Conference Volume | 6th Symposium for Research in Protected Areas 2 to 3 November 2017, Salzburg | pages 119 - 122

From long-term ecosystem monitoring to regional modelling of ecosystem function in the National Park Kalkalpen, Austria

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Abstract

Here we show the usefulness of Long-Term Ecosystem Research (LTER) for scrutinizing climate change impacts on forest carbon (C) sequestration in the National Park Kalkalpen, Austria. Climate change will accelerate forest disturbances causing a decrease in forest C sink strength in the future. Delayed forest regeneration after stand replacing disturbances due to ungulate browsing opens an additional window for enhanced C loss. However, the dense grass layer, developing after large-scale disturbances, reduces ecosystem C loss by half, causing less climate feedback than expected. By applying two ecosystem models, we could show that wind and spruce bark beetle disturbances, which occurred during the last two decades throughout the National Park, increased soil organic C decomposition by 20% and will, together with future climate change, cause a 4% drop in forest ecosystem C stock by the year 2200.

Keywords

ecosystem monitoring, LTER, climate change, carbon sequestration, modelling

Introduction

Site-based infrastructure for Long-Term Ecosystem Research (LTER) has already been established in the 19th (e.g., 1891 Plön, Germany; 1840 Rothamsted, UK) and the 20th centuries (e.g., 1906 Lunz, Austria; 1925 Trout Lake Station, Wisconsin, US; 1955 Hubbard Brook, New Hampshire, US; 1960 Solling, Germany). In recent years, LTER has gained momentum since the research infrastructure strategy of the European Commission (ESFRI) is establishing a coherent network of LTER sites and seamless access to long-term data (MIRTL 2010). Since function, state and trends in unmanaged natural ecosystems are particularly interesting, many LTER sites are located in protected areas.

The National Park Kalkalpen, Upper Austria, with the LTER master site Zöbelboden is one such example where ecological monitoring infrastructure and long-term data is increasingly used by researchers. The site has been set up in the framework of the pan-European monitoring programmes in 1992 to evaluate abatement measures for the reduction of air pollutants being harmful to ecosystems (sulphuric acids, nitrogen, ozone, etc.). These days, LTER Zöbelboden focuses on several environmental changes (air pollution, climate change, forest management) and their effects on ecosystem services provided by mountain forests (pollutant filtration, carbon sequestration, biodiversity, etc.). During the last 25 years, LTER Zöbelboden became the most intensively investigated mountainous karst ecosystem in Austria, participating in many national and international monitoring and research projects.

As an example of a successful integration of LTER-born knowledge for supporting decision making in the National Park Kalkalpen, we present results addressing the carbon (C) sink function of forests and its modification due to forest disturbances from wind and spruce bark beetle (*Ips typographus* L.). Temperate forests currently act as sinks for atmospheric C. However, wide-spread tree damage, which has been occurring in increasing intensity during the last two to three decades, causes a release of C thereby increasing the CO_2 concentrations in the atmosphere. In an effort to scrutinize the impacts of forests disturbances on C sequestration in the National Park, long-term ecological monitoring data, additional field measurements, reconstruction of historic forest management and disturbance, and regionalized ecosystem modelling were employed.

Methods

Several design characteristics serve an efficient usage of LTER Zöbelboden data and infrastructure for National Park management purposes. Key components of the forest C cycle of widespread regional forest types (i.e. tree growth, litter fall, soil C dynamics) have been monitored at intensive measurement plots since 1993. In addition, soil CO_2 efflux surveys in combination with the root trenching method were conducted in order to calculate net ecosystem production (NEP), which is the net amount of C released or sequestered over time in an ecosystem. With tree replacing disturbances occurring in these plots after the year 2004, effects of forest disturbance on the forest C cycle could further be monitored. Additionally, space-per-time substitution was used to study long-term post-disturbance changes in the NEP. Two different well-established ecosystem models (LandscapeDNDC, http://svn.imk-ifu.kit.edu/; iLand, http://iland.boku.ac.at/startpage) used these data in combination with (monitoring) data of the National Park (forest inventory, modelled soil maps, Lidar data, aerial photo interpretation) for model initialization, calibration and validation at the landscape level. These model exercises aim to study both the historic and the future temporal trajectories of forest C sequestration within the National Park Kalkalpen (Fig. 1).

Results and discussion – Forest carbon sink

Field measurements in the LTER site Zöbelboden showed that mature forest stands on Cambisols with Norway spruce as the major tree species sequester 0.5 to 2 t C ha^{-1} per year (KOBLER et al. 2015, ZEHETGRUBER et al. 2017). Shortly after stand replacing disturbance, large amounts of C (~5.5 t C ha^{-1} y^{-1}) were released. Fast growth of a dense grass layer subsequently reduced C losses by ~50% (ZEHETGRUBER et al. 2017). After that, disturbed sites gradually return to a C sink due to accelerated C uptake from tree regeneration (Fig. 2). In contrast to these stand-replacing disturbances damage of single trees or group of trees did not fully diminish the C sink. KOBLER et al. (2015) found, that replacement of 31% of all trees in a spruce dominated stand at Zöbelboden did not lead to negative NEP.

