Carbon stocks and fluxes in New Zealand Myrtaceae

Prepared for: Ngā Rākau Taketake, Biological Heritage National Science Challenge

December 2021

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Contract Report: LC5003

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Manaaki Whenua – Landcare Research

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Abstract

To help understand the potential impacts of myrtle rust on the integrity of natural forest ecosystems in New Zealand we conducted an analytical stocktake of the contribution of Myrtaceae to national forest biomass stocks and fluxes. Our assessment was based on two measurement cycles (2002–2007 and 2009–2014) using the network of LUCAS (Land Use Carbon Analysis System) forest plots, a representative sample of pre-1990 natural forests.

Starting from standardised tree measurements within plots and published allometric functions, we estimated total live carbon stocks (above- and below-ground and over the mapped area of natural forests) for Myrtaceae and non-Myrtaceae families. Carbon fluxes were partitioned as component fluxes of productivity (recruitment and growth), mortality losses, and net overall changes (balances of productivity and losses). Fluxes in total live carbon were assessed as a function of standing stocks for each of the main Myrtaceae tribes (Leptospermeae, Metrosidereae, Myrteae) and for a reference group of all non-Myrtaceae taxa combined.

Overall, the Myrtaceae ranked fourth most dominant family, with 138.91 Mt (95% CI 110.30–185.44 Mt; 9.7% of total stocks) of live above- and below-ground carbon, which was nearly equal to the amount of carbon stored by Podocarpaceae. In terms of family totals, Metrosidereae, Leptospermeae and Myrteae accounted for 70.9%, 28.5%, and 0.4% of the family stock, respectively. The main stocks in Metrosidereae were *Metrosideros umbellata* and *M. robusta*, with other *Metrosideros* species contributing far less.

Broad assessment of carbon fluxes showed that Leptospermeae had a moderate rate of net carbon sequestration (0.153 t·C·ha^{-1}·y^{-1}), with losses to mortality not fully counterbalancing the productivity gains from growth and recruitment. A reverse trend was found for Metrosidereae, which had a net loss of live carbon into deadwood (-0.308 t·C·ha^{-1}·y^{-1}) due to carbon losses to mortality not being replaced by productivity gains. Myrteae were quite stationary, with very low rates of carbon productivity, carbon loss and, as a result, near zero net changes.

Assessment of component fluxes as a function of standing stocks indicated a clear increase in productivity, with larger stocks for Leptospermeae reaching a mean of c. 1.55 t·C·ha^{-1}·y^{-1} at 100 t·C·ha^{-1}. Both Myrteae and Metrosidereae were, on average, notably stationary in terms of productivity, with near-zero stand-level rates of change. The combination of carbon productivity and loss resulted in near-zero net carbon changes for all Myrtaceae tribes in most contexts. Surprisingly, the carbon productivity trends observed for Leptospermeae were mostly cancelled out by corresponding carbon losses, with near-zero net gains in live carbon for this group. Net carbon changes for the combined non-Myrtaceae taxa were generally positive up to a certain reference stock value, resulting in net carbon sequestration to wood in low-to-mid carbon stock contexts. We conclude with an initial discussion on the primary results above.

1   Introduction

As one of the major plant families in New Zealand the Myrtaceae span the entire latitudinal range, from shoreline to alpine, and from the wettest to the driest regions (McCarthy et al. 2021). Several species account for some of the largest biomass stores both nationally (Peltzer & Payton 2006) and in specific locations (cf. Mason et al. 2013; Holdaway et al. 2017). New Zealand's Myrtaceae also encompass a variety of ecologies, ranging from early-successional to old-growth forest species, and from light-demanding to shade-tolerant species. As well as free-standing trees and shrubs, the family includes climbers and a stranglers.

Four botanical tribes are represented – the Leptospermeae, Metrosidereae, Myrteae, and Syzygieae – and these tend to correspond to different ecologies. The first three are the most common in New Zealand, comprising:

- shorter-statured pioneer trees that can be distinctly early successional in a wide variety of conditions (*Leptospermum* and *Kunzea*, Leptospermeae) or characteristic of extreme environments
- a group of tall canopy trees and climbers with some capacity for epiphytic recruitment (*Metrosideros*, Metrosidereae)
- short, shade-tolerant understorey trees associated with old-growth forest (*Lophomyrtus* and *Neomyrtus*, Myrteae).

The final tribe, Syzygieae, comprises one tree species (*Syzygium maire*) that inhabits waterlogged soils and streamside margins.

Some Myrtaceae species can form pure stands (*Leptospermum, Kunzea, Metrosideros excelsa, M. kermadecensis*, sometimes *M. umbellata*), while others more commonly occur in mixed forest communities (Wiser et al. 2011). The population dynamics of these groups is presumed to vary widely, with natural disturbance driving dynamics in many species, and invasive herbivores having novel interacting pressures for some species (Bellingham & Lee 2006). The specific features, however, are incompletely known.

Concern has arisen from the recent arrival to New Zealand of *Austropuccinia psidii*, a Myrtaceae-specific pathogen causing myrtle rust, after significant tree mortality losses to the disease reported for Australia (Carnegie et al. 2016). Invasive pests and pathogens can have major effects on forest structure and function, with reduction or loss of tree species in other forest ecosystems having resulted in significant impacts on fluxes of energy and nutrients (Ellison et al. 2005).

Understanding the potential impacts of myrtle rust on the integrity of natural forest ecosystems thus hinges on understanding the contribution of the Myrtaceae to the structure and dynamics of natural forests. Comprehensive assessments of tree-mediated contribution to wood production in the context of changing climates (Coomes et al. 2014) and stand-level forest biomass stock and growth (Holdaway et al. 2017) provide valuable initial background. However, understanding the specific role of Myrtaceae requires a new assessment, which we undertake here. To this end we provide an analytical stocktake of Myrtaceae's contribution to national forest biomass stocks and fluxes.

2   Objectives

We estimated and synthesised the contribution of Myrtaceae trees to carbon stocks and fluxes in New Zealand forests, collectively and by sub-taxa, and with reference to other coexisting tree taxa. Specifically, we addressed the following questions:

1   How large are the Myrtaceae carbon stocks in New Zealand indigenous forests?

2   How are those stocks partitioned across the main forest types?

3   What is the net carbon productivity of the Myrtaceae, and how does it vary among Myrtaceae tribes and according to compositional context?

4   How dynamic are the component fluxes (mortality versus growth and recruitment) underlying net carbon productivity?

In addressing the above questions, the project attempted to improve our understanding of the role of Myrtaceae trees for carbon dynamics in New Zealand forests.

3   Methods

Our assessment is based on the national network of LUCAS forest plots, which systematically sample the natural forests of New Zealand at intersections of an 8 km grid overlay (Holdaway et al. 2014b; Holdaway et al. 2017). We present results for 874 remeasured plots that sample areas mapped as natural forest pre-1990, with two measurement cycles carried out in 2002–2007 and 2009–2014. This set represents 72% of 1,215 potential grid intersections sampling the universe of mapped pre-1990 natural forests and shrublands. Access prohibitions, safety considerations, and adjustments to the area sampled meant that not all grid points were originally visited or revisited. Plots have been systematically measured following standard protocols (Payton et al. 2004) and the resulting digitised dataset has subsequently undergone extensive data checks following a series of automated and manual routines (Holdaway et al. 2014a).

Sample plots monitor all individual self-supporting stems ≥ 2.5 cm diameter at breast height (DBH). Neither saplings (stems > 1.3 m height and < 2.5 cm DBH) nor lianas or climbers (including Myrtaceae climbers) are captured in our assessment. Sapling pools make only a small contribution to total carbon stocks relative to trees (Holdaway, Easdale, Mason et al. 2014; Holdaway et al. 2017), and climbers are also likely to account for only a small fraction relative to trees, although it is unknown how this fraction compares to that of saplings.

Furthermore, a small subset of plots established on early successional shrublands were measured using methods that trace the crown volume of shrubs and tree saplings instead of individual stems (mostly stems <2.5 cm DBH). These measurements were excluded from calculations because they mostly correspond to small stems, and species identities were not determined where individuals were tightly clumped. Deadwood, litter, and soil carbon are also excluded from reported values (litter and soil carbon, in particular, not being feasible to associate with a specific taxon). Because the revision of the taxonomy of kānuka

that split *Kunzea ericoides* into nine species (de Lange 2014) post-dates the data used here, we were unable to distinguish these newly recognised species in our analysis. We therefore consider *Kunzea ericoides sensu lato* in all calculations.

3.1 Data checks and edits

To consolidate the carbon flux analyses we ran additional stem-level data checks for large tree recruits, unmatched stem tags, and anomalous heights (Appendix A). Any inconsistencies that could be clearly resolved from inspection of the original datasheets were corrected in the data. Some remaining inconsistencies that could not be resolved from the data checks were handled by analytical decisions; as noted below, these were limited to unrealistically large recruits and anomalous height growth. Further to the individual stem-level data checks, we inspected the records for plots with extreme (positive or negative) carbon or carbon change estimates. Those checks were mainly focused on influential large trees.

3.2 Carbon stocks

We started by estimating carbon stocks for the 2009–2014 period using published allometric functions. For individual trees, above-ground carbon was estimated as a function of stem diameter, tree height, and species stem specific density (i.e. wood density), assuming that 50% of biomass is carbon (Beets et al. 2012). Where not measured directly, individual tree heights were estimated based on species-specific allometric functions, in turn based on stem diameter and plot elevation (Holdaway et al. 2014c). Stem-specific density values were taken from an updated database that incorporates recent measurements across a range of taxa, including Myrtaceae species, and compiled records, which provided estimates for 133 out of 223 recorded species (Appendix B). For tree ferns, separate functions were used to predict carbon from stem diameter, height, and stem-specific density (Beets et al. 2012). Below-ground carbon for individual trees was estimated from above-ground carbon and updated taxon-specific root:shoot ratios for dicot trees, podocarps, tree ferns, and the monocot *Cordyline* (Easdale et al. 2019). Root fractions for nīkau palm (*Rhopalostylis sapida*) were inferred from values reported for other palm species (Ledo et al. 2018).

Live total (above- and below-ground) carbon stocks ($t·C·ha^{-1}$) of each plot were calculated by summing the carbon stocks of live trees and tree-ferns and dividing by plot area. Estimates were slope-corrected using horizontal projections of the area of the plot. Taking the 874 plots as a representative sample of natural forests, national carbon stocks were then calculated by scaling up the plot-level estimates to total natural forest cover using remote sensing estimates of pre-1990 natural forest cover (i.e. land area covered by indigenous forest on or before December 1989). This area was estimated from the LUCAS land-use map at 7,813,375 ha for December 2012 (Ministry for the Environment 2019), which aligns with the second measurement cycle, and relates to areas classified as natural forest cover at 1990, revised by any classification improvements from image resolution and any deforestation that had occurred by 2012. Land-use maps were based on a semi-automated classification process of Landsat and SPOT satellite images, complemented by ancillary data sources (e.g. Land Cover databases 1 and 2, Thompson et al. 2004; New

Zealand Land Resource Inventory, Eyles 1977), and verification procedures with aerial photography (Ministry for the Environment 2019). All remeasured plots sampling pre-1990 natural forest, including plots measured with shrub methods, were included in calculations.

