Carbon assessment of wetland vegetation

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Executive Summary

An international review of New Zealand's 2019 greenhouse gas inventory recommended that the methods and estimations of carbon stored in wetlands should be improved to better capture carbon lost when land is converted from wetlands to other land uses. New Zealand's vegetated wetlands are mapped using the 'vegetated non forest wetland' class of the Land Use Map (LUM), and this land use class is the focus of this report.

Vegetated non forest wetlands encompass a wide range of coastal and inland ecosystems, from short-statured turfs with very low biomass, through to tall woody shrublands with significant biomass stocks. However, this variation is not mapped by the LUM. The Land Cover Data Base (LCDB) provides spatial information on vegetation cover across New Zealand, and can be used to subdivide the vegetated non forest wetlands land use class into different types of wetland vegetation (e.g. 'Flaxland', 'Mānuka and/or Kānuka'). Neither the LUM nor the LCDB explicitly map coastal ecosystems separately from inland ecosystems, yet this separation is needed to meet reporting requirements.

To reduce uncertainty in estimates of carbon stored in vegetation on wetlands, this report:

Determines an approach for delineating coastal wetlands from inland wetlands within the area mapped as vegetated non forest wetlands by the LUM;

Presents the results of a literature review of vegetation biomass carbon for wetland vegetation in New Zealand;

Estimates area-weighted carbon stocks for vegetated non forest wetlands and documents change in those carbon stocks between 2008 and 2016 for New Zealand.

We delineated coastal wetlands from inland wetlands using a combination of elevation and distance from the coast line. An advantage of this approach is that it yields a 'hard' boundary based on abiotic features of the landscape, rather than relying on vegetation cover or composition that can change through time.

Our literature review identified 14 studies and 42 biomass estimates for wetland vegetation in New Zealand. Biomass estimates were available for five structural classes of herbaceous vegetation, and mangroves. Total above-ground carbon density (live and dead plant material combined) in herbaceous classes ranged from 4.82 Mg C ha^{-1} (sedgelands) to 27.16 Mg C ha^{-1} (tussocklands). The above-ground carbon density of mangroves were 31.58 Mg C ha^{-1}. Records of below-ground ground biomass were scarce except for mangroves, where below-ground carbon densities were about twice that of their above-ground densities (60.28 Mg C ha^{-1}). No data were available for some widespread wetland vegetation types such as flaxlands, or woody vegetation such as wetland mānuka or exotic willows. No assessments of biomass change in wetland vegetation were identified.

We did not find adequate information on biomass from coastal wetland vegetation types to justify reporting on coastal systems separately from inland systems.

We calculated an area-weighted grand mean vegetation carbon density for LUM vegetated non forest wetlands by applying our literature estimates of carbon density to the area mapped as vegetated non forest wetlands in the LUM. We did this by subdividing the 217,039 ha of vegetated non forest wetlands in the LUM using the LCDB. We used the 2012 reporting period for this exercise. We assigned our literature estimates of carbon density to LCDB classes, and where data were missing, we supplemented with additional sources and surrogates for managed grasslands, shrublands and forests. Using the area of each LCDB class within the LUM vegetated non forest wetlands class, we were able to calculate an area-weighted grand mean estimate of vegetation carbon density for LUM vegetated non forest wetlands.

We estimated an area-weighted grand mean carbon density of 20.22 (11.07 – 29.38, 95% CI) Mg C ha^{-1} for above-ground biomass and 7.40 (1.85 – 12.9, nominal error range) Mg C ha^{-1} for below-ground biomass. Scaled nationally to the area of LUM vegetated wetlands, we estimated total stocks in 2012 as 6,000,274 (1,500,068 – 10,500,479, nominal error range) Mg of vegetation carbon. High uncertainties in estimates from shrublands underpinned a high uncertainty in the grand mean for above ground carbon density (with confidence limits 45% above- and below- the grand mean). Insufficient data on belowground biomass from our literature review prevented us from quantifying uncertainty in below-ground carbon stocks.

We assessed two methods to quantify change in vegetation carbon stocks from 2008 – 2016. In the first method, we applied a constant carbon density value (i.e., the grand mean) across LUM vegetated non forest wetlands, so that changes in total carbon stocks were directly proportional to changes in wetland area between reporting periods. In the second method, we applied LCDB intersects to each reporting period to provide spatially-explicit estimates of carbon stocks. In this second method, changes in total carbon stocks depend both on the total area of wetlands and the mapped land cover in those wetlands between reporting periods. Both approaches yielded a loss in wetland vegetation carbon stocks over the period 2008–2016, but the size of the loss was greater with the second approach (96,790 Mg C, a 1.60% loss) relative to the first approach (71,547 Mg, a 1.18% loss).

We considered a further option for reporting losses over the period 2008–2016. We kept the LCDB composition of the LUM static to our 2012 estimate (as per our first method, above), and only reported on losses from the area mapped as vegetated wetlands by the LUM using that static area-weighted mean. We assessed the similarity of the LCDB composition within the area mapped as vegetated wetlands by the LUM in 2012 to the LCDB composition within the area of vegetated wetlands *lost* from the LUM over the period 2008–2016. The LCDB composition in these two areas was not similar, with substantial over- and under-representation of key land cover categories, including under-representation of Herbaceous Freshwater Vegetation in the area lost. We determined the implications of these differences by calculating the area-weighted grand mean carbon density for the area of vegetated wetlands *lost* from the LUM over the period 2008–2016, which was 21.32 Mg ha^{-1}, 23% less than the area-weighted grand mean for 2012 (27.62 Mg ha^{-1}).

The study identified the following recommendations to improve wetland C state and trend estimates:

1. Refine our approach for applying a coastal-inland delineation by running sensitivity analyses to determine combinations of elevation and distance from the coast line to identify combinations of these variables that yield the most satisfactory partition of LUM vegetated wetlands into coastal and freshwater ecosystems based on the relative apportionment of freshwater and saline herbaceous vegetation, defined from LCDB, in each ecosystem.
2. Collect new, empirical estimates of vegetation carbon stocks paired with an unbiased survey of vegetated wetlands. Our estimates of carbon stocks had high uncertainty because the data available from the literature review were fragmentary, particularly for woody vegetation types, belowground pools, and coastal ecosystems.
3. Determine the recovery potential of carbon stocks on non-forest vegetated wetlands in different contexts.
4. Account for changes in land cover within the area mapped by the LUM at each measurement period.

Introduction

The Ministry for the Environment (MfE) is responsible for documenting and reporting on carbon stocks and carbon stock changes in New Zealand. MfE have identified the need to improve the method for reporting on carbon stocks and stock changes associated with vegetation biomass on areas mapped as non-forest vegetated wetlands by the Land Use and Carbon Accounting System (LUCAS) Land Use Map (LUM)[a], and for reporting on land use changes into or out of the non-forest vegetated wetland class of the LUM. There are no default emission factor values available for the vegetated wetland class in the IPCC 2006 and 2019 guidelines, or the IPCC Wetlands Supplement (IPCC 2014). The IPCC Wetlands Supplement (IPCC 2014) requires countries to report on 'coastal' and 'inland' wetlands separately, hence there is a need for country-specific estimates that distinguish 'coastal' or 'inland' wetland types.

Non-forest vegetated wetlands encompass a high diversity of ecosystems that vary widely in their plant species composition, function, and structure (Johnson and Gerbeaux 2004). They include short-statured turfs of mat-forming species through to tall shrublands with dense herbaceous understories. Surface water is present all year in some, but absent entirely in others. Wetlands can be saline or freshwater, and freshwater wetlands range in their hydrology and abiotic characteristics from nutrient-rich swamps and marshes to nutrient-impoverished bogs (Johnson and Gerbeaux 2004, Hunt 2007, Clarkson et al. 2015). New Zealand has lost > 90% of its wetlands since European settlement (Ausseil et al. 2011), and losses are ongoing (Robertson 2016, Robertson et al. 2019). There is growing interest in restoring wetland ecosystems to recover some of their lost biogeochemical and ecological functions (Peters & Clarkson 2010).

Vegetated wetlands are mapped as one unit by the LUM without discriminating different types of wetlands that are likely to have different carbon stocks (e.g. ombrotrophic bogs with herbaceous *Empodisma* vegetation vs. gleyed soils with mānuka shrublands). Furthermore, these different wetland types may vary in their vulnerability to land-use change (McGlone 2009, Ausseil et al. 2011, Robertson et al. 2019). Similarly, wetlands will vary in the degree to which they are 'stable' vs undergoing changes in physiognomy and composition because of natural succession (e.g. recovery of wood wetlands after historical fires; Johnson 2001, McGlone 2009). Lastly, coastal wetlands may have lower stocks and productivity than comparable wetlands inland because of the constraints on plant growth from high salinity, onshore winds and frequent disturbance by tidal surges. For these reasons, it is important to consider variation in wetland type within the LUM when estimating carbon stocks.

Objectives

1. Determine an approach for **subdividing the LUM vegetated wetland class into coastal and inland land cover classes** to allow separate reporting of coastal and inland carbon stocks in vegetated wetlands. Use the LCDB and appropriate GIS layers, and calculate (i) the proportion of the total vegetated wetland area for each of these subclasses as of 2012 and (ii) the proportion of the total area of vegetated wetland lost between 2007 and 2016 that was in each of these subclasses.
2. Search the **literature** and online databases to find values of vegetation carbon stocks for wetlands in New Zealand. Tabulate data, partition data into above- and below-ground, and live and dead components where possible, assign wetland type, LUM class, and New Zealand Land Cover Database (LCDB) class to each published study, and summarise values. Summarised values will include the uncertainty around each estimate. Summarise rates of vegetation carbon stock change from published studies, where available.

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[a] https://data.mfe.govt.nz/document/22713-lum-1990-2008-2012-2016-v008-data-descriptionpdf/download/

3. Calculate **area-weighted carbon stock values** for the total area mapped as vegetated wetlands by the LUM in 2012, and for coastal and inland vegetated wetlands separately, if possible. Report on **changes in area-weighted carbon stocks** in vegetated wetlands between 2008 and 2016 using two approaches. The first will always use the 2012 area-weighted mean carbon stock and apply this to the area mapped as LUM vegetated wetlands in each time period. The second approach will recalculate the area-weighted mean carbon stock in each time period using the land cover classes in each period.

Methods

Subdividing the LUM vegetated wetland class into coastal and inland land cover classes

Spatial data description and overview

We used two key data sources in this report: the LUCAS LUM[b], and the New Zealand Land Cover Database (LCDB)[c]. For all analyses, we used LUM v.8 (described further below) and LCDB v.5 (also described further below). Both the LUM and LCDB incorporate data relating to previous timesteps (e.g. 2016, 2012, *and* 2008 for the LUM). Unless otherwise stated, we used the 2012 time period for both LUM and LCDB.

The LUCAS LUM captures wetlands as: (i) open water wetlands (i.e., lakes, rivers, dams, reservoirs, and estuaries where they are within the New Zealand coastline) and (ii) *non-forest* vegetated wetlands (i.e., herbaceous and/or non-forest woody vegetation, including trees of any stature, in a wetland context (periodically or permanently flooded); areas under peat extraction; estuarine–tidal areas including mangroves; MfE 2022, [b]). Our assessment of wetland extent relied on LUM v.8, which updated pre-existing mapping with improved wetland detection and delineation (Newsome et al. 2018) according to two spatial layers: the LCDB at v4.0 - v4.1 and the Waters of National Importance (WONI) mapping, which reviewed the current and historic location and extent of New Zealand wetlands by wetland type (Ausseil et al. 2008).

Since wetlands span a wide range of vegetation types and structures, we intersected the spatial layer of vegetated wetlands defined by the LUM with land cover type mapping as defined by the land cover database LCDB v.5. By intersecting the LUM vegetated wetlands with LCDB, we seek some description of the structural composition of wetlands and their relative extent. This could aid both the estimation of the carbon stored by vegetation in these systems and carbon change (as captured by the mapped land cover). LCDB v.5 is the latest release of the land cover data base, which maps 33 land cover classes with improved delineation and mapping accuracy backtracked onto all mapping years (1996/7, 2001/2, 2008/9, 2012/13, 2018/19)[c]. All land cover classes overlapping with vegetated wetlands as mapped by the LUM are included in our assessment, and so they span a wide spectrum of vegetation structures, from herbaceous, to shrub and forest cover.

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[b] https://environment.govt.nz/assets/publications/GhG-Inventory/New-Zealand-Greenhouse-Gas-Inventory-1990-2020-Chapters-1-15.pdf

[c] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

Method for subdividing coastal and inland land cover classes

The IPCC Wetlands Supplement (IPCC 2014; refer Note 8) provides the guidance in delineating coastal land:

> Coastal land is land at or near the coast. It is good practice for a country to clearly define the concept of 'coastal land' and its sea- and landward limits in accordance with its national circumstances, and to apply that definition consistently across the entire national land area and over time. All land that is not coastal is inland.
>
> A coastal wetland is a wetland (see Note 4) at or near the coast that is influenced by brackish/saline water and/or astronomical tides. Coastal wetland may occur on both organic and mineral soils. Brackish/saline water is water that normally contains more than 0.5 or more parts per thousand (ppt) of dissolved salts. Every mineral soil wetland that is neither a coastal wetland, a Flooded Land (see Note 6) nor a constructed wetland for waste water treatment (see Note 7) is classified as inland wetland (cf. Chapter 5).

We considered multiple ways of delineating coastal and inland wetlands, in the absence of a definitive national layer with attributes as to salinity and coastal influence. We first considered defining 'coastal wetlands' as areas mapped as 'saline herbaceous vegetation' by LCDB. We rejected this for two reasons: firstly, inland saline areas would be included without some further criteria; secondly, coastal influence is more stable through time than land cover, and we consider land cover could change in the absence in any change of tidal influence. This latter issue could violate the IPCC definition (above) that a definition be applied 'consistently over time'.

We then considered an approach which defined coastal wetlands as those within a certain distance of New Zealand's coastline. We found this to be an imperfect, but preferred, approach. We used a widely applied version of the New Zealand coastline at a 1:50,000 resolution, available from the LINZ website[d]. As an approximate guide for selecting a distance from the coastline, we plotted the distribution of each LCDB cover class as a function of the distance to this coastline (Figure 1) and determined that across the first 500 m from the coastline, 'saline herbaceous vegetation' peaked at ca.110 m. To accommodate those areas inland of this peak we chose 150 m as the distance from coast within which a wetland polygon would be classified as 'coastal'; anything further inland was 'inland' (Figure 1). We acknowledge that this approach is imperfect because both the LINZ coastline and saline wetlands are part of LCDB so they are not independent.