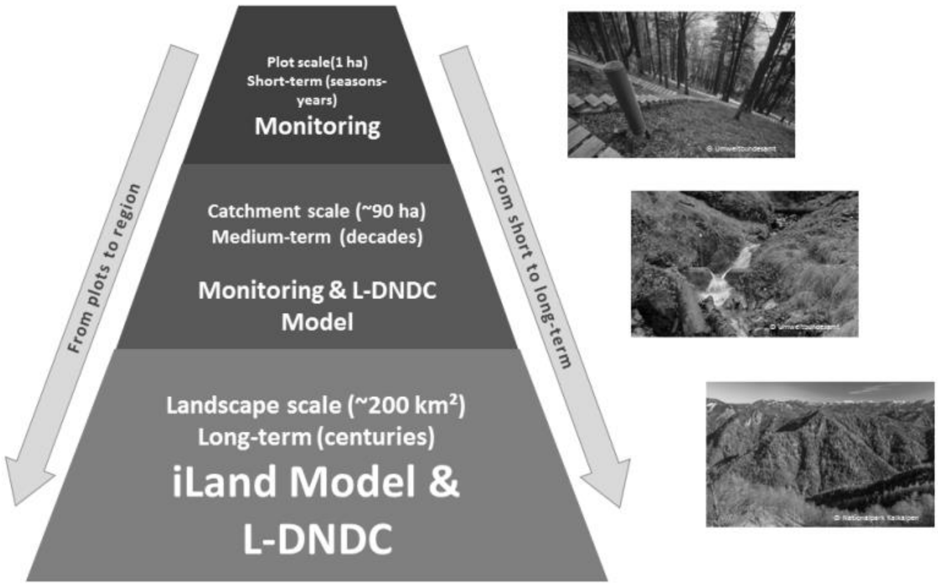

Figure 1: Using long-term monitoring data (plot to catchment scale) and ecological modelling (iLand and LandscapeDNDC) to study forest C sequestration at the landscape scale.

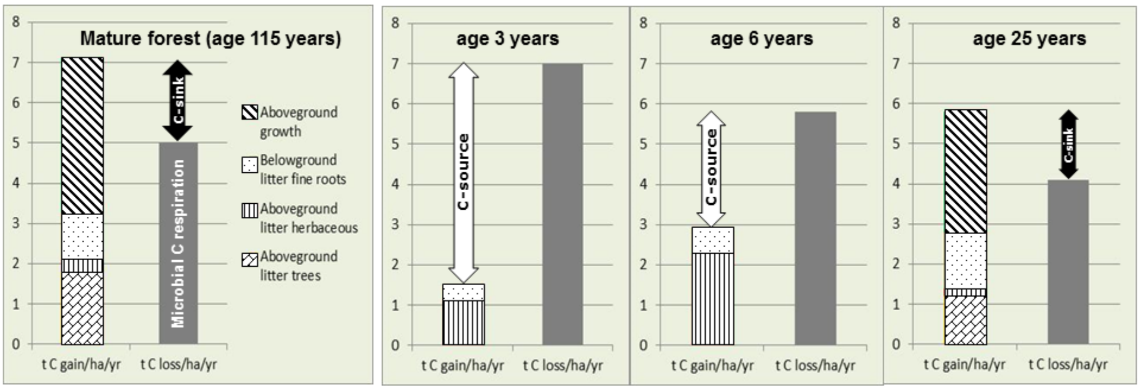

Figure 2: The forest C sink and source of spruce dominated forests three, six and twenty-five years after stand replacing disturbance in the LTER site Zöbelboden.

LandscapeDNDC, an ecosystem model for C, nitrogen and water cycles was successfully calibrated with long-term plot measurements from the Zöbelboden monitoring program (Fig. 3). The regional application of the model showed that forest disturbances during the last decade caused a 20% increase in soil CO_2 emissions (= soil respiration) (Fig. 3).

By applying iLand with roughly the same input data and climate scenarios to the National Park Kalkalpen area, THOM et al. (2017) showed that climate change, including disturbances, induced a reduction in tree biomass between -11.6% to -14.9% resulting in a -4% drop in the total C stock by the year 2200.
In an ongoing EU research project (www.ecopotential-project.eu) we are exploring the potential of the most novel remote sensing products for their usefulness in improving C-related modelling. These activities aim at finding a practicable monitoring schema for the National Park.