We also assessed the distribution of estimated carbon stocks by forest type. To this end, we relied on forest type definitions given by EcoSat, a digital map of indigenous forest classes in New Zealand (Shepherd et al. 2005). Sampling uncertainty associated with reported carbon values was estimated by bootstrapping with the *boot* package and function (Canty and Ripley 2021) in R 4.1.1 (R Core Team 2021). However, reported uncertainties do not incorporate measurement or modelling error (Holdaway et al. 2014c).

3.3 Carbon fluxes

We analysed live wood carbon fluxes for each of the three main Myrtaceae tribes (Leptospermeae, Metrosidereae, and Myrteae) and for a reference set of all other tree taxa combined between the 2002–2007 and 2009–2014 measurement cycles. Syzygieae was not analysed due to insufficient representation for statistical assessment, with only one New Zealand native member of the tribe, *Syzygium maire*, captured in only one of the 874 remeasured plots. Component fluxes were partitioned into:

- annualised gains attributed to growth of live stems and recruitment of new stems (productivity)
- annualised losses resulting from tree mortality
- the combined net outcome from both (net carbon change; e.g. Rutishauser et al. 2020).

Positive values for net change equate to net sequestration of carbon into live wood; negative values equate to net carbon loss from live wood into dead wood. Carbon fluxes were expected to vary as a function of standing biomass and the size of component trees (coarse correlates of the biomass of assimilating tissues and the biomass exposed to physiological- or disturbance-related mortality). Thus, we related all carbon fluxes to the corresponding live carbon stocks for each taxon category.

All assessments were at stand level, with underlying data points corresponding to the sum of all individuals of a taxon within a plot, and with each plot encompassing between one and four data points depending on the number of Myrtaceae tribes present. To account for uncontrolled environmental, successional, and some compositional context, relationships were assessed separately for sets of plots with the same combination of co-occurring tribes based on the presence of tribes on plots (e.g. Leptospermeae and Metrosidereae were jointly assessed only where they co-occurred). Relationships were fitted with generalised additive models (GAMs) because they can flexibly accommodate complex non-linear relationships by fitting smoothing splines on any modelled covariates. Fitted relationships represent space-for-time substitutions, which means fitted curves may not reflect the true developmental trajectories of individual stands.

3.4 Analytical decisions

The recruitment of large individuals is unlikely and can considerably overestimate productivity in a plot if not accounted for. For putative large recruits ≥15 cm DBH that could not be resolved through checks of the underlying data, we assumed the stem was either present and missed at first measurement or that it was located along the plot boundary and was determined to be outside the plot at first measurement and then incorrectly determined to be inside the plot at remeasurement. In both instances our assumption equates to nil productivity from those stems.

Tree heights influence carbon change estimates. Following previous criteria (Holdaway et al. 2014b), and given that measured heights are generally expected to be more accurate than modelled heights, carbon estimates relied on measured heights where they were available for both measurement periods. Where only one height measurement was available, the combination of measured and modelled heights has been observed to lead to inconsistencies (e.g. for stems with broken tops; Holdaway et al. 2014b), in which cases we used modelled tree heights for both measurements.

Stem lean angles can have a major influence on estimated tree height. For leaning trees we:

- discarded any height measurements made from a position that aligned with the direction of lean (174 stems), as these measurements are prone to measurement error (Payton et al. 2004)
- discarded height measurements for stems where lean angle was more than 20° lower at remeasurement than at first measurement (seven stems)
- assumed the same lean angle for stems with two height measurements but a lean angle recorded only once (1,441 tree stems with missing first lean angle, 82 with missing second lean angle)
- discarded lean-adjusted heights for stems with lean angles of 20–26° and lean-adjusted heights of 46 to 77 m (seven stems).

We also discarded height measurements for 20–40 m tall tree stems with anomalous height growth of >2 m per year (six stems). These discarded tree heights were replaced by modelled tree heights.

After tree-level checks we checked the records for plots with extreme carbon change and removed one outlier plot with an unfeasibly high carbon change value that could not be resolved. Further, four influential 'tail' data points with disparately high or low carbon stocks were removed from the 2,324 data point set. Three of these points had disparately high carbon stocks (945 to 985 t·C·ha^{-1}) and one a single low carbon stock within the group sample (i.e. the combination of co-occurring tribes). These 'tail' values are feasible but their exclusion avoids undue influence of a few points for conditions (stocks) with low 'replication' (cf. Rutishauer et al. 2020).

We note that some negative stand growth is possible because productivity losses may be attributed to partial stem mortality (e.g. snapped or rotting stems). Negative stand growth can also result from measurement error (e.g. stems subsequently measured over and

under climbers, changing line of sight for height measurements, etc.), but we assume this tends to be counterbalanced by 'positive' measurement error. Any data points indicating negative stand productivity were thus retained for analysis.

4   Results

4.1   Carbon stocks

The total stocks of live above-ground carbon in New Zealand natural forests are estimated as 1,433.28 Mt (95% CI 1,367.15–1,508.50 Mt). Carbon tallies, which incorporate both the distribution of carbon stocks per unit area for each taxa and the spatial extent covered by forests, span almost six orders of magnitude from the most to the least dominant plant family (Figure 1). The Myrtaceae ranked as the fourth most dominant family with 138.91 Mt (95% CI 110.30–185.44 Mt; 9.7% of total stocks) of live above- and below-ground carbon. This amounts to about one-fifth of the carbon stored by Nothofagaceae, the most dominant family, and nearly the same amount as stored by Podocarpaceae. Carbon stocks decrease broadly in exponential form from most to least dominant woody plant family (Figure 1) and Myrtaceae makes up 48.3% of the collective carbon accumulated by the 51 families ranked below it (Lauraceae to Argophyllaceae).
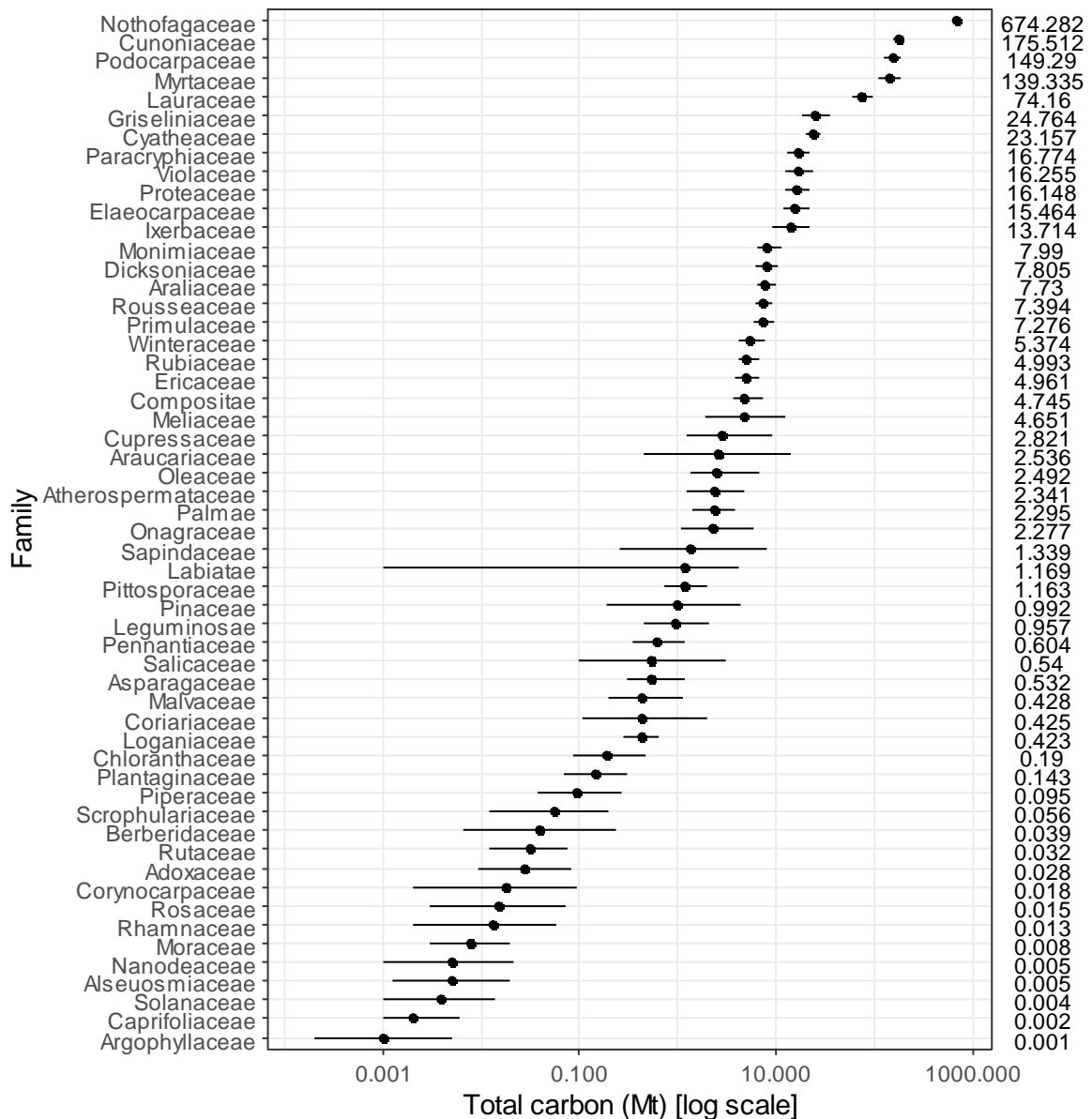
Figure 1. Total live above- and below-ground carbon within New Zealand natural forests for 55 woody plant families, as estimated from the 2009–2014 LUCAS measurement cycle. Carbon estimates are presented in megatonnes (Mt) with their respective 95% confidence intervals. Values on the right margin are mean estimates. Note the logarithmic scale on the x-axis.