[d] https://data.linz.govt.nz/layer/51153-nz-coastlines-and-islands-polygons-topo-150k

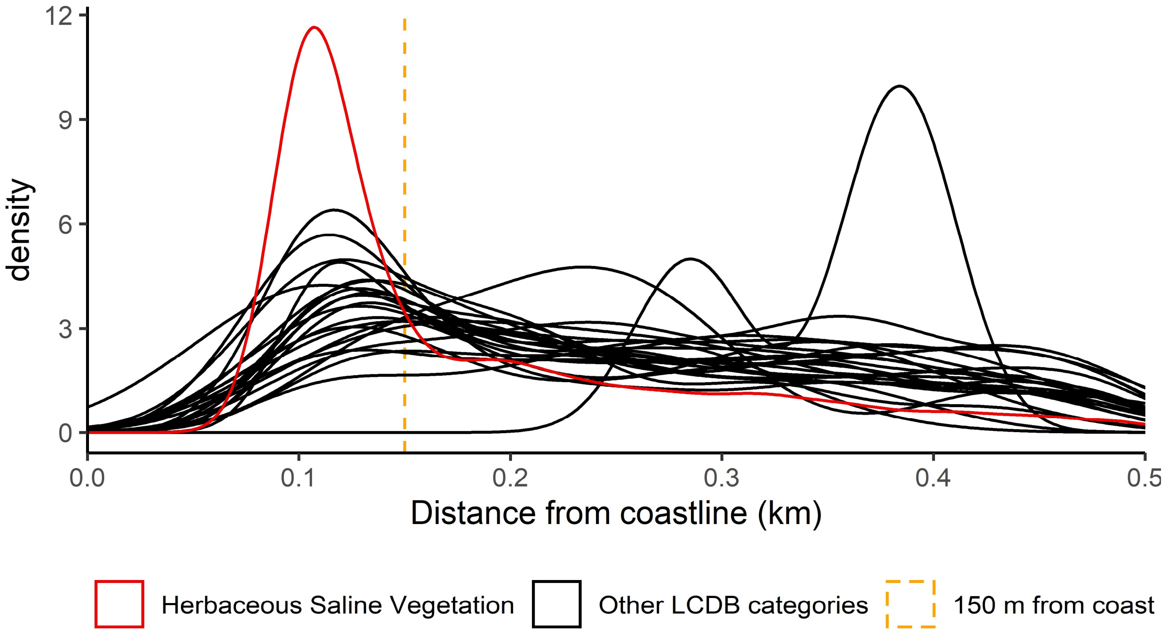

Figure 1: Density plot [*] showing the distribution of LCDB-mapped 'Herbaceous Saline Vegetation' along a distance from coastline gradient, along with other LCDB categories. All other LCDB categories are included, except that we exclude LCDB categories which are irrelevant or by their nature also coastal – these are: 'Not Land', 'Mangrove', 'Estuarine Open Water', and 'Transport Infrastructure'. [*] A density plot is similar to a histogram, but shows the distribution of variables of interest, where the area under the curve sums to 1. A density plot is unitless.

We then included two modifications of the 1:50,000 coastline to maximise the accuracy of the layer, while keeping it as simple as possible in line with IPCC guidance (above). The first modification was applied to amend the coastline in areas of saline and tidal influence. When we examined the distribution around the coastline of 'herbaceous saline vegetation', a reasonable indicator of tidal influence in coastal areas, we found that the coastline missed tidal areas in systems such as lagoons that are regularly or intermittently open to the sea. Two examples are Ōkarito Lagoon, Westland (strong tidal influence) and Waituna Lagoon, Southland/Murihiku (intermittent tidal influence but saline influenced) (see as an example Figure 2, below). To remedy this issue, we used the "NZ Coastal Hydrosystems layer" (Hume et al. 2016) to modify the coastline layer, as this allowed us to incorporate large river mouths and lagoon. The NZ Coastal Hydrosystems layer describes 'coastal features that span a gradient from near coast freshwater lakes/wetlands (lacustrine/palustrine environments) to marine'. We did *not* exclude any features from this layer, such as 'freshwater lakes', but this could be incorporated into future work after further investigation.

We combined the coastline (negatively buffered by 150 m) and coastal hydrosystems layer (positively buffered by 150 m) to create a revised inland/coastal boundary for New Zealand. Except in cases where the coastal hydrosystems layer identified features within the coastline of NZ, the revised inland/coastal boundary lay 150 m inland of the existing coastline.

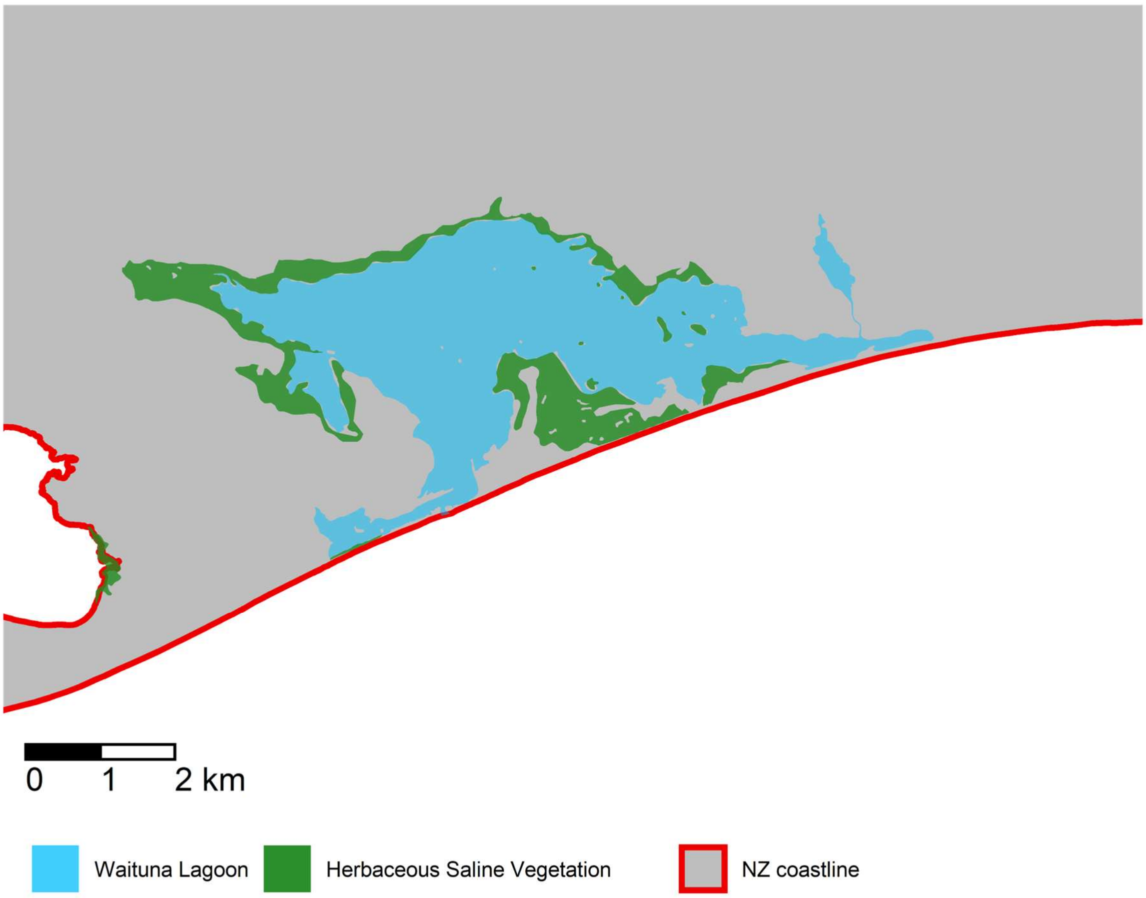

Figure 2: **Illustration of the coastline of NZ and how it excludes saline influenced hydrosystems, such as Waituna Lagoon (Southland), around which lies LCDB-mapped herbaceous saline vegetation.**

The second modification was to account for sudden changes in elevation near the coast – cliffs, for example – and to allow wetlands near the coastline, but highly vertically displaced from the ocean, to be considered to be 'inland' wetlands. We used a 25 m digital elevation model[e] (DEM) for New Zealand to shift the revised inland/coastal boundary back towards the ocean where necessary. Future improvements might include a different way of delineating cliffs (e.g., using different elevation from 25 m, or LiDAR, when available at the national-scale).

This process (coastline -> hydrosystems -> DEM; Figure 3) created a revised inland/coastal boundary. We then undertook a spatial union of the revised boundary with the union of the LUM/LCDB layers. This allowed us to tabulate the area of inland/coastal wetlands within the LUM vegetated wetlands class, by LCDB category.

[e] https://lris.scinfo.org.nz/layer/48127-nzdem-south-island-25-metre/ and https://lris.scinfo.org.nz/layer/48131-nzdem-north-island-25-metre/

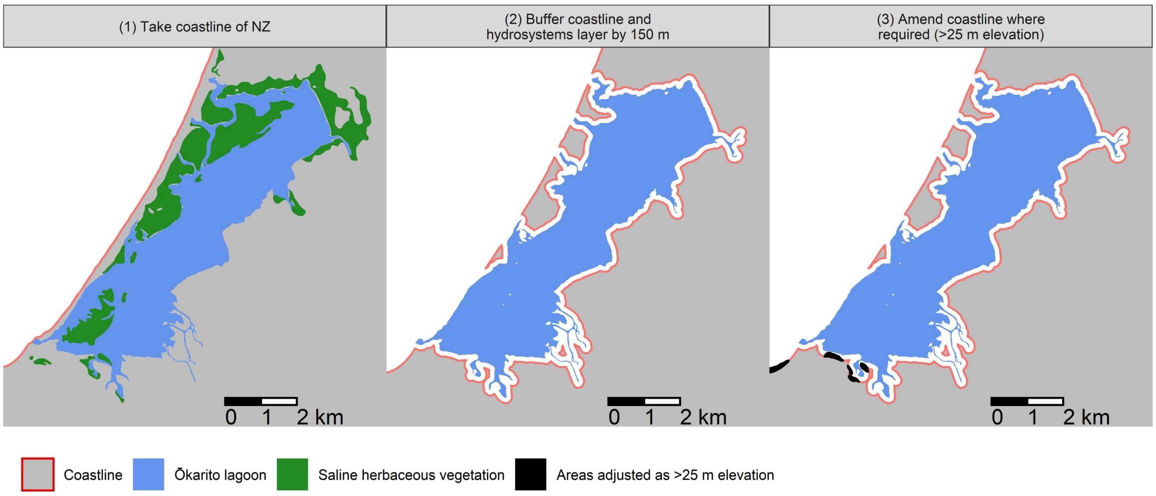

Figure 3: Illustration of the steps to calculate the revised delineation of coastal vs. inland wetlands.

Literature review of wetland vegetation carbon stocks

To review information on vegetation carbon for New Zealand wetlands (and ultimately recommend carbon stock values for the LUM vegetated wetlands layer) we conducted a comprehensive literature search. We used standard search tools: Web of Science; a New Zealand database of theses from all tertiary academic institutions (*nzresearch.org.nz*); and the Manaaki Whenua – Landcare Research library catalogue of unpublished reports. These were complemented with Google Scholar searches to discover articles that had cited key papers. We searched for any studies that contained the terms ‘wetland’ and ‘New Zealand’, and ‘biomass’ or ‘carbon’. Search outputs were screened to identify and classify publications relevant to our objectives. We first screened by publication title, and then by abstract and methods. Our focus was vegetation biomass carbon so we discarded studies on soil carbon, soluble organic carbon (SOC), litter decomposition, wastewater treatment, methane fluxes, or biomass/carbon of individual plants (cf. those that sampled vegetation stands or vegetation per unit area). Any studies on shrubland or forest vegetation in a wetland context were also captured by our literature search.

Once relevant studies were identified, we sourced and scanned details on location, wetland type, biomass pool, vegetation carbon stock, information on sampling methods, and ancillary information that could help interpret the values (e.g., drainage history). Where biomass estimates were only available in graphic format, we extracted the plotted values with Plot Digitiser 2.6.6 (Huwaldt 2014).

For each data source we compiled reported estimates of live, dead- and total- above-ground biomass pools and included below-ground pools where available. We also searched for any information on rates of vegetation carbon change. As compiled here, total above-ground biomass pools account both for live and dead plant material (reported in some sources and abundant for tussocks, restiad rushes and some deciduous taxa) as well as for coarse deadwood in woody vegetation types; soil litter was generally not reported in the reviewed sources and was thus not included in our assessment. Soil carbon and historical buried deadwood (e.g., swamp kauri) were out-of-scope for this exercise. In the few instances of vegetation types dominated by deciduous species (as in some rhizomatous macrophytes) where biomass values were reported at different times in a year, we computed and relied on the inter-seasonal mean. For each study, we compiled the reported sources of errors (either standard deviations or standard errors).

We completed the assembly of biomass data with a few additional steps that enabled the sources to be compared and synthesised by subsequent analysis. First, we standardised wetland type and structural class of vegetation following definitions from Johnson & Gerbeaux (2004). Second, we transformed estimates of biomass density into standard carbon units (Mg C ha^{-1}). We did this by assuming a 44% carbon content in dried plant biomass for herbaceous species and 42% for mangroves. The 44% content was based on an approximated 0.2-0.5-0.3 stem-leaf-root biomass fractions for herbaceous plants (Poorter et al. 2011) and a 0.424-0.447-0.425 stem-leaf-root carbon concentration for herbaceous plants (Ma et al. 2018). For mangroves we relied on the 42% carbon concentration determined for *Avicennia marina* wood (Bulmer et al. 2016a). Third, we converted any measures of uncertainty reported as standard errors into standard deviations. Last, we used the location data of study sites to determine their LCDB v.5 class as of 2012.

