Development of a Recovery Index to Quantify Ecological Recovery of Reclaimed Wellsites -- Dave Huggard, Feb. 28, 2016; revised Apr. 18, 2016

Summary

The Ecological Recovery Monitoring project measured habitat structures, soil characteristics and plant species composition in certified reclaimed wellsites and paired adjacent control areas. The wellsites were abandoned and certified from 7 to 48 years previously. Eighteen wellsite-control pairs were surveyed in the Grasslands, and 15 each in the Boreal and Foothills Natural Regions.

This report summarizes each measured variable in each region, using paired wellsite-control comparisons (wellsite:control ratios for individual habitat structures, percent similarity for species composition). The ratios or similarity values were plotted against certification age to identify variables that show recovery with age or consistent differences between wellsites and controls. Those variables were used for recovery scores, scaling the values between a starting value expected in recently abandoned wellsites and an ending (fully recovered) value given by the adjacent control. Scores for related variables were combined into 5 composite recovery scores: LiveCanopy with live basal area and canopy cover (forested regions only), Deadwood with snags and coarse and small woody debris (forested regions only), Vegetation layers with a similarity metric based on 2D cover layers, Soils with three or six soil variables, and Species with percent similarity of plant species. The LiveCanopy, Layers and Species scores respond to certification age, and were further combined into a Short-term recovery score. Deadwood and Soils maintain persistent differences between wellsites and controls, and form a Long-term recovery score.

The Short-term recovery score increases consistently with certification age in the Foothills. It also increases with age in the Boreal, but three sites have anomalously high recovery scores at younger ages, possibly because certification ages inaccurately represent time since recovery started at those sites. The Short-term recovery score decreases with age of grassland wellsites, because of a known confounding problem, in which more severe rehabilitation and non-native seeding was used in older wellsites. Long-term recovery shows small increases with age in the forested regions.

The paired wellsite-control sampling design with four quadrats in each control is an important part of allowing relatively simple scoring of recovery for individual wellsites. Further sampling of old wellsites that used modern rehabilitation methods would help to better delineate recovery rates with wellsite age in the forested region. Older wellsites with modern rehabilitation probably do not exist in the grasslands, so confounding of age and management method will remain an issue there. Suggestions are made about a reduced set of field methods that are needed for the recovery scores, although compatibility with ABMI may preclude changes. Overall, the recovery scores developed here should be useful for operational monitoring, with some additional refinement as more wellsites are sampled. Long-term monitoring of some sites would ultimately be needed to show that recovering wellsites are on a trajectory that consistently leads to full recovery.

Contents

1. Introduction

Ensuring ecological recovery of abandoned wellsites is an important management responsibility and legal requirement. Abandoned wellsites that are thought to be on a trajectory towards recovery receive certification. The Ecological Recovery Monitoring project was set up to measure how habitat variables of certified wellsites changed with time since certification (=”certification age”). Measured habitat variables included trees, snags and downed wood on forested sites, cover layers (e.g., canopy, shrubs, forbs, grass, litter, bare soil), physical and chemical characteristics of soils, and plant species composition, including non-native plants.

The project sampled eighteen pairs of wellsites and adjacent control habitats in the Grasslands, and fifteen paired sites in both the Boreal and Foothills Natural Regions, using a chronosequence approach, with a range of wellsite certification ages from 7 years to 40+ years. In the grasslands, known changes in wellsite rehabilitation techniques about 20 years ago are a confounding factor in the chronosequence. Management techniques were more consistent over time in the forested regions, although certification age may not always accurately reflect time since recovery started, due to delays in issuing certificates.

This report summarizes the results for each habitat, soil and species composition variable, using the paired wellsite-control comparisons and examining changes with certification age. Variables that showed a relationship to certification age or that showed continuing differences between wellsites and controls were selected to contribute to recovery scores. Related variables were grouped into scores that represent recovery of five ecological aspects: live trees and deadwood in forest; cover layers, soils and species composition in all regions. These were further grouped into scores showing short-term recovery within the age span sampled in this project, and those that showed continued wellsite-control differences but are expected to recover in the long-term. The scores are intended to be helpful as indices of recovery in operational monitoring of abandoned wellsites and in further studies of recovery rates in older wellsites.

2. Overview of analysis

There were several steps in the analysis to go from the data collected in the field to development of a few scores that can be used as indices of ecological recovery of wellsites:

Step 1. <u>Summarize variables from the data</u>. Some of these were measured directly (e.g., soil pH), while others were processed from the data (e.g. live tree basal area) [section 3].

Step 2. <u>Compare each wellsite value with its paired control</u>. For many variables, this was done using the wellsite:control ratio [section 4.1]. For plant species composition variables, percent similarity of the wellsite and its control communities was calculated, and scaled to account for differences among plots within the control [section 4.2]. Scaled percent similarity was also calculated using many of the cover layers from the 2D cover sampling. Relationships between certification age and the wellsite:control ratio or scaled percent similarity were plotted, and used to assess whether the variable recovered with certification age (ratio getting closer to 1, or percent similarity increasing), whether there was a consistent difference between controls and wellsites, or whether there was simply wide variability in that variable.