Within the Myrtaceae, carbon stocks differ by half an order of magnitude between the Metrosidereae and Leptospermeae tribes, and by two orders of magnitude between Leptospermeae and Myrteae (Figure 2). If considered in the context of the family totals, Metrosidereae, Leptospermeae, and Myrteae account for 70.9%, 28.5%, and 0.4% of the family stock, respectively. For Myrtaceae species, carbon stocks decrease more or less exponentially from the most to least dominant species, with a five-order-of-magnitude difference in stocks (Figure 3). The stocks in Metrosidereae are mainly provided by *Metrosideros umbellata* and *M. robusta*, with other *Metrosideros* species contributing far less. Species in Leptospermeae, *Kunzea ericoides sensu lato*, and *Leptospermum scoparium* have relatively high stocks nationally (Figure 3).
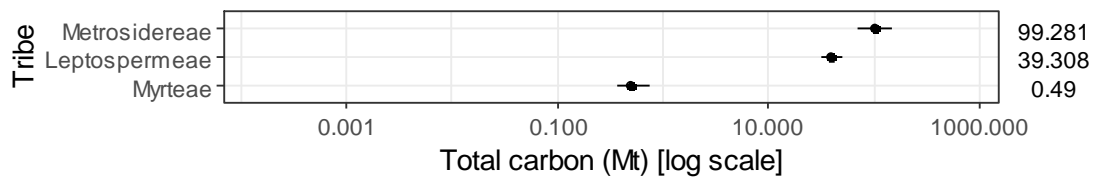
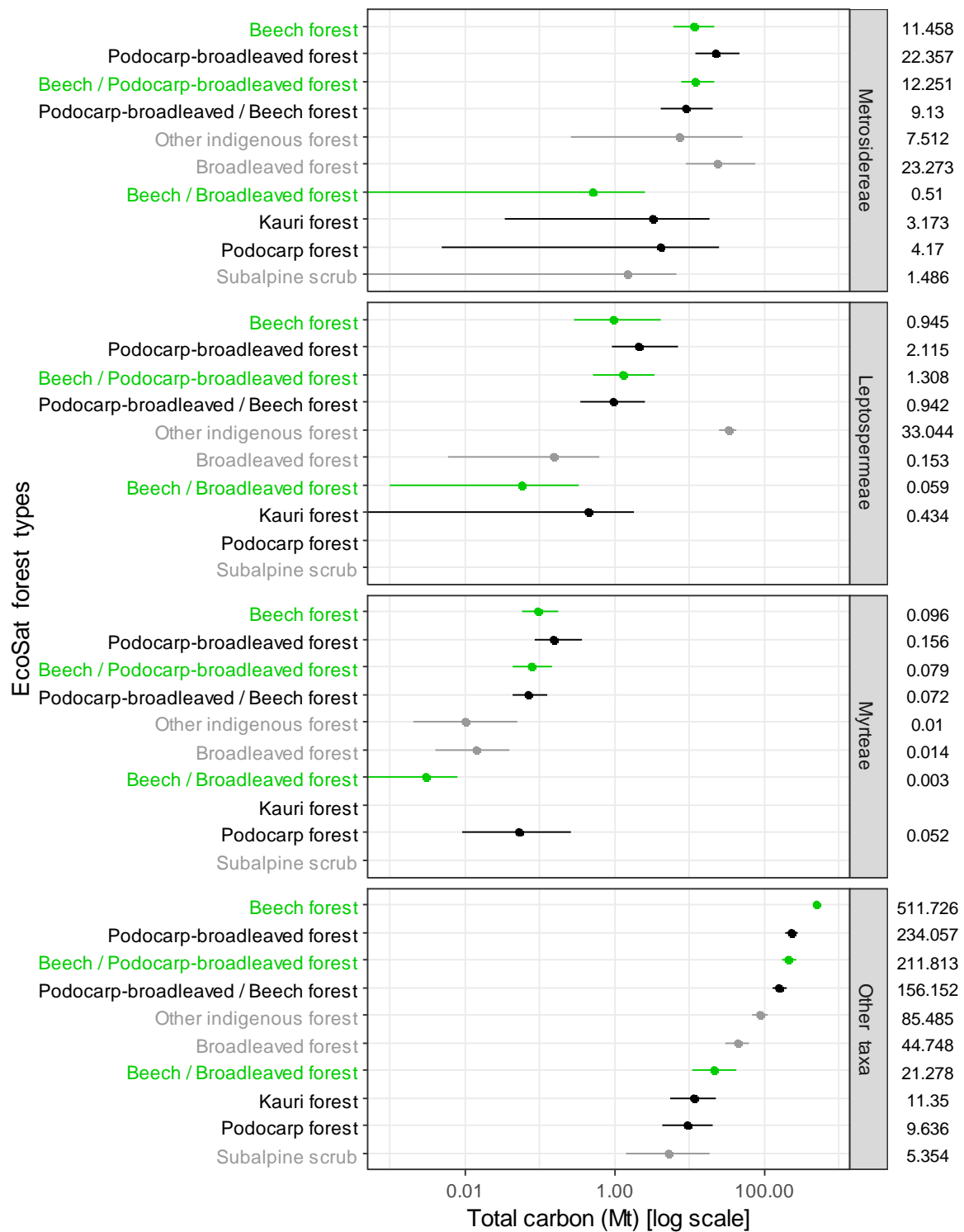**Figure 2. Total live above- and below-ground carbon for the main Myrtaceae tribes present in New Zealand forests (for the 2009–2014 measurement cycle). Carbon estimates are presented in mega tonnes (Mt) with their respective 95% confidence intervals. Values on the right margin are mean estimates. Note the logarithmic scale on the x-axis.**
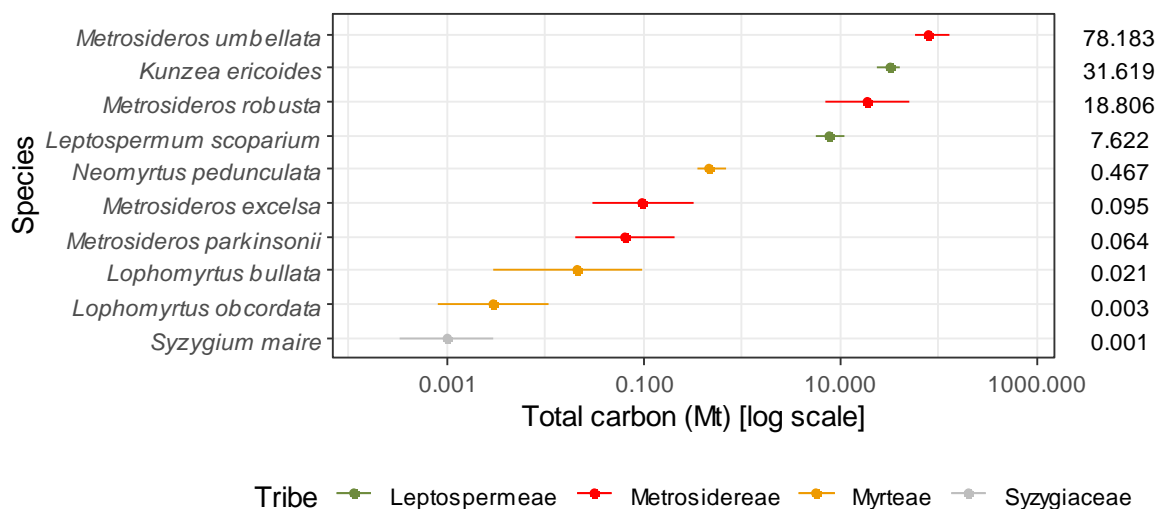
Figure 3. Total live above- and below-ground carbon for the main Myrtaceae species present in New Zealand forests (for the 2009–2014 measurement cycle). Carbon estimates are presented in mega tonnes (Mt) with their respective 95% confidence intervals. Values on the right margin are mean estimates. Note the logarithmic scale on the x-axis.

Myrtaceae carbon is unevenly distributed in space. Myrtaceae are present in all forest types, but, in terms of individual tribes, Leptospermeae was absent from 'Podocarp forest' and 'Subalpine scrub' plots, and Myrteae was absent from 'Kauri forest' and 'Subalpine scrub' plots (Figure 4). Metrosidereae was present in all forest types. In terms of combined live carbon:

- Metrosidereae accumulates most carbon within the six forest types with the largest carbon stores, especially 'Broadleaved forest' and 'Podocarp–broadleaved forest' (we note that rankings of forest type totals coincide with rankings of subtotals for other taxa, Figure 4 bottom panel)
- Leptospermeae accumulates markedly more carbon in 'Other indigenous forest' (probably comprising various seral forests)
- Myrteae accumulates more carbon within the four forest types with the largest carbon stores ('Podocarp–broadleaved forest' and 'Beech forest' and combinations of these) (Figure 4).

Figure 4. Total live above- and below-ground carbon for the main Myrtaceae tribes and other taxa (non-Myrtaceae) by Ecosat forest types for the 2009–2014 measurement cycle. Forest types are sorted according to their accrued carbon and are colour coded according to dominant composition ('Beech forest' in green, 'Podocarp–broadleaved' and 'Kauri forest' in black, 'Broadleaved' and 'Other indigenous forest' in grey). 'Unspecified indigenous forest' and 'Other indigenous forest' are combined into a single category. Mean carbon estimates (megatonnes; Mt) are presented on the right margin.

4.2 Carbon fluxes

Broad assessment of total live carbon fluxes across the plot network shows that Leptospermeae had a moderate rate of net carbon sequestration (0.153 t·C·ha^{-1}·y^{-1}), with losses to mortality not fully counterbalancing the productivity gains from growth and recruitment (Figure 5). The reverse was found for Metrosidereae, which had a net loss of live carbon into deadwood (-0.308 t·C·ha^{-1}·y^{-1}) due to carbon losses to mortality not being replaced by productivity gains. Myrteae were quite static, with very low rates of carbon productivity and carbon loss, and as a result near zero net changes.
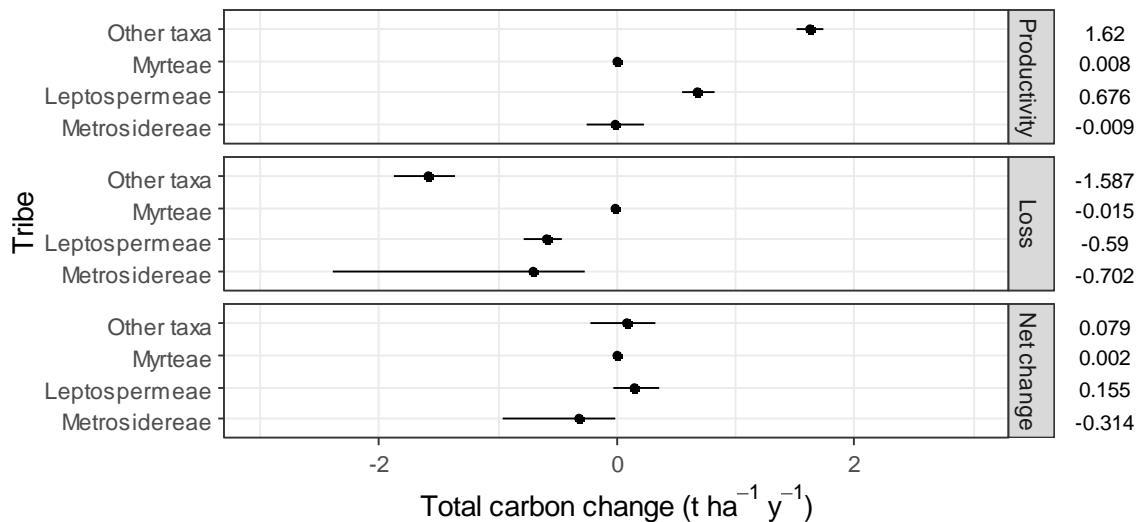
Figure 5. Carbon fluxes by tribe and their associated 95% confidence intervals. Mean carbon flux estimates (t·ha^{-1}·y^{-1}) are presented in the right margin.