New Zealand-specific area-weighted approaches to estimating state and trend of wetland vegetation carbon stocks

Once the records identified by the literature review were compiled and standardised, we estimated the mean carbon density in biomass for different wetland types, vegetation structural classes, and LCDB v.5 land cover classes captured by the studies identified in the review. We used a random-effects metanalyses to summarise the 'pooled' mean carbon densities for different groups. The method combines and weights the estimates from individual studies according to their precision (individual means are weighted by the inverse of associated variances) and accounts for the within- and between-study variances. A random-effects meta-analysis accounts for two variance components (within- and between-study variances) by allowing the means from different studies to differ from one another as a random sample from a population of outcomes (Gurevitch et al. 2018, Harrer et al. 2021). In line with available data, we estimated group means both for total above-ground and below-ground biomass. The meta-analyses results are presented via standard 'forest' diagrams (Gurevitch et al. 2018, Harrer et al. 2021) and include accounts of the variation between source studies. Two measures of between-study heterogeneity are presented: τ, an estimate of the standard deviation between individual means (that excludes within study variances), and the I^2 statistic, a measure of the percentage of variability in effect sizes that is not caused by sampling error. As a rule of thumb, I^2 values of 25%, 50% and 75% are correspondingly interpreted as low, moderate, and substantial between-study heterogeneity (Harrer et al. 2021).

We scaled up carbon densities from vegetation structural classes to the LUM using LCDB. We intersected the LUM vegetated wetlands class with LCDB to calculate the area of each LCDB type; by assigning structural classes to LCDB types we were able to calculate area-weighted estimates of carbon stocks. We refer here to carbon density on an area basis and simply as values of carbon stock per unit area, consistent with use elsewhere in forests (e.g., Mascaro et al 2011, Pan et al. 2013) and wetlands (e.g., Lovelock et al 2017, Tran et al 2017).

Carbon densities for vegetation structural classes (Johnson and Gerbeaux 2004) were assigned to land cover classes based on class descriptions from LCDB v.5 (Appendix B). Where possible, we assigned structural classes to LCDB classes using information in the source studies. However, given the many land cover types intersecting mapped wetlands and given that our literature review only identified biomass records for herbaceous vegetation in a wetland context, we had to draw estimated or surrogate carbon density values from alternative sources for various land cover classes. Values for grasslands and croplands were obtained from literature searches and consultation with colleagues (see footnotes to Table 3 for details of this process). We used existing estimates of carbon density from the LUCAS natural forest inventory to provide values for indigenous forests and shrublands Holdaway et al. 2014 for shrublands, Paul et al. 2019 for forests) but only used subsets of the plots in specific forest classes that were selected as proxies for the LCDB cover class descriptions (see footnotes to Table 3, Wiser et al 2011, Wiser and De Cáceres 2013).

Where more than one vegetation structural class informed a given land cover class, we took an unweighted average to assign to the land cover class. We lacked the information to do an area-weighted average as there is no data on the extent of different wetland vegetation structural classes in New Zealand. Mangroves were an exception, as the relative extent of dwarf and tall mangroves has been assessed for a large region of northern New Zealand (Suyadi et al. 2020) and thus these two height classes could be accounted for.

New Zealand-specific biomass and carbon data were unavailable to split estimates for each LCDB class that fell into the coastal and inland areas into stocks of costal-biomass and inland-biomass. This in turn impeded a meaningful split of carbon calculations for inland and coastal areas. Primary data gathering is required to address this data gap.

We concluded by obtaining (i) an area-weighted grand mean carbon density for vegetation in wetlands, with the relative extent of component land cover classes informing the weights on the grand mean and (ii) total carbon stocks for wetland vegetation nationally. And to capture some of the wide variety of LCDB v.5 classes intersecting the LUM vegetated wetland, we also present weighted means for groups of aggregated cover classes.

Error propagation and estimated uncertainties

At the level of vegetation structural class, we obtained estimated uncertainties from the meta-analysis, where τ and the corresponding τ^2 provide measures of between-study heterogeneity (Harrer et al. 2021). Specifically, τ is an estimate of the standard deviation of effect sizes, and τ^2 is an estimate of the variance of effect sizes. Most of the compiled records correspond to single location estimates and so these measures of between-study heterogeneity may be interpreted as capturing some of the spatial heterogeneity in carbon densities. Only two of the herbaceous structural classes (rushlands and mixed rushlands) had sufficient data to allow estimates of τ and thus we assumed equivalent levels of heterogeneity for other herbaceous structural classes and scaled those by the corresponding coefficient of variation (CV, where CV = SD/mean = τ/mean). Comparable approaches are used in ecosystem modelling (Håkanson 2003). In the case of estimated carbon densities for shrublands and forests, we relied on the standard error of estimates as a measure of variability. Since the standard error is an estimate of the standard deviation for the population mean (Gotelli and Ellison 2004) we interpret it to be at the same level as τ (a measure of deviation of the population mean around individual sample means). Here also, given the systematic and wide distribution of LUCAS forest plots, these estimates are interpreted to partly capture the spatial variability in carbon densities within specific forest classes.

The variances from individual carbon estimates (structural classes within a land cover class) were then combined or 'propagated' by quadrature (the square root of the mean of squares), where the variance for a mean estimated from *n* independent random variables can simply be estimated from the average of their variances (Morrison 2021, [f]). Corresponding with our procedure for estimating an area-weighted grand mean carbon density, we propagated the corresponding uncertainties by using weighted averages in quadrature:

$$\sigma_w = \sqrt{\frac{\omega_i \times \sigma_i^2 + \ldots + \omega_n \times \sigma_n^2}{\omega_i + \ldots + \omega_n}}$$

where the weighted standard deviation σ_w is estimated from a total n of i individual standard deviations σ_i weighted by their corresponding weights ω_i (extent of land cover class in our case).

[f] https://jameshanley.github.io/statbook/randomVariables.html#sumsmeansdifferences-of-rvs

Uncertainties are estimated with their own level of uncertainty (Harrer et al. 2021) and as many of the uncertainties presented here are approximated from surrogates or based on small sample sizes, they should be interpreted as indicative and applied with caution. We were unable to estimate uncertainties for below-ground carbon stocks due to insufficient studies reporting these stocks in our literature review. Specifically, we could not obtain estimates of between-study uncertainty for below-ground carbon in wetland vegetation because there was only one density estimate for each of three different structural vegetation classes in herbaceous vegetation (see Figure 8, below). While an estimate of uncertainty was feasible and is presented for mangroves (Figure 8), their atypical allometries and high investment in below-ground biomass meant this could not realistically be used to approximate uncertainties in below-ground carbon for other vegetation types. As a result, we default to reporting a nominal error range of ±75% for the mean (IPCC 2006) both for below-ground and for total biomass carbon. The range is interpreted as equivalent to two times the standard deviation above and below the mean (IPCC 2006).

Estimating changes in carbon stocks arising from land-use change

We were asked to calculate carbon stock change (2008-2016) using two methods:

1. Applying a weighted mean of carbon ha^{-1} derived from 2012 LCDB composition. This method assumes no (or negligible) net land cover change, such that overall land cover composition of the LUM vegetated wetlands class remains the same (using the methods described in the previous section, above)
2. Reweighting the mean carbon ha^{-1} for years 2008 and 2016, using the 2008 and 2018 LCDB data, respectively, allowing for land cover to be incorporated. This uses the same method as for 2012.

An option for reporting change over the period 2008–2016 would be to assume that the LCDB composition of the LUM remains static (as per method (a)), and only report on losses from the area mapped as vegetated wetlands by the LUM using that static area-weighted mean. To evaluate this method we assessed the similarity of the LCDB composition within the area mapped as vegetated wetlands by the LUM in 2012 to the LCDB composition within the area of vegetated wetlands *lost* from the LUM over the period 2008–2016.

Finally, we were asked to consider an additional, hybrid approach, which re-weights, once, *only the areas in 2016 that are additional* to the 2012 LUM vegetated wetlands area. However, we rejected this approach because areas that transition into LUM vegetated wetlands will be assigned the LCDB class at the point of that first transition, but many subsequent LCDB transitions are likely to occur and these will not be captured. This leaves the method open to systematic under-estimates of new LUM vegetated wetlands areas. Such wetland land cover transitions have been described in Burge et al. (2017) (Figure 4).

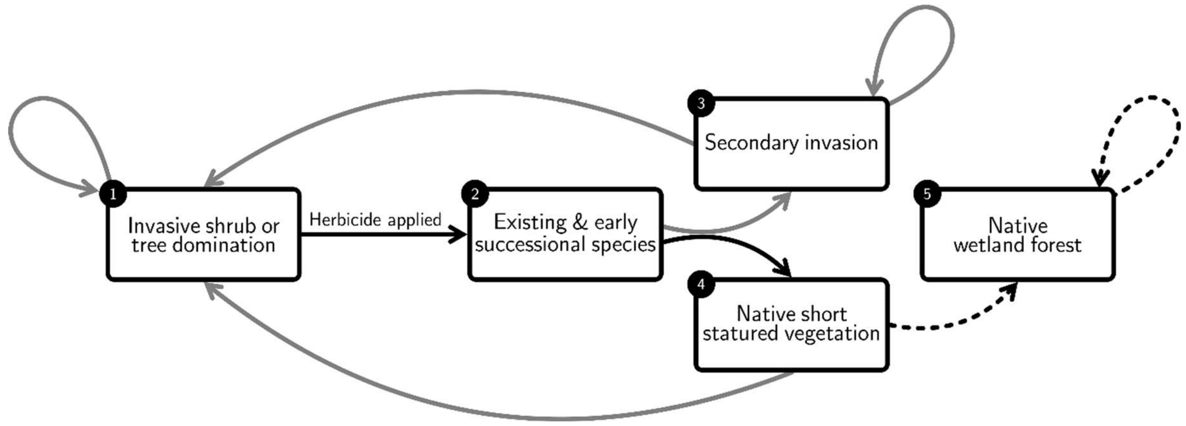

Figure 4: **A state-and-transition model for wetland sites invaded by shrub or tree species and subsequently treated with herbicide showing possible trajectories of change (reproduced from Burge et al 2017). Black lines indicate the trajectory at Whangamarino (North Island, New Zealand). Black dashed lines indicate a potential trajectory after intensive management. Grey lines indicate additional potential trajectories; stable states are indicated by lines to and from the same node (nodes 1, 3b and 4). At least four LCDB classes could occur across the trajectories.**

Results

Subdividing the LUM vegetated wetland class into coastal and inland land cover classes

We calculated the area of LUM vegetated wetland mapped as 'inland' and 'coastal' areas, for the 2012 year. The areas of coastal LUM vegetated wetland was 15,868 ha (7.3% of LUM vegetated wetland class) and inland was 201,366 ha (92.7% of LUM vegetated wetland class). These areas are partitioned by LCDB classes in Table 1. An example of the coastal/inland delineation using Ōkarito Lagoon is shown in Figure 5.

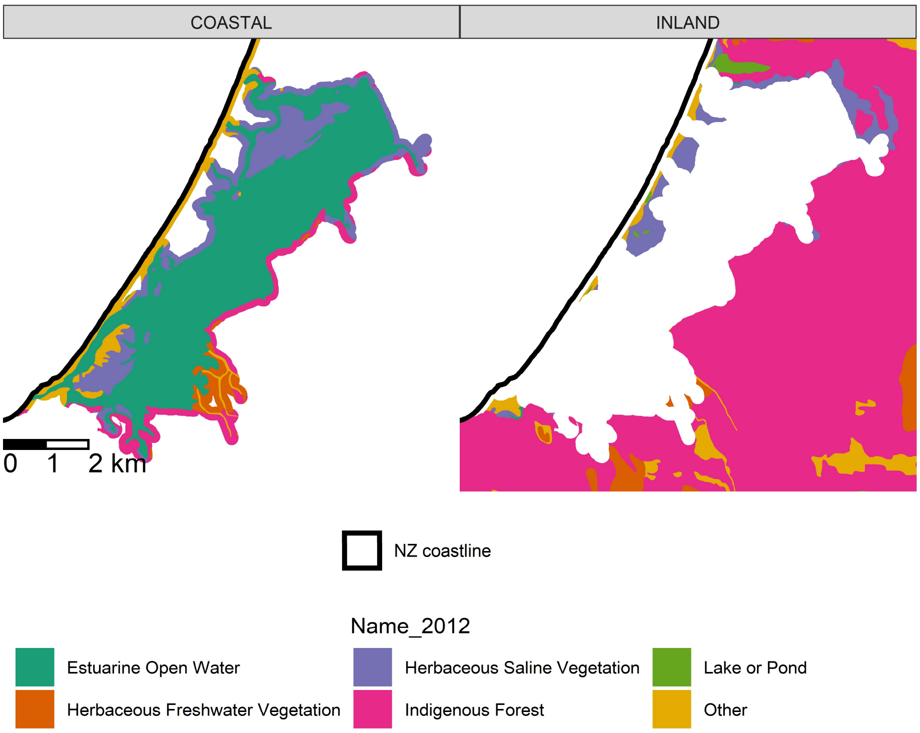

Figure 5: Example of LCDB classes split by a coastal/inland delineation, at Ōkarito Lagoon. Note that for visual simplicity land covers were not subset to just the LUM vegetated wetlands class, and thus land covers within this illustration represent a range of land uses.

Table 1: Area (ha) of LUM vegetated wetlands in 2012 by LCDB class in 2012 split by a coastal/inland delineation. See Figure 5 for graphical example.

LCDB class in 2012	Coastal	Inland
Not covered by LCDB[g]	195.1	0.0
Alpine Grass/Herbfield	0.0	78.1
Broadleaved Indigenous Hardwoods	192.2	3369.6
Built-up Area (settlement)	12.5	21.1
Deciduous Hardwoods	571.6	10227.5
Depleted Grassland	0.0	28.6
Estuarine Open Water	1393.3	544.6
Exotic Forest	97.6	1059.6
Fernland	70.2	3789
Flaxland	416	5173.2
Forest - Harvested	3.2	77.4
Gorse and/or Broom	158.5	2329.7
Gravel or Rock	4.1	537.6
Herbaceous Freshwater Vegetation	2043	110158.1
Herbaceous Saline Vegetation	7719.4	4410.7
High Producing Exotic Grassland	672.9	7820.3
Indigenous Forest	172.7	5173.2
Lake or Pond	76.1	1271.2
Landslide	0.0	2.3
Low Producing Grassland	422.5	6869
Mangrove	562.1	58.7
Manuka and/or Kanuka	597.1	26003.9
Matagouri or Grey Scrub	47.2	465.3
Mixed Exotic Shrubland	115	1060.6
Orchard, Vineyard or Other Perennial Crop	1.9	7.5
River	140.5	447.6
Sand or Gravel	151.9	480
Short-rotation Cropland	7.1	69.6
Sub Alpine Shrubland	0.0	66
Surface Mine or Dump	1.9	22.1
Tall Tussock Grassland	6	9699.2
Transport Infrastructure	0.6	1.6
Urban Parkland/Open Space	15.4	43.3

[g] further investigation of these areas using aerial imagery could be done to assign vegetation structure

Literature review of wetland vegetation carbon stocks

We identified 42 original biomass estimates for wetland vegetation from 14 New Zealand studies mostly conducted from the 2000s, with three earlier studies (Appendix A). While most records corresponded to location-specific estimates, 11 records from two studies were available as multi-site means. All the source studies were conducted in natural, and mostly unmodified wetlands. Most studies did not involve experimental manipulations but for the few that were experimental studies (Clarkson et al. 2009, Burge et al. 2020), we used biomass records from untreated control plots.