Step 3. Select variables to use in recovery scores. Variables that showed a relationship with certification age or consistent differences between controls and wellsites, and had a good biological basis as a recovery indicator, were selected to be used in recovery scores [section 5].

Step 4. Scale the variables to scores. Each selected variable was scaled from a recovery value of 0% at an initial starting value to a recovery of 100% at an end value. The starting value was 0 for variables absent on wellsites (e.g., live tree basal area, canopy cover), and the 25th percentile of non-zero variables (e.g. soil pH) in the youngest sampled sites (age 7 or 8 years). The end value was set by the paired control – i.e., a ratio of 1 or percent similarity of 100%. [Explained in section 6.1].

Step 5. Combine related individual scores into composite scores. For example, 4 (grassland) or 6 (forest) soil variables were combined into a Soil score. Other composite scores were LiveCanopy for live trees (forest only), Deadwood for snags, CWD and SWD (forest only), Layers for cover layers and Species for species similarity. Composite scores were then combined into Short-term and Long-term recovery scores. Short-term recovery was a weighted average of LiveCanopy, Layers and Species, because these variables all responded to certification age over the age span sampled. Long-term recovery was an average of Soils (all regions)and Deadwood (forest only), because these showed consistent differences between wellsites and controls that did not change strongly with certification age [section 6.2].

Explanation of each step is given in the indicated section, along with narrative and/or graphical summary of results. Section 7 discusses the sampling design, field methods and recovery scores.

3. Variables summarized

Summaries compared measured variables on the wellsite plots with their adjacent reference (control) plots, separately for grassland, and forest (boreal and foothills) study areas. I used the following variables:

3.1 Habitat and soil variables

Habitat variables included measured vegetation, woody debris and soils. Species composition is treated separately.

Trees (forest only)

- Basal area (m^2/ha) for live deciduous trees, live conifer trees, and all live trees combined.
- Stocking density (/ha) of live trees >3m tall, for deciduous trees, conifers and all live trees combined. Stocking density of trees of this minimum height is often used to assess regeneration in forestry cutblocks. Heights were measured for only a subset of trees, so the relationship between diameter at breast-height (DBH) and height was used to assign heights to trees without height measurements (Figure 1). Based on that relationship, trees with DBH ≥2.6cm were considered to be ≥3m tall.

Snags (forest only)

- Basal area (m^2/ha) of all snags (excluding stumps)

Coarse woody debris (CWD) (forest only)

- Volume (m^3/ha) of all CWD and of soft (decay class 4 or 5) CWD. CWD volume was calculated from the intercept transect data following van Wagner (1968). CWD has intercept diameter ≥7cm.

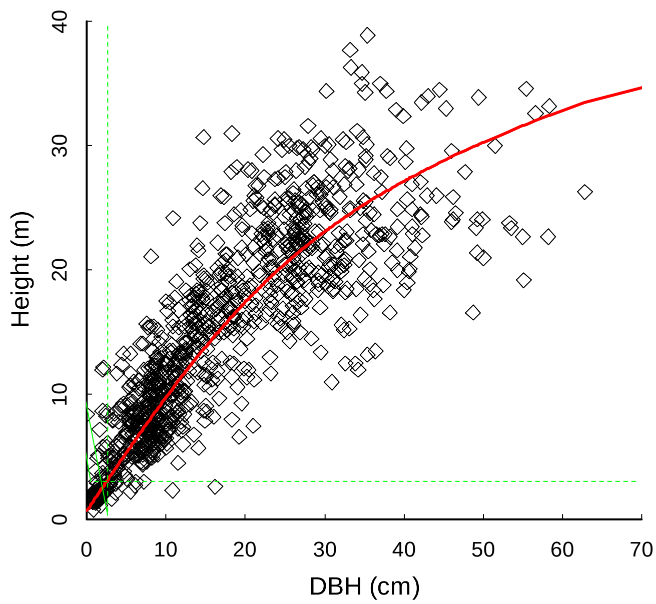

Figure 1. Relationship of height to diameter at breast-height (DBH) for measured live trees. Trees without height measurements but with DBH ≥2.6cm were considered to be ≥3m tall for calculating stocking density.

Small woody debris (SWD) (forest only)

- Number of pieces per intercept transect for small woody debris 1-3cm diameter, 3-5cm diameter, 5-7cm diameter and percent cover of all SWD. Percent cover was calculated by summing the amounts in the 3 diameter classes and assuming each piece in the class had diameters of 2cm, 4cm and 6cm, respectively, then dividing the total SWD diameter by the total length of the SWD intercept transect.

Canopy (forest only) and cover layers from small (quadrat) plots

- Average percent cover of: canopy, shrub, total vegetation, wood, litter and mineral soil+rock. Canopy cover was quantified by calculating the percentage of the 37 cross-hairs in the densiometer graticule grid that intercepted cover (covered intercepts/37)*100. Other percent cover attributes were based on ocular estimates by the field observer. Several other cover layers were recorded in the plots, but had too few non-zero values to summarize.

