

Popular summary

Boreal ecosystems are a globally important carbon sink, currently storing at least a fifth of all the carbon contained in terrestrial ecosystems. However, the fate of this carbon sink is uncertain because rising air temperatures and changes in precipitation and the frequency of natural disturbances are impacting the movement of carbon between these ecosystems and the atmosphere. For example, although higher air temperatures may prolong the growing season, allowing plants to photosynthesize and capture carbon over a longer period each year, warmer conditions also stimulate the release of carbon by plants and by soil microbes as they decompose organic matter. The balance of these two processes, photosynthesis and ecosystem respiration (ER), determines whether ecosystems are net sinks or sources of carbon dioxide (CO₂). Being able to accurately predict photosynthesis and ER is crucial, since a change in either of these carbon fluxes has a direct impact on atmospheric carbon concentrations and the rate of climate change.

This thesis is comprised of four papers and has two main aims. The first aim was to develop new and simple methods to model ER using data collected by thermal cameras on drones and satellites. Thermal cameras take images of temperature, which is one of the main factors controlling the rate of ER. By using these cameras, temperature, and therefore ER, can be mapped over far bigger areas and in greater detail than can be measured on the ground. Attaching cameras to drones allows the collection of highly detailed data over a few hectares, whereas satellites collect data in less detail but over larger areas, from a few hectares to the whole globe. However, producing reliable temperature data from the low-cost, miniaturized thermal cameras used on drones is not straightforward. Therefore Paper I tested the performance of such a camera in the laboratory and in the field to identify the potential sources of error and quantify how much uncertainty they contributed to the temperature measurements.

Papers II and III focused on modelling the ER of peatlands, because peatlands contain dense carbon stocks that have been accumulating for thousands of years. Peatlands are also characterized by variations in microtopography that can lead to substantial differences in microclimate and vegetation species over just a few centimetres. Paper II investigated how the high resolution data from drones could be used to understand the effects of this spatial variation on carbon fluxes within a peatland, whilst Paper III focused on modelling and predicting variations in the carbon fluxes among five peatlands spread across Sweden and Finland.

The second aim of this thesis was to investigate how an extreme drought in 2018 impacted the carbon exchange of Nordic ecosystems. Peatlands are particularly vulnerable to drought because they are dependent on maintaining waterlogged conditions to slow the decomposition of their dense carbon stocks. Warmer temperatures and dry conditions are thus expected to have a large impact on their carbon emissions. The carbon flux data collected in Papers II and III provided an opportunity to test this assumption. In Sweden, the 2018 drought led to the worst wildfire season in over a century. Paper IV quantified the effects of the largest wildfire that year on forest soils, including how it affected the exchange of two greenhouse gases (CO₂ and methane), soil microclimate and chemistry. In particular, it investigated how the characteristics of the burn (burn severity), forest age and post-fire salvage-logging (versus leaving the trees standing) affected the forest soil.

There were four main outcomes from this thesis. Firstly, Paper I produced a set of best practices for using thermal cameras on drones that will benefit anyone seeking to use these cameras to record reliable temperature data. There are many applications for this type of data, from precision agriculture, where crop

temperature is used to assess irrigation needs, to archaeology, where temperature maps are used to detect buried structures.

Secondly, Papers II and III showed that even simple remote sensing models could produce reasonably good predictions of peatland ER. The papers also highlighted that accounting for the spatial variability of vegetation composition and water table depth, both within and between peatlands, is key to producing accurate ER estimates. The drone data in Paper II enabled, for the first time, ER to be mapped across a peatland in high detail and such maps could be used to evaluate whether our carbon flux measurements are capturing the full range of peatland CO₂ emissions. Furthermore, the models developed in Paper III provide a foundation for estimating peatland CO₂ fluxes across the whole of Scandinavia, which could help policymakers develop sustainable management policies for these areas.

Thirdly, Papers II-IV showed that the effect of drought and wildfire on carbon exchange is closely tied to the severity of the disturbance, but that at times of very acute water stress or after a severe burn, ecosystem CO₂ emissions can decrease. The reduction of ER did not prevent peatlands from turning into net carbon sources during the 2018 drought because the drought also led to declines in photosynthesis (i.e. carbon uptake). Nevertheless, these results suggest that some peatlands may lose less carbon than expected during extreme drought.

Finally, Paper IV showed that the amount of time between forest disturbances exerts a substantial influence on forest soils. Salvage-logging directly after a fire had no additional effects on forest soils compared to not salvage-logging, although this result was only applicable where the trees had already been killed by the fire. However, when fire occurred 12 years after a previous clear cut, the young forest had much less time to recover its soil carbon and nutrient stocks compared to stands which were mature at the time of the fire. The increasing frequency of wildfire in certain parts of the boreal region could therefore threaten the long-term carbon storage capacity of these forests.