Component fluxes for Myrtaceae tribes as a function of standing stocks and tribe co-occurrence are synthesised in Figure 6. Leptospermeae exhibited a clear increase in productivity with larger stocks (Figure 6, first and second productivity panels), reaching a mean of c. 1.55 t·C·ha^{-1}·y^{-1} at 100 t·C·ha^{-1} (second productivity panel). Both Myrteae and Metrosidereae were, on average, notably stationary in terms of productivity with near-zero stand-level rates of change (third and fifth productivity panels and first, third, and fourth productivity panels, respectively). Some variability was observed in the underlying plot records for productivity in Metrosidereae, but variability was minimal to unnoticeable for Myrteae (Figure C1, Appendix C).
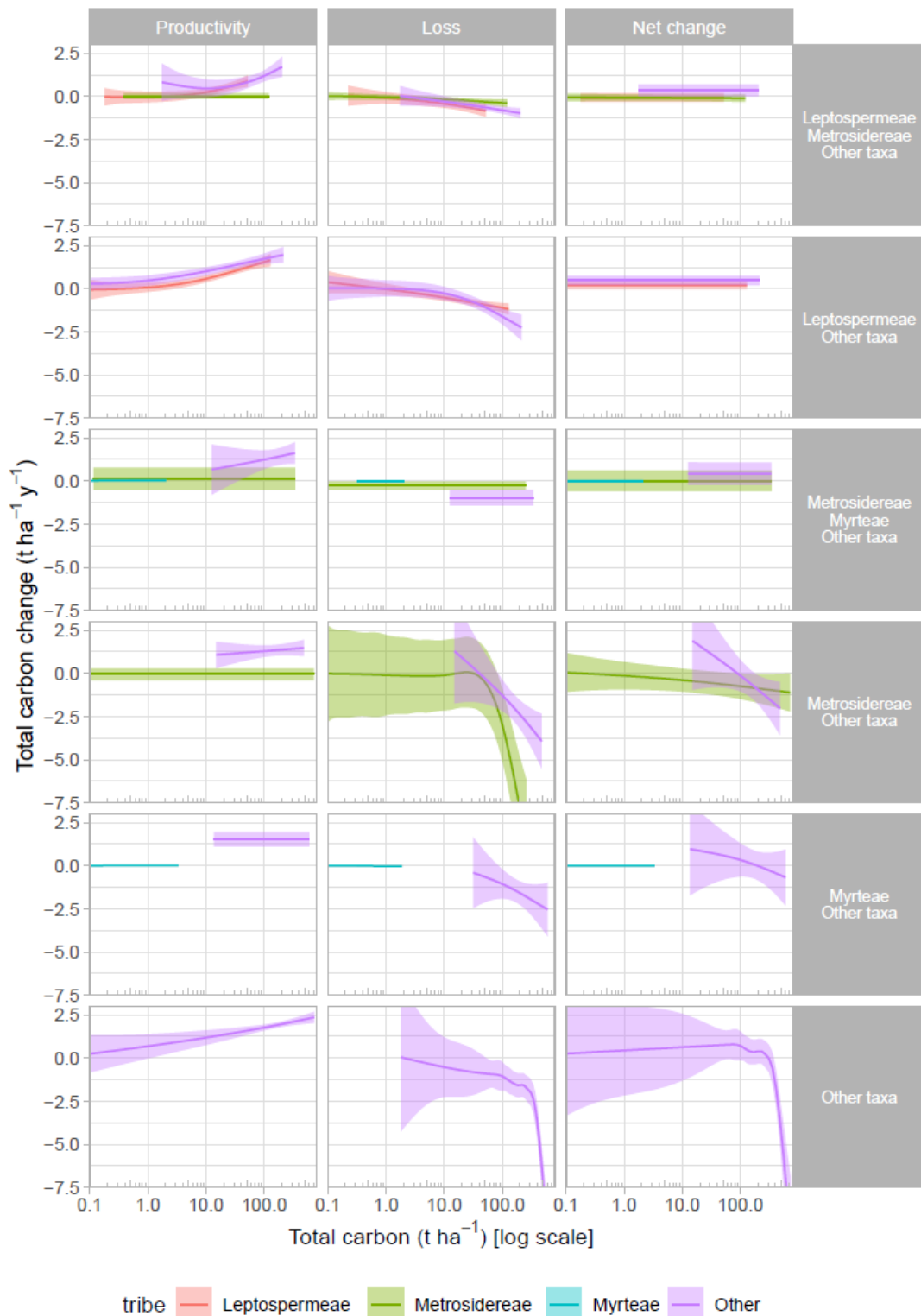
Figure 6. Trends in carbon productivity (pooled tree recruitment and tree growth, first column), carbon loss (pooled tree mortality, second column) and net carbon change (productivity minus losses, third column) as a function of standing carbon stocks for individual Myrtaceae tribes and a reference set of all 'Other' co-occurring tree taxa combined. Rows of panels correspond to the predominant combinations of co-occurring taxa and exclude combinations with small sample sizes (the three Myrtaceae tribes and Leptospermeae with Myrteae). Relationships are presented with their associated 95% confidence intervals. Note that reference carbon values for the Myrtaceae tribes on the y-axis correspond to the *taxon* total within stands (i.e. not the *stand* total). Further detail for the carbon productivity and carbon loss models that show underpinning data points are presented in Figures C1 and C2 (Appendix C). Note the logarithmic scale on the x-axis.

For each Myrtaceae tribe, productivity curves were generally consistent across plots for different co-occurring taxa (Figure 6, left column). Some differences in productivity between plot groups for non-Myrtaceae taxa are unsurprising, given the broad range of compositional, environmental, and successional conditions encompassed. However, differences tended to be moderate and were often non-significant.

Different carbon loss patterns were noted among Myrtaceae tribes (Figure 6, centre column). Leptospermeae showed gradual losses with increasing carbon stocks. Myrteae and Metrosidereae showed near-nil losses at low carbon stocks. Rates of loss at low stocks were, however, quite variable for Metrosidereae, as indicated by wide confidence intervals, and were followed by a steep acceleration in carbon losses beyond stocks of c. 50 $t \cdot C \cdot ha^{-1}$. Differences in carbon loss were also noted for the combined non-Myrtaceae taxa across plot groups. General trends were shallow to modest increases in losses at low stocks and very steep loses beyond c. 300 $t \cdot C \cdot ha^{-1}$.

The combination of carbon productivity and loss resulted in net near zero carbon changes for all Myrtaceae tribes across almost all plot groups (Figure 6, right column). An exception was Metrosidereae in plots shared only with other taxa (fourth panel for net change), where there were sustained increases in net carbon loss with increasing stocks (up to c. −1 $t \cdot C \cdot ha^{-1} \cdot y^{-1}$ at 300 $t \cdot C \cdot ha^{-1}$). Surprisingly, the carbon productivity trends observed for Leptospermeae were mostly cancelled out by corresponding carbon losses, with near-zero net gains in live carbon for this group.

Net carbon changes for the combined non-Myrtaceae taxa were generally positive up to a certain reference stock value, resulting in net carbon sequestration to wood in low-to-mid carbon stock contexts. Rates of uptake were, however, low on average (<1 $t \cdot C \cdot ha^{-1} \cdot y^{-1}$). Where rates of net carbon change varied according to standing stocks (fourth to sixth panels), rates tended to decline with increasing stocks and at some point became negative (c. 100 to 300 $t \cdot C \cdot ha^{-1}$), indicating net transfers of carbon into the dead-wood pool beyond those carbon stocks.

5   Cross-verification

5.1   Carbon stocks

The above results have been cross-checked for consistency. When we estimate natural forest carbon stocks only for the above-ground compartments using prior stem-specific density estimates (1,233,650,000 t·C), and rescale that value to a per hectare basis (with a 2012 pre-1990 forest area of 7,813,375 ha), our estimate (157.89 tC ha^{-1}) is consistent with those presented by Holdaway et al. (2014b) for the 2009–2014 LUCAS measurement cycle (158.30, 95% CI 150.39 to 166.19 t·C·ha^{-1}).

5.2   Carbon fluxes

Checks indicate that the results are analytically robust. The GAM response functions presented here were consistent with fitted 'loess' splines and with polynomial response functions, with a caveat that outputs for those alternative methods tended to be wavier and (with a minor exception noted below) none of the responses seem unrealistic or biologically unreasonable. The above results also remain largely unaffected when outputs are grouped by Ecosat forest types (result not shown).

Any fitted carbon 'losses' on the positive range (as shown by the carbon loss curve for non-Myrtaceae taxa; Figure 6, fourth panel in centre column) are spurious outcomes, as losses to mortality can only take zero or negative values. Uncertainty associated to fitted GAM models increases where underlying data points are sparse. Some of the models fitted near-linear trends as the most parsimonious fit to the mortality data and in two cases the fitted curve cut across zero even though none of the underpinning records were positive values (Figure C2). We may thus assume a truncated response function of zero carbon loss up to the x-intercept with fitted curves.

The carbon productivity estimates presented here for non-Myrtaceae taxa (Figure 6, bottom panels) show broad consistency with above-ground wood production values for *Nothofagus solandri* var. *cliffortioides*, as estimated from 246 remeasured plots throughout the Harper/Avoca catchments in the central Southern Alps (Coomes et al. 2012). Mean growth-related productivity for 'thinning' and 'disturbed' stands (i.e. those with a net loss of trees and an increase in mean tree size over time, and those with extensive tree death) were 1.17 ± 0.027 and 1.08 ± 0.037 t·C·ha^{-1}·y^{-1}, respectively. The Harper/Avoca results indicated either no or some decline in productivity with increases in standing mass (Coomes et al. 2012), while here we observed a positive association between productivity and standing mass. These differences may be attributable to study scale. A much wider range of environments and compositional variation encompassed by our national-scale analysis would combine situations of high carbon stocks and productivity in forest communities associated with more favourable growing conditions and vice versa. Within a more homogeneous compositional and environmental context such as that encompassed by the study of Coomes et al. 2012, the productivity–standing mass relationship will more closely reflect processes of internal stand development.

6   Discussion

The finding that Myrtaceae are the fourth most dominant family in terms of carbon stocks and of comparable carbon stocks to the Podocarpaceae is notable, and is consistent with a recent assessment that, among New Zealand woody taxa, Myrtaceae has high importance values in terms of combined canopy cover, stem basal area, and species richness relative to other plant families (Jo et al. in press). It was also interesting that two successional Leptospermeae species made up 28.5% of the total carbon store of the family, despite trees generally being comparably small (mean tree heights of 7.1 m and 10.3 m and mean stem diameters of 6.3 and 18.0 cm in Leptospermeae and Metrosidereae, respectively) and stem diameter scaling quadratically with tree carbon (Chave et al. 2014). The result can be attributed to the extent of successional forests dominated by Leptospermeae.

A marginal trend for lower productivity in Leptospermeae relative to coexisting non-Myrtaceae taxa (Figure 6, first and second productivity panels) could be partly attributed to high wood densities in the Leptospermeae. Higher wood density may correspond to lower leaf to stem mass fractions. All else being equal, low leaf fractions could result in low photosynthetic potential and higher respiration costs to maintain non-photosynthetic tissues, which, in turn, would translate into lower availability of photosynthates for woody growth (Wright et al. 2019). Similar interpretations may also explain the very low productivity noted for other Myrtaceae tribes.