Cover layers from the 2D cover plots

- Average percent cover of: shrubs <0.5m tall, shrubs 0.5-2m tall, shrubs >2m tall, forbs, grass, moss, lichen, litter and bare ground.

Non-native plant richness and cover

- Using ABMI's list of non-native plants, number of species per cover quadrat, total cover of non-native species (%), number of species per site using the vascular search, and total number of non-native plant occurrences using the vascular search. The latter two measures differ because number of species per site just uses presence/absence across the whole site for each species, while total occurrences sums the number of quadrats (0-4) that each non-native species was recorded in.

Soils

- Bulk density (g/cm^3)
- pH and electrical conductivity (µS/cm)

- total nitrogen (%), total organic carbon (%) and carbon:nitrogen ratio
- LFH depth (cm)(forest only)

3.2 Plant species composition

Vascular plant cover by species
- Average cover of each vascular plant species in the small quadrat plots with cover estimates

Shrub cover by species
- Average cover of each shrub species from the larger shrub cover plots

Vascular plant searches by species
- The number of quadrants (0-4) that each species was found in.

4. Methods – Summary of variables

The above variables were summarized with the objective of selecting those which showed a relationship to certification age, or showed consistent differences between wellsite and controls, as these are most useful for indicating ecological recovery. The summaries relied on the paired wellsite-control sampling, which has the advantage of factoring out site-to-site variation. That allows simpler scores without complex statistical models to account for covariates like habitat type and geographic location, and it will be the only way to measure recovery for individual wellsites (rather than for a large statistical sample of similar wellsites). Regardless of analysis method, only a relatively short time series of wellsite ages is available to try to anticipate recovery towards older forest or natural grassland conditions.

4.1 Summary of habitat and soil variables

For individual habitat and soil variables, two sets of figures were plotted:

i. Wellsite values with paired controls

These figures are intended to show how the values for each variable change with certification age of the wellsite (years since certification), while also allowing comparisons with each wellsite's adjacent control plots. The plots were done separately for grassland, boreal and foothills study areas. For each variable, these plots showed the mean value at each wellsite and the mean value at its paired control plots, connected by a thin line. The values were plotted against the certification age of each wellsite (with the wellsite and control points offset from each other a small amount to reduce overlap). Error bars represented the standard deviation of plots within the individual wellsite or within the controls at the wellsite.

A smoothing spline was fit to the relationship between the wellsite values and certification age. The smoothing spline was fit on the log scale, but back-transformed to the ordinal scale for plotting. This avoided impossible negative values. Confidence intervals were placed on the spline relationship using bootstrapping, in which wellsites were resampled with replacement 100 times and the spline fitted to the resampled data. The 5 and 95 percentiles of the bootstrapped samples were used for the 90% confidence intervals.

ii. Wellsite:control ratio

A second set of figures are intended to show how wellsites recover (or fail to recover) towards the control values. The ratio of the value of the variable at the wellsite to the value at its paired control was plotted for each wellsite, versus the certification age of the wellsite. In these figures, wellsite recovery over time would be shown by the ratio approaching 1. The y-axis (the ratio) was plotted on the log scale, so that ratios of 0.01 (=100 times higher value of the variable in the controls), 0.1, 1, 10 and 100 would be equally spaced. The ratio at an individual wellsite can be 0 if the variable is absent in the wellsite but present in the control, or infinite if the variable is present on the wellsite but absent in the control. Both situations produce infinite values on the log-scale y-axis. Ratios <0.001 were therefore truncated at 0.001, while ratios >1000 were truncated at 1000.

Smoothing splines were fit to the relationship between the wellsite:control ratio and certification age. The smoothing spline was fit on the log scale, as is normal practice with ratios. Confidence intervals were placed on the spline relationship using bootstrapping, in which the ratios for individual wellsites were resampled with replacement 100 times and the spline fitted to the resampled data. The 5 and 95 percentiles of the bootstrapped samples were used for the 90% confidence intervals.

4.2 Summary of species composition variables and 2D layer cover using percent similarity

Percent similarity values were used to compare the species composition of wellsites with their paired controls. Percent similarity is a simple and robust measure of community similarity. It is calculated by first expressing the abundance of each species in a plot as a percentage of the total abundance of all species in the plot. Then, for each species, the minimum of the percentage in the wellsite and the percentage in the control is taken, and these minimums are summed across all species. If a wellsite and control had the same proportions of all species, percent similarity would be 100%. If they had no species in common, percent similarity would be 0%. Partial overlap of species and/or different relative abundances of shared species produce intermediate levels of percent similarity. In practice, similarity indices are always less than 100%, because of sampling error. Even if a wellsite had exactly the same species composition as its control, sampling error would produce differences that would lower similarity.

Percent similarity for species composition

I used the four small quadrats in the controls to estimate how much sampling error lowers similarity. Percent similarity was calculated for each pair of control quadrats (6 pairs). The average of these values was used as a benchmark, showing the maximum value that percent similarity could reach, given sampling error. The average similarity of each wellsite quadrat with each control quadrat was calculated and scaled to the within-control similarity. For example, if the average similarity of the pairs of control quadrats was 80% and the average similarity of wellsite-control quadrats was 50%, then the scaled wellsite-control similarity was 62.5% (=50%/80%*100). Comparing each pair of quadrats ensures that the wellsite-control similarity and the within-control benchmark similarity are both calculated on the same scale (the quadrat). Note that the scaled similarity value here could be >100% if wellsite quadrats happened to be more similar to control quadrats than the control quadrats were to each other.

