Accounting for landscape heterogeneity in eddy covariance fluxes and effects on carbon budgets when scaling

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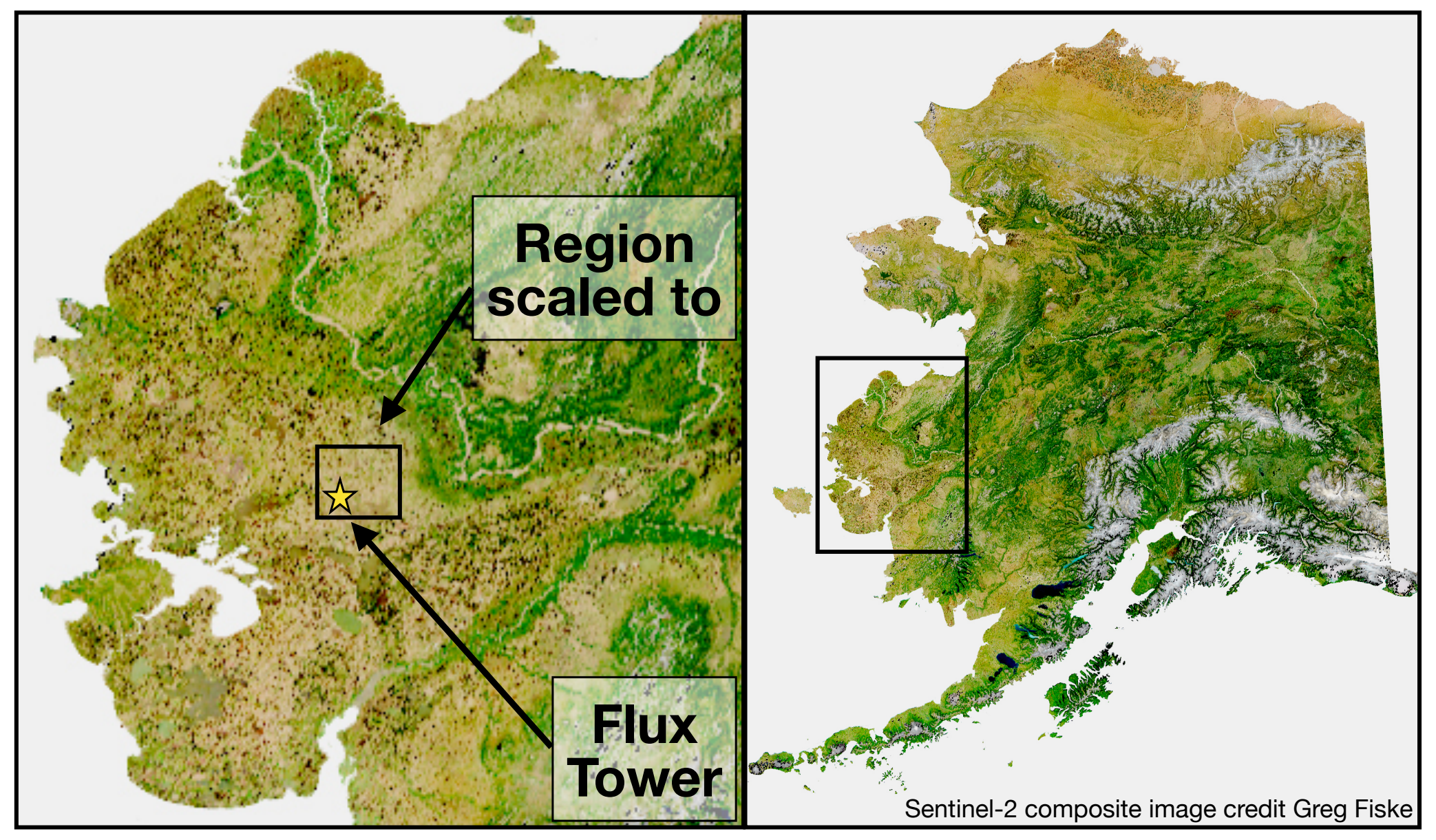
The Problem

1. Tundra landscapes are extremely heterogeneous.
2. The landscape eddy covariance towers 'see' is variable: footprints change with wind direction, speed, atmospheric stability.
3. When we use eddy covariance fluxes to scale up or benchmark models, we assume the landscape is homogeneous.

Research Questions

1. How does assuming a homogeneous landscape (vs. accounting for heterogeneity) affect carbon budgets when scaling up eddy covariance fluxes?
2. How does the scale of landscape heterogeneity that we consider affect carbon budget estimates and uncertainties?
3. How does our choice of footprint model affect carbon budget estimates and uncertainties?



Sentinel-2 composite image credit Greg Fiske

Methods

- Half-hourly eddy covariance fluxes of CO_2 from July 2019 - April 2021, data processed using EddyPro.
- 2D analytical footprint models calculated for each flux observation using Hsieh et al. 2000/Detto et al. 2006, Kormann & Meixner et al. 2001, and Kljun et al. 2015.
- Landcover map from Ludwig et al. 2022 (5x10 m resolution).
- Net ecosystem exchange (NEE) was modeled using eq 1-3, where each landcover type was allowed to find its own set of parameters.
- Surface waters were modeled as a constant but unknown CO_2 flux.
- Tower CO_2 flux observations are the linear combination of each landcover NEE flux weighted by its influence in the footprint.
- Prior information was vague to enforce physically realistic bounds (e.g. non-negative Q_{10}).
- Parameters were solved for using Bayesian MCMC (RJAGS). Model fit was assessed using Bayesian p-values and WAIC.