The near zero net carbon balance found for Leptospermeae (Figure 6, second net change panel) is striking and seems at odds with our assumptions about these successional taxa. Results indicate that much of the productivity gains resulting from tree recruitment and growth in this group are offset by mortality. These findings may reflect that:

- *Kunzea* stands typically do not self-replace (Esler & Astridge 1974; Payton et al. 1984)
- *Kunzea* and *Leptospermum* communities span long environmental gradients and are components of highly varying successional trajectories, meaning that some contexts counterbalance others when these taxa are combined (e.g. losses to mortality in *Leptospermum*, which tends to be shorter lived than *Kunzea*, could counterbalance any carbon gains made by the latter) (Esler & Astridge 1974; de Lange 2014)
- our analysis focuses on pre-1990 forests, and the underlying mapping does not account for areas of younger post-1990 regenerating forest.

A near-zero mean productivity estimated for Metrosidereae is interesting and could indicate either slow metabolism or high costs of producing dense wood in the genus/tribe commonly referred to as 'ironwoods' (Simpson 2005). Notably, that was even the case in contexts where *Metrosideros* coexists with Leptospermeae and what possibly comprise seral and more dynamic communities (Figure 5, first panel for productivity). This highlights the significant importance these taxa have relative to irrecoverable carbon (Goldstein et al. 2020). A trend of net decline in Metrosidereae because of losses to mortality in communities where this is the only Myrtaceae tribe present (Figure 5, fourth panel for net change) is of concern. However, where Metrosidereae coexists with other Myrtaceae tribes, it appears to have been stable during the study period.

Collectively and on average, non-Myrtaceae woody families have comparably more potential for net carbon sequestration than do Myrtaceae families. Net carbon sequestration was observed in all cases for stocks up to 100 t·C·ha^{-1}, while between 100 and 300 t·C·ha^{-1}, net carbon changes exhibited a crossover into negative values, likely to be due to the higher losses that can result when old-growth high biomass stands are affected by tree mortality and disturbance (e.g. Coomes et al. 2012). We note that while overall rates of productivity for non-Myrtaceae were 1.6 t·C·ha^{-1}·y^{-1} and corresponding net uptake was generally <1 t·C·ha^{-1}·y^{-1} for stocks up to 100 t·C·ha^{-1}, these rates are not necessarily low in the broad context of median rates of carbon productivity of c. 2 t·C·ha^{-1}·y^{-1} for tropical forests (ForestPlots.net et al. 2021).

The results presented here correspond to total (above- and below-ground) carbon and carbon flux associated with 'live' stems. Losses to mortality represent transfers of carbon into deadwood and, in turn, some into soil organic matter and so influence the dynamics of those pools. To varying extent and duration, carbon lost to mortality will persist as 'fixed' terrestrial carbon for some time (Mason et al. 2013). Empirical studies indicate remarkably slow decomposability in *Metrosideros umbellata* for stems ≥30 cm DBH, with wood density in coarse deadwood being c. 94% that of live stems after over 20 years. Of the 19 species studied, the next species with slowest decomposition were *Dacrydium cupressinum*, *Podocarpus cunninghamii* and *Dacrycarpus dacrydioides* (all Podocarpaceae), with coarse dead wood retaining between c. 76% and 51% of the live wood density after >20 years from tree death, while the remaining of indigenous species retained 40% or less (Mason et al. 2013).

Overall, as the fourth most dominant family with 9.7% of the carbon store in New Zealand forests, the Myrtaceae are an important component in the structure of native forests. Our results show that the carbon sink from Myrtaceae is very slow or static, particularly for Metrosidereae and Myrteae, the two tribes generally associated with mature forests. A slow sink in Leptospermeae was unexpected and will require further enquiry, but appears to relate to the comparatively rapid growth and replacement and transitional nature of the seral communities these taxa are part of. At present, death of Myrtaceae individuals from myrtle rust is rare and confined to species in the Myrteae tribe[1], but the effects of myrtle rust on tree mortality can take years to manifest (Carnegie & Pegg 2018; Pegg et al. 2018). In the long term, wide-scale mortality, especially of large trees, has the potential to significantly reduce the carbon stocks of New Zealand forests.

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[1] https://www.landcareresearch.co.nz/news/myrtle-rust-update-mature-native-trees-now-dying/

7   Acknowledgements

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Appendix A – Summary of data checks and edits

Data checking procedures are an essential component of forest monitoring (Wiser et al. 2001; Lopez-Gonzalez et al. 2011). The LUCAS natural forest plot data have already undergone a comprehensive series of data checks and ensuing corrections that render the data internally consistent (Holdaway et al. 2014). This appendix summarises some supplementary checks done for large stem recruits, unmatched tags, and tree heights for leaning stems.

These conditions can affect and be influential on demographic assessments and carbon stock and flux estimates. Large stem recruits are important in that, beyond certain size thresholds and census intervals, they are biologically unfeasible and, if left uncorrected, can lead to overestimating biomass growth. As an elemental component of permanent forest plot sampling, tagged stems allow monitoring of trees over time.

The processing of vast numbers of stems associated with forest monitoring (from tagging and measurement to data entry and processing) inevitably means that not all tags of live surviving stems are automatically matched at time of data assembly and processing. Unmatched tags lead to an artefact of false mortality and false recruitment events, which, if frequent, will result in inflated rates of recruitment and mortality.

In other respects, carbon stock and change estimates are sensitive to height due to the multiplicative effect of height on tree carbon estimates (cf. Chave et al. 2014). This influence of height on carbon estimates is compounded by the indirect nature of height measurements, instances of limited tree top visibility at time of measurement, and cases of leaning stems and their influence on estimated height (Payton et al 2004; Holdaway et al. 2014). Plot-level carbon stock and flux estimates tend to be more sensitive to taller and larger stems, so these generally are the first focus of attention.

The checks procedures listed here involved:

- identifying data inconsistencies
- comparing the corresponding records against other stems in the same plot and subsequent or prior measurements
- manual checks of field sheets on a case-by-case basis to verify the electronic data and inspect field notes that could resolve inconsistencies
- editing a copy of the data where the inconsistency could be clearly resolved.

As data editing can introduce bias to the data, with consequences for subsequent interpretation (Muller-Landau et al. 2013), we took a precautionary approach and incorporated corrections only where inconsistencies could be clearly resolved. Any remaining inconsistencies were handled by analytical decisions, as specified in the main document.

Large recruits and matching tags

We checked large recruits for 281 stems with a DBH of ≥15 cm in the second measurement cycle and excluding tree ferns and palms (this represented 1.5% of all recruits for those species groups). For a mean census interval of 7.7 years, stems would have to grow at a sustained rate of 1.6 cm DBH per year to be true new recruits. Those putative growth rates are possible for some species and growth conditions, but they become progressively unlikely for recruits of c. 20 cm DBH or larger.

Our checks comprised manual surveys of the data for any tagged stems recorded only at the first measurement cycle (i.e. presumed mortality events) that were of similar size, the same species and the same plot sector to that of the large recruit. We also compared tag numbers and inspected for corresponding numbering sequences (e.g. tag prefixes) or field notes (e.g. double tags) that would allow us to match the large recruit with a false mortality event. This procedure allowed us to resolve 104 large recruits (37% of large recruits ≥15 cm DBH) and to match the corresponding tags. Further, in a few plots the procedure identified strings of unmatched stems with recurring differences in tag prefixes and allowed us to resolve unmatched tags for 'small' recruits with <15 cm DBH in the second measurement cycle (n = 94).

Tree heights for leaning stems

Following previous assessments, our analytical procedures relied on measured heights for surviving stems with two height measurements, and on modelled heights for all other instances (Holdaway et al. 2014). As a standard procedure, the heights of leaning stems are corrected as a function of stem lean angle. This correction and its flow-on effect on tree carbon estimates become increasingly influential at increasing angles and for larger stems.

Initial assessments linked some atypical carbon change values to leaning stems, which led us to incorporate a few checks. Although changes in lean angle are affected by measurement error, true temporal changes in stem lean are possible where there is an increase in stem lean (e.g. due to soil mass movement, tree-fall knock-on effects, wind disturbance), while decreases in stem lean generally seem unrealistic. As part of the checking procedures, we:

- checked that leaning stems with two height measurements had a lean angle estimated at both measurement times
- checked that estimated lean angles corresponded between consecutive measurements, with differences not greater than 20°
- checked records for markedly leaning trees (<40° from the horizontal), particularly if large trees.

Most inconsistencies identified as part of these procedures were generally not resolvable from field-sheet inspection and were managed as analytical decisions (see section 3.4).

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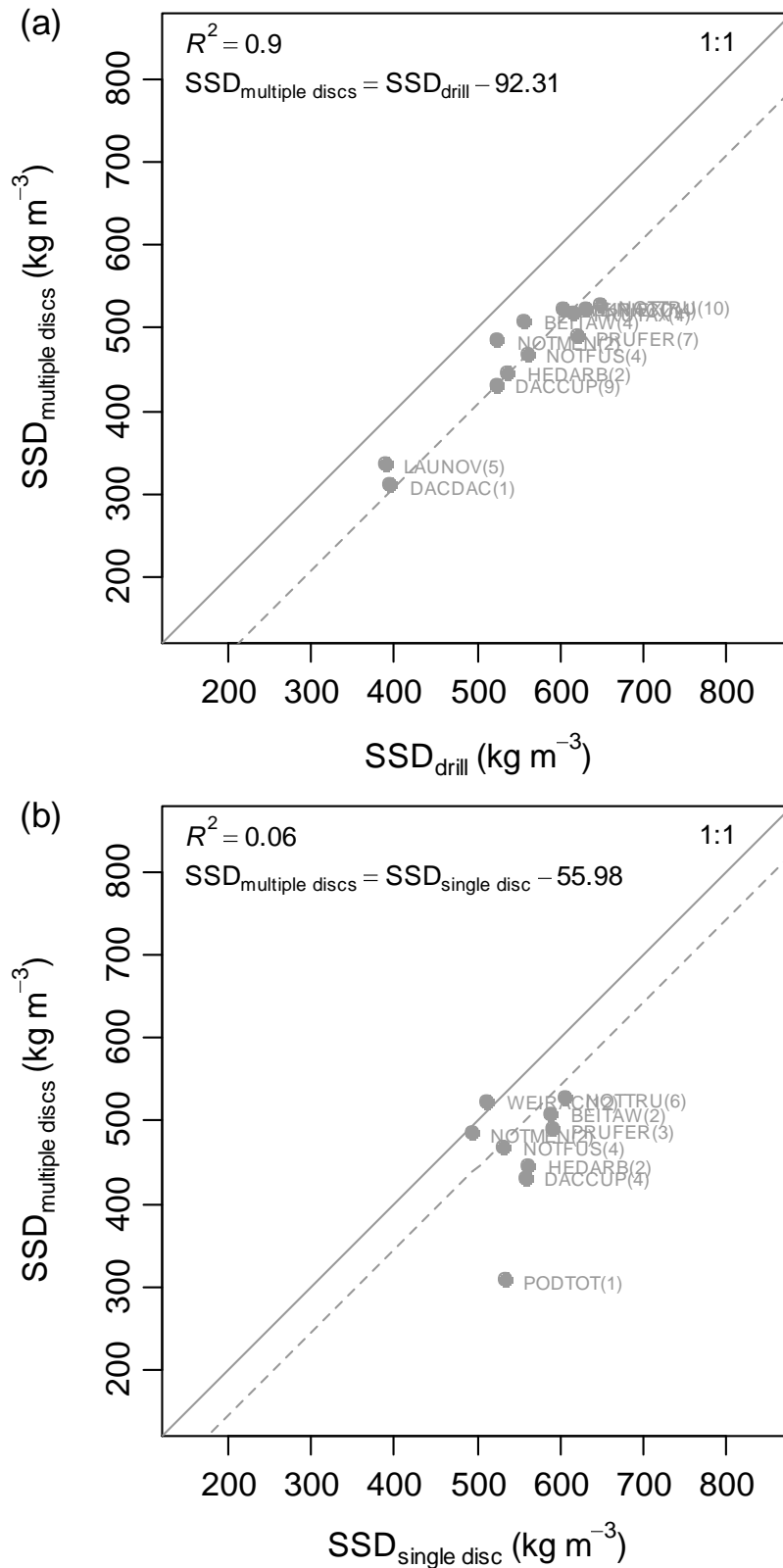# Appendix B – Stem-specific density estimates for carbon calculations

This appendix updates the stem specific density data (SSD) previously compiled by Holdaway et al. (2015). Initial data sources (Beets et al. 2008, 2012, and original data samples from SJ Richardson and DA Peltzer) are here expanded with records from new trait measurements (SJ Richardson, J McCarthy; original unpublished data) and from two other published sources (Schwendenmann & Mitchell 2014; Marden et al. 2021), providing records for 149 species. Collectively, records derive from over-bark samples collected using different methods (single-stem discs, multiple discs per tree, and drill samples) for a range of applications and processed as oven-dried mass to green volume measured following Pérez-Harguindeguy et al. 2013.