Biomass was usually estimated from harvests within a set area, except for mangroves, which relied on locally-derived biomass allometries. Two of the compiled records only reported fresh plant biomass and were included in the summary table (Appendix A) and used to match wetland structural classes to land cover classes, but were otherwise left out from grouped biomass estimates. Further, some source studies reported only live above-ground biomass and thus could not be included in the analyses of total above-ground carbon.

Compiled biomass estimates spanned six wetland types and six structural classes (plus subdivisions in rushlands and mangroves) (Figure 6, Figure 7, Figure 8). However, estimates appear to be lacking for some wetland vegetation types. We did not find any studies that assessed biomass for flaxlands, mānuka wetlands, exotic willows or wetlands with woody vegetation in general.

None of the studies reporting on vegetation biomass assessed biomass *change* and we did not find any direct assessments of vegetation biomass or carbon *change* on unmanaged New Zealand wetlands. Some sources (e.g., Goodrich et al. 2017) related to total net carbon exchange and/or methane budgets in peatlands measured by carbon flux towers that account for whole ecosystem exchange from both vegetation and soils. A few studies related to restoration plantings in wetlands or responses at individual plant level (e.g., Waring 2017), but these studies do not account for variable size structures or plant competition and were thus not suitable for quantifying vegetation biomass or carbon change at stand level.

For wetland types, total above-ground carbon varied from a group mean of 3.6 Mg C ha^{-1} for pakihi to 10.8 Mg C ha^{-1} for swamps and to 32.0 C ha^{-1} for mangroves (Figure 6). Among structural classes, total above-ground carbon varied from a mean of 4.8 Mg C ha^{-1} for sedgelands to 10.5 Mg C ha^{-1} for reedlands and from 21.0 Mg C ha^{-1} for dwarf mangroves to 40.3 Mg C ha^{-1} for tall mangroves (Figure 7). Estimates of below-ground biomass were uncommon (n = 10 estimates from 3 studies, Appendix A) but the limited data available suggest that below-ground carbon was 34–83% that of total above-ground carbon in three herbaceous structural classes and 75–226% that of total above-round carbon in mangroves (Figure 8).

Six structural classes were represented among the 25 source records with associated map locations (i.e., all the studied structural classes except herbfields and some combinations of mixed rushlands). The matches between these structural classes and three land cover classes mapped by LCDB v.5 were ecologically plausible: 13 locations with non-woody structural vegetation were mapped by LCDB v.5 as 'herbaceous freshwater vegetation', one mixed rushland /tussockland was mapped as tussockland, and 11 mangrove sites were mapped as mangroves by LCDB v.5 (Figure 9). Changes in land use and land cover between sampling dates from source studies and mapping dates are possible. However, we suggest this is unlikely because most studies (except for mangroves) were conducted in unmodified wetlands, including those on public conservation land.

When mapped biomass estimates were grouped by these land cover classes we found that, mean total above-ground carbon in mangroves was more than double that of herbaceous freshwater vegetation (Figure 10). Mean total below-ground vegetation carbon in mangroves was an order of magnitude greater than that in freshwater vegetation (Figure 10).

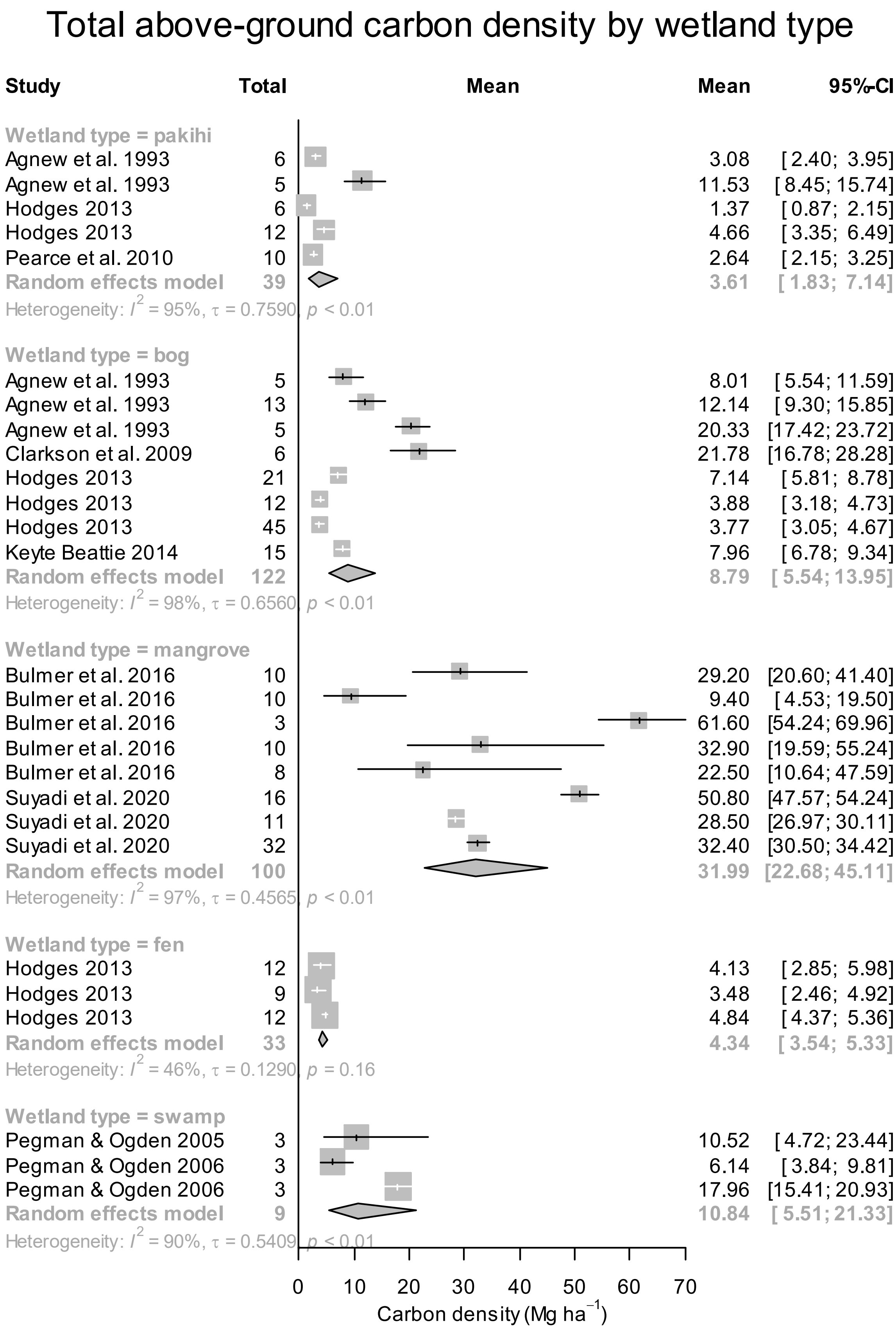

Figure 6: **Summary of total above-ground carbon density by wetland type. Cross-study group means and heterogeneity estimates (in grey) were derived from a random effects meta-analysis.**

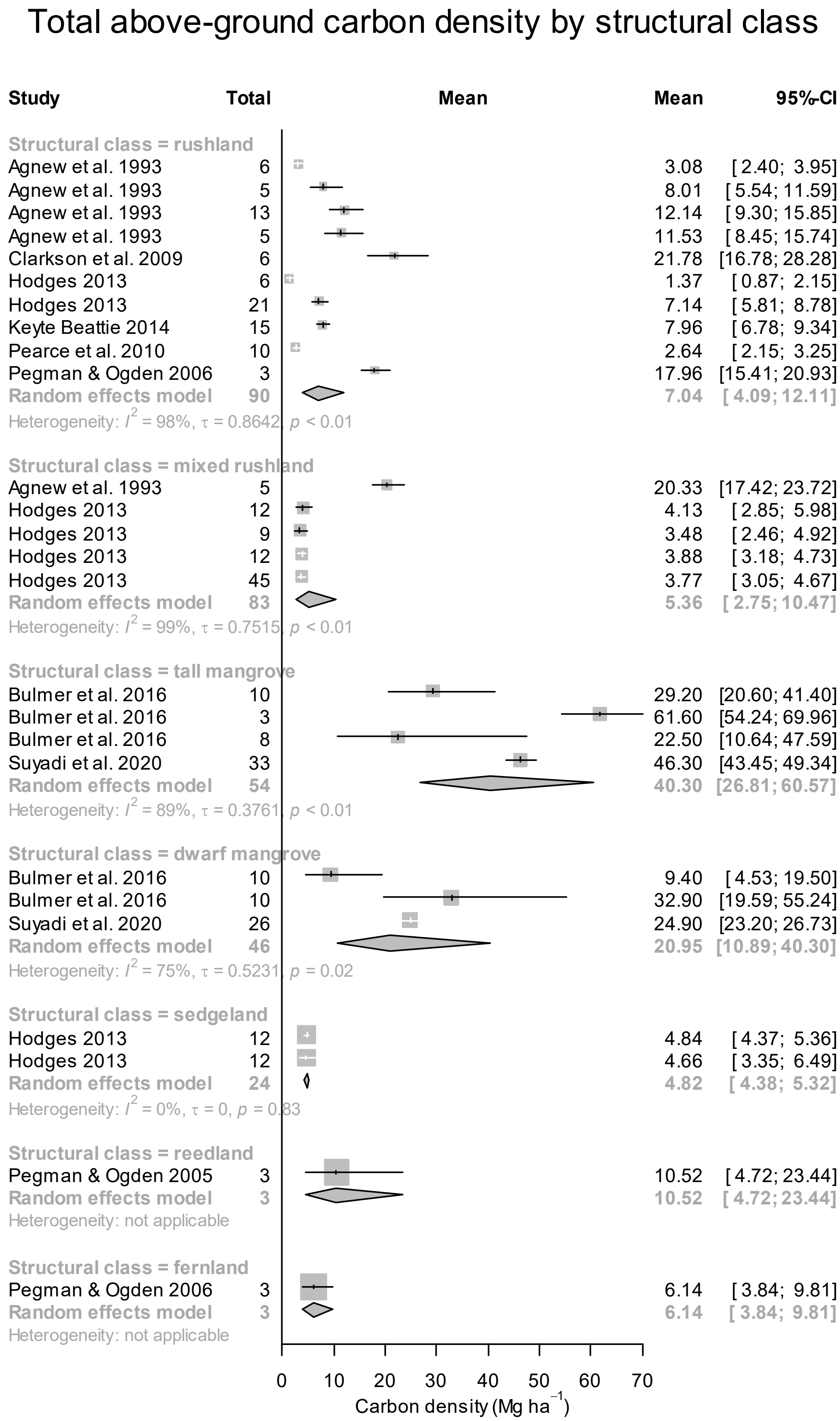

Figure 7: **Summary of total above-ground carbon density by vegetation structural class. Cross-study group means and heterogeneity estimates (in grey) were derived from a random effects meta-analysis.**

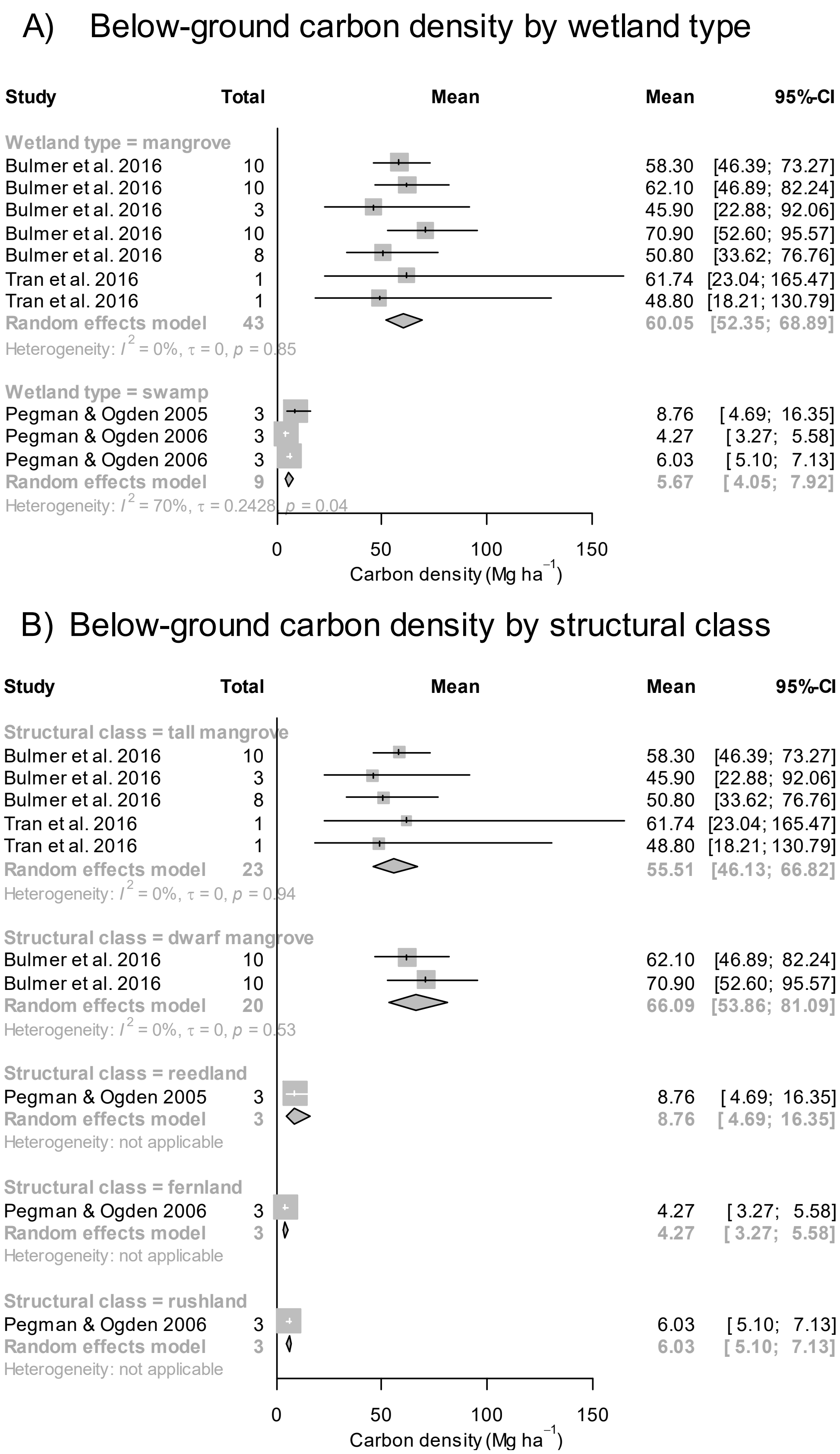

Figure 8 **Summary of total below-ground carbon density by (A) wetland type and (B) structural class. Cross-study group means and heterogeneity estimates (in grey) were derived from a random effects meta-analysis.**

