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Quantifying terrestrial ecosystem carbon stocks for future GHG mitigation, sustainable land-use planning and adaptation to climate change in the Québec province, Canada

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Abstract

Organic carbon (C) stocks have accumulated in boreal peatlands and forest soils since the early Holocene (< 10,000 years BP), actively removing CO_2 from the atmosphere and creating a net cooling effect on global climate over this period. Based on various databases, C stocks of terrestrial ecosystems in the boreal and Arctic biomes of the Quebec province were quantified as part of an evaluation of their capacity to mitigate anthropogenic greenhouse gas (GHG) emissions and estimate their vulnerability with respect to recent climate change and land use changes. The results of this project are contributing to the establishment of the Strategy for Climate Change Adaptation as well as the 2013-2020 Climate Change Action Plan of the Québec Ministry of Environment, which aim to adapt the Quebec society to the effects of climate change and the reduction of GHG emissions. Results show that mean C density in peatlands is 85.5 kg C m^{-2} and decreases with latitude. Mean forest soil C density is 11.7 kg C m^{-2}, of which 57% stored in mineral horizons and 43% in organic horizons. The total boreal Québec peatland and forest soil C stock is quantified at 14.1 Gt, of which 56% is stored in peatlands. Per surface unit, peatlands store seven to eight times more C than forest soils. These ecosystems are less affected by disturbance than forests, hence they deserve particular consideration in conservation policies. In 2013, total anthropogenic emissions in Québec attained 82.6 Mt CO_2-equivalent. The total boreal peatland and soil C stock thus represents about 627 years of anthropogenic emissions at their current rate. Future GHG mitigation policies and sustainable land-use planning should be supported by an increase in investments in peatland, wetland and forest conservation, management and rehabilitation to limit greenhouse gas emissions. Quebec is the first province in Canada that initiated such quantification.

Keywords: boreal, carbon, peatland, forest, soil, ecosystem, Canada

Introduction, scope and main objectives

Organic matter is accumulated in terrestrial ecosystem soils as long as litter production exceeds heterotrophic decomposition. Organic carbon (C) stocks have accumulated in boreal peatlands and forest soils since the early Holocene, actively removing CO_2 from the atmosphere and creating a net global climatic cooling effect over this period. These ecosystems thus have the potential to mitigate anthropogenic greenhouse gas (GHG) emissions but they are also vulnerable to recent climate and land use changes. Here we present the boreal Québec C stock and its spatial distribution obtained using databases of ecosystem type and inventories of C density (kg C m^{-2}). The results of this project are contributing to the establishment of the Strategy for Climate Change Adaptation as well as the 2013-2020 Climate Change Action Plan of the Québec Ministère du Développement durable, Environnement et Lutte contre les changements climatiques (MDDELCC), which aim to adapt the Québec society to the effects of climate change and the reduction of GHG emissions.

Methodology

Peatlands

A database of 30 deep peat cores was used for multiple regression analysis on six climate-related variables (Garneau et al., 2014; Turunen et al., 2004; Gorham et al., 2003). These variables included mean annual temperature, number of growing-degree days above 0°C, growing-season precipitation, annual precipitation, growing-season average shortwave radiation and growing-season cumulative shortwave radiation. As deep, central peat cores tend to overestimate C density at the scale of the peatland (van Bellen et al., 2011), a correction was applied based on an empirical equation. The obtained relationship between C density and selected climate variables was applied to an adapted database of peatland areas from the MDDELCC (Bissonnette and Lavoie, 2015). The total C stock per *natural region* was defined by the product of its mean C density and the total peatland area of each region. The *natural region* classification corresponds to the ecological framework (*CERQ*) of the MDDELCC.

Forest stands

Two databases were used to quantify soil C density (kg C m^{-2}). In the southern part of the boreal biome quantifications were based on a model created from soil survey data (Tremblay et al., 2002). For the northern part, data were limited to the inventory from Natural Resources Canada (Siltanen et al., 1997). Both C density databases included separate quantification of organic and mineral horizons. Total C stocks were quantified using the spatial database from the MDDELCC.