For carbon estimation applications, sets of multiple discs collected along the stem of large individual trees are generally expected to provide a more representative sample than other methods. This sampling approach is, however, resource intensive and SSDs sampled this way are limited. More commonly, samples consist of single discs collected on individual stems (often of smaller diameter), drill samples (across a range of tree stem sizes), or increment core samples. On contrasting SSD estimates for species sampled with alternative methods, existing data suggests that drill samples and, less so, single discs tend to yield higher estimates compared to multiple discs (Figure B1). The data suggest also that drill samples tend to correspond more tightly with multiple disc samples compared to single discs (Figure B1).

The basis for these trends is unknown and is partly conditioned by a small and different set of species being sampled in different ways, but the trends could be attributed to an effect of radial variation in stem-specific density (known to occur for many species) and drill samples capturing larger stems than disc samples (often collected from smaller stems).

Based on the above, we estimated SSDs as follows:

- We first extracted mean SSDs from multiple disc samples for dicot and gymnosperm species, where available, and estimated mean SSDs for tree ferns and monocots, regardless of sample method.
- Alternatively, we extracted mean SSDs from drill samples and adjusted them by the fixed-slope model presented in Figure B1a. Here, we also included samples of *Kunzea ericoides* sensu lato (Marden et al. 2021) but using only large disc samples (≥10 cm DBH).
- Lastly, for species not sampled by either of the above methods, we computed mean SSDs from disc samples and adjusted them by the fixed-slope model presented in Figure B1b. Estimates from increment core samples were not incorporated here. Final SSD estimates used for carbon calculations are presented in Table B1 below.

Figure B1. Stem-specific density (SSD) estimates for dicots and gymnosperms as derived from alternative sampling methods. Data points are mean values for species sampled by alternative wood sampling methods and correspond to different trees and locations. Regression lines (dashed line) correspond to a fixed-slope linear model, weighted by the minimum number of samples per species from either method (value beside species code). The solid line represents the 1:1 relationship. Figures are presented within the range of values recorded across New Zealand woody species. Note the outlier point for *Podocarpus totara* originates from a single sample (thus a relatively uncertain estimate).

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Table B1. Estimated stem-specific density (SSD) and associated standard errors for 149 tree and shrub species sampled throughout New Zealand. Estimates originate from a range of sources and were sampled using bark and alternative methods, as noted in the table. _n_ is the number of published values or individual samples used to calculate the mean.

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
ACEPSE	_Acer pseudoplatanus_	_Acer_	Sapindaceae	73	467	-	1	SJR	disc
AGAAUS	_Agathis australis_	_Agathis_	Araucariaceae	45	426.4	-	27	PNB, PNB comp.	mult. discs, comp.
ALSMAC	_Alseuosmia macrophylla_	_Alseuosmia_	Alseuosmiaceae	78	468.7	17.6	5	JKM	disc
ARCTRA	_Archeria traversii_	_Archeria_	Ericaceae	103	512	-	1	DAP	drill
ARIFRU	_Aristotelia fruticosa_	_Aristotelia_	Elaeocarpaceae	60	449.5	-	1	SJR	disc
ARISER	_Aristotelia serrata_	_Aristotelia_	Elaeocarpaceae	9	278.6	11	6	DAP, SJR	disc
ASCLUC	_Ascarina lucida_	_Ascarina_	Chloranthaceae	13	304.4	21.7	5	JKM	disc
BEITAR	_Beilschmiedia tarairi_	_Beilschmiedia_	Lauraceae	117	527	-	1	PNB comp.	comp.
BEITAW	_Beilschmiedia tawa_	_Beilschmiedia_	Lauraceae	99	508	-	12	PNB, PNB comp.	mult. discs, comp.
BRABUC	_Brachyglottis buchananii_	_Brachyglottis_	Compositae	83	474.7	12	6	JKM	disc
BRAREP	_Brachyglottis repanda_	_Brachyglottis_	Compositae	68	462.4	5.9	5	SJR	disc
BRAROT	_Brachyglottis rotundifolia_	_Brachyglottis_	Compositae	94	492.6	21.4	3	SJR	disc
CARSER	_Carpodetus serratus_	_Carpodetus_	Rousseaceae	77	468.1	11.9	2	DAP	drill
COPCOL	_Coprosma colensoi_	_Coprosma_	Rubiaceae	137	586.3	16	5	JKM	disc
COPCRA	_Coprosma crassifolia_	_Coprosma_	Rubiaceae	115	526.1	32.7	4	SJR	disc
COPDMO	_Coprosma dumosa_	_Coprosma_	Rubiaceae	132	570.6	11.3	4	JKM	disc
COPFOE	_Coprosma foetidissima_	_Coprosma_	Rubiaceae	86	479.1	14.9	7	DAP, JKM, SJR	disc
COPGRA	_Coprosma grandifolia_	_Coprosma_	Rubiaceae	26	384.75	11.4	10	JKM, SJR, PNB comp.	disc, comp.
COPLIN	_Coprosma linariifolia_	_Coprosma_	Rubiaceae	104	513.3	11.7	6	JKM, SJR	disc

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
COPLUC	*Coprosma lucida*	*Coprosma*	Rubiaceae	47.5	431.4	35.7	4	DAP, SJR	disc
COPMIC	*Coprosma microcarpa*	*Coprosma*	Rubiaceae	109.5	519.6	7.2	3	JKM	disc
COPPRO	*Coprosma propinqua*	*Coprosma*	Rubiaceae	57	447.9	44.2	3	SJR	disc
COPPSC	*Coprosma pseudociliata*	*Coprosma*	Rubiaceae	87	481.9	9.3	4	JKM	disc
COPPSE	*Coprosma pseudocuneata*	*Coprosma*	Rubiaceae	114	523.7	13.5	7	JKM, SJR	disc
COPRHA	*Coprosma rhamnoides*	*Coprosma*	Rubiaceae	126	549.6	17.1	2	SJR	disc
COPRIG	*Coprosma rigida*	*Coprosma*	Rubiaceae	71	464.3	-	1	SJR	disc
COPROB	*Coprosma robusta*	*Coprosma*	Rubiaceae	49	439.3	6	5	JKM, SJR	disc
COPROT	*Coprosma rotundifolia*	*Coprosma*	Rubiaceae	50	439.7	13.1	8	JKM, SJR	disc
COPRUB	*Coprosma rubra*	*Coprosma*	Rubiaceae	66	461	10.2	3	SJR	disc
COPRUG	*Coprosma rugosa*	*Coprosma*	Rubiaceae	93	491.6	7.5	8	JKM, SJR	disc
COPTAY	*Coprosma tayloriae*	*Coprosma*	Rubiaceae	88	486	17.7	5	SJR	disc
COPTEF	*Coprosma tenuifolia*	*Coprosma*	Rubiaceae	92	490.5	11.7	5	SJR	disc
CORAUS	*Cordyline australis*	*Cordyline*	Asparagaceae	7	272.3	-	2	SJR	disc
CORBAN	*Cordyline banksii*	*Cordyline*	Asparagaceae	18	333.6	-	1	SJR	disc
CORARB	*Coriaria arborea*	*Coriaria*	Coriariaceae	14	311.3	20.1	5	SJR	disc
CORBUD	*Corokia buddleioides*	*Corokia*	Argophyllaceae	75	467.8	-	1	SJR	disc
CORCOT	*Corokia cotoneaster*	*Corokia*	Argophyllaceae	100	509.7	-	1	SJR	disc
CORLAE	*Corynocarpus laevigatus*	*Corynocarpus*	Corynocarpaceae	44	425.8	27.6	8	JKM, LS, SJR	disc
CRAMON	*Crataegus monogyna*	*Crataegus*	Rosaceae	97	502.2	-	1	SJR	disc
CYADEA	*Cyathea dealbata*	*Cyathea*	Cyatheaceae	5	258.9	-	21	PNB	mult. discs
CYAMED	*Cyathea medullaris*	*Cyathea*	Cyatheaceae	2	198	-	22	PNB, SJR	mult. discs, disc
CYASMI	*Cyathea smithii*	*Cyathea*	Cyatheaceae	1	173.1	-	27	DAP, PNB, SJR	mult. discs, disc