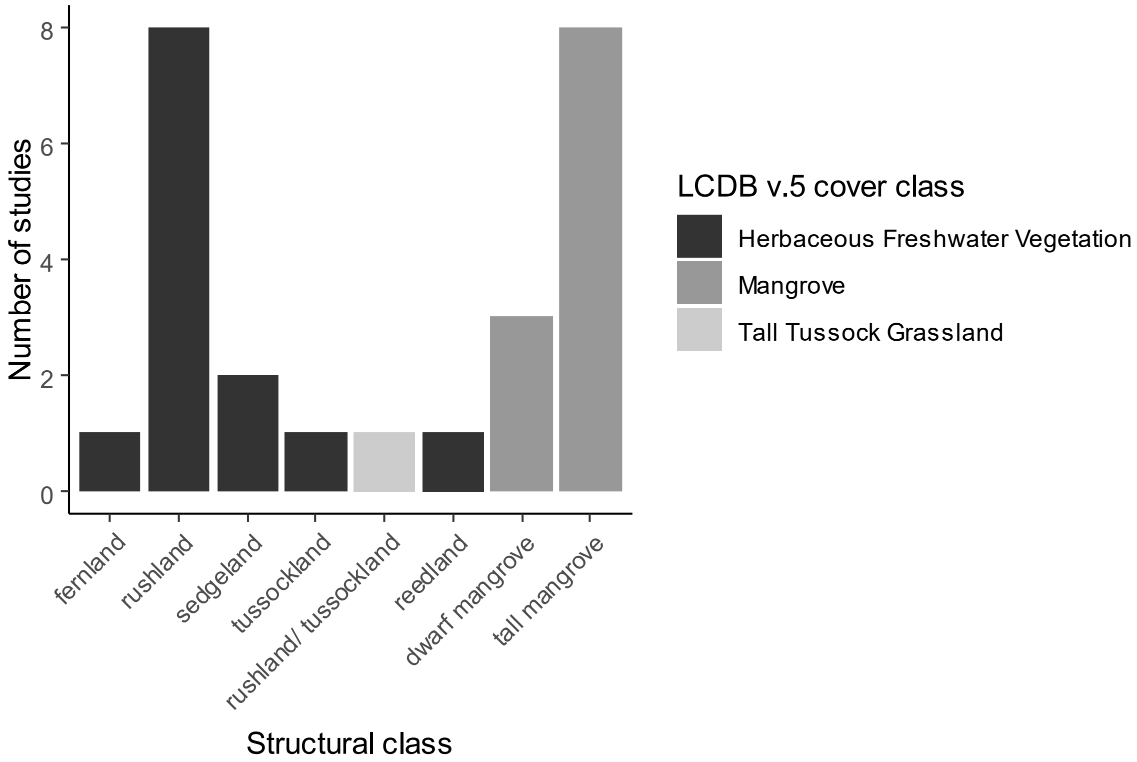

Figure 9: Sampled wetland vegetation classified by vegetation structure and their correspondence with mapped LCDB v.5 cover. Only source studies with location records for sampled sites are shown.

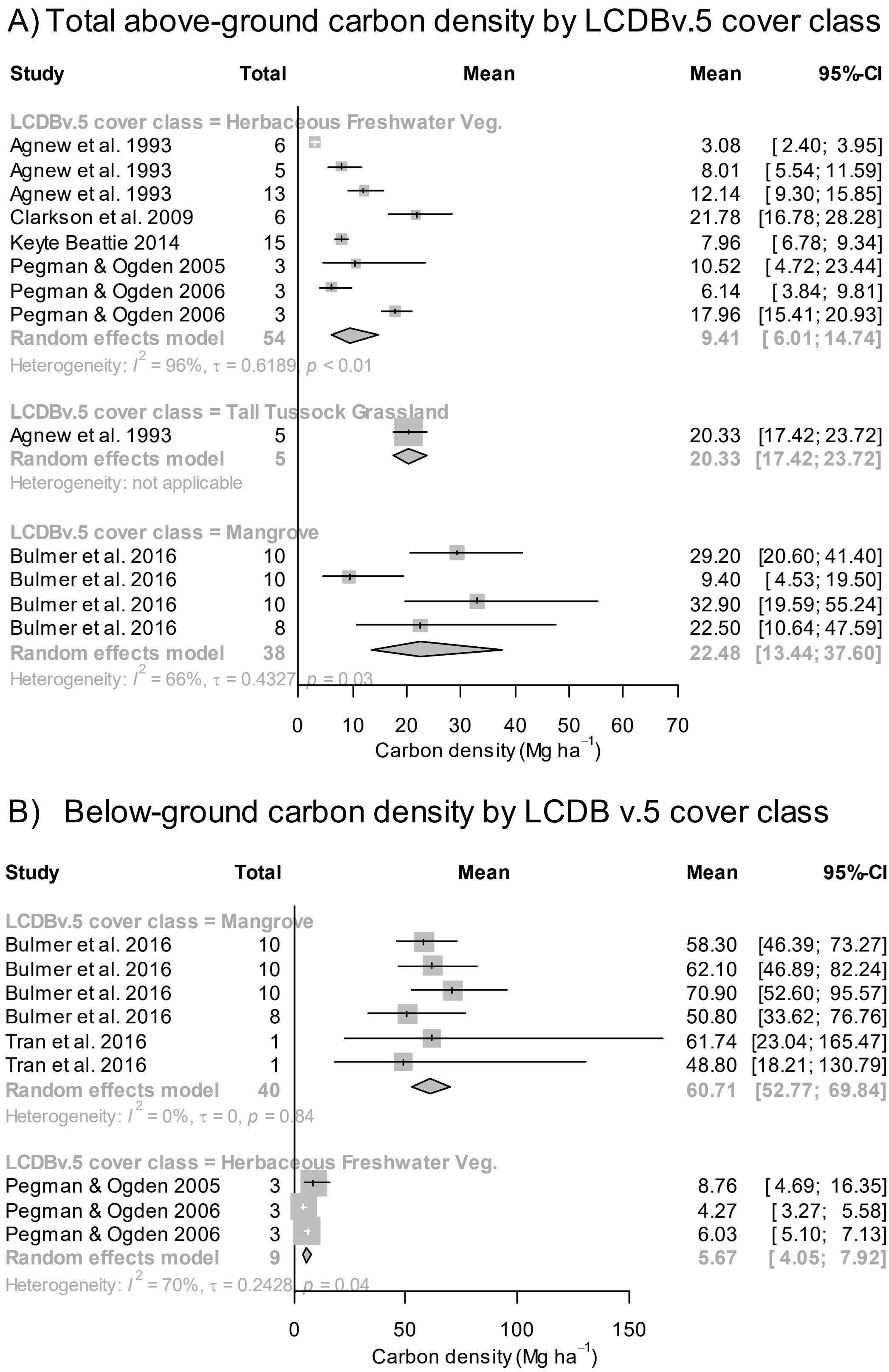

Figure 10: Summary of (A) total above-ground and (B) total below-ground carbon density by LCDB cover classes. Cross-study group means and heterogeneity estimates (in grey) were derived from a random effects meta-analysis.

New Zealand-specific area-weighted approaches to estimating state and trend of wetland vegetation carbon stocks

Scaling-up carbon stocks to 2012 carbon estimate

As described in the Methods, New Zealand-specific biomass and carbon data were unavailable to calculate separate coastal and inland carbon stocks for each LCDB class, hence we only report on an overall carbon stock by each LCDB class.

An intersect of LCDB v.5. with the LUM v.8 vegetated wetland layer for the map year 2012 yielded 32 land cover classes (21 vegetated classes) overlapping with vegetated wetlands. The two most extensive cover classes were "Herbaceous Freshwater Vegetation" and "Mānuka and/or Kānuka" with 112,201 and 26,601 ha, respectively, followed by a series of cover classes between 12,130 ha and 512 ha, and then a group of 11 cover classes with cover of 81 ha or less (Table 3). These cover classes may be grouped into six aggregated land cover classes: herbaceous freshwater (147,382 ha, 67.9% of vegetated wetlands mapped by LUM), herbaceous saline (12,130 ha, 5.6%), mangroves (621 ha, 0.3%), shrubland (30,843 ha, 14.2%), forest (20,945 ha, 9.7%), and non-vegetated areas (5,118 ha, 2.4%). A further 195 ha of land is not covered by LCDB.

The carbon density estimates derived from the literature review were used to inform carbon densities and stocks for some of these intersected LCDB v.5. cover classes. For a few cover classes, carbon density can be inferred directly from underlying links between classified land cover and sampled wetland vegetation (Figure 9) or are evident from class definitions (i.e., fernlands and tussocklands). However, in other cases, the associations between cover classes and carbon density estimates can only be partially inferred from descriptions of land cover classes (Appendix B); for these, we applied the best available surrogate or approximations from the literature or existing data (see corresponding footnotes for Table 3).

Based on the carbon densities estimated for the land cover classes intersecting wetlands (Table 3, Figure 11), we obtained area-weighted carbon densities for the five aggregated land cover classes that are vegetated (Table 2). Estimated uncertainties are proportionally largest for shrublands (CV ≈ 34%), followed by 'herbaceous freshwater' vegetation (CV ≈ 17%), forests (CV ≈ 9%), 'herbaceous saline vegetation' (CV ≈ 6%), and mangroves (CV ≈ 1.4%).

Table 2: Area-weighted biomass carbon densities for the five aggregated land cover classes that are vegetated

Aggregated land cover class	Above-ground biomass carbon in Mg C ha^{-1} (95% CI in parentheses)	Below-ground biomass carbon in Mg ha^{-1} (nominal error range in parentheses)
Herbaceous freshwater vegetation	10.20 (6.76–13.65)	6.60 (1.65–11.54)
Herbaceous saline vegetation (based on studies in coastal environments)	8.84 (7.84–9.84)	6.59 (1.65–11.53)
Mangroves	31.58 (30.70–32.46)	60.28 (60.26–60.30)
Shrublands	28.09 (9.28–46.90)	5.65 (1.41–9.89)
Forests	90.32 (74.08–106.56)	16.34 (4.09–28.60)

The area-weighted grand mean total carbon density for biomass in vegetated wetlands (and spanning all wetland categories as mapped in 2012) is 20.22 (11.07–29.38 for 95% CI) Mg C ha^{-1} for above-ground biomass, 7.40 (1.85–12.9 nominal error range) Mg C ha^{-1} for below-ground biomass (i.e., excluding soils) (Figure 11) and 27.62 (6.91–48.34 nominal error range) Mg C ha^{-1} for total above and below-ground biomass combined. When scaled nationally to the total vegetated wetland area mapped by LUM, the total vegetation carbon stocks at 2012 were estimated at 6,000,274 (1,500,068–10,500,479 nominal error range) Mg C and these partition into LCDB v.5 cover classes and above and below ground components as shown in Figure 12. Total carbon stocks combine both carbon densities and land area of a corresponding cover class and so the large extent of 'herbaceous freshwater vegetation' means it stands out as the larger biomass store. Similarly, the large extent of 'herbaceous Saline Vegetation' make it a larger than expected carbon store from its biomass density alone and the narrow extent of mapped mangroves make is a smaller than expected carbon store.

Table 3: Extent of LCDB v.5 land cover classes (for 2012) intersecting areas of vegetated wetlands mapped by the LUM v.8 (2012) and corresponding carbon density estimates identified from the literature, subsets of LUCAS natural forest plots (shrublands and forests), or alternative sources (grasslands). Both above-ground (AG) and below-ground (BG) carbon density estimates are presented. Land cover classes are grouped into six aggregated classes and sorted from the largest to the smaller area in 2012. Carbon density values are assigned to a land cover class according to empirical associations (Figure 9), homonym land cover and carbon density classes (e.g., fernlands, tussocklands), or presumed approximations (e.g., reedland biomass as a surrogate for flaxland cover). Herbfields are excluded due to insufficient data (a single estimate of live biomass for an exotic species).

Land cover grouping	LCDB v.5 2012 cover	Area in 2012 (ha)	Carbon density (Mg C ha−1)								Mean carbon density (±1 SD) (Mg C ha−1)
			fernland	reedland	rushland	mixed rushland	sedgeland	tussockland	dwarf mangrove	tall mangrove	
Herbaceous freshwater	Herbaceous Freshwater Vegetation	112201	6.14 AG 4.27 BG	10.52 AG 8.76 BG	7.04 AG 6.03 BG	5.36 AG 6.72 BG[h]	4.82 AG 8.20 BG[i]	27.16 AG[j] 8.35 BG[k]			10.17 (1.68) AG 7.06 BG
	Tall Tussock Grassland	9705						27.16 AG[j] 8.35 BG[k]			27.16 (3.57) AG 8.35 BG
	High Producing Exotic Grassland	8493									1.05 (0.14) AG[l] 1.22 BG[m]

[h] Approximated from live AG carbon estimates and a root:shoot ratio of 2.35 based on this review (rushlands, reedlands, fernlands) and observations from Williams (1977) for grasses

[i] Approximated from live AG carbon estimates and a root:shoot ratio of 2.0 based on observations from Williams (1977)

[j] Based on live AG carbon estimates from Burge et al. (2020) and a dead:live AG biomass ratio of 2.72 (based on a review by O’Connor et al. 1999)

[k] As reviewed by O’Connor et al. 1999

[l] Mean May-December rising plate meter estimates for ryegrass-white clover pastures from ten dairy farms in the Waikato (Edirisinghe et al. 2012). Estimate corresponds closely with modelled estimates for two Waikato and three Canterbury farms (Anderson et al. 2020).