Results

Peatlands

- C density (kg C m^{-2}) is positively correlated with growing-season cumulative shortwave radiation and precipitation in Québec.
- A model was created with growing-season cumulative shortwave radiation and total precipitation during the growing season as predictors for C density ($r^2 = 0.55$).
- Mean boreal peatland C density is 85.5 kg C m^{-2} and decreases with latitude. This trend is explained by shorter growing seasons in the northernmost regions, with limited biomass productivity. Peatland C stocks are concentrated in the central-western part of the province, south of James Bay, because large areas of peatlands have developed here (Fig. 1).
- Total boreal peatland area is estimated at 92,500 km^2.
- The best peatland C stock estimate is 7.9 Gt C, with a 95% confidence interval of 5.6 to 10.6 Gt C.

Forest stands

- Southern boreal forest stands cover 416,800 km^2 with a mean soil C density of 11.7 kg C m^{-2}, of which 57% is stored in mineral horizons and 43% in organic horizons.
- Northern boreal forests cover 139,700 km^2 with an average C density of 9.4 kg C m^{-2}, of which 59% is stored in the mineral horizons.
- The total boreal forest soil C stock is 6.2 Gt C, of which 4.9 Gt C is contained in the southern boreal forests and 1.3 Gt C in the northern latitudes. The major part of the forest stand soil C stock is located in the southern and eastern regions.

- Mineral horizon C stock is highest in the eastern and southern parts of the province, while organic horizon C stock generally increase with latitude and the presence of closed black spruce stands, with an optimum around 51ºN (Fig. 2).

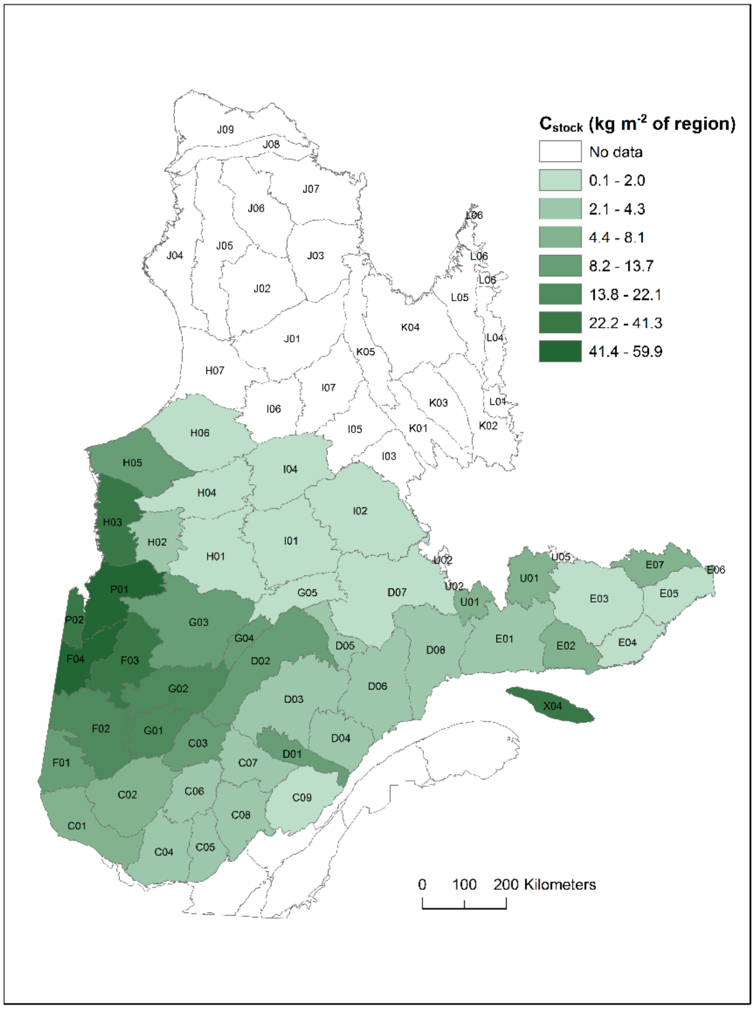

Figure 1: Spatial pattern in peatland C stock, represented by the total peatland C stock per *natural region* (*sensu* MDDELCC), divided by its total surface area.