The above procedure for scaling similarity to account for sampling error works for the quadrat-based vascular plant and shrub percent cover results. It does not work for the vascular plant searches, which give only presence/absence per plot, and so were summarized as the number of quadrants (0-4) where the species occurred on wellsites or in the controls. Wellsite-control similarity for the vascular searches was calculated using those 0-4 values for each species. To scale these similarity values for sampling error effects, I calculated the similarity among all pairs of control sites within a study area. The wellsite-control similarity for each site was then scaled to this similarity among controls. For example, if the similarity of a wellsite and its adjacent control was 50% based on vascular plant searches, and the average similarity among control sites in that study area was 70%, then that wellsite-control similarity would be scaled to 71.4% (=50%/70%*100).

<u>Percent similarity for 2D cover layers</u>

Percent similarity of cover layers from the 2D cover plots was used to show how similar the overall layer structures of the wellsite and its paired control are. This may be a more sensitive single variable than any one of the cover layers on its own. The cover layers included in the percent similarity calculation were: shrubs <0.5m, shrubs >0.5m (summing shrubs 0.5-2m and shrubs >2m), forbs, grass, mosses+lichens combined, litter and bare ground. In analogy to percent similarity of species composition, each of these 2D cover layers is treated as a “species”.

To calculate percent similarity when there were very different absolute levels of different layers, each cover layer was first standardized so that the maximum wellsite or control within a region had a value of 1. I.e., standardized cover at a wellsite or control = observed cover / maximum observed cover at any wellsite or control in that region. A couple rare cover types in grasslands were given half the weight of other layers in the analysis: shrubs <0.5m and moss+lichen. Shrubs >0.5m were nearly absent in the sampled grassland habitats and were excluded. In the boreal and foothills, bare ground was rare and was weighted half as much as all the other cover layers.

Percent similarity was then calculated using the standardized and weighted cover variables in the same way that percent similarity was calculated for the species data. An example of the steps in the calculation of percent similarity for cover layers between a (hypothetical) wellsite and control are given in Table 1. Highlighted steps are the scaling and weighting used with the cover layers. The other steps are the same as used in calculating percent similarity with species composition. The sum of the minimum pairwise values (last column) is percent similarity, 68.6% in this hypothetical example.

Table 1. Example of steps in calculating percent similarity of a wellsite and a control site, as explained in text.

	Raw value		Maximum	Scaled value (% of max)			Weighted scaled value		Scaled to sum=100%		Pairwise
Layers	**Wellsite**	**Control**	**anywhere**	**Wellsite**	**Control**	**Weighting**	**Wellsite**	**Control**	**Wellsite**	**Control**	**minimum**
Shrubs >0.5m	2	10	50	4	20	1	4	20	2.7	16.7	2.7
Shrubs <0.5m	40	30	80	50	37.5	1	50	37.5	34.1	31.3	31.3
Forbs	30	20	100	30	20	1	30	20	20.5	16.7	16.7
Grass	20	5	100	20	5	1	20	5	13.7	4.2	4.2
Moss+lichen	1	5	20	5	25	1	5	25	3.4	20.8	3.4
Litter	25	10	100	25	10	1	25	10	17.1	8.3	8.3
Bare ground	5	1	20	25	5	0.5	12.5	2.5	8.5	2.1	2.1
Sum							146.5	120			68.6

5. Results - Summary of variables

Results for each variable in the grasslands, boreal and foothills are presented in Appendix 1. There are two figures for each variable: 1) wellsites with paired controls, and 2) wellsite:control ratios (see section

4.1 for explanation). The results are grouped into: 1) Trees, snags and CWD (forest only), 2) Small woody debris (forest only), 3) Cover layers from the cover quadrats, 4) Cover layers from the 2D cover plots, 5) Non-native plants, and 6) Soil variables. The section with 2D cover layers includes an extra figure showing percent similarity of wellsites and control based on the cover layers (explained in section 4.2). The last section shows the percent similarity figures for plant species from the cover plots, shrub species from the cover plots, and species from the vascular searches. Each section has some points describing main results, focusing on which variables would be useful indicators of recovery.

The following sections summarize the possible useful recovery indicators for each region. Useful variables show either recovery (wellsites becoming more similar to controls) with certification age in the available data, or consistent differences between controls and wellsites that may be useful for indicating longer-term recovery beyond the time scales that we have studied.

5.1 Summary of variables – Grassland

In general, grassland variables do not show recovery over the sampled chronosequence of certification ages, because of known problems of confounding between age and reclamation techniques. Potential recovery variables are based on consistent differences between wellsites and controls, and biological considerations (e.g. whether the variable is expected to continue changing as sites age, and whether it is highly patchy or widespread).

