



Impact of decade-long warming, nutrient addition and shading on emission and carbon isotopic composition of CO₂ from two subarctic dwarf shrub heaths



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ABSTRACT

This study investigated ecosystem respiration, soil respiration and carbon isotopic composition in CO₂ emitted from two subarctic shrub heaths with contrasting moisture regimes. The reported measurements were conducted 22 years (mesic heath) and 12 years (wet heath) upon initiation of *in situ* climate change related manipulations of temperature, nutrient availability and light.

The aim was to quantify expected climatic change effects on soil and ecosystem respiration, and to investigate whether the emitted CO₂ originates from old carbon stores in the soil or from newly fixed carbon. Ecosystem and soil respiration was measured using closed chambers and CO₂ in the soil profile was sampled with gas probes installed at different depths.

At the mesic heath ecosystem respiration was increased 46% by warming while soil respiration increased 133% by nutrient addition. At the wet heath, warming increased ecosystem respiration by 99% and soil respiration by 58%. Litter addition, short time warming and shading generally did not change ecosystem- and soil respiration.

The carbon isotope compositions of the sources to CO₂ were not significantly altered by any of the treatments at the two heaths across the growing season. However, there was a tendency across growing season towards an increased $\delta^{13}\text{C}$ source value after 22 years of warming in the mesic shrub heath, and the effect was statistically significant in June, indicating increased decomposition of ¹³C enriched material. Hence, although more of the old carbon stock in the soil was possibly mineralized under warmed conditions, indicating a risk of long lasting positive feedback on climate warming, the effect was only periodically strong enough to gain statistical significance, despite strong warming-induced effect on ecosystem respiration, and may be counteracted by increased C gain by higher primary production.

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1. Introduction

As a result of cold temperature, ecosystems of northern latitudes are characterized by low mineralization and low primary production. During geological time this region is considered a net carbon sink, removing carbon dioxide (CO₂) from the atmosphere and incorporating this in organic form in the ecosystems. As a result there is a large carbon stock in soil (SOC) at northern latitudes, and the total storage for the permafrost region is estimated to 1300 Pg C

(Hugelius et al., 2014).

Anthropogenic release of greenhouse gases is expected to change the global climate. During the last 30 years the temperature increase in the Arctic region has been around 0.6 °C per decade (IPCC, 2013), affecting arctic ecosystem structure and functions.

Higher temperature increases ecosystem respiration (ER) in arctic heath ecosystems (Grogan and Chapin, 2000; Jonasson et al., 2004; Dorrepaal et al., 2009) primarily as a result of stimulated decomposition. As a consequence of higher mineralization the soil nutrient availability, which is normally a limiting factor for plant growth in arctic ecosystems (Shaver and Chapin, 1980), is stimulated. Increased temperature is likely to lead to higher plant biomass (Jonasson et al., 1999) and changes in plant community

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composition and function (Sorensen and Michelsen, 2011; Campioli et al., 2012). For instance, higher abundance of shrubs in heath and tundra ecosystems is observed (Sturm et al., 2001; Tape et al., 2006; Elmendorf et al., 2012). These changes in the environment are expected to have great influence on ecosystem carbon cycling, e.g. ER (Hobbie, 1996) and gross ecosystem production (GEP) (McKane et al., 1997; Grogan and Chapin, 2000; Welker et al., 2004), and may affect the balance between these fluxes, potentially turning the ecosystem from a carbon sink into a net source of CO₂ to the atmosphere (Oechel et al., 1993).

Investigating of carbon isotopic composition (¹³C:¹²C ratio) in ecosystem respired CO₂ may identify the source of the respired carbon. This can be achieved since different substrates are expected to have different carbon isotope ratios (Ågren et al., 1996); for instance the ¹³C:¹²C ratio in leaves is lower than in soil organic matter (Fry, 2006). This may provide an opportunity to investigate whether climate change induced increase of ER is a result of increased emission of newly fixed carbon containing more of the lighter ¹²C isotope, or old carbon containing more of the heavy ¹³C isotope (Dorrepaal et al., 2009).

An increase of the ecosystem respiration can be a result of an increased heterotrophic mineralization of the old carbon stock in the soil. This is partly because decomposition of stable and more resilient carbon may be characterized by high temperature sensitivity (Davidson and Janssens, 2006; Lefevre et al., 2014). And also because an increased input of easily available organic substrate to the soil, due to increased GEP, can result in an acceleration of mineralization of soil organic matter, a phenomena referred to as priming (Kuzyakov et al., 2000; Bader and Cheng, 2007; Bengtson et al., 2012). Accelerated production and emission of this CO₂ containing “old” carbon from the soil stock will contribute to a further increase in atmospheric CO₂ concentration and thus result in a positive feedback on global climate change (Oechel et al., 1993; Schuur et al., 2015).

It is also possible that the temperature driven increase in CO₂ emission is a result of autotroph respiration and mineralization of newly fixed carbon indicating an overall acceleration of the biosphere-atmosphere carbon cycling, with little impact on atmospheric CO₂ and global climate change (Grogan et al., 2001); but still with profound effects on ecosystem structure and function such as increased shrub abundance (Sturm et al., 2001) and decreased abundance of bare ground (Elmendorf et al., 2012).