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
CYTSCO	*Cytisus scoparius*	*Cytisus*	Leguminosae	128	556.4	-	1	SJR	disc
DACDAC	*Dacrycarpus dacrydioides*	*Dacrycarpus*	Podocarpaceae	15	324.7	-	3	PNB, PNB comp.	mult. discs, comp.
DACCUP	*Dacrydium cupressinum*	*Dacrydium*	Podocarpaceae	47.5	431.4	-	11	PNB, PNB comp.	mult. discs, comp.
DICFIB	*Dicksonia fibrosa*	*Dicksonia*	Dicksoniaceae	4	237	-	1	SJR	disc
DICSQU	*Dicksonia squarrosa*	*Dicksonia*	Dicksoniaceae	3	224.2	-	30	DAP, PNB, SJR	mult. discs, disc
DRALAT	*Dracophyllum latifolium*	*Dracophyllum*	Ericaceae	59	448.8	10.5	6	SJR	disc
DRALON	*Dracophyllum longifolium*	*Dracophyllum*	Ericaceae	63	455.5	8.1	7	JKM, SJR	disc
DRAOLI	*Dracophyllum oliveri*	*Dracophyllum*	Ericaceae	40	419.7	-	1	SJR	disc
DRATRA	*Dracophyllum traversii*	*Dracophyllum*	Ericaceae	61	449.8	10.4	8	JKM, SJR	disc
DRAUNI	*Dracophyllum uniflorum*	*Dracophyllum*	Ericaceae	121	534.3	12.9	5	JKM	disc
DYSSPE	*Dysoxylum spectabile*	*Dysoxylum*	Meliaceae	43	424	-	1	PNB comp.	comp.
ELADEN	*Elaeocarpus dentatus*	*Elaeocarpus*	Elaeocarpaceae	24	378.4	24.9	9	DAP, PNB comp.	drill, comp.
ELAHOO	*Elaeocarpus hookerianus*	*Elaeocarpus*	Elaeocarpaceae	58	448	-	1	PNB comp.	comp.
FUCEXC	*Fuchsia excorticata*	*Fuchsia*	Onagraceae	51	440.5	14.8	5	SJR	disc
GAUANT	*Gaultheria antipoda*	*Gaultheria*	Ericaceae	37	411.9	17.3	5	JKM	disc
GAUDEP	*Gaultheria depressa*	*Gaultheria*	Ericaceae	53	446.1	10.1	5	JKM	disc
GAURUP	*Gaultheria rupestris*	*Gaultheria*	Ericaceae	23	364.8	30.7	4	JKM	disc
GENLIG	*Geniostoma ligustrifolium*	*Geniostoma*	Loganiaceae	25	381	11.7	4	SJR	disc
GRILIT	*Griselinia littoralis*	*Griselinia*	Griseliniaceae	133	575	38.6	4	DAP, SJR	drill
GRILUC	*Griselinia lucida*	*Griselinia*	Griseliniaceae	102	510.6	-	1	JKM	disc
HALBID	*Halocarpus bidwillii*	*Halocarpus*	Podocarpaceae	140	601.5	14.7	8	JKM, SJR	disc
HALBIF	*Halocarpus biformis*	*Halocarpus*	Podocarpaceae	142	609.5	9.1	7	JKM, SJR	disc
HEBSAL	*Hebe salicifolia*	*Hebe*	Plantaginaceae	55	446.4	2.4	2	SJR	disc

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
HEBSTR	*Hebe stricta*	*Hebe*	Plantaginaceae	134	576.2	14.6	4	SJR	disc
HEBSUB	*Hebe subalpina*	*Hebe*	Plantaginaceae	123	545.6	30.6	2	SJR	disc
HEDARB	*Hedycarya arborea*	*Hedycarya*	Monimiaceae	62	453	-	3	PNB, PNB comp.	mult. discs, comp.
HELLAN	*Helichrysum lanceolatum*	*Helichrysum*	Compositae	124	546.7	13.9	5	JKM	disc
HOHGLA	*Hoheria glabrata*	*Hoheria*	Malvaceae	36	408.3	8.8	6	SJR	disc
HOHPOP	*Hoheria populnea*	*Hoheria*	Malvaceae	64	456	27.7	3	SJR	disc
IXEBRE	*Ixerba brexioides*	*Ixerba*	Ixerbaceae	111	519.9	17.2	5	SJR	disc
KNIEXC	*Knightia excelsa*	*Knightia*	Proteaceae	108	519.2	-	5	PNB, PNB comp.	mult. discs, comp.
KUNERI	*Kunzea ericoides*	*Kunzea*	Myrtaceae	148	725.6	32.2	42	DAP, MM, PNB comp.	drill, comp.
LAUNOV	*Laurelia novae-zelandiae*	*Laurelia*	Atherospermataceae	19	337	-	7	PNB, PNB comp.	mult. discs, comp.
LEPJUN	*Leptecophylla juniperina*	*Leptecophylla*	Ericaceae	144	627.9	38.5	3	JKM	disc
LEPSCO	*Leptospermum scoparium*	*Leptospermum*	Myrtaceae	130	567	18.9	12	DAP, JKM, SJR	disc
LEUFAS	*Leucopogon fasciculatus*	*Leucopogon*	Ericaceae	120	529.9	24.8	11	JKM, SJR	disc
LIBBID	*Libocedrus bidwillii*	*Libocedrus*	Cupressaceae	16	329	-	1	PNB comp.	comp.
LITCAL	*Litsea calicaris*	*Litsea*	Lauraceae	56	446.6	-	8	PNB, PNB comp.	mult. discs, comp.
LOPBUL	*Lophomyrtus bullata*	*Lophomyrtus*	Myrtaceae	84.5	475	8	5	JKM	drill
LOPOBC	*Lophomyrtus obcordata*	*Lophomyrtus*	Myrtaceae	141	607.2	24.9	5	JKM, SJR	disc
MANCOL	*Manoao colensoi*	*Manoao*	Podocarpaceae	65	459.75	-	2	DAP, PNB comp.	drill, comp.
MELSIM	*Melicope simplex*	*Melicope*	Rutaceae	41	421.2	25	4	SJR	disc
MELLAN	*Melicytus lanceolatus*	*Melicytus*	Violaceae	12	304.1	-	1	SJR	drill
MELMIC	*Melicytus micranthus*	*Melicytus*	Violaceae	52	443.4	-	1	SJR	disc
MELRAM	*Melicytus ramiflorus*	*Melicytus*	Violaceae	17	330.48	14.8	5	DAP, PNB comp.	drill, comp.
METCAR	*Metrosideros carminea*	*Metrosideros*	Myrtaceae	32	400.2	-	1	JKM	disc

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
METDIF	*Metrosideros diffusa*	*Metrosideros*	Myrtaceae	38	412.1	30.7	3	RJH comp.	comp.
METEXC	*Metrosideros excelsa*	*Metrosideros*	Myrtaceae	107	516.3	7.3	2	JKM	disc
METPAR	*Metrosideros parkinsonii*	*Metrosideros*	Myrtaceae	147	711.6	16.6	5	JKM	disc
METROB	*Metrosideros robusta*	*Metrosideros*	Myrtaceae	131	570.16	21.4	5	JKM, PNB comp.	drill, comp.
METUMB	*Metrosideros umbellata*	*Metrosideros*	Myrtaceae	149	777.5	15.6	7	DAP, PNB comp.	drill, comp.
MYOLAE	*Myoporum laetum*	*Myoporum*	Scrophulariaceae	34	405.8	-	1	JKM	disc
MYRAUS	*Myrsine australis*	*Myrsine*	Primulaceae	67	461.2	125.6	2	DAP	drill
MYRDIV	*Myrsine divaricata*	*Myrsine*	Primulaceae	135	576.9	-	1	SJR	drill
MYRSAL	*Myrsine salicina*	*Myrsine*	Primulaceae	139	600.6	10.6	4	SJR	disc
NEOPED	*Neomyrtus pedunculata*	*Neomyrtus*	Myrtaceae	118	527.2	10.4	6	JKM	disc
NESCUN	*Nestegis cunninghamii*	*Nestegis*	Oleaceae	146	673.25	23.7	4	SJR, PNB comp.	disc, comp.
NOTFUS	*Nothofagus fusca*	*Nothofagus*	Nothofagaceae	72	465.4	-	5	PNB, PNB comp.	mult. discs, comp.
NOTMEN	*Nothofagus menziesii*	*Nothofagus*	Nothofagaceae	79.5	471.7	-	3	PNB, PNB comp.	mult. discs, comp.
NOTSOL	*Nothofagus solandri*	*Nothofagus*	Nothofagaceae	82	472.5	5.9	109	DAP, SJR, PNB comp.	drill, comp.
NOTCLI	*Nothofagus solandri* var. *cliffortioides*	*Nothofagus*	Nothofagaceae	84.5	475	187.5	1	DAP, PNB comp.	drill, comp.
NOTCXF	*Nothofagus solandri* var. *cliffortioides* × *fusca*	*Nothofagus*	Nothofagaceae	76	468	-	1	RJH comp.	comp.
NOTTRU	*Nothofagus truncata*	*Nothofagus*	Nothofagaceae	119	527.3	-	11	PNB, PNB comp.	mult. discs, comp.
OLEARB	*Olearia arborescens*	*Olearia*	Compositae	113	522.5	14.9	3	JKM	disc
OLEAVI	*Olearia avicenniifolia*	*Olearia*	Compositae	98	503.5	13.2	3	SJR	disc
OLEFUR	*Olearia furfuracea*	*Olearia*	Compositae	74	467.6	64.2	2	SJR	drill
OLEILI	*Olearia ilicifolia*	*Olearia*	Compositae	70	464.1	5.4	2	JKM, SJR	drill

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
OLELAC	*Olearia lacunosa*	*Olearia*	Compositae	125	547.8	-	1	DAP	disc
OLERAN	*Olearia rani*	*Olearia*	Compositae	35	407.9	54	4	SJR	disc
OZOLEP	*Ozothamnus leptophyllus*	*Ozothamnus*	Compositae	79.5	471.7	-	1	SJR	disc
PENCOR	*Pennantia corymbosa*	*Pennantia*	Pennantiaceae	29	394	8.1	7	DAP, JKM, SJR	disc
PHYALP	*Phyllocladus alpinus*	*Phyllocladus*	Podocarpaceae	96	501.2	-	1	DAP	drill
PHYTRI	*Phyllocladus trichomanoides*	*Phyllocladus*	Podocarpaceae	90	489	-	1	PNB comp.	comp.
PINCON	*Pinus contorta*	*Pinus*	Pinaceae	6	261	72.3	3	DAP	disc
PIPEXC	*Piper excelsum*	*Piper*	Piperaceae	11	292.5	9.9	5	JKM	disc
PITCOL	*Pittosporum colensoi*	*Pittosporum*	Pittosporaceae	89	486.5	37.8	2	SJR	drill
PITDIV	*Pittosporum divaricatum*	*Pittosporum*	Pittosporaceae	129	562.3	29	3	SJR	disc
PITEUG	*Pittosporum eugenioides*	*Pittosporum*	Pittosporaceae	101	510.5	30.2	2	DAP	drill
PITRIG	*Pittosporum rigidum*	*Pittosporum*	Pittosporaceae	136	584.4	11.4	7	JKM	disc
PITTEN	*Pittosporum tenuifolium*	*Pittosporum*	Pittosporaceae	127	550.3	15.8	12	DAP, LS, SJR	disc
PLAREG	*Plagianthus regius*	*Plagianthus*	Malvaceae	28	391.1	4.3	2	SJR	drill
PODACU	*Podocarpus acutifolius*	*Podocarpus*	Podocarpaceae	30	395.9	-	1	SJR	disc
PODCUN	*Podocarpus cunninghamii*	*Podocarpus*	Podocarpaceae	46	430.5	111.6	4	DAP	drill
PODTOT	*Podocarpus totara*	*Podocarpus*	Podocarpaceae	20.5	339.5	-	2	PNB, PNB comp.	mult. discs, comp.
PRUFER	*Prumnopitys ferruginea*	*Prumnopitys*	Podocarpaceae	91	489.2	-	8	PNB, PNB comp.	mult. discs, comp.
PRUTAX	*Prumnopitys taxifolia*	*Prumnopitys*	Podocarpaceae	106	514.2	-	5	PNB, PNB comp.	mult. discs, comp.
PRUAVI	*Prunus avium*	*Prunus*	Rosaceae	105	513.4	-	1	SJR	disc
PSEARB	*Pseudopanax arboreus*	*Pseudopanax*	Araliaceae	39	412.8	11.1	7	DAP, SJR	disc
NEOCOL	*Pseudopanax colensoi*	*Pseudopanax*	Araliaceae	42	423.4	11.9	6	JKM, SJR	disc
PSECRA	*Pseudopanax crassifolius*	*Pseudopanax*	Araliaceae	95	496	-	1	DAP	drill

