keith et al., 2009; Pan et al., 2011; Stinson et al., 2011), but projected changes in natural disturbance regimes may affect their ability to act as sustained C sinks (Kurz et al., 2008a; Scott et al., 2008; Keith et al., 2009; Metsaranta et al., 2010). The future C balance of Canada's forests is uncertain because of uncertain future impacts of natural disturbances, but the prevailing expectation amongst policy makers and managers is that forests in Canada's national parks have a role to play in climate change mitigation because protection from harvesting has resulted in greater forest C stocks (i.e., C sequestration).

The C budget of Canada's managed forests, including protected areas, is tracked by the Canadian Forest Service (Stinson et al., 2011) but there are limited data specifically about the C balance of National Park forests (Kulshreshtha et al., 2000; Scott et al., 2008). To date no studies have explicitly examined National Park forest C dynamics relative to surrounding managed forests.

In order to understand the role that Canada's national parks may play in climate change mitigation, we put forth four key questions:

1. Are forests protected by Parks currently disturbed less frequently than those in the surrounding managed forest landscape?
2. Are forests in national parks older than those in the surrounding managed forest landscape?
3. Do forests in national parks have higher C density than those in the surrounding managed forest landscape?
4. Do forests in national parks take up more atmospheric CO_2 than those in the surrounding managed forest landscape?

We chose three national parks in British Columbia, Canada (Glacier, Kootenay, and Yoho National Parks) that were established between 1885 and 1920 to estimate the impacts of a century of conservation on forest C dynamics and to quantify the past role of protected areas in climate change mitigation.

We examined the forest stand age structures and the nature and frequency of disturbances, and compared total C stocks and fluxes in protected forest areas with surrounding forests using the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, Kurz et al., 2009). We hypothesized that natural disturbances occur at a similar extent and scale inside and outside of parks. Since parks and protected areas are relatively unaffected by anthropogenic disturbances such as timber harvesting, the lower disturbance frequency should result in a higher average forest stand age in parks compared to surrounding forests. We also hypothesized that parks have higher C stocks and lower CO_2 uptake because older forest stands tend to have higher C density and lower productivity than younger forest stands (Coursolle et al., 2012).

2. Methods

2.1. Study area

Our study area (Fig. 1) is located in south-eastern British Columbia, Canada, covering a geographic area of 26,000 km^2, including 15,000 km^2 of forest. The study area boundary corresponds with the boundaries of the Invermere and Golden Timber Supply Areas (BC MFLNRO, 2012). The study area includes three national parks (Yoho, Kootenay and Glacier), numerous provincial protected areas, large publicly owned managed forests (Crown Timber Supply Area (TSA) and Tree Farm License (TFL) lands) and a few small privately owned forests and woodlots.

In the center of this area lies the Rocky Mountain Trench – a broad, flat valley through which the Kootenay River flows south and the Columbia River flows north. The trench is straddled by two mountain ranges – Rocky Mountains to the east and Purcell Mountains to the west. The area contains 6 biogeoclimatic zones (Meidinger and Pojar, 1991). Glacier National Park covers portions of three zones: Alpine Tundra (AT), Engelmann Spruce Subalpine Fir (ESSF) and Interior Cedar Hemlock (ICH). Kootenay National Park includes AT, ESSF, and Interior Douglas-fir (IDF) zones while Yoho National Park includes AT and Montane Spruce (MS) biogeoclimatic zones (Fig. 1).

Natural disturbances have a strong influence on forest ecology throughout the study area (Wong et al., 2003). Wildfire is the dominant stand-replacing disturbance at the landscape scale, while other disturbances such as avalanche and wind throw are locally important. Fires regularly occur during the hot, dry summer months and many dominant tree species have developed specific adaptations to this fire regime. Fires are generally confined by topography to the mountain valley in which they ignited. Large areas of forest can burn in one valley during a bad fire year while a nearby valley remains unburned, even with similar fuel loadings and fire weather conditions.

When forest stands are not burned and the trees are able to grow old, they often become more susceptible to attack by insects or disease, and uneven-age stand structures develop as individuals or groups of trees are killed. Periodically, outbreaks of bark beetles or other insects cause widespread tree mortality (Safranyik et al., 2004). In order to restore ecological integrity to forests that have been affected by fire suppression, Parks Canada has recently begun prescribed burning in many of its national parks including Kootenay and Yoho but these have been limited to small areas and were not considered in this study.

The size of the forested valleys in our study area is relatively small, and our study period is relatively short within the context of the natural history and life-cycle of disturbance and regeneration in these forests. The forests in one valley could have been younger than those in a neighbouring valley 100 years ago (before park establishment) simply as a result of random chance (e.g., lightning happened to ignite fires in one valley but not the other). The C dynamics of the forests we see today are strongly influenced