[m] Combined estimate from Mudge (2009), Dodd and Mackay (2011) and McNally et al. (2015) for ryegrass-white clover pastures.

Land cover grouping	LCDB v.5 2012 cover	Area in 2012 (ha)	Carbon density (Mg C ha−1)								Mean carbon density (±1 SD) (Mg C ha−1)
			fernland	reedland	rushland	mixed rushland	sedgeland	tussockland	dwarf mangrove	tall mangrove	
Herbaceous freshwater (cont.)	Low Producing Grassland	7292									0.84 (0.11) AG[n] 3.02 BG[o]
	Flaxland [p]	5589		10.52 AG 8.76 BG							10.52 (1.38) AG 8.76 BG
	Fernland	3859	6.14 AG 4.27 BG								6.14 (0.81) AG 4.27 BG
	Alpine Grass/Herbfield	78	6.14 AG 4.27 BG		7.04 AG 6.03 BG	5.36 AG 6.72 BG[h]	4.82 AG 8.20 BG[i]	27.16 AG[j] 8.35 BG[k]			10.10 (1.74) AG 6.71 BG
	Short-rotation Cropland	77									3.50 (1.91) AG[q] 1.5 BG[q]
	Urban Parkland/Open Space	59	6.14 AG 4.27 BG	10.52 AG 8.76 BG	7.04 AG 6.03 BG	5.36 AG 6.72 BG[h]	4.82 AG 8.20 BG[i]	27.16 AG[j] 8.35 BG[k]			10.17 (1.68) AG 7.06 BG
	Depleted Grassland	29									0.37 (0.05) AG[r] 2.12 BG[s]

[n] Cross-season estimate from a typical hill farm with extensive sheep grazing, Hawke's Bay (Hoogendoorn et al. 2016).

[o] Cross-season estimate for moderately diverse pasture swards (McNally et al. 2015)

[p] Flaxlands were assigned the carbon density value for reedlands as this was the nearest match in terms of physiognomy

[q] IPCC default for annual cropland (IPCC 2006) with a 0.3 root:shoot ratio according to estimates for alfalfa, barley, corn and wheat (Acock and Allen 1985).

[r] Estimate from Norbury et al. (2002).

[s] Unknown. Mean estimate from high- and low-producing grassland assumed.

Land cover grouping	LCDB v.5 2012 cover	Area in 2012 (ha)	Carbon density (Mg C ha−1)								Mean carbon density (±1 SD) (Mg C ha−1)
			fernland	reedland	rushland	mixed rushland	sedgeland	tussockland	dwarf mangrove	tall mangrove	
Herbaceous Saline	Herbaceous Saline Vegetation	12130									8.84 (0.51) AG[t] 6.59 BG[u]
Mangroves	Mangrove	621							20.95 AG 66.09 BG	40.30 AG 55.51 BG	31.58 (0.45) AG[v] 60.28 BG[v]
Shrubland	Manuka and/or Kanuka	26601									26.30 (7.97) AG[w] 5.24 BG[w]
	Gorse and/or Broom	2488									34.39 (6.49) AG[x] 7.56 BG[x]
	Mixed Exotic Shrubland	1176									50.72 (28.56) AG[y] 10.17 BG[y]

[t] A mean from carbon density values for saltmarsh herbfields (*Sarcocornia*, *Sporobolus*) grasslands (*Samolus*) and rushlands (*Isolepis*, *Juncus*) mostly from estuaries in SE Australia (Kelleway et al. 2016; Santini et al. 2019; Owers et al. 2018) with one New Zealand source (*Isolepis* in Bassett et al. 2010).

[u] Estimate for glasswort herbfields (*Sarcocornia*) from SE Australia (Santini et al. 2019).

[v] Incorporates a tall:dwarf mangrove cover ratio of 1.22, as estimated from a remote sensing assessment for the Auckland region (Suyadi et al. 2020).

[w] Carbon value was derived from LUCAS plots classified as 'mānuka shrubland' (n = 5) and measured within 2009-2014 (Holdaway et al. 2014). Above-ground tally comprises shrub biomass, live trees and coarse woody debris.

[x] Carbon value derived from LUCAS plots (n = 5) classified as 'gorse shrubland with cabbage trees' and measured within 2009-2014 (Holdaway et al. 2014).

[y] Carbon value derived from LUCAS plots (n =3) identified as successional shrublands and with a distinct component of the exotic shrubs *Buddleja davidii*, *Sambucus nigra* or *Crataegus monogyna* (Holdaway et al. 2014).

Land cover grouping	LCDB v.5 2012 cover	Area in 2012 (ha)	Carbon density (Mg C ha−1)								Mean carbon density (±1 SD) (Mg C ha−1)
			fernland	reedland	rushland	mixed rushland	sedgeland	tussockland	dwarf mangrove	tall mangrove	
Shrubland (cont.)	Matagouri or Grey Scrub	512									29.54 (3.98) AG[z] 5.84 BG[z]
	Sub Alpine Shrubland	66									98.17 (34.51) AG[aa] 17.14 BG[aa]
Forest	Deciduous Hardwoods	10799									29.34 (10.32) AG[bb] 4.98 BG[bb]
	Indigenous Forest	5346									193.28 (3.31) AG[cc] 34.65 BG[cc]
	Broadleaved Indigenous Hardwoods	3562									124.32 (7.33) AG[dd] 22.06 BG[dd]

[z] Carbon value derived from LUCAS plots (n = 27) classified as 'grey scrub with kānuka' and measured within 2009-2014 (Holdaway et al. 2014).

[aa] Carbon value derived from LUCAS plots (n = 3) classified as 'Mountain neinei–inanga low forest and subalpine shrubland' and measured within 2009-2014 (Holdaway et al. 2014).

[bb] LCDB v.5 class corresponds to "exotic deciduous woodlands, predominantly of willows or poplars". In the context of vegetated wetlands, we interpret these as areas invaded by *Salix cinerea*. No carbon estimates were found for *Salix* spp. in New Zealand (or Australia) as per Burrows et al. (2018). Further, *Salix* spp. are absent from LUCAS forest plots reclassified as wetlands. Our carbon estimate (Holdaway et al. 2014) is from a single LUCAS plot (DE64) where both *Salix cinerea* and *Salix fragilis* were present.

[cc] Estimate from 2009-2014 LUCAS sample for beech, broadleaved and podocarp forest alliances (Paul et al. 2019). Above-ground value comprises live tree biomass and coarse woody debris.

[dd] LCDB v.5 class corresponds to "communities of mixed broadleaved short trees indicative of advanced succession toward indigenous forest". Carbon value derived from 2009-2014 LUCAS sample for 'māhoe forest', 'pepperwood–fuchsia–broadleaf forest' and 'silver fern–māhoe forest' alliances in Paul et al. (2019).

Land cover grouping	LCDB v.5 2012 cover	Area in 2012 (ha)	Carbon density (Mg C ha−1)								Mean carbon density (±1 SD) (Mg C ha−1)
			fernland	reedland	rushland	mixed rushland	sedgeland	tussockland	dwarf mangrove	tall mangrove	
Forest (cont.)	Exotic Forest	1157									85.39 (5.77) AG[ee] 21.35 BG[ee]
	Forest – Harvested	81									0[ff]
Non-vegetated (or low cover) areas	Estuarine Open Water	1938									0
	Lake or Pond	1347									0
	Sand or Gravel	632									0
	River	588									0
	Gravel or Rock	542									0
	Built-up Area (settlement)	34									0
	Surface Mine or Dump	24									0
	Orchard, Vineyard or Other Perennial Crop	9									0[gg]
	Landslide	2									0
	Transport Infrastructure	2									0

[ee] Based on carbon density values for pre-1990 and post-1989 planted forests (Paul et al. 2020) weighted by the corresponding pre-1990 and post-1989 planted forest areas (Ministry for the Environment 2021). Applies a 0.2 root:shoot ratio for radiata pine (Beets et al. 2012).

[ff] In a wetland context, we interpret areas of harvested forest as probably involving permanent deforestation, either due to harvest of (i) exotic species planted in unsuitable conditions, producing timber of low commercial value and unlikely to be replanted or (ii) clearing of invasive tree species such as willows. In accordance with international GHG accounting approaches and national Tier 1 inventory reporting, carbon emissions resulting from permanent deforestation are assumed to be immediate on harvest and residues of biomass carbon are assumed to be zero (Steven Wakelin, personal observation 1 July 2022).

[gg] This cover class has very minor influence on total carbon stocks (~0.004% of total wetland area) and was not accounted for.

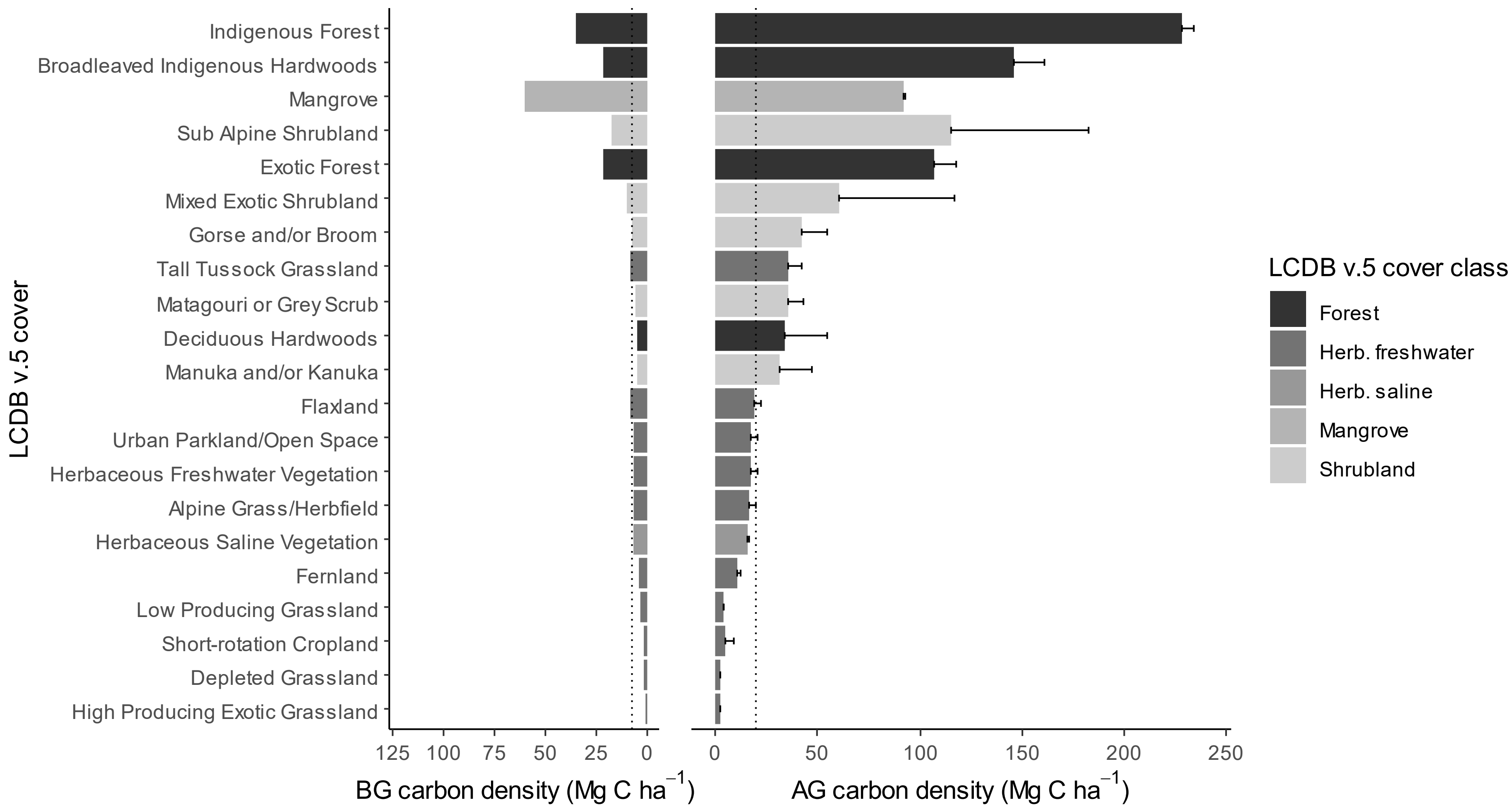

Figure 11: Carbon densities per LCDB class (and their 95% upper confidence limit) within LUM Vegetated wetlands non-forest at 2012. Cover classes are sorted according to total carbon density and dotted lines indicate the grand above-ground (AG) and below-ground (BG) mean densities. Note that the weight of cover classes on the grand mean varies according to the spatial extent of those classes and that 11 non-vegetated cover classes (2.4% of total LUM vegetated wetland area) are not presented. Herb.: herbaceous.

