The impact of mammalian browsers on carbon storage

The following questions were asked during our live webinar on 9 September 2025 with Dr. Duane Peltzer.

1. In the graphs, what is the range for the whiskers? It looks like most, if not all, of those with a positive mean overlap with zero or went negative?

   There are a few graphs with whiskers, but most will be 95% confidence limits (or credible intervals for Bayesian stats), so if these overlap with zero the effect is not 'significant' in a statistical sense.

2. How big an issue, do you think our relatively poor understanding of deep soil carbon dynamics is for drawing conclusions from exclosure trials?

   Soil carbon is a major terrestrial sink, but we have very little data on either shallow (0-30cm depth) or deeper soil C. Most soil C turns over far more slowly that plant biomass, and should be less responsive to animal browsing effects. Measuring deeper soil C is unlikely change our interpretation of exclosure effects at least over a few decades.

3. Is there any thought on long term trends where carbon is stored in dead trees, and these are unlikely to be replaced with another tree due to browse? Thinking of places like North Island Beech forests which are moving towards canopy collapse.

   There's a bit to unpick here, so I'll give three responses; the role of deadwood, tree dieback, and regeneration failure. Dead wood can be a major C stock, but decay rates vary enormously among tree species. For beech, they are on the faster end of the decay spectrum. Why trees dieback is complicated; this can be from pests, diseases, disturbance, or cohort senenesence (trees often recruit or die in similar-aged waves). Last is recruitment failure; if both tree mortality is high and regeneration or recruitment is too low, then we could see a canopy collapse. There are methods for measuring this, like the red listing of ecosystems that define 'collapse'. In some sites there are trends toward lower recruitment or higher mortality, it's possible to have an animal-induced decline.

4. Over time, if seedlings and saplings browsed, while it won't show in effect of Carbon in shorter timeframes, once those adult trees die, there will be far less recruitment and then a potentially quite a large decrease in Carbon. Has anyone done projections of carbon storage based on these longer-term parameters?

   Good question. One way to think of this is about recruitment, growth and mortality of tree species: declines can result from either low recruitment, or increased mortality. There are a few studies looking at how browsers affect these demographic parameters, but little to no work on the long-term carbon consequences (e.g., studies by Hawcroft et al. https://doi.org/10.1016/j.biocon.2024.110637 and Husheer and Tanentzap https://doi.org/10.1111/1365-2664.14544). What we'd expect is that some tree species might decline over the long-term, but other tree species will compensate or take advantage for this decline (see nice review by Coomes et al. 2003 on this, https://doi.org/10.1046/j.1523-1739.2003.15099.x, and Wyse et al.l 2018 review of long-term forest dynamics, https://www.jstor.org/stable/26538101).

5. The change in "big trees" will be slow - they grow slowly. Have you looked at the regeneration of tree seedlings when browsers are removed - that is where the long, long-term changes will come.

   See responses above about effects on tree regeneration. Browsers are rarely 'removed' to zero density, so the impacts of browsers will usually be density-dependent. What this means is for some very palatable species, regeneration could be affected at low animal density whereas higher animal densities could be required to affect regeneration of less palatable/selected species.

6. Are you excluding methane from ungulates in looking at carbon balances of interventions? What about the non-zero methane emissions from possums? With the no difference between ungulate excluded areas and other areas, surely if the grazed areas stop new trees, then after the trees die or are destroyed in a storm event won't the browsing stop new trees replacing the old ones?

   We haven't included methane emissions from animals for any projects we've been involved in. Similarly, we haven't included the carbon/energy costs of doing browsing management itself (e.g., by including the carbon costs of travel, helicopter use etc). A full cost of operations and emissions would be useful for someone to compile.

   The second point about species replacement is mostly covered in previous questions about animal impacts on regeneration or recruitment. The point about disturbance providing a window of opportunity' for animal effects on recruitment is an interesting one for a couple of reasons: First, managing animals post disturbance could be used to prioritise when and where management should be targeted in the future. Second, how much recruitment is needed to

replace canopy species over the long-term? Most seedlings/saplings die or self-thin anyhow even without browsing effects, so what we'd need to work out is how much recruitment is needed to maintain tree species. Wider use of tree demographic models or projections would be helpful here.

7. Rather than measuring Carbon gains, post intervention, could avoided losses of Carbon post intervention instead be quantified?