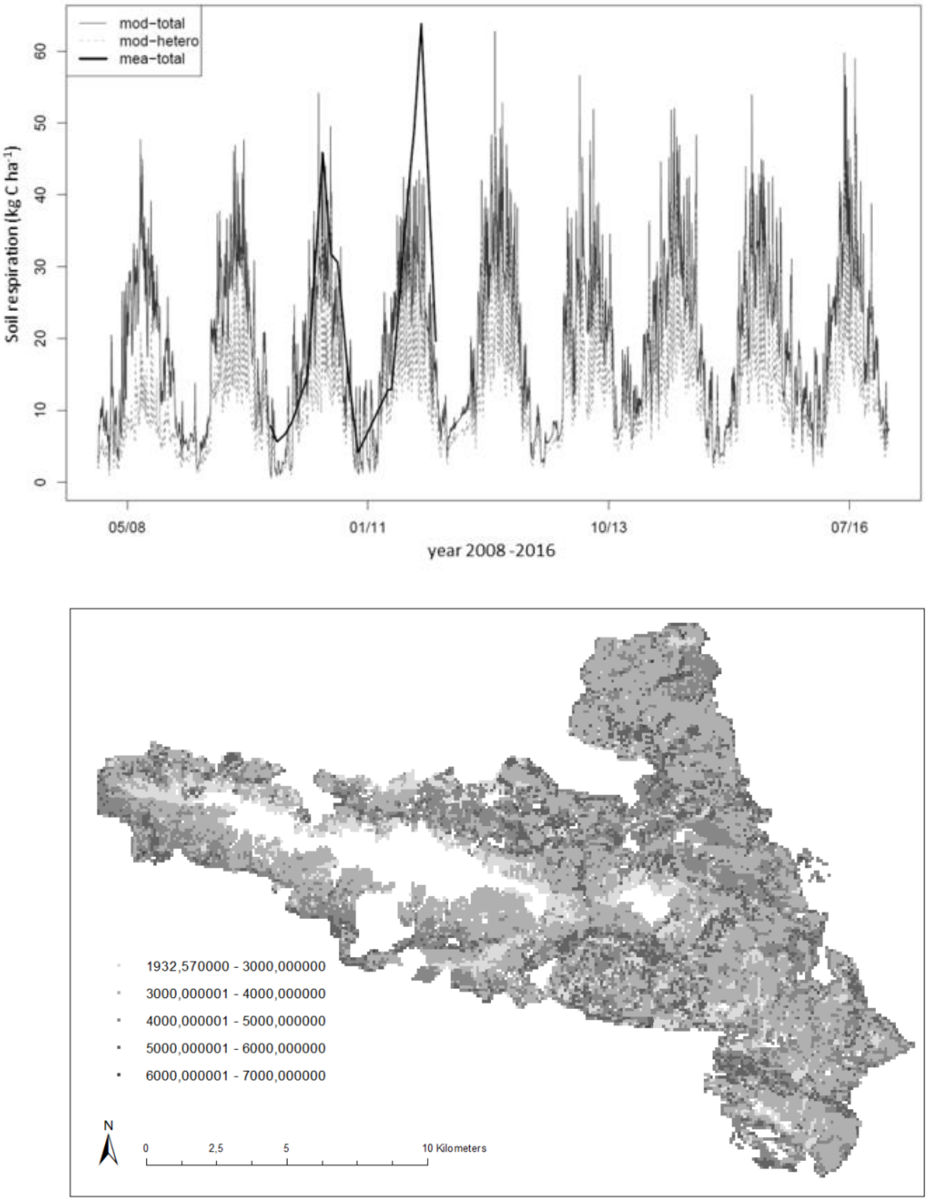

Figure 3: Top: Measured and modelled (LandscapeDNDC) soilrespiration at LTER Zöbelboden. Bottom: Modelled microbial soil C respiration (kg C ha^{-1} y^{-1}) for the National park area.

Conclusions

Our studies on climate feedbacks in the National Park Kalkalpen show that climate change will accelerate forest disturbances causing a drop in their C sink strength in the future. This lowering effect is due to a loss in standing biomass and respiration of large amounts of soil C by soil microorganism right after disturbance. Soil C respiration seem not to be significantly affected in the often small scale, patchy outbreaks of bark beetle infestations and wind throws of single trees or group of trees because soil climate is still regulated by the surrounding forest. In larger-scale disturbance areas, vital tree regeneration usually reduces C loss during only a few years after stand replacement. However, tree regeneration fails for many years when browsing pressure by large ungulates is too high. We found that the dense grass layer developing in such areas reduces ecosystem C loss by half, causing much less climate feedback than expected. That's however only half the truth because delayed forest regeneration after stand replacing disturbances opens a window for enhanced C loss, thereby causing a positive feedback on climate warming. Non-intervention management during and after forest disturbance, as is applied in many protected areas, has to additionally address regulative measures for controlling large ungulates.

Acknowledgements

These studies received funding from the Austrian Federal Ministry of Agriculture, Forestry, the Austrian Climate Research Programme (Project number KR14AC7K11960), the Austrian Science Fund FWF (project P 25503), and the European Union's Horizon 2020 research and innovation program under grant agreement No 641762.

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