Can Native Woodland Regeneration in Scotland mitigate climate change?

Project members: Dr. François-Xavier Joly (project leader, previously Lecturer Uni. Stirling, now Junior Professor at INRAE, France); Dr. Alan Law (Lecturer, Uni of Stirling); Maria Kuhn (Master student, Uni. Stirling), Alex Cristobal (Bachelor student, Uni. Stirling).

Context: Native woodland regeneration ('NWR' hereafter) is increasingly viewed as a nature-based solution which can mitigate climate change by increasing carbon (C) sequestration. In Scotland, this often involves restricting grazer access (deer/sheep) to grasslands or heather moorlands through fencing or culling, thereby allowing tree establishment. While NWR likely increases C sequestration in the vegetation through tree growth, it may not necessarily lead to a net C gain at the ecosystem-scale: in terrestrial ecosystems and Scotland in particular, the vast majority of C is not stored in the vegetation or the atmosphere, but belowground as soil organic matter (Lehmann & Kleber, 2015). Thus, changes in C sequestration following NWR largely depend on the soil C response. This is critical as recent work, including our own, on tree planting (Friggens et al. 2020; Joly et al. in prep) and on NWR at Ben Lawers NNR (Starr et al., in prep) in Scotland, have reported large decreases in soil C stocks following tree establishment, reducing, or even cancelling out increases in vegetation C stock (Friggens et al. 2020). Carbon benefits of NWR on previously grazed areas in Scotland cannot be estimated from tree growth alone: we also need to consider the associated change in soil C stock – the largest terrestrial C stock. Since soil processes that control soil C sequestration depend on plant community composition, climate, and their interaction (Joly et al., 2023), the response of soil C stocks – and thus of ecosystem C stocks – to NWR likely vary with environmental parameters. There is thus an urgent need to evaluate the response of ecosystem C stocks to NWR across Scotland by explicitly considering soil C and environmental parameters, to determine if, where and by how much NWR can mitigate climate change.

Project aim: To answer the question "*Can NWR in Scotland mitigate climate change?*", we aimed to quantify, in a network of five NWR initiatives across Scotland, how NWR affects the quantity of C stored in plant biomass (above and belowground) and in the soil. Based on previous studies (Friggens et al. 2020, Joly et al. in prep), we expected that following woodland regeneration, net ecosystem C stock decreased due to a decrease in soil C stock that is not counterbalanced by an increased in vegetation C stock (Fig. 1).