<u>Cover layers</u> Litter cover is usually somewhat higher in wellsites than controls, and mineral soil + rocks is often much higher in wellsites (Figures A1.1 to A1.4). However, both cover types are uncommon, so both would be weak recovery indicators on their own. Percent similarity of 2D cover layers is an alternative indicator of layer structure, although it is also weak because half the wellsites already have high (near 100% similarity) values of this variable (Figure A1.5).

<u>Non-native plants</u> Non-native plant species richness and cover are higher in wellsites than paired controls, with the strongest difference shown for total non-native cover (Figures A1.6 and A1.7). It would be a useful recovery indicator, with some caveats about possible elevated levels in controls adjacent to old wellsites, if non-natives seeded on the wellsites have spread.

<u>Soils</u> Several variable are consistently different in wellsites than paired controls: bulk density and electrical conductivity are higher, while total nitrogen is (less consistently) lower (Figures A1.8 and A1.9). None show any trends towards recovery over the time span, and the changing treatments, sampled in the grasslands.

<u>Species composition</u> Similarity of species composition from the cover quadrats distinctly shows the effects of seeding on the older wellsites, but the younger ones are also distinctly different from their controls (Figure A1.10). This variable would make a good indicator. The vascular searches were much less sensitive to the wellsite-control differences and to the effects of the old seeding treatment.

→<u>Conclusion</u>: Best recovery indicators in the grasslands are: percent similarity of 2D cover layers, non-native plants, 3 soil variables (bulk density, electrical conductivity, total nitrogen), and species composition based on the cover quadrats. None of these show improving trends with certification age, but that is not expected in the grasslands, due to the improvements in reclamation criteria and associated techniques over time (e.g., non-native seed mixes are no longer used to restore vegetation cover on reclaimed wellsites).

5.2 Summary of variables – Boreal and Foothills

Details of the boreal and foothills results differ (Appendix 1), but the main conclusions for potential recovery indicators are the same, so the two regions are summarized together.

A few boreal sites with younger or intermediate certification ages appeared to have features of older forest. Certification may have been issued to these wellsites long after they actually started to recover. That makes the chronosequence in the boreal less reliable.

The foothills chronosequence included one wellsite that had a much older certification age than any others, which has a large influence on plotted recovery curves at the upper ages. However, flexible curves were used, so that one old site has no influence on the curve at younger or middle ages.

Trees, snags, CWD, SWD Tree basal area is a clear indicator of recovery over the time spans covered in both regions (Figures A1.11 to A1.14 for boreal, Figures A1.24 to A1.27 for foothills). A few old wellsites in the boreal had mostly deciduous cover compared to coniferous controls, or vice versa, which may or may not be considered a negative for recovery, depending on whether the goal is to return to forested land vs returning to forested land with the original stand type. Stocking density added little compared to basal area, but may be easier to measure. In the medium or long term, snag basal area and CWD volume would indicate recovery of forest habitat structures produced by tree mortality. Total SWD cover would be a somewhat shorter-term indicator of recovery of some habitat features.

Cover layers Canopy cover could be a useful recovery indicator (Figures A1.15 and A1.16 boreal, Figures A1.28 and A1.29 foothills). Moss and lichen 2D cover in both regions showed improving trends over the chronosequence (Figures A1.17 and A1.18 boreal, Figures A1.30 and A1.31 foothills), but both are rare or patchy in controls, decreasing their value. Percent similarity of 2D cover is probably the best single variable representing structure of all 2D cover layers (Figure A1.19 boreal, Figure A1.32 foothills).

Non-native plants Number and cover of non-native plants peaked at about 20 years post-certification in the boreal region (Figure A1.20), which probably reflects some confounding factor. There was less evidence of an intermediate peak in the foothills (Figure A1.33). Non-native plants were always much more common in wellsites, so their decrease towards control levels would be a good indicator of recovery. Total non-native cover is probably the most biologically meaningful measure.

Soils In both regions, bulk density, pH and electrical conductivity were usually higher in wellsites than controls, while total nitrogen, total organic carbon and LFH depth were usually lower (Figures A1.21 and A1.22 boreal, Figures A1.34 and A1.35 foothills). Some of these showed hints of recovery over the chronosequence span, but all would be potentially useful recovery indicators in the longer term.

Species composition In the boreal, similarity of species composition in the wellsites and controls remained low for the vascular plants and shrubs[1] in the cover quadrats, while similarity based on vascular searches remained at moderate levels (Figure A1.23). In the foothills, all three showed

[1] The vascular plants include shrub species, but shrubs species were also recorded separately in the field, and could be useful as a distinct group within vascular plants.

evidence of recovery with certification age (Figure A1.36). Any of these would make useful indicators of species recovery over time, although the higher initial values from the vascular searches may make them less sensitive.

→Conclusion: The most useful recovery indicators in the forested regions are: i) Live tree variables (basal area and canopy cover), ii) dead wood variables (snag basal area, CWD volume, SWD cover), iii) 2D cover layers, especially percent similarity of 2D layers, iv) species composition (vascular plant and species similarity from the cover quadrats, and non-native cover; and v) soil variables (bulk density, pH, electrical conductivity, total nitrogen, total organic carbon, and LFH depth).