Eq 1) $$NEE = ER - GPP$$

Eq 2) $$ER = R_0 * e^{\beta T}$$

Eq 3) $$GPP = T_{scale} * \left(\frac{P_{max} * E_0 * I}{P_{max} + E_0 * I} \right)$$

References

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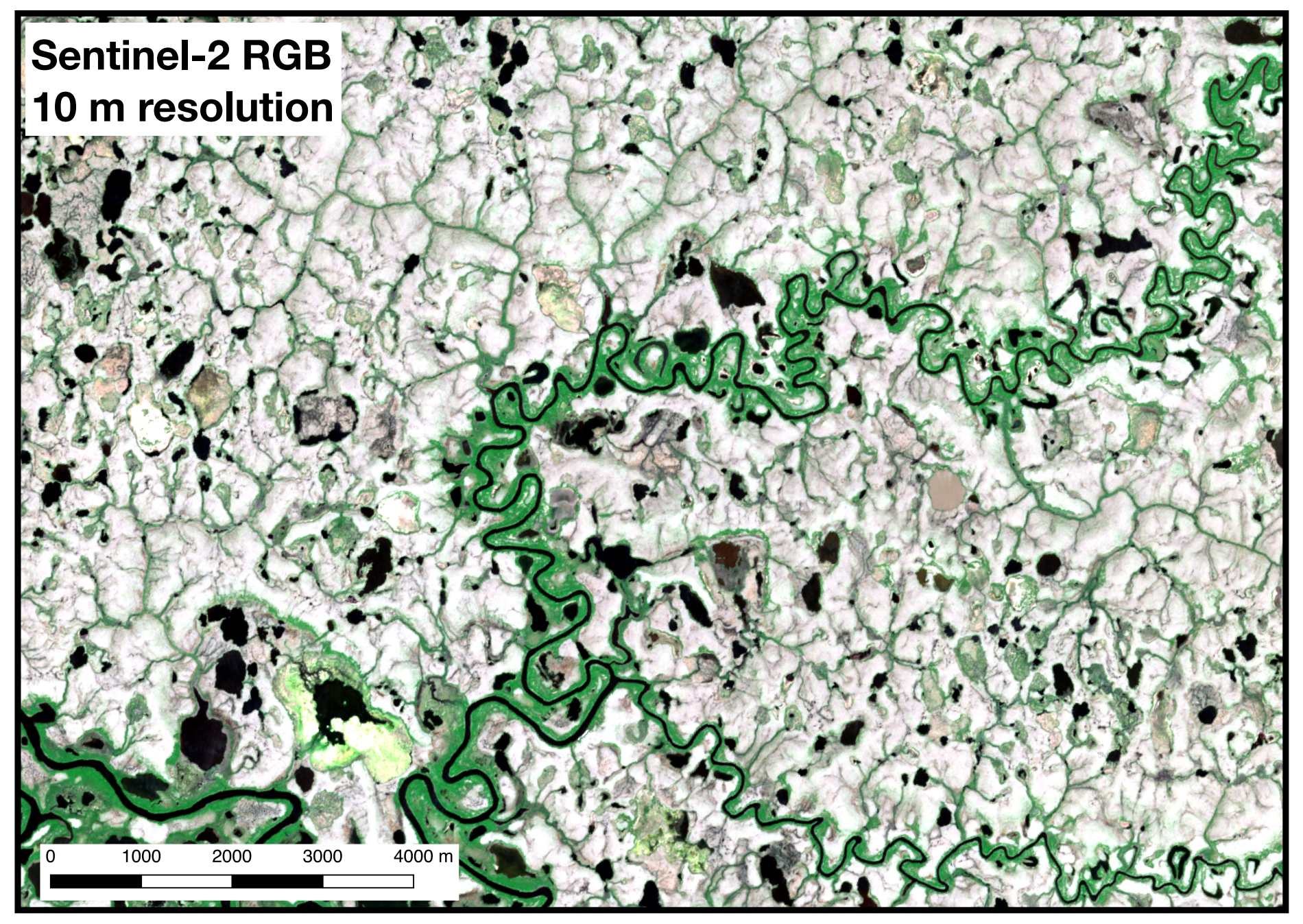
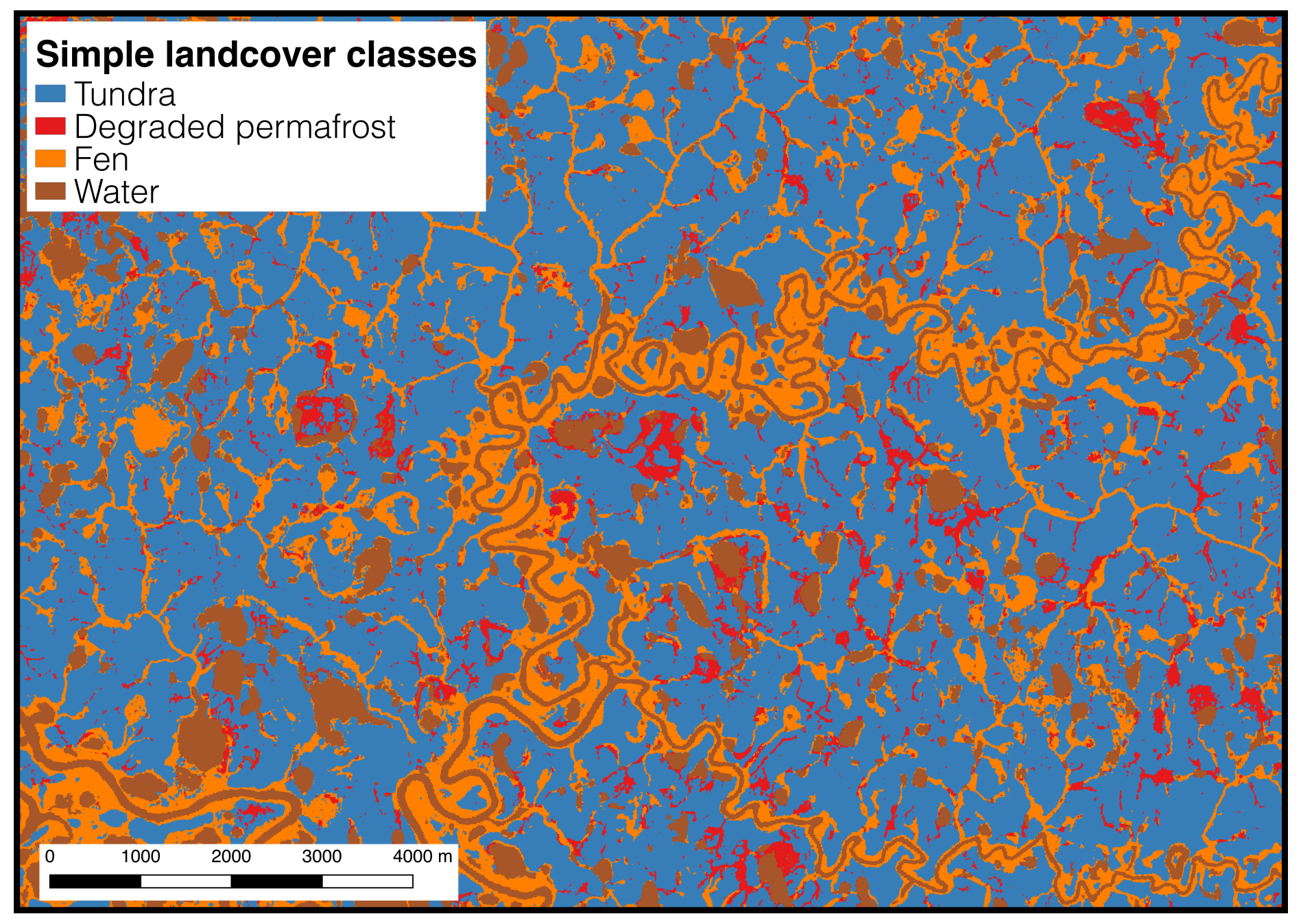
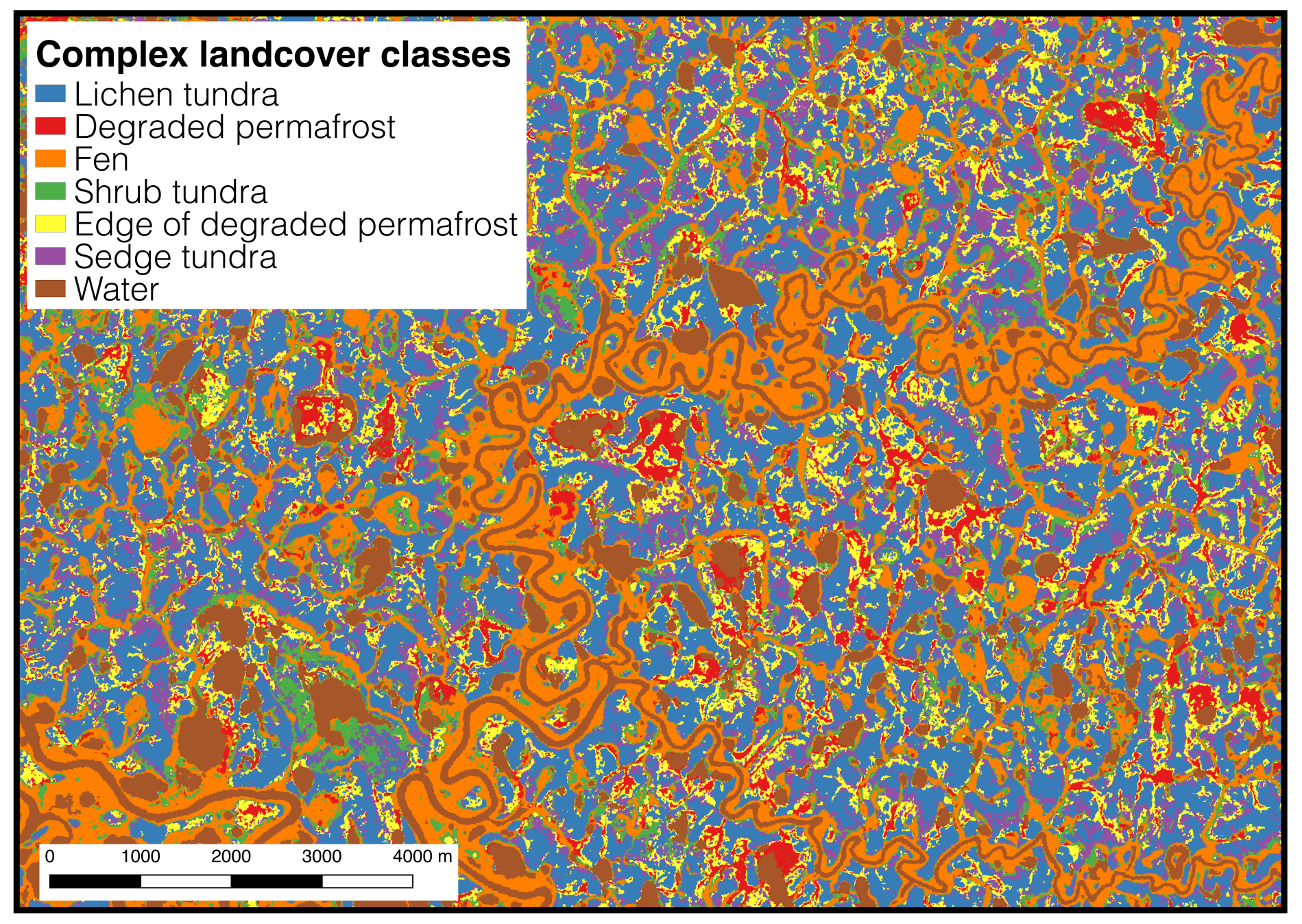
Carbon flux scaling levels of comparison:

1. **Three model choices for analytical footprint influence:** Hsieh et al. 2000/Detto et al. 2006, Kormann & Meixner 2001, & Kljun et al. 2015.
2. **Three levels of landscape heterogeneity:**
    1. None: assuming a homogenous landscape (i.e. traditional NEE-partitioning and gap-filling)
    2. Simple: four landcover types: tundra, fen, water, degraded permafrost.
    3. Complex: tundra further split into four types: lichen, shrub, sedge, and edge of degrading permafrost.







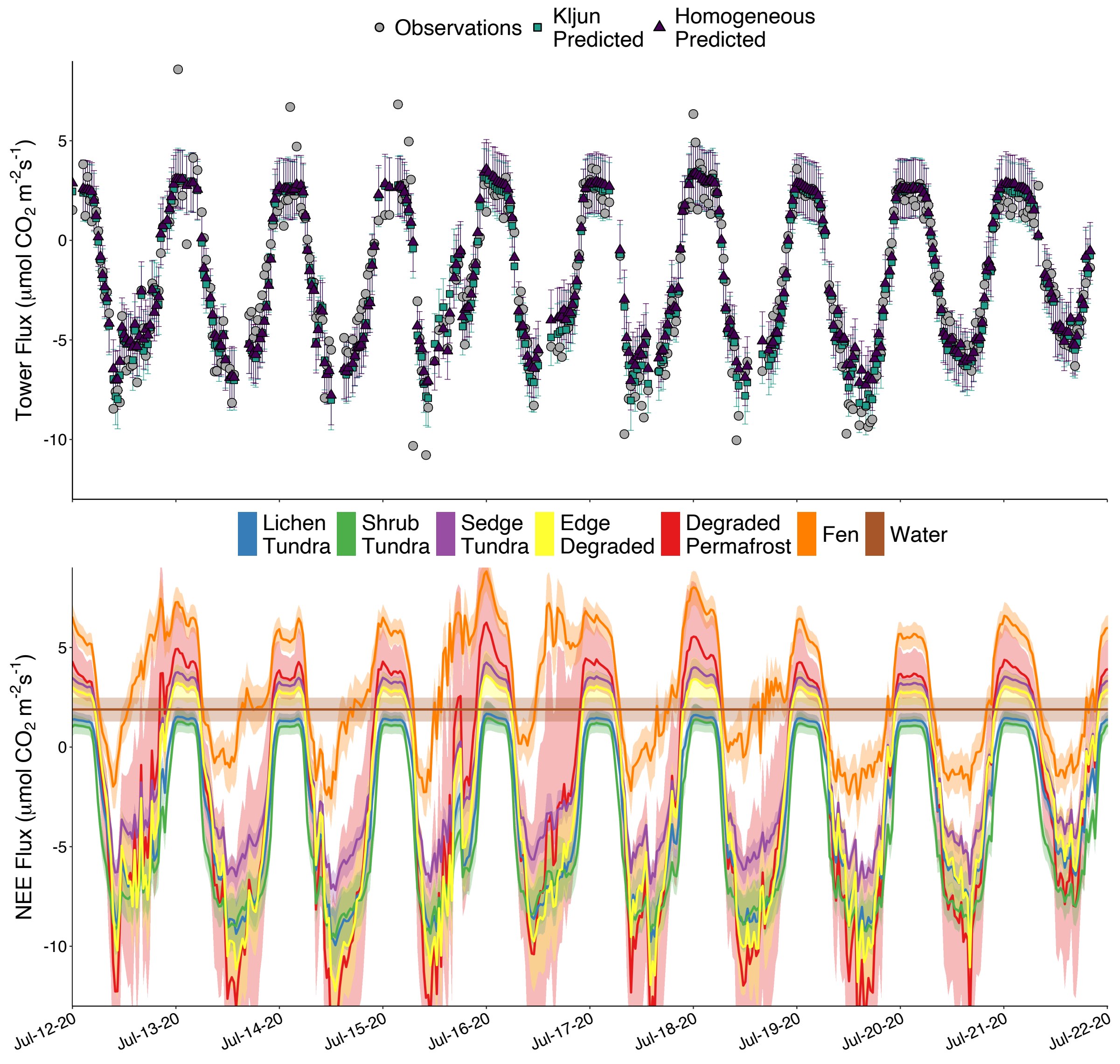


Fig 1. Top: Tower CO_2 fluxes observed, predicted using Kljun et al. 2015 footprints, and predicted using traditional approach assuming homogeneity. Bottom: derived NEE fluxes from landscape that comprise the Kljun predicted fluxes in top panel. Predictions fit using July data. Error-bars and shading indicate 25-75% percentile range.