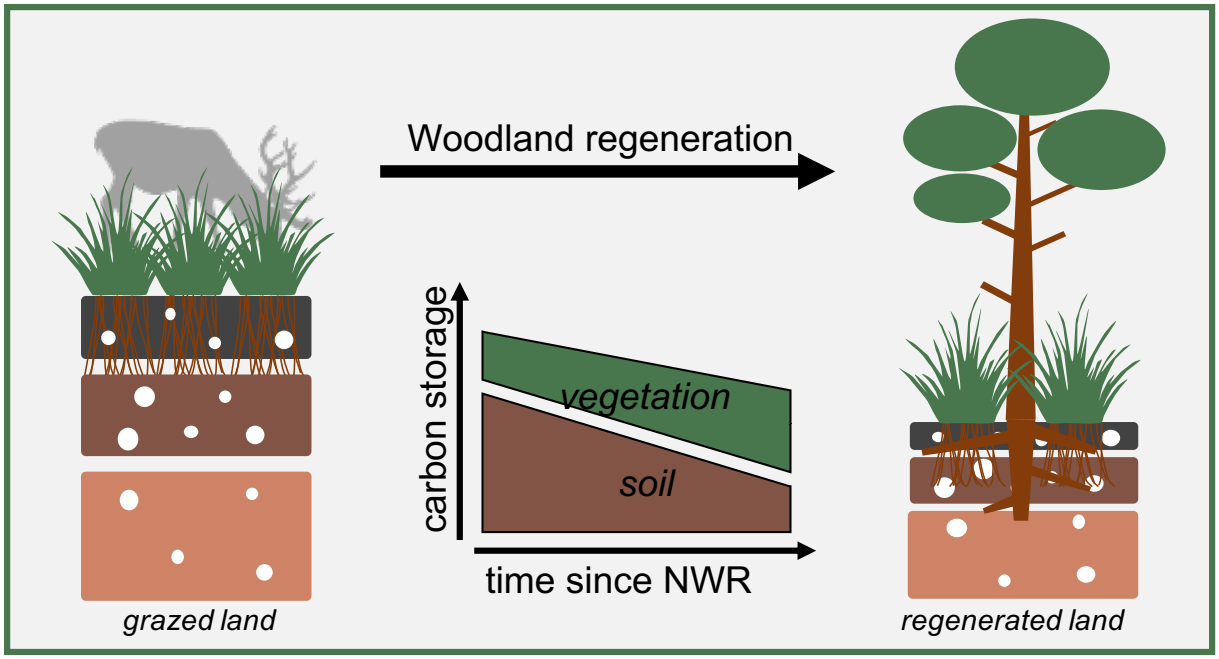

Figure 1: Schematised hypothesis. *Hypothesised negative relationship between time since woodland regeneration and ecosystem C storage, driven by an increase in vegetation C storage and a simultaneous larger decrease in soil C storage.*

Methods: Thanks to the funding by Future Woodland Scotland, we organised a field campaign in the summer of 2023. In the spring, we assembled a network of five sites across Scotland, varying in environmental conditions and woodland regeneration practices. These sites included Ben Lawers National Nature Reserve (NNR), Creag Meaghaidh NNR, Invereshie and Inschriach NNR, Mar Lodge Estate NNR, and Corehead (Fig. 2), were NWR occurred through fencing to exclude grazers and some moderate planting, or through deer culling, thereby allowing natural tree regeneration for 10-30 years.