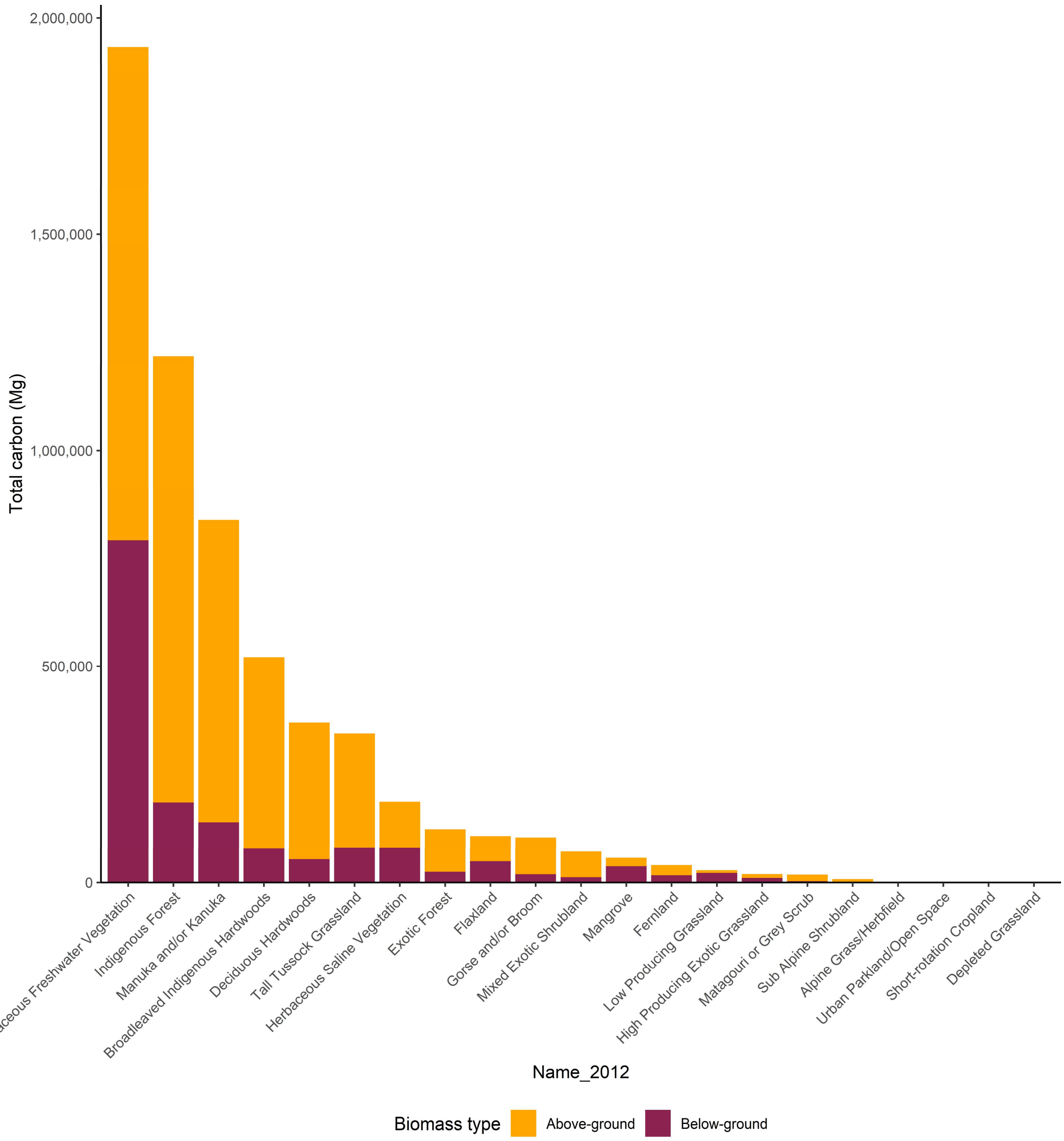

Figure 12: **Carbon stocks per LCDB class within LUM Vegetated wetlands non-forest as at 2012. LCDB classes for which the carbon estimate was zero have been excluded.**

Estimating changes in carbon stocks arising from land-use change

We quantified the carbon stocks for the three LUM mapping periods (2008, 2012, 2016), using both the 2012 weighted mean density, and by re-weighting the carbon density in each year using the relative abundance of each LCDB class (Table 4).

Table 4: Grand mean carbon density and total (above- and below-ground) carbon stocks in wetland vegetation within areas mapped as LUM non-forest vegetated wetland. Carbon stocks account for change in the extent of LUM vegetated wetlands and were calculated (i) assuming proportional adjustments in LCDB v.5 land cover composition (fixed weights) or (ii) accounting for any unequal changes in land cover composition (updated weights). Nominal error ranges are presented in parenthesis (see methods section on 'error propagation and estimated uncertainties').

LUM map year	Area-weighted total mean carbon density (Mg ha^{-1})	Total carbon stocks based on fixed weights (Mg)	Total carbon stocks based on updated weights (Mg)
2008	27.622 (6.91–48.34)	6,057,543 (1,514,385–10,600,701)	6,057,783 (1,514,445–10,601,120)
2012	27.621 (6.90–48.34)	6,000,274 (1,500,068–10,500,479)	6,000,273 (1,500,068–10,500,479)
2016	27.506 (6.79–48.22)	5,985,996 (1,496,499–10,475,493)	5,960,993 (1,490,248–10,431,739)

We also looked at the representativeness of using the 2012 LUM to estimate the carbon lost from 2008–2016. We note substantial over- and under-representation of key land cover categories, including Herbaceous Freshwater Vegetation (Table 5). To assess the implications of this, we calculated the weighted mean carbon (Mg ha^{-1}) in the area lost between 2008 and 2016. The weighted mean carbon for the area lost was 21.32 Mg ha^{-1} whereas the weighted mean for 2012 overall (Table 4) was 27.62 Mg ha^{-1}.

We also calculated the relative inland/coastal area of the LUM vegetated wetland class that was lost from 2008-2016. The total area lost was 2840 ha. This was made up of 35.7 ha of coastal areas (1.3% of total lost) and 2804 ha of inland areas (98.7% of total lost); meaning disproportionate loss occurred in inland areas.

Table 5 **Comparison of LCDB categories in 2012 and LCDB categories in the area of LUM vegetated wetland lost between 2008 and 2016. If unbiased losses occurred, the final two columns (% total area in 2012, % total area lost 2008-2016) would be similar[34].**

LCDB category in 2012	C density (Mg ha^{-1})	Area in 2012 (ha)	Area lost 2008-2016 (ha)	% area in 2012	% area lost 2008-2016
Herbaceous Freshwater Vegetation	17.23	112,201.1	731	51.6	25.7
Manuka and/or Kanuka	31.54	26,601.0	445.7	12.2	15.7
Herbaceous Saline Vegetation	15.43	12,130.1	15.6	5.6	0.5
Deciduous Hardwoods	34.32	10,799.1	20.7	5	0.7
Tall Tussock Grassland	35.51	9,705.2	25.9	4.5	0.9
High Producing Exotic Grassland	2.27	8,493.2	480.8	3.9	16.9
Low Producing Grassland	3.86	7,291.5	415.8	3.4	14.6
Flaxland	19.28	5,589.2	72	2.6	2.5
Indigenous Forest	227.93	5,345.8	21.6	2.5	0.8
Fernland	10.41	3,859.1	144.4	1.8	5.1
Broadleaved Indigenous Hardwoods	146.38	3,561.8	18.7	1.6	0.7
Gorse and/or Broom	41.95	2,488.2	337.9	1.1	11.9
Mixed Exotic Shrubland	60.89	1,175.6	32.9	0.5	1.2
Exotic Forest	106.74	1,157.2	21.7	0.5	0.8
Mangrove	91.86	620.9	0	0.3	0
Matagouri or Grey Scrub	35.38	512.4	7.8	0.2	0.3
Alpine Grass/Herbfield	16.81	78.1	0	0	0
Short-rotation Cropland	5	76.7	0	0	0
Sub Alpine Shrubland	115.31	66	0	0	0
Urban Parkland/Open Space	17.23	58.8	0	0	0
Depleted Grassland	2.49	28.6	0	0	0
Estuarine Open Water	0	1,938.0	0	0.9	0
Lake or Pond	0	1,347.3	24	0.6	0.8
Sand or Gravel	0	632.0	10.2	0.3	0.4
River	0	588.1	2	0.3	0.1
Gravel or Rock	0	541.7	0	0.2	0
NOT MAPPED	–	195.1	0	0.1	0
Forest - Harvested	0	80.6	5	0	0.2
Built-up Area (settlement)	0	33.6	0	0	0
Surface Mine or Dump	0	24	6.4	0	0.2
Orchard, Vineyard or Other Perennial Crop	0	9.4	0	0	0
Landslide	0	2.3	0	0	0
Transport Infrastructure	0	2.2	0	0	0

[34] The LCDB category "NOT MAPPED" is an area of the LUM that is not mapped by LCDB and as such has no total carbon density associated. It was excluded from the weighted mean calculations.

Discussion

Coastal-inland delineation

The intent of the definition in the IPCC Wetlands Supplement (IPCC 2014) is to capture wetland vegetation influenced by coastal processes, i.e., "*covered or saturated, for all or part of the year, by tidal freshwater, brackish or saline water*", defined as water with a salinity of ≥0.5 ppt (see Annex 4A.1 in IPCC 2014). We were unable to delineate coastal wetland systems on this basis because we lack spatial data on salinity,

We considered a conservative interpretation of the definition of coastal wetlands provided by the IPCC Wetlands Supplement (IPCC 2014): "*The boundary of coastal wetlands may extend to the landward extent of tidal inundation and may extend seaward to the maximum depth of vascular plant vegetation.*" If we used the same coastline as the LUM, which extends for the most part to the land inside the coastline, this definition would yield almost no coastal wetlands. While this definition is simple to implement, we did not consider it to be a fair representation of coastal, saline ecosystems in New Zealand. However, this definition might yield a robust representation of seagrass meadows, a vegetation type specifically envisaged by the IPCC Wetlands Supplement (IPCC 2014) as both holding biomass and forming part of a country's 'coastal wetlands'. Because seagrass meadows are most likely to occur in the LUM class 'Wetland – Open Water', they were out of scope for this report. We recommend that seagrass meadows are considered in any further work to refine the coastal / inland wetland delineation.

We considered delineations based on the saline herbaceous vegetation cover class in the LCDB, but these were problematic. Land cover classes in the LCDB are not based on salinity, and they are not uniquely coastal or inland. For example, saline herbaceous vegetation exists inland[35], and some widespread land cover classes such as flaxland or mānuka/kānuka can occur in coastal wetlands and be subject to marine salinity (Wardle 1977). An additional problem arises when land cover classes change over time. For example, if an area of saline herbaceous vegetation was converted to low producing grassland but remained in a wetland use, this site would change into a freshwater wetland without any change in the salinity of the site.

We chose an approach using a GIS workflow based on elevation, and distance from the coast, buffered by the NZ hydro system layer. We chose this because it yielded a 'hard' boundary that would be robust to land use and land cover transitions within those wetlands, and be a proxy for hydrological connectivity to marine, saline systems. In this regard our approach met the IPCC criteria (IPCC 2014) but we did not reach a definitive solution because our chosen combination of elevation and distance misclassified areas mapped as saline herbaceous vegetation and freshwater wetland vegetation.

We advocate for an approach that yields a 'hard' boundary and we recommend refining the elevation- and distance from coast-based criteria from our pilot. Specifically, we recommend running a sensitivity analysis on combinations of elevation, distance from coast, and methods for buffering the coast line using the NZ coastal hydrosystems layer, to identify combinations of these variables that yield the most satisfactory partition of LUM vegetated wetlands into coastal and freshwater ecosystems (judged by the relative apportionment of freshwater and saline herbaceous vegetation, defined from LCDB, in each). Our approach could be modified to focus only on elevation, because distance from coast is, to some extent, a proxy for elevation.

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[35] https://www.landcareresearch.co.nz/publications/naturally-uncommon-ecosystems/inland-and-alpine/inland-saline/

Mangroves

One potential issue for future reporting of vegetation carbon stocks and stock changes in mangroves is that only 3,198 ha (11%) of the area mapped as mangroves by LCDB in 2021 (28,232 ha) are captured within the spatial extent of the LUM. This seems to arise because mangroves lie beyond the coastline of New Zealand (Figure 13).

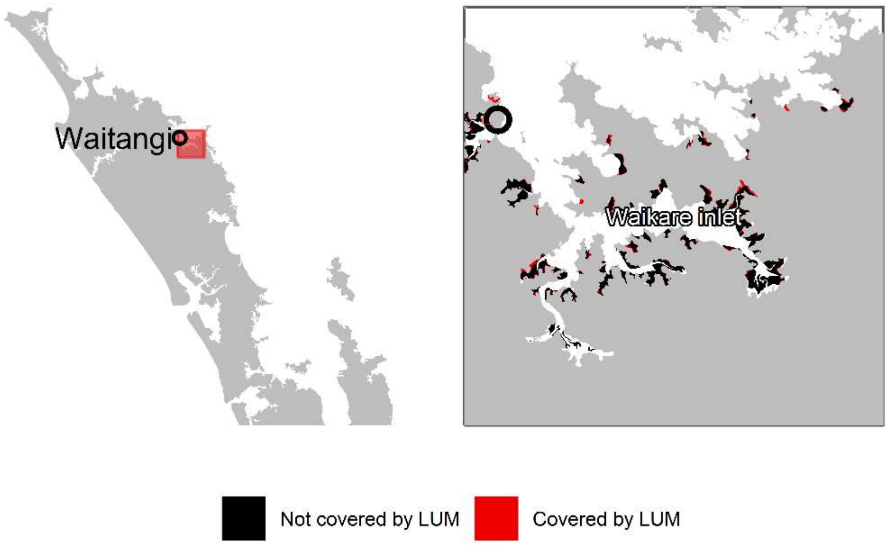

Figure 13: Example of mangroves mapped by LCDB, and extent of those mangroves not within the spatial extent of the LUM.

The LUM vegetated wetland non-forest class is defined as including mangroves, but twice the area of mangroves is mapped within the LUM class 'natural forest' as in the non-forest vegetated wetlands LUM class (Table 6). If mangroves currently not within the spatial extent of the LUM were included in the LUM as non-forest vegetated wetlands, they would be the largest vegetation carbon stock of all LCDB categories for the LUM vegetated wetland class (data not shown). Although current greenhouse gas inventories only report on stocks and stock changes within the spatial extent of the LUM, future changes in the extent and distribution of mangroves as a result of sedimentation, coastal development, and climate change, could warrant a reappraisal of the LUM spatial extent so as to include all mangrove vegetation.

Table 6: **Area of mangrove mapped by different LUM categories, and area not mapped by LUM (refer row "Outside extent of LUM"), as at 2012. Only LUM categories including more than 100 ha of mangrove are shown.**

LUM category 2012	Area (ha)
Outside extent of LUM	25,034
Natural Forest	1,253
Wetland – Vegetated non forest	621
Grassland – High producing	451
Wetland – Open water	325
Grassland – With woody biomass	245
Grassland – Low producing	189

Carbon density in wetland vegetation

Limited biomass estimates are available for wetland vegetation in New Zealand. When classified according to vegetation structure, mean carbon density estimates are relatively uniform for some herbaceous structural classes, with above-ground total carbon density ranging between 4.82 – 7.04 Mg C ha^{-1} for rushland, sedgeland, and fernland. Carbon densities then rise to 10.52 Mg C ha^{-1} for reedlands and to an estimated 27.16 Mg C ha^{-1} for tussocklands.

The carbon estimates reviewed here indicate comparably high carbon densities for vegetation in bogs but otherwise broadly correspond in order of magnitude with wetland vegetation sampled overseas (Table 7). Some discrepancies are expected given floristic and structural differences.