6. Recovery scores

6.1. Scaling to recovery scores - Methods

Based on the results in sections 5.1 and 5.2, I created recovery scores using variables that either showed a relationship to certification or showed consistent differences between wellsites and paired controls. For grasslands, the variables were: i) Percent similarity of 2D cover layers, ii) Three soil variables (bulk density, electrical conductivity and total nitrogen), iii) Percent similarity of plant species from the cover quadrats, and iv) Cover of non-native plants. For both boreal and foothills regions, the variables were: i) Live tree basal area, ii) Snag basal area, iii) CWD volume, iv) SWD cover, v) Canopy cover, vi) Percent similarity of 2D cover layers, vii) Six soil variables (bulk density, pH, electrical conductivity, total nitrogen, total organic carbon, and LFH depth), viii) Percent similarity of plant species from the cover quadrats, ix) Percent similarity of shrub species from the cover quadrats, and x) Non-native cover.

All scores are based on the paired comparison of the wellsite and its control, to account for the natural variation in many of these variables from site to site. The score for single variables is based on the wellsite:control ratio in all cases, except non-native cover uses the simple difference (wellsite – control), because many controls in the forest have 0 non-native cover. The score for the species composition or 2D layer structure is based on the (scaled) percent similarity of the wellsite and its control.

Converting the observed ratios (or difference) to a score requires setting a starting point and an ending point – i.e., the values of the ratio (or difference) or percent similarity where the score is 0% recovered in a recently abandoned wellsite and where it is 100% recovered. For some variables like live basal area, canopy cover or CWD, active wellsites have none of the features, so the starting value of the ratio is set at 0. For other variables, such as soil parameters, wellsites have some value of the variable, which may be lower or higher than the control (i.e., wellsite:control ratios <1 or >1). The study does not have samples of sites immediately after active use, which could provide starting ratios directly. Instead, I estimated starting values using the 25th percentile of the ratios at the youngest ages sampled (7 or 8 years in the different regions) for ratios <1 (i.e., where wellsites have a lower value of the variable than the controls), and the 75th percentile of the ratios at the youngest ages sampled for ratios >1. This is equivalent to saying that 25% of wellsites at ages 7 or 8 years would have scores of 0% recovery for those variables. For all ratios, the ending value where the recovery score reaches 100% was set at 1 (i.e. full recovery occurs when wellsite = control). For non-native plant cover, where the simple difference was used, the starting value was the mean difference (wellsite - control) for the region, while the ending value for 100% recovery was a difference of 0 (i.e., where the non-native cover on the wellsite decreases to the level found in the paired control). The starting and ending values for each variable are shown in Table 2.

With these starting and ending values, the recovery score is simply equal to: (observed ratio or difference – starting value) / (ending value – starting value) *100%. In other words, the recovery score is the percent of the way from the starting value towards the ending value that the wellsite has gone. Values <0% are truncated to 0% and values >100% are truncated to 100%.

Table 2. Variables used for recovery scores, starting and ending values (i.e., values where recovery = 0% and 100%, respectively), and how the variables are used in the composite scores and summary scores.

Region	Variable	Measure[1]	Starting Value	Ending Value	Composite Score	Weight of Variable in Composite Score	Summary Score	Weight of Composite Score in Summary Score
Grassland	Layers %Similarity	Ratio	0.822	1	Layers	1	Short-term	1
	Non-native Cover	Difference	27.147	0	Species	1	Short-term	2
	Plant Cover %Similarity	Similarity	0.529	1	Species	1		
	Bulk Density	Ratio	1.084	1	Soil	1	Long-term	1
	Electrical Conductivity	Ratio	1.889	1	Soil	1		
	Total Nitrogen	Ratio	0.884	1	Soil	1		
Boreal	Layers %Similarity	Similarity	0.432	1	Layers	1	Short-term	1
	Live Total Basal Area	Ratio	0	1	LiveCanopy	2	Short-term	2
	Canopy Cover	Ratio	0	1	LiveCanopy	1		
	Non-native Cover	Difference	26.748	0	Species	1	Short-term	2
	Plant Cover %Similarity	Similarity	0.059	1	Species	2		
	Shrub Cover %Similarity	Similarity	0.065	1	Species	1		
	Snag Basal Area	Ratio	0	1	Deadwood	1	Long-term	1
	CWD Volume	Ratio	0	1	Deadwood	1		
	SWD Cover	Ratio	0	1	Deadwood	1		
	Bulk Density	Ratio	1.578	1	Soil	1	Long-term	1
	pH	Ratio	1.166	1	Soil	1		
	Electrical Conductivity	Ratio	1.290	1	Soil	1		
	Total Nitrogen	Ratio	0.316	1	Soil	1		
	Total Organic Carbon	Ratio	0.174	1	Soil	1		
	LFH Depth	Ratio	0.212	1	Soil	1		
Foothills	Layers %Similarity	Similarity	0.544	1	Layers	1	Short-term	1
	Live Total Basal Area	Ratio	0	1	LiveCanopy	2	Short-term	2
	Canopy Cover	Ratio	0	1	LiveCanopy	1		
	Non-native Cover	Difference	26.566	0	Species	1	Short-term	2
	Plant Cover %Similarity	Similarity	0.058	1	Species	2		
	Shrub Cover %Similarity	Similarity	0.013	1	Species	1		
	Snag Basal Area	Ratio	0	1	Deadwood	1	Long-term	1
	CWD Volume	Ratio	0	1	Deadwood	1		
	SWD Cover	Ratio	0	1	Deadwood	1		
	Bulk Density	Ratio	1.279	1	Soil	1	Long-term	1
	pH	Ratio	1.281	1	Soil	1		
	Electrical Conductivity	Ratio	1.896	1	Soil	1		
	Total Nitrogen	Ratio	0.533	1	Soil	1		
	Total Organic Carbon	Ratio	0.476	1	Soil	1		
	LFH Depth	Ratio	0.290	1	Soil	1		