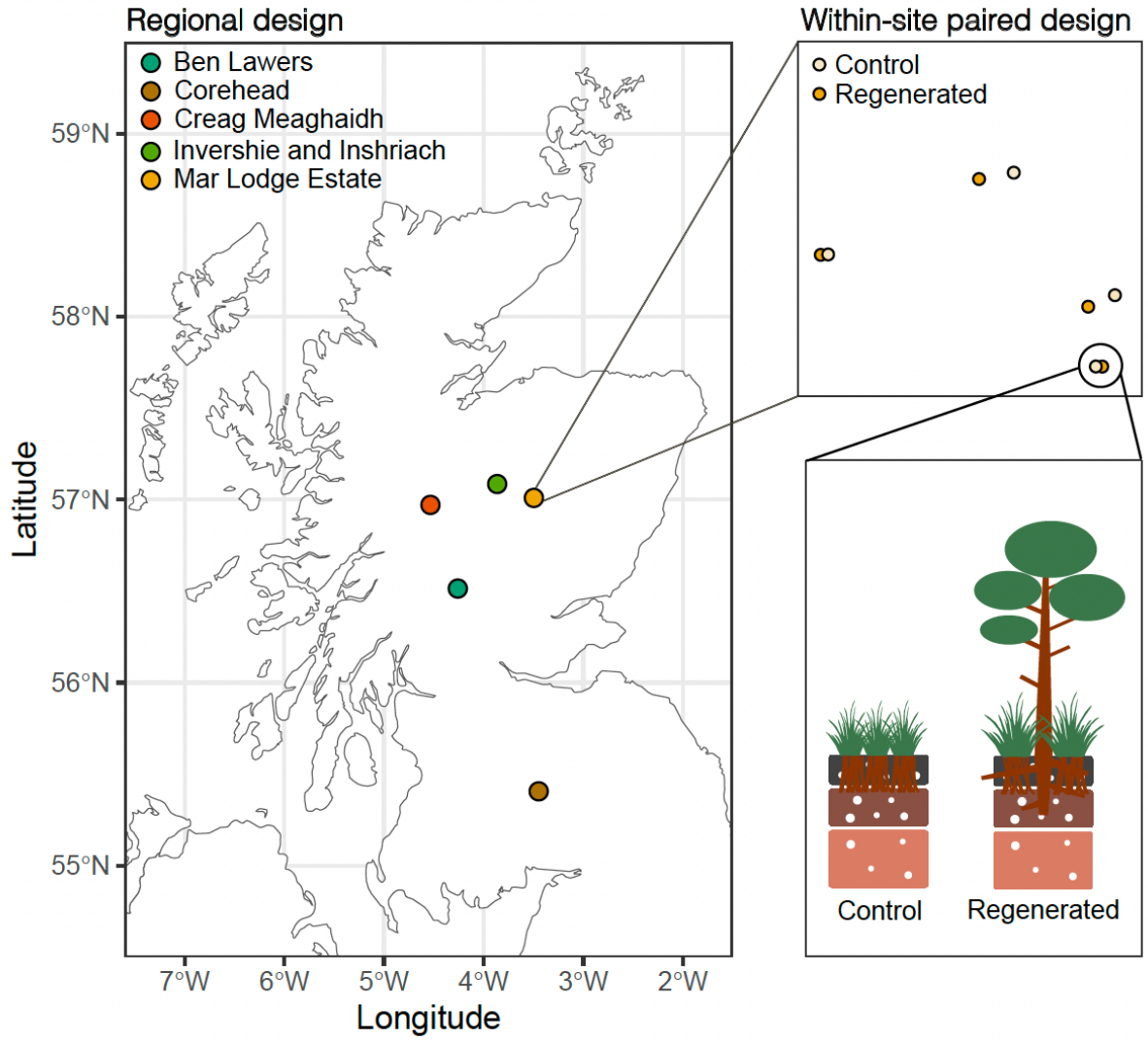

Figure 2: Overview of the study design. *We established a network of 40 plots, consisting of 20 pairs of a regenerated woodland and a nearby (within 10-100m) control site without trees. These 20 pairs were spread across five study sites across Scotland, where various forms of natural woodland regeneration have taken place in the last 10-30 years.*

At each site, we identified four pairs of plots, with each pair consisting of a regenerated plot and a nearby control plot without any trees. This allowed to have four true replicates within each site. In each plot, we establish a five-meter radius circle in which we measured the diameter and height of all trees to estimate their carbon content. We then randomly took four samples of the vegetation by clipping all vegetation with a 20 x 20 cm quadrat, four samples of the organic soil layer, and four samples of the 0-30 cm mineral soil samples (divided in 0-5, 5-15, 15-30 cm increments). For each plot, we pooled the four replicate samples into a composite sample, for each vegetation/soil category. Between September 2023 and April 2024, we dried, weighed and analysed the samples to determine their C stock. This led to 200 samples and carbon determination (40 plots x 5 samples (vegetation, organic layer, 0-5, 5-15, 15-30 cm mineral soil)).

Preliminary results:
We did not find significant differences in carbon stock belowground between NWR and control plots (data pending re-analyses of some samples) (Fig. 3).

Instead, we did find a decrease in carbon stock in the understory vegetation following NWR, and an (obvious) increase in carbon stock in the overstory vegetation due to the growth of trees (Fig. 3).

Despite the lack of differences in carbon stock belowground, there appeared to be a trend of decrease in mean belowground carbon stock which appeared to be of comparable size to the increase in carbon stock aboveground (Fig. 3).

Because of these non-significant decreases in soil carbon stocks that counterbalanced the creation of tree carbon stocks, the total ecosystem carbon stock did not change significantly between NWR and control plots.