Sp. code	Species	Genus	Family	SSD rank	mean SSD	se of mean	n	Source	Method
PSELIN	*Pseudopanax linearis*	*Pseudopanax*	Araliaceae	122	536.9	10.1	9	JKM, SJR	disc
PSEMEN	*Pseudotsuga menziesii*	*Pseudotsuga*	Pinaceae	20.5	339.5	-	1	DAP	drill
PSEAXI	*Pseudowintera axillaris*	*Pseudowintera*	Winteraceae	54	446.3	14.6	7	DAP, SJR	disc
PSECOL	*Pseudowintera colorata*	*Pseudowintera*	Winteraceae	81	471.8	16.5	8	JKM, SJR, PNB comp.	disc, comp.
QUISER	*Quintinia serrata*	*Quintinia*	Paracryphiaceae	33	403.5	13.3	11	DAP, SJR, PNB comp.	drill, comp.
RAUANO	*Raukaua anomalus*	*Raukaua*	Araliaceae	112	520.6	12.8	8	JKM, SJR	disc
RAUAXS	*Raukaua anomalus × simplex*	*Raukaua*	Araliaceae	138	597.3	-	1	RJH comp.	comp.
RAUSIM	*Raukaua simplex*	*Raukaua*	Araliaceae	69	463.5	-	1	SJR	drill
SAMNIG	*Sambucus nigra*	*Sambucus*	Adoxaceae	31	396.5	-	1	SJR	disc
SCHDIG	*Schefflera digitata*	*Schefflera*	Araliaceae	10	291.9	6	3	DAP	drill
SOLAVI	*Solanum aviculare*	*Solanum*	Solanaceae	8	277.2	-	1	JKM	disc
SOPMIC	*Sophora microphylla*	*Sophora*	Leguminosae	145	643.7	11.8	2	SJR	drill
SYZMAI	*Syzygium maire*	*Syzygium*	Myrtaceae	22	339.9	17.3	5	JKM	drill
ULEEUR	*Ulex europaeus*	*Ulex*	Leguminosae	143	614.2	9	5	JKM	disc
URTFER	*Urtica ferox*	*Urtica*	Urticaceae	27	384.9	12.6	2	SJR	disc
VERSAL	*Veronica salicifolia*	*Veronica*	Plantaginaceae	116	526.3	16.9	5	JKM	disc
WEIRAC	*Weinmannia racemosa*	*Weinmannia*	Cunoniaceae	109.5	519.6	-	16	PNB, PNB comp.	mult. discs, comp.

Appendix C – detail on carbon productivity and carbon loss models
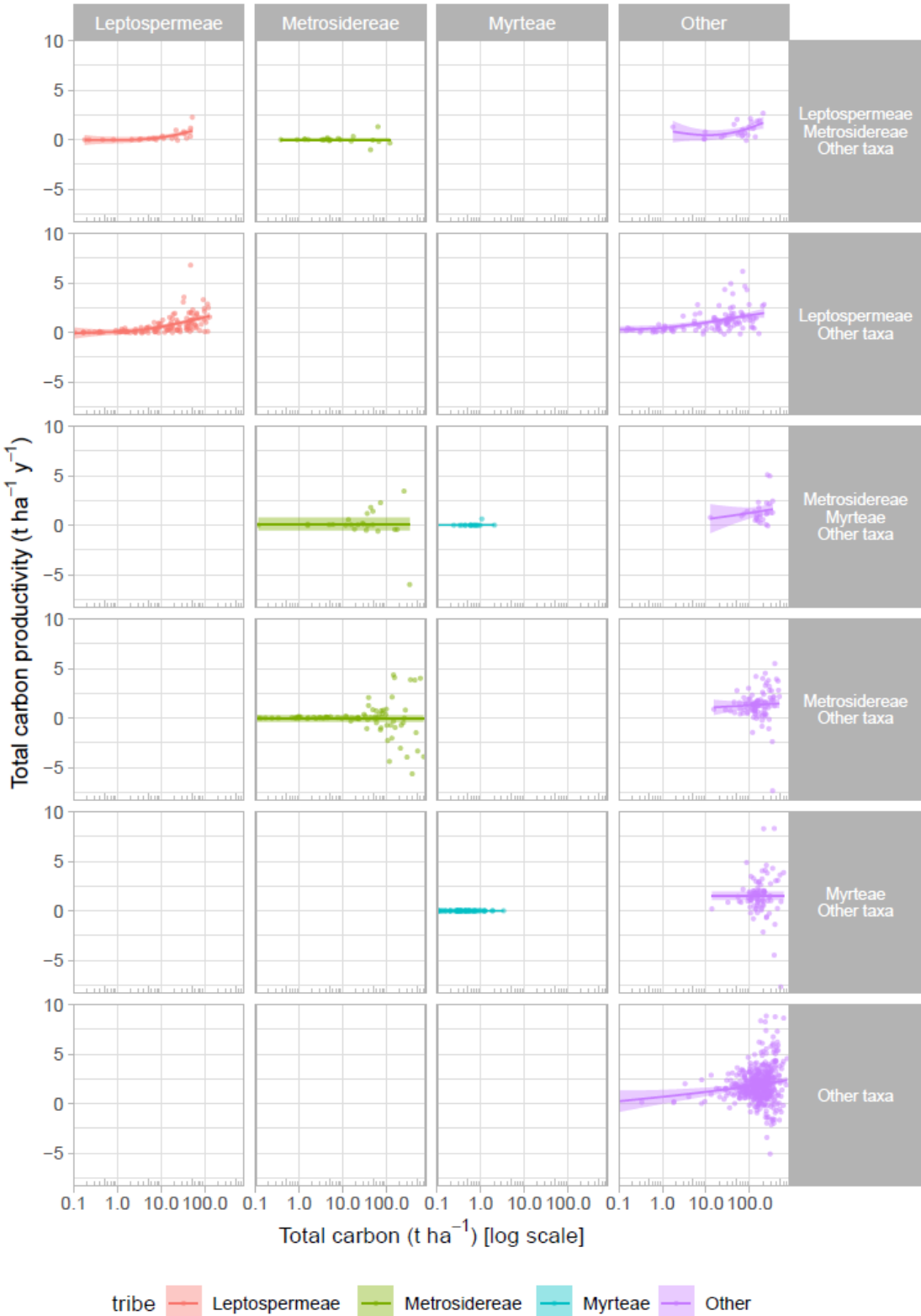
Figure C1. Carbon productivity (pooled tree recruitment and tree growth) as a function of standing carbon stocks for individual Myrtaceae tribes and a reference set of all 'Other' co-occurring tree taxa combined (columns). Rows of panels correspond to alternative combinations of taxa. Relationships are presented with their associated 95% confidence intervals and underlying pool records. Note that reference carbon values for the Myrtaceae tribes in the abscissa correspond to the taxon total within stands (i.e. not the stand total). Note the logarithmic scale on the x-axis.
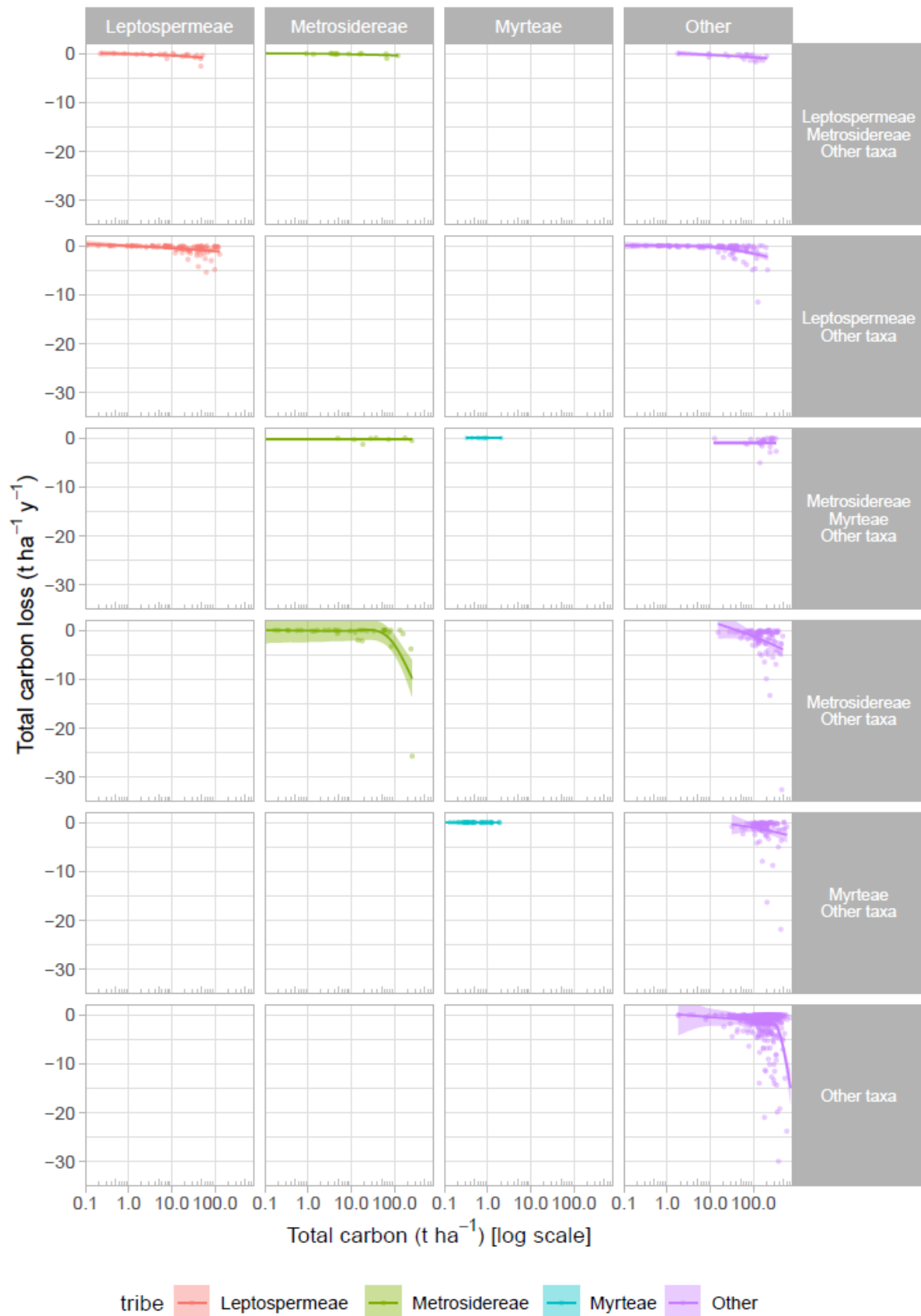
Figure C2. Carbon loss to tree mortality as a function of standing carbon stocks for individual Myrtaceae tribes and a reference set of all 'Other' co-occurring tree taxa combined (columns). Rows of panels correspond to alternative combinations of taxa. Relationships are presented with their associated 95% confidence intervals and underlying pool records. Note that reference carbon values for the Myrtaceae tribes in the abscissa correspond to the taxon total within stands (i.e. not the stand total). Note the logarithmic scale on the x-axis.