Table 7: **Ranges in live above-ground carbon densities for comparable wetland types found overseas (Sorrel 2008) and in New Zealand (this review).**

Origin	Wetland type	Live above-ground carbon density (Mg C ha–1)
International (Sorrel 2008)	herbaceous bogs	0.00044 – 0.57
	woody bogs	0.35 – 4.49
	fens	0.079 – 16.40
	swamps and marshes	0.88 – 44.00
New Zealand (this review)	fens	4.34
	bogs	8.79
	swamps	10.84

With LUM non-forest vegetated wetlands further classified according to LCDB v.5 land cover, and linking carbon densities from the literature review to the corresponding land cover classes, we find that the most extensive wetland cover class – 'herbaceous freshwater' wetlands – is estimated to have area-weighted carbon densities of 10.20 (6.76–13.65 for 95% CI) Mg C ha^{-1} and 6.60 (1.65–11.54 nominal error range) Mg C ha^{-1} for the above- and below-ground compartments, respectively. These values are approximately one third of a published estimate of c. 50 Mg C ha^{-1} for summed above and below-ground biomass reported for wetland vegetation globally (Mitra et al. 2005). Differences could be attributable to the published global estimate being a generic estimate for both herbaceous and woody wetlands. However, our estimate of an area-weighted grand mean of 27.62 (6.91–48.34 nominal error range) Mg C ha^{-1} for total above and below-ground biomass combined, which accounts for data from both herbaceous and woody vegetation, is still only approximately half that of the global estimate.

Our compiled carbon density estimates for New Zealand mangroves are 31.58 (30.70–32.46 for 95% CI) Mg C ha^{-1} and 60.28 (15.07–105.49 nominal error range) Mg C ha^{-1} for above and below-ground biomass carbon, respectively. Of particular note is the high biomass carbon stored below ground, almost twice that of biomass carbon above ground. However, at a combined 92 Mg C ha^{-1}, values for New Zealand mangroves are 29% lower than the estimate of 130 Mg C ha^{-1} for Australian mangroves (Page and Dalal 2011).

Our literature review did not capture empirical studies involving estimates of carbon change (repeated measurements or chronosequences on a unit area basis) for wetland vegetation in New Zealand. While our searches were not necessarily exhaustive, this is consistent with previous observations of a lack of carbon sequestration estimates for vegetation alone (i.e., excluding soils or whole-ecosystem carbon exchange) for natural or constructed wetlands in New Zealand (Quinn and Burrows 2018) and indicates of an manifest information gap in this respect.

Representativeness of carbon density estimates and implications for scaling-up

Biomass estimates were not available for several important vegetation structural classes, such as flaxlands, coastal saltmarshes (nor vegetation within inland saline areas), and some shrublands and forests. This is important given the estimated extent of these structural classes and their potential carbon densities. In this assessment we used carbon density surrogates from non-wetland contexts but if biomass distribution differs between terrestrial and wetland sites within the same vegetation structural class, the use of surrogates introduces uncertainty into our estimates and raises the question of how best to represent unsampled vegetation structural classes on wetlands.

Whilst individual source studies largely follow objective sampling designs and use standard procedures for defining a sampling universe and estimating biomass, collectively, these combined sources were not designed for, and are insufficiently robust, for an unbiased estimation of vegetation biomass or carbon at national scale. New Zealand non forest vegetated wetland types vary widely in their vegetation composition, function, and structure (Johnson and Gerbeaux 2004, Clarkson et al. 2015, Figure 7, Figure 8). Beyond those land cover classes mapped by LCDB v.5, the spatial extent of different wetland vegetation structural classes is unknown, and thus the carbon densities presented here do not account for the relative extent of different vegetation structural classes. A recent international study noted that uncertainties in sampling design and under-sampling of spatial variation can result in potential over- or under-estimations of biomass by more than 30% (cf. O’Connor et al. 2019). Mangroves in New Zealand are an exception though as they have been extensively sampled, including both biomass estimates and extent of dwarf and tall mangroves (Suyadi et al. 2020) allowing us to account for the relative abundance of dwarf and tall mangroves across within the area mapped as mangroves by LCDB v.5. The benefit of this rich information source is evident in the low sampling uncertainty for mangroves (CV ≈ 1.4%).

Recommendations

1. **Refine our approach for applying a coastal-inland delineation**. Specifically, we recommend running sensitivity analyses to determine combinations of elevation, distance from the coast line, and methods for buffering the coast line using the NZ coastal hydrosystems layer, to identify combinations of these variables that yield the most satisfactory partition of LUM vegetated wetlands into coastal and freshwater ecosystems based on the relative apportionment of freshwater and saline herbaceous vegetation, defined from LCDB, in each ecosystem.

    1. **Seagrass meadows in open water.** Consider allocating a biomass value to the LUM open water wetland class, particularly where it overlaps with the LCDB estuarine open water class, so as to capture seagrass meadows. Seagrass meadows are vulnerable to high nutrient inputs and may be subject to large scale losses in the future.

    2. **Mangroves.** Reappraise the spatial extent of the LUM to include the areas of mangrove vegetation captured by LCDB v.5.

New empirical estimates of vegetation carbon stocks. Our estimates of carbon stocks had high uncertainty because the data available from the literature review were fragmentary, particularly for woody vegetation types and belowground pools, and coastal ecosystems. We recommend making new empirical estimates of wetland vegetation biomass and pairing these with an unbiased survey of vegetated wetlands, building on the successful approach developed for carbon accounting in natural forests. Empirical sampling could be comprehensive, partial, or targeted:

1. **Comprehensive sampling.** Destructive above- and below-ground biomass harvests coupled with the field measurements to develop the allometric relationships required to link vegetation dimensions to vegetation biomass. Harvests and measurements would need to span the full range of vegetation structural classes present in wetlands (e.g. scattered shrublands, diverse herbaceous forms). Apply these measurements to an unbiased network of permanent vegetation plots to sample vegetation within the vegetated wetland land use class. This approach would be the most costly, but would reveal the true vegetation cover within the LUM (without relying on the LCDB composition within the LUM), and field measurements would provide empirical biomass estimates for a range of vegetation types. Remeasurement would provide empirical data on change in vegetation cover across the LUM class.

2. **Partial sampling.** Visit an unbiased sample of points within the vegetated wetland LUM class, stratified by LCDB cover class, and record the vegetation structural class (e.g. flaxland, rushland). Destructively harvest above- and below-ground biomass at those sites. This approach would not require the establishment or remeasurement of permanent plots, and would be significantly less costly than then ‘comprehensive’ approach. It would allow us to partition the area mapped as vegetated wetland into vegetation structural classes, and would provide field measurements of biomass for all wetlands types to complement the literature review.

3. **Targeted sampling.** Destructively harvest above- and below-ground biomass in common vegetation structural classes, and those LCDB classes and vegetation structural classes where the information from the literature review was weakest. This approach would be the least expensive option because it would assume that current mapping information is adequate and would focus only on improving the biomass values applied to existing mapped area. Key examples to focus on would be:

1. Woody ecosystems in a wetland context. Carbon density estimates for shrublands and forests were estimated in this report using data from non-wetland contexts. As shrublands and forests have a high carbon density and can be spatially extensive, additional data would improve the grand mean estimate of carbon density;
2. Coastal and inland examples of common LCDB classes to enable reporting of inland and coastal carbon individually;
3. Herbaceous freshwater vegetation as this is the largest LCDB class by area.

Determine the recovery potential of carbon stocks on non-forest vegetated wetlands in different contexts. Further research is required to test the validity of applying the default 20 year transition period for land entering the vegetated wetlands class to reach the carbon density estimates reported here. Such an investigation would need to determine a method for estimating such a recovery period across the range of situations likely to occur in wetlands.

Account for changes in land cover within the area mapped by the LUM. In the absence of an empirical, permanent plot-based sampling approach (Recommendation 2, above), we recommend a review of carbon accounting practices for wetlands such that changes in the LCDB composition within the LUM can be accounted for at each measurement period. This approach would more appropriately account for the diversity of vegetation structure and composition within wetlands, and more closely trace the underlying transitions they experience. Simultaneous sampling of the LCDB and the LUM would facilitate stronger inferences from the LCDB to the LUM[36].

[36] In writing this report, we have confirmed that although the metadata for the LUM and LCDB suggest that the 2008 nominal steps differed by 11 months, the imagery used to derive those layers is the same.

Appendix A – Compiled estimates of biomass carbon for wetland vegetation

See: https://datastore.landcareresearch.co.nz/dataset/wetland-biomass

Appendix B – Description of LCDB cover classes

Table B1: LCDB classes present in vegetated wetlands mapped by the LUM. Only vegetated LCDB categories are shown, ordered alphabetically within herbaceous, shrubland, and forest structural categories.

Class Code	Class Name	Class Description	Broad structural category
15	Alpine Grass/ Herbfield	Typically sparse communities above the actual or theoretical treeline dominated by herbaceous cushion, mat, turf, and rosette plants and lichens. Grasses are a minor or infrequent component, whereas stones, boulders and bare rock are usually conspicuous.	herbaceous
44	Depleted Grassland	Areas, of mainly former short tussock grassland in the drier eastern South Island high country, degraded by over-grazing, fire, rabbits and weed invasion among which Hieracium species are conspicuous. Short tussocks usually occur, as do exotic grasses, but bare ground is more prominent.	herbaceous
50	Fernland	Bracken fern, umbrella fern, or ring fern, commonly on sites with low fertility and a history of burning. Manuka, gorse, and/or other shrubs are often a component of these communities and will succeed Fernland if left undisturbed.	herbaceous
47	Flaxland	Areas dominated by New Zealand flax usually swamp flax (harakeke) in damp sites but occasionally mountain flax (wharariki) on cliffs and mountain slopes.	herbaceous
45	Herbaceous Freshwater Vegetation	Herbaceous wetland communities occurring in freshwater habitats where the water table is above or just below the substrate surface for most of the year. The class includes rush, sedge, restiad, and sphagnum communities and other wetland species, but not flax nor willows which are mapped as Flaxland and Deciduous Hardwoods respectively.	herbaceous
46	Herbaceous Saline Vegetation	Herbaceous wetland communities occurring in saline habitats subject to tidal inundation or saltwater intrusion. Commonly includes club rush, wire rush and glasswort, but not mangrove which is mapped separately.	herbaceous
40	High Producing Exotic Grassland	Exotic sward grassland of good pastoral quality and vigour reflecting relatively high soil fertility and intensive grazing management. Clover species, ryegrass and cocksfoot dominate with lucerne and plantain locally important, but also including lower-producing grasses exhibiting vigour in areas of good soil moisture and fertility.	herbaceous
41	Low Producing Grassland	Exotic sward grassland and indigenous short tussock grassland of poor pastoral quality reflecting lower soil fertility and extensive grazing management or non-agricultural use. Browntop, sweet vernal, danthonia, fescue and Yorkshire fog dominate, with indigenous short tussocks (hard tussock, blue tussock and silver tussock) common in the eastern South Island and locally elsewhere.	herbaceous

Class Code	Class Name	Class Description	Broad structural category
30	Short-rotation Cropland	Land regularly cultivated for the production of cereal, root, and seed crops, hops, vegetables, strawberries and field nurseries, often including intervening grassland, fallow land, and other covers not delineated separately.	herbaceous
43	Tall Tussock Grassland	Indigenous snow tussocks in mainly alpine mountain-lands and red tussock in the central North Island and locally in poorly-drained valley floors, terraces and basins of both islands.	herbaceous
2	Urban Parkland/ Open Space	Open, mainly grassed or sparsely-treed, amenity, utility and recreation areas. The class includes parks and playing fields, public gardens, cemeteries, golf courses, berms and other vegetated areas usually within or associated with built-up areas.	herbaceous
55	Sub Alpine Shrubland	Highland scrub dominated by indigenous low-growing shrubs including species of *Hebe*, *Dracophyllum*, *Olearia*, and *Cassinia*. Predominantly occurring above the actual or theoretical treeline, this class is also recorded where temperature inversions have created cooler micro-climates at lower elevations e.g., the 'frost flats' of the central North Island.	shrubland
51	Gorse and/or Broom	Scrub communities dominated by gorse or Scotch broom generally occurring on sites of low fertility, often with a history of fire, and insufficient grazing pressure to control spread. Left undisturbed, this class can be transitional to Broadleaved Indigenous Hardwoods.	shrubland
70	Mangrove	Shrubs or small trees of the New Zealand mangrove (*Avicennia marina* subspecies *australascia*) growing in harbours, estuaries, tidal creeks and rivers north of Kāwhia on the west coast and Ōhiwa on the east coast.	shrubland
52	Manuka and/or Kanuka	Scrub dominated by mānuka and/or kānuka, typically as a successional community in a reversion toward forest. Mānuka has a wider ecological tolerance and distribution than kānuka with the latter somewhat concentrated in the north with particular prominence on the volcanic soils of the central volcanic plateau.	shrubland
58	Matagouri or Grey Scrub	Scrub and shrubland comprising small-leaved, often divaricating shrubs such as matagouri, *Coprosma* spp, *Muehlenbeckia* spp., *Cassinia* spp., and *Parsonsia* spp. These, from a distance, often have a grey appearance.	shrubland
56	Mixed Exotic Shrubland	Communities of introduced shrubs and climbers such as boxthorn, hawthorn, elderberry, blackberry, sweet brier, buddleia, and old man's beard.	shrubland
54	Broadleaved Indigenous Hardwoods	Lowland scrub communities dominated by indigenous mixed broadleaved shrubs such as wineberry, mahoe, five-finger, *Pittosporum* spp, fuchsia, tutu, titoki and tree ferns. This class is usually indicative of advanced succession toward indigenous forest.	forest
68	Deciduous Hardwoods	Exotic deciduous woodlands, predominantly of willows or poplars but also of oak, elm, ash or other species. Commonly alongside inland water (or as part of wetlands), or as erosion-control, shelter and amenity plantings.	forest

Class Code	Class Name	Class Description	Broad structural category
71	Exotic Forest	Planted or naturalised forest predominantly of radiata pine but including other pine species, Douglas fir, cypress, larch, acacia and eucalypts. Production forestry is the main land use in this class with minor areas devoted to mass-movement erosion-control and other areas of naturalised (wildling) establishment.	forest
64	Forest - Harvested	Predominantly bare ground arising from the harvesting of exotic forest or, less commonly, the clearing of indigenous forest. Replanting of exotic forest (or conversion to a new land use) is not evident and nor is the future use of land cleared of indigenous forest.	forest
69	Indigenous Forest	Tall forest dominated by indigenous conifer, broadleaved or beech species.	forest

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