This study was conducted 12 years after the onset of *in situ* climate manipulation at a wet subarctic shrub heath, and 22 years after the onset of similar climate manipulation at a mesic subarctic shrub heath; these experiments represent some of the longest ongoing ecosystem manipulation experiments at northern latitudes (Michelsen et al., 2012). The duration of this experiment gives us the opportunity to address the risk of long term positive feedback to the climate. Acclimation of the ecosystems respiration and photosynthesis could be expected to happen due to for instance observed changes of the vegetation (Graglia et al., 2001; Campioli et al., 2012) during the long time frame. The current study combines a long time ecosystem manipulation experiment and the use of isotopic techniques, which may facilitate the understanding of altered CO₂ effluxes under environmental changes (Subke and Bahn, 2010).

The aim of this study was to investigate long-time effects of climate and environmental manipulations (enhanced temperature, nutrient or litter addition) on the magnitude and source characteristics of respiratory CO₂ emission from dwarf-shrub dominated subarctic heathlands (Northern Sweden) under mesic and wet moisture regimes. To achieve these goals we visited the experimental field sites four times during one growing season and collected samples in order to i) quantify ecosystem respiration (ER),

soil respiration (SR) and soil CO₂ gas concentration profiles, and ii) determine the ¹³C:¹²C stable isotope ratio characteristics of CO₂ and belowground carbon pools of roots and organic matter.

2. Method

The field work was carried out near Abisko in northern Sweden (68°19'N, 18°51'E) in the growing season 2011. The climate at the location is subarctic and the growing season lasts from mid-June to early September (Illeris et al., 2004). The mean annual temperature is −0.5 °C and annual precipitation is 315 mm (1970–2000; www.polar.se/abisko-naturvetenskapliga-station). Our measurements were conducted at two heath ecosystems with different moisture regimes, i.e. mesic and wet, respectively.

2.1. Mesic heath

The mesic heath is a well-drained dwarf-shrub heath close to the treeline of *Betula pubescens* ssp. *tortuosa*, at 450 m a.s.l. The experimental plots are established at a slope facing WNW with a dominant vegetation of *Cassiope tetragona* (L.) D. Don, which makes up one third of the aboveground biomass (Michelsen et al., 1996). Other frequent low or dwarf shrubs at the site are *Empetrum hermaphroditum* Hagerup., *Vaccinium uliginosum* L., *Rhododendron lapponicum* (L.) Wahlenb., *Salix hastata* L. and *Betula nana* L. (Havström et al., 1993). Moss cover at the site is approximately 36% (Sorensen et al., 2012). The bedrock consists of base-rich mica schists. The upper 0–10 cm of the soil profile has an organic content of approximately 80% and the soil pH (H₂O) in 0–10 cm is around 7.1.

Experimental manipulations of this mesic ecosystem were started in 1989 in order to simulate direct or indirect effects of global warming. Treatments are replicated in six blocks organized in a randomized block design. In this study focus is on control (C) plots and plots with fertilization (F), warming (T) and shading (S), i.e. a total of 24 plots, each 120 × 120 cm².

Warming in the summer season is achieved with dome-shaped, 50-cm-high, open-top (Ø 50–60 cm) plastic tents. The plastic used is 0.05 mm thick polyethylene film which is optically neutral and reduces PAR by 9%. Air temperature is enhanced by 3–5 °C and soil temperature at 1–5 cm depth by 1–1.9 °C (Havström et al., 1993) simulating temperature conditions in a warmer climate. Shading in the summer season is achieved with dome-shaped, 50-cm-high sack cloth tents that reduces PAR with 64% (Havström et al., 1993). This reduction of incoming light is similar to that caused by canopy of *Betula pubescens* ssp. *tortuosa*, and simulates an upward expansion of the birch forest. The tents are in place each summer from late May to early September. In 2011 both types of tents were raised on 3rd of June and removed 1st of September. Addition of fertilizer simulates an increased nutrient availability due to enhanced mineralization in a warmer climate (Havström et al., 1993). The annual nutrient addition is 10 g N m⁻², 2.6 g P m⁻² and 9 g K m⁻² (Illeris et al., 2004). In 2011 fertilizer was added on the 10th of August.

2.2. Wet heath

The wet site is established at a moist heath 400 m a.s.l. and surrounded by *Betula pubescens* ssp. *tortuosa* forest. The content of soil organic matter at 0–5 cm is 93% and the pH is 6.9 (Rinnan et al., 2007). The dominant plant species are low or dwarf shrubs such as *Empetrum nigrum* ssp. *hermaphroditum* Hagerup, *Andromeda polifolia* L., and *Vaccinium uliginosum* L. Also forbs and graminoids are present such as *Tofieldia pusilla* Michx., *Bistorta vivipara* L., and *Carex vaginata* Tausch, and the moss cover is 62.7% ± 15.5

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