[1] How the variable is measured. Ratio = wellsite:control ratio; difference = wellsite - control; similarity = percent similarity of the wellsite and control.

CWD = Coarse woody debris; SWD = Small woody debris

6.2. Recovery scores – Composite scores

The four variables with recovery scores for grasslands and the ten variables for forested regions were combined into three and five composite scores, respectively (Table 2). For the grassland, the three composite scores are:

i) Soils. The scores for the three soil variables (bulk density, electrical conductivity, total nitrogen) were averaged.
ii) Layers. This is the percent similarity of 2D layers variable.
iii) Species. This is the average of the scores based on percent similarity of plant species, and non-native cover.

For the two forested regions, the five composite scores are:

i) LiveCanopy. This is a weighted average of the scores based on live tree basal area and canopy cover, with twice as much weight given to live tree basal area, because it is a fundamental variable in forest regeneration.
ii) Deadwood. This is a simple average of the scores for snag basal area, CWD volume and SWD cover.
iii) Soils. This is a simple average of the scores for the six soil variables.
iv) Layers. This is the percent similarity of 2D layers variable.
v) Species. This is a weighted average of the scores based on percent similarity of vascular plants from the cover quadrats, percent similarity of shrubs, and cover of non-native plants. Percent similarity of plants was given twice the weight of the other two variables, because there are many more plant species than shrub species, and non-native species are less prevalent in the forested regions than in the grasslands.

For summary reporting, the 3 or 5 composite scores were further summarized into 2 recovery index scores, representing shorter-term recovery measures and longer-term measures. Variables that showed evidence of recovery within the range of ages studied were classified as short-term recovery indicators, whereas variables that were consistently different between wellsite and control were classified as long-term indicators of recovery. The expectation is that the value of the long-term recovery indicators on wellsites will eventually tend towards the control values, but at wellsite ages greater than were sampled in this project.

In the grasslands, the short-term recovery index score was a weighted average of the Layers score and the Species score, with twice the weight given to the latter, because it incorporates information on many species, compared to relatively simple cover layer structures in the grasslands. The long-term recovery index score in the grassland was simply the Soil score.

In the forested regions, the short-term recovery index score was a weighted average of the LiveCanopy, Layers and Species scores, with twice the weight given to the LiveCanopy and Species scores than to the Layers score, because LiveCanopy represents basic forest recovery while information on many species is incorporated in the Species score. These variables generally showed moderate to substantial recovery over the sampled range of wellsite ages. The long-term recovery index score in the forested regions was the simple weighted average of the Deadwood and Soil scores, both of which showed only small amounts of recovery over the span of wellsite ages sampled in this study.

6.3. Recovery scores – Results

Note: Figures are not presented for the recovery scores for each individual variable, because these are just scaled versions of the ratio figures presented in Appendix 1. The individual score results show the exact same pattern as the original variable, except that the y-axis ranges from 0% to 100% recovery, with more extreme values truncated to those limits.

6.3.1. Recovery scores – Grassland

The short-term summary score and its two components, the Layers score and the Species score, all showed declines with certification age of grassland wellsites (Figure 2). This reflects the continuing effects of different past conservation and reclamation techniques, particularly seeding with non-native species >20 years ago. The long-term score, which is the same as the Soil score in the grasslands, showed no real decline with certification age. Because of the confounding with different conservation and reclamation criteria in the past, it is not clear how quickly the recovery scores would be expected to improve over time for wellsites that undergo current reclamation methods.