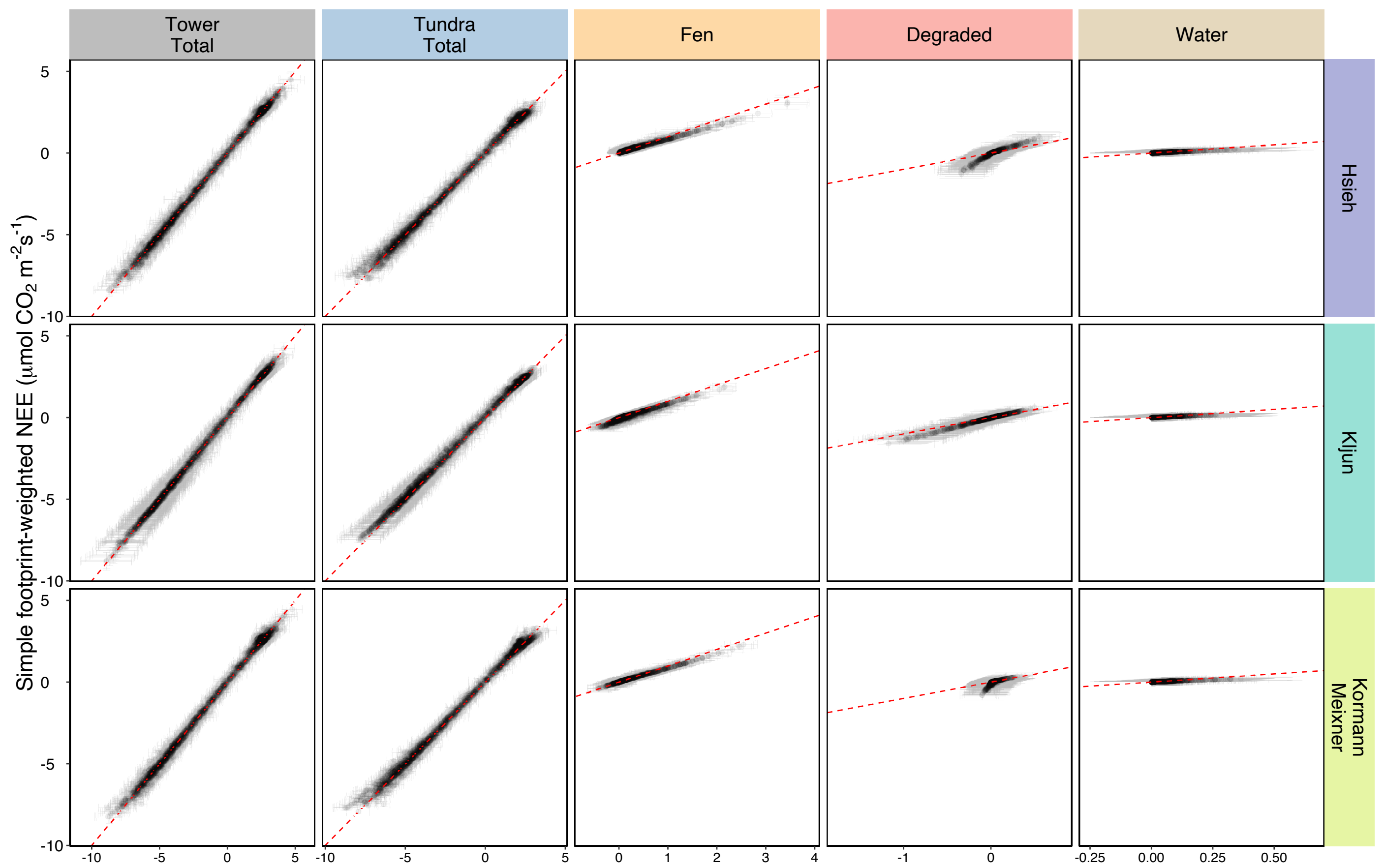


Fig 2. NEE time-series for July model results, weighted by footprint to be comparable between footprint models and landcover maps. Fluxes near one-to-one line (red-dashed) indicate agreement between landcover maps.