This is potential quite a complex question, and opens up debates about whether 'avoided losses' should be included in carbon claims or reporting – this is out of my area of expertise! The issue of how carbon (or other outcomes we care about, like biodiversity) is changing under current conditions and management is an area of active interest and research. One helpful approach here is to use counterfactuals, based on narrative, or better, predictive or quantitative models to answer the 'what if' questions. For indigenous forests, monitoring data do not show a progressive loss of C nationally, but there are gains or losses within sites. What all of this highlights is the importance of monitoring or data in place to understand what impacts interventions are having.

8. Enduring Carbon sink = investing in the long term. Current seedlings and saplings are the long term. So, I get the big trees are the Big Carbon-sink. But we are in for the long haul or not at all?

I think this is answered in responses above aside from how long is the 'long haul'!? For carbon, there is no agreed definition of 'permanence', but 50 years is about what we should expect to plan for. However, if we're interested in indigenous forest condition and maintenance, then long-term is at least a century or longer because of the longevity and sporadic recruitment of many indigenous tree species.

9. While the browsers don't affect large established trees, could this change over time if saplings are eaten and the number of large trees reduces, so reducing carbon sequestration?

I think this is covered in responses above.

10. Has there been any research into the short-term increase in carbon released when pests are eradicated/killed through toxins/trapping etc? Would this be taken into consideration when looking at overall numbers for carbon sequestration, or would this be minimal?

    I'm not aware of carbon/energy costs of operations are captured, or compared against carbon changes in forest.

11. Will this system ultimately be completed for the whole the country for regional councils and others to utilise – and to allow them to align their current Singers and Rogers mapping with?

    I think this question was for the previous LINK seminar on ecosystem typologies?

12. Point of interest around the long-term Carbon effect via large trees - Scotland has some interesting cases. Post- wolves disappearing due to hunting -> deer ramping up in numbers, browsing was an issue for saplings ergo large trees down the line. On a tramp there I saw some enclosures with/without deer over a long-time and they looked completely different. Unfortunately, I don't know any names for studies on this after seeing in person, but I would guess this may be similar.

    Interesting. For better or worse the only predators of concern here are hunters, commercial harvesting or control operations! Some of the long-term exclosures or fences are the 'best case' scenario for reducing browsing animals to zero over a few decades, and in many cases, there is absolutely an increase in the number and diversity of seedlings and saplings (see Allen et al. 2023 https://doi.org/10.1002/eap.2836).

13. Is work being undertaken on sterility of invasive species e.g., possums, that will be a mitigation for control and increasing permanent baseline, and in the long term saving funds?

    Great question. This isn't an area of research I know much about, but is a topic worth putting up for a future LINKOnline webinar!

14. Could seedling ratio index and recruitment measurements not be used to at least justify 'security' for sustaining the present carbon storage in the large trees? Still thinking about canopy collapse, just from personal imperial evidence.

I think much of this question is covered above. Canopy collapse or tree dieback is a perennial concern, but whether this is because of higher than expected tree mortality rates, animal or disturbance impacts, or cohort senescence (i.e., an even-aged wave of old trees dying) is not usually determined. A related question is whether there are sufficient seedlings or recruitment to replace canopy tree species; this is where measures like seedling ratio index could be used, in combination with tree longevity and mortality, to indicate regeneration success or failure. Briefly, we'd need to know how many seedlings are needed to maintain canopy species.

15. I would also be interested in the impacts of carbon sequestration via browsing of undergrowth... are fungi etc impacted and how do they knock on to e.g., tree decay etc.

Because most C is in large trees, undergrowth browsing doesn't lower total ecosystem C over several decades (but see responses to regeneration and long-term forest responses above). However, understorey biodiversity and ecological functions can be changed by browsing. For example, one of the biggest effects of excluding (fencing) ungulates is declines in large-bodied invertebrates and the litter layer with trampling.

16. The case for managing browsers for C outcomes in the short term may be weak, but what about in the long term? Given the present impact of deer in our forests, in the longer term this is likely to lead to forest collapse, and we will loose a lot of carbon then (when all the big trees die and no new ones are recruited).

I think this is covered in responses above.

17. Would you think that if there was browse of palatable species (and hence the understory was dominated/replaced by avoided species) that the C would balance out?

That appears to be the case from forest monitoring data. What this means is we'd expect species that aren't damaged by browsers to increase in abundance, or compensate for declines in palatable species.