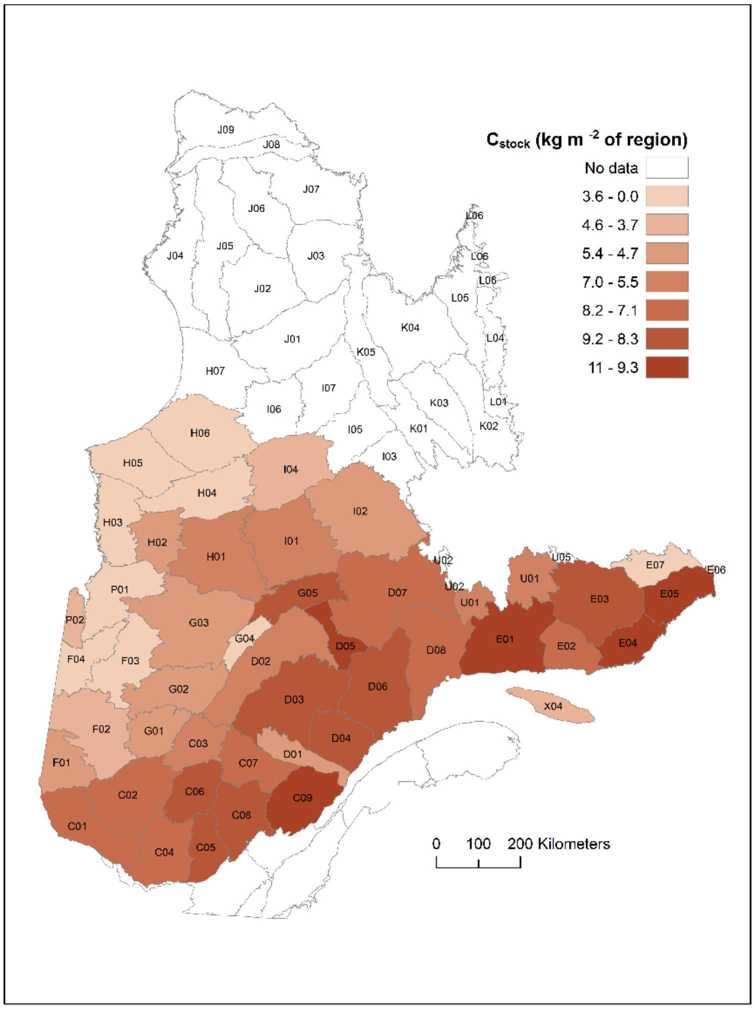

Figure 2: Spatial pattern in total forest soil C stock, represented by the C stock per *natural region* (*sensu* MDDELCC), divided by its total surface area.

Discussion

Our quantifications of C stocks show that C density is on average seven to eight times higher in peatlands (85.5 kg C m^{-2}) than in forest soils (11.1 kg C m^{-2}) in boreal Quebec. Climate projections for 2041-2070 by Consortium Ouranos (www.ouranos.ca) suggest warmer and more humid conditions than present in the northern part of the boreal region, but warmer and drier conditions in the southern part (Mearns et al., 2009). These trends are likely to affect the evolution of boreal C stocks:

- Increasing summer soil water deficit in southern boreal peatlands may decrease C sequestration because of an increase in decomposition.
- In the northern part of the boreal biome, warmer and more humid conditions may benefit C sequestration, due to longer growing seasons and higher plant productivity.
- Forest stands south of 51˚N may risk more frequent burning and larger fires, yet migration of less flammable hardwoods to these regions may attenuate these trends (Terrier et al., 2013). C in mineral horizons is relatively immobile, but organic horizons C stocks may be affected by a higher summer water deficit.
- Lower average forest stand age, resulting from more frequent burning, will imply lower total C stocks.

Conclusions

As stated by IPCC (2013), future GHG mitigation policies and sustainable land-use planning should be supported by more scientific data on terrestrial ecosystem C stocks. The total boreal Québec peatland and soil C stock is quantified at 14.1 Gt, of which 56% is stored in peatlands. Per surface unit, peatlands store seven to eight times more C than forest soils. They are less affected by disturbance than forests, hence they deserve particular consideration in conservation policies. In 2013, total anthropogenic emissions in Québec attained 82.6 Mt CO_2-equivalent (Environment Canada, 2015). The total boreal peatland and soil C stock thus represents about 627 years of anthropogenic emissions at their current rate.

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