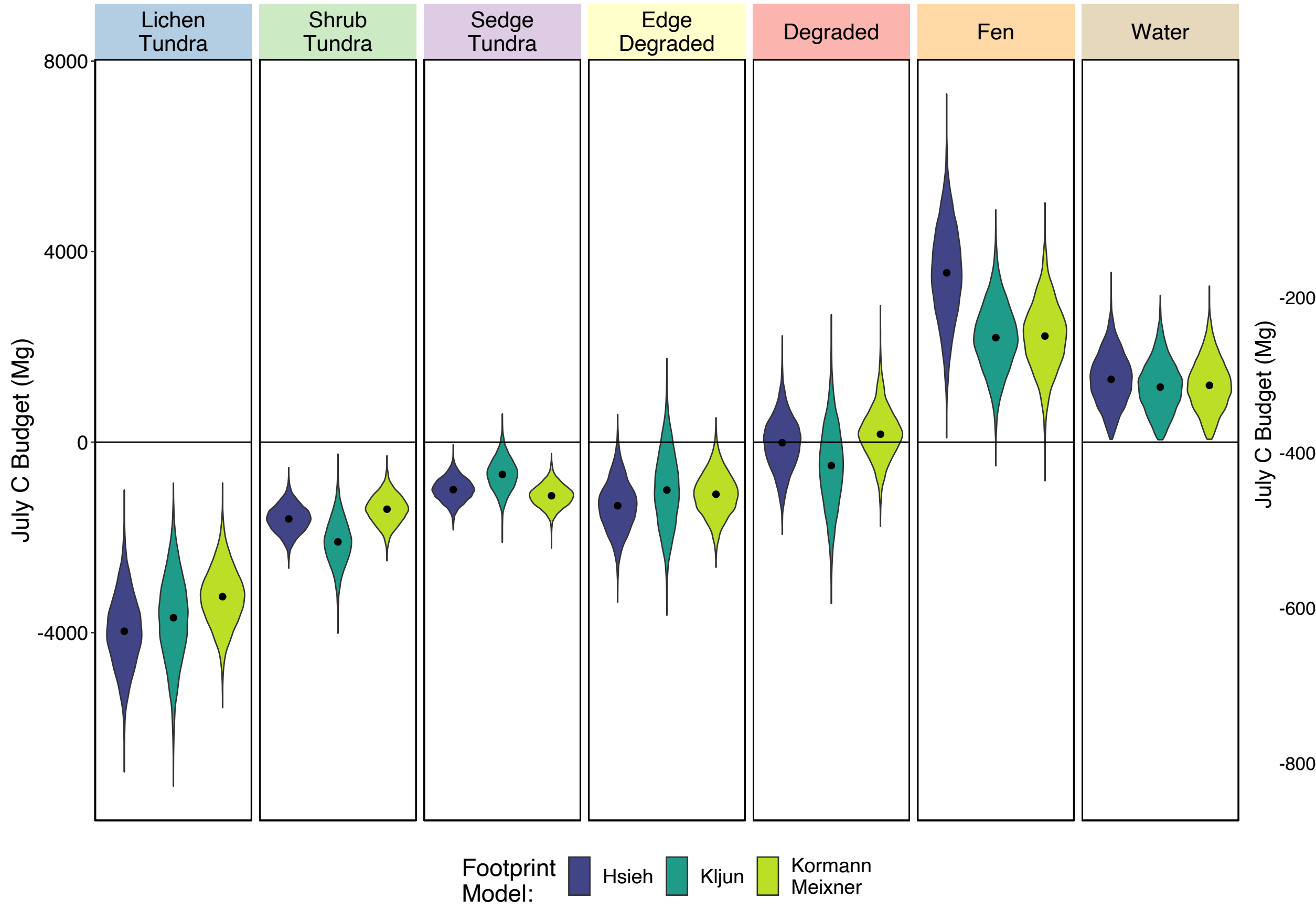


Fig 3. July carbon budgets for landcover types in the complex map, when scaled up to the region above. There is little difference between footprint models.