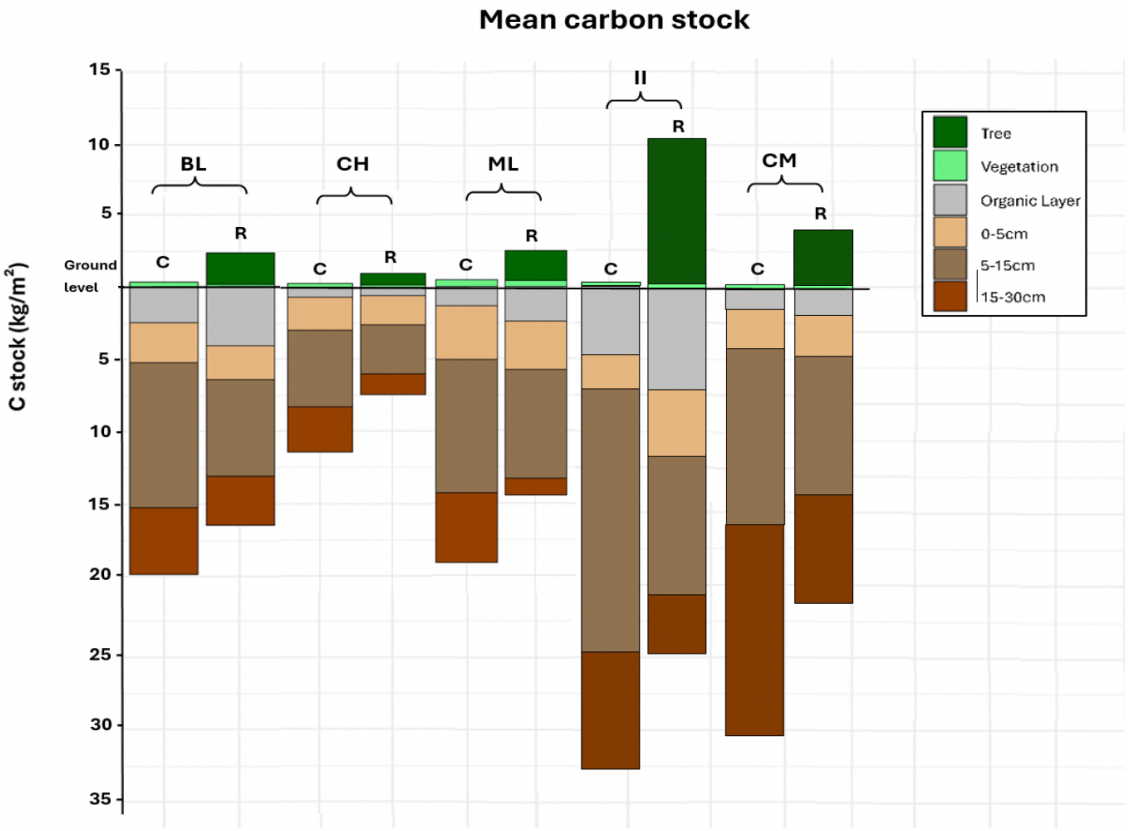

Figure 3: Ecosystem carbon stocks between control and NWR plots. *Mean carbon stock found at each aboveground component (trees, vegetation) and belowground layers (organic layer, 0-5cm, 5-15cm and 15-30cm) for control (C) and rewilded (R) plots across all sites; Ben Lawers (BL), Corehead (CH), Mar Lodge (ML), Invereshie and Inshriach (II) and Creag Meagaidh (CM).*

Preliminary conclusions:
The preliminary analyses of the data that we collected in this project suggest that NWR neither increase nor decrease ecosystem carbon storage. Note that these results are preliminary, while we await the re-analyses of a subset of vegetation and soil samples for carbon determination. Additionally, once more environmental data will be collected from each site by a follow-up project (see section 'Future development' below), we will expand the analyse of these data to determine how the change in ecosystem carbon stocks correlates with environmental variable. If this lack of response of ecosystem carbon stock is confirmed, it would have several implications:

- Given the recent suggestions that tree planting on former grassland (Joly et al. in prep) and heather moorland (Friggens et al. 2020) leads to declines in soil C stocks, this study would provide relief that NWR in contrast does not significantly reduce soil C stocks, and thus that if anything, it does not contribute to climate change.
- The absence of changes in ecosystem-scale carbon stock would indicate that NWR does mitigate climate change and should not be advertised as a way to tackle the climate crises.
- In turn, NWR may have potential benefits in terms of biodiversity and the absence of contribution of NWR to climate change would suggest that it would be safe to use NWR as a way to promote biodiversity (if this is proven to work).

Limitations and perspectives:

- *Plot-scale vs landscape-scale:* It is important to note that we used patches of trees as NWR plots and nearby tree-less patches as control. This maximises the contrasts between NWR and control, and on average, these patches of trees do no make up for most of the space in NWR landscape, as NWR leaves a lot 'treeless' spaces in between regenerated patches. A more thorough assessment of the spatial distribution of C in NWR landscape compared to unregenerated control landscape would be needed to determine if ecosystem C storage changes in response to NWR at the landscape scale.
- *Surface soil vs deep soil:* We focussed on the 0-30 cm soil layer as this was the deepest that we could consistently sample across sites. In further studies it would be important to core deeper, if possible, to determine the response of deeper soil carbon.
- *Bulk soil vs soil fractions:* We focused on changes in soil C by looking at the overall soil. However, soil C is stored in different fractions (roots, particulate organic matter, mineral-associated organic matter) which have different persistent and resistance to climate change. If the lack of change in soil C is due to a change in the balance of the different fractions.
- *Climate vs. biodiversity crises:* while we focused on the potential of NWR to mitigate climate change, it would be key to determine its parallel potential to mitigate the biodiversity crisis.

Future development: As part of this project, Dr. Alan Law (Uni. Stirling) volunteered to help with the fieldwork. As a freshwater specialist, he took advantage of this field campaign to sample, at each site, the river within the regenerated area, and upstream of the area as a control, to determine changes in water chemistry and invertebrate biodiversity. Additionally, thanks for this funded project, Dr. Law and myself have been able secure additional funding for a fully-funded PhD studentship (IAPETUS DTP) allocated to Kerry Campbell (2023-2027). Following my departure from the Uni. of Stirling to join the INRAE institute in France, Dr. Jens-Arne Subke (Uni. Stirling) is now Kerry Campbell's primary supervisor and I remain involved in this PhD as an external supervisor. In this PhD, Kerry continues the work initiated by this project, by expanding the research to a larger network of sites, and to work on both the response of soil C and soil biodiversity to NWR. This will allow determining how NWR contribute to, or mitigate, the climate crisis and the biodiversity crisis.

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