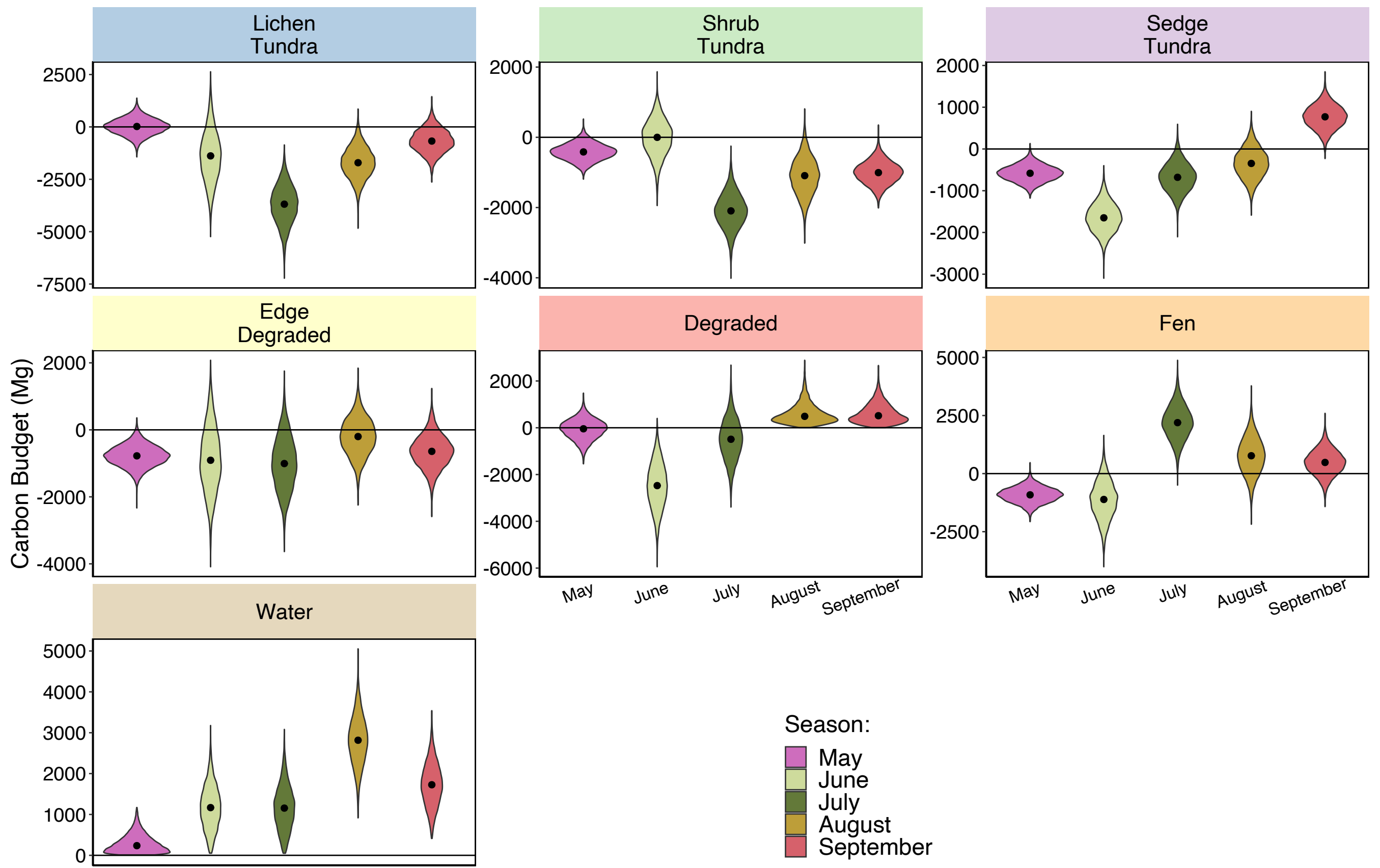


Fig 4. Monthly carbon budgets when scaling up with the complex landcover map using the Kljun et al. 2015 footprints. NEE parameters for each month of data were fit independently. Results demonstrate clear seasonality, with peak carbon uptake in June or July.

Key points

- **Assuming a homogenous landscape overestimates the carbon sink compared to any method of accounting for landscape heterogeneity.**
- Deriving landcover specific fluxes from eddy covariance towers provides insight about ecosystem carbon cycles, e.g. seasonality, temperature sensitivity.
- This method carries through uncertainty in partitioning and gap-filling eddy covariance fluxes to carbon budgets.
- No significant difference in carbon budgets between simple and complex landcover maps, though greater uncertainty from estimating more parameters using complex map.
- General agreement between the three analytical footprint models, though Kljun et al. 2015 was most consistent.

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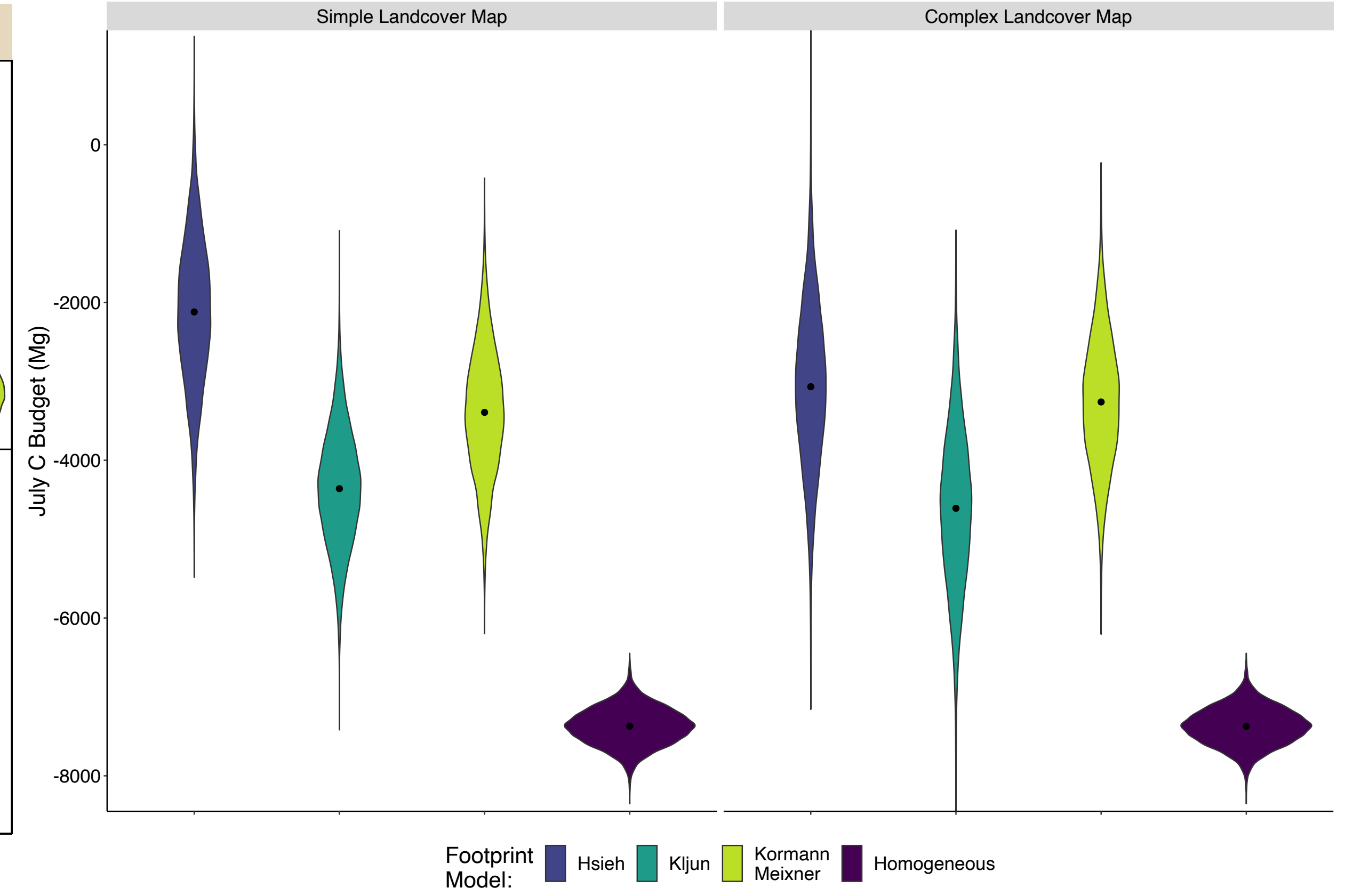

Fig 5. Total July carbon budgets from scaling using both simple and complex landcover maps, all three types of footprints, and traditional partitioning and gap-filling assuming homogeneous landscape. Complex heterogeneity led to greater uncertainty. Assuming homogeneous overestimated the carbon sink.

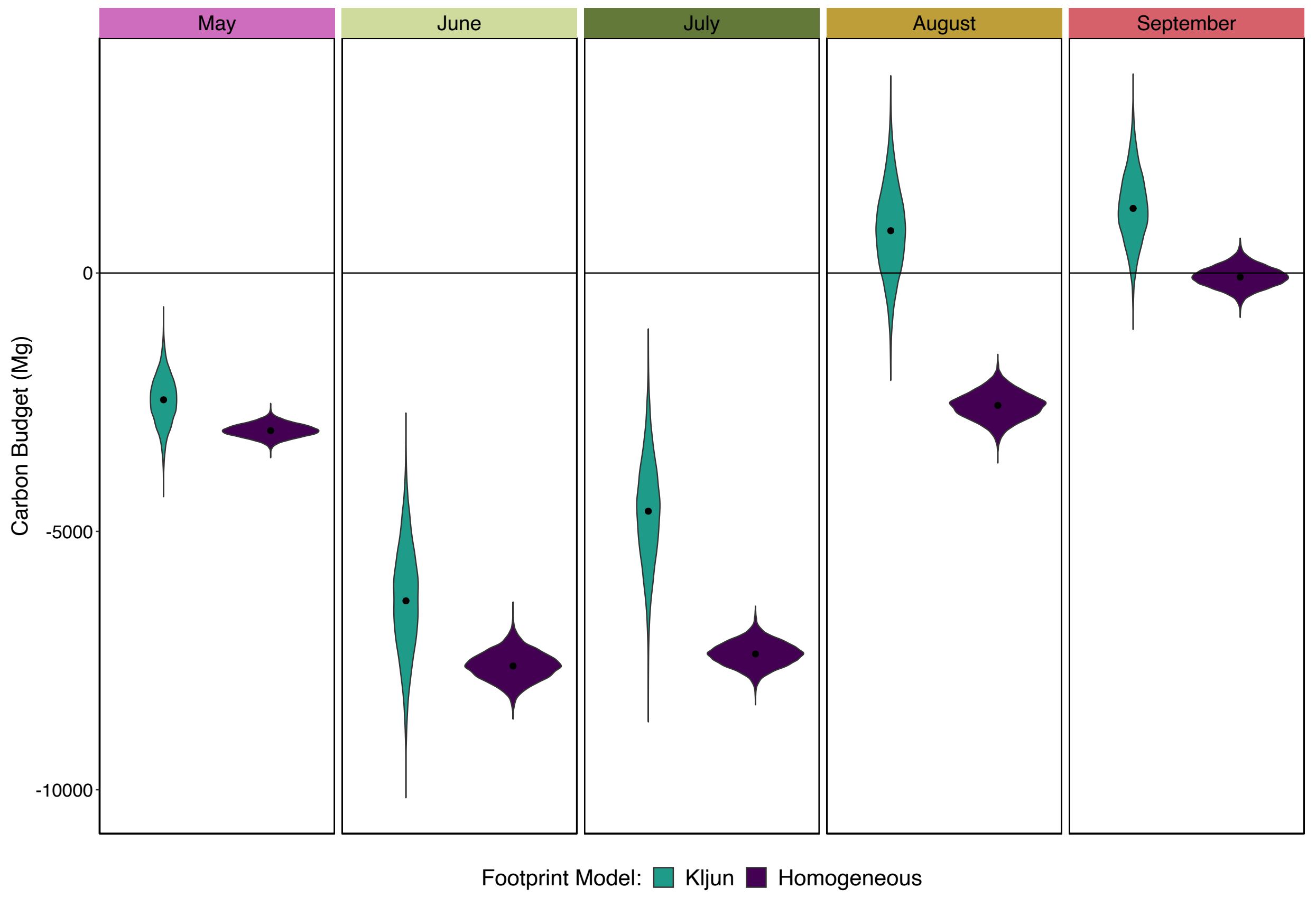

Fig 6. Monthly total carbon budgets from scaling using the complex landcover map and Kljun et al. 2015 footprints, compared to partitioning and gap-filling assuming a homogeneous landscape. Incorrectly assuming homogeneity consistently overestimated the carbon sink.