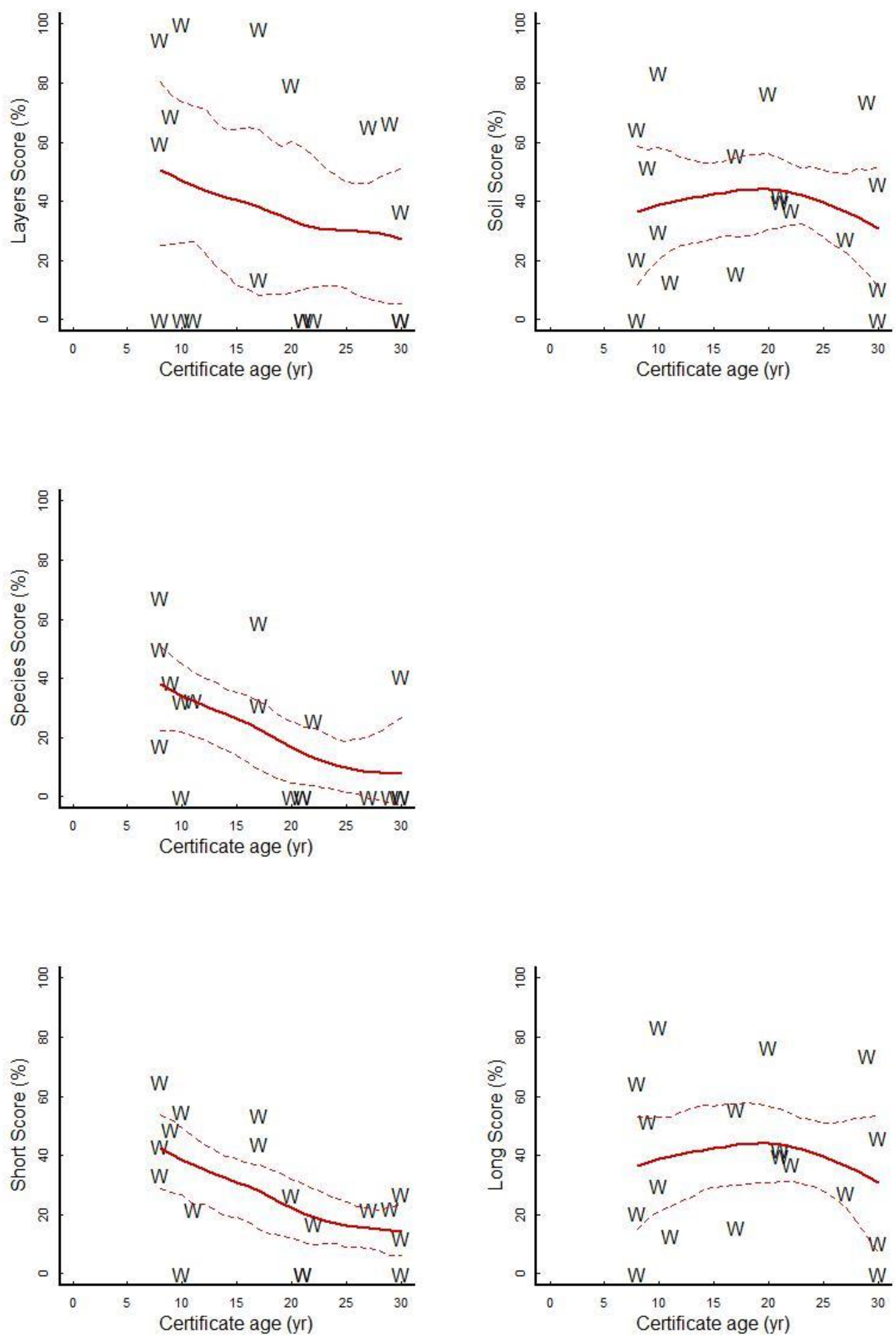

Figure 2. Composite recovery scores – Layers, Soil and Species – and summary recovery index scores – Short-term and Long-term – for reclaimed grassland wellsites. W = individual wellsite/control pair, solid red line = smooth spline, dotted lines = 90% confidence intervals on smooth spline.

6.3.2. Recovery scores – Boreal

In the boreal region, the short-term recovery score increased from 20% at age 8 to 60% at age 40 (Figure 3). There is wide uncertainty at the upper end, because there are only two old wellsites, one with high and one with moderately low recovery scores. The three composite scores that make up the short-term summary score showed somewhat different changes with wellsite age post-certification. The LiveCanopy score, which includes live tree basal area, increased strongly for the older wellsites, the Layers scores increased for the young to mid-range wellsites, while the species score did not show a strong trend over the sampled age range. Three moderately young wellsites in the boreal region showed anomalously high short-term recovery scores, probably due to their actual recovery time being greater than the certification ages. They may also have been intensively rehabilitated, including tree planting.

The long-term recovery score showed little or no increase with wellsite age (Figure 2). The Soil score, which is one of its two components, did increase consistently up until about 25 year, but then leveled off. However, that levelling off was driven by one of the two old wellsites, where soils remain very different from the adjacent control. The deadwood score showed no trend across the sampled age range, with only scattered snags, CWD or some SWD cover appearing in a few wellsites. Deadwood is expected to have long recovery times on cleared sites, because it depends on trees being established, growing and dying.

6.3.3. Recovery scores – Foothills

The short-term recovery score in the foothills increased consistently from near 0 in 8-year old wellsites to about 60% by age 48 (with only one site over 30 years old) (Figure 4). The component scores all showed increases with age, with a consistent increase in the LiveCanopy score, a quick initial increase in the Layers score, and a slower rise with more variation in the Species score. The summary short-term score helped to average out some of the variation in the individual composite scores.

The long-term score increased slightly with age, except that the one old wellsite had only a moderate score. The Soil component increased with age, except for a low score in the old site. Deadwood was nearly absent in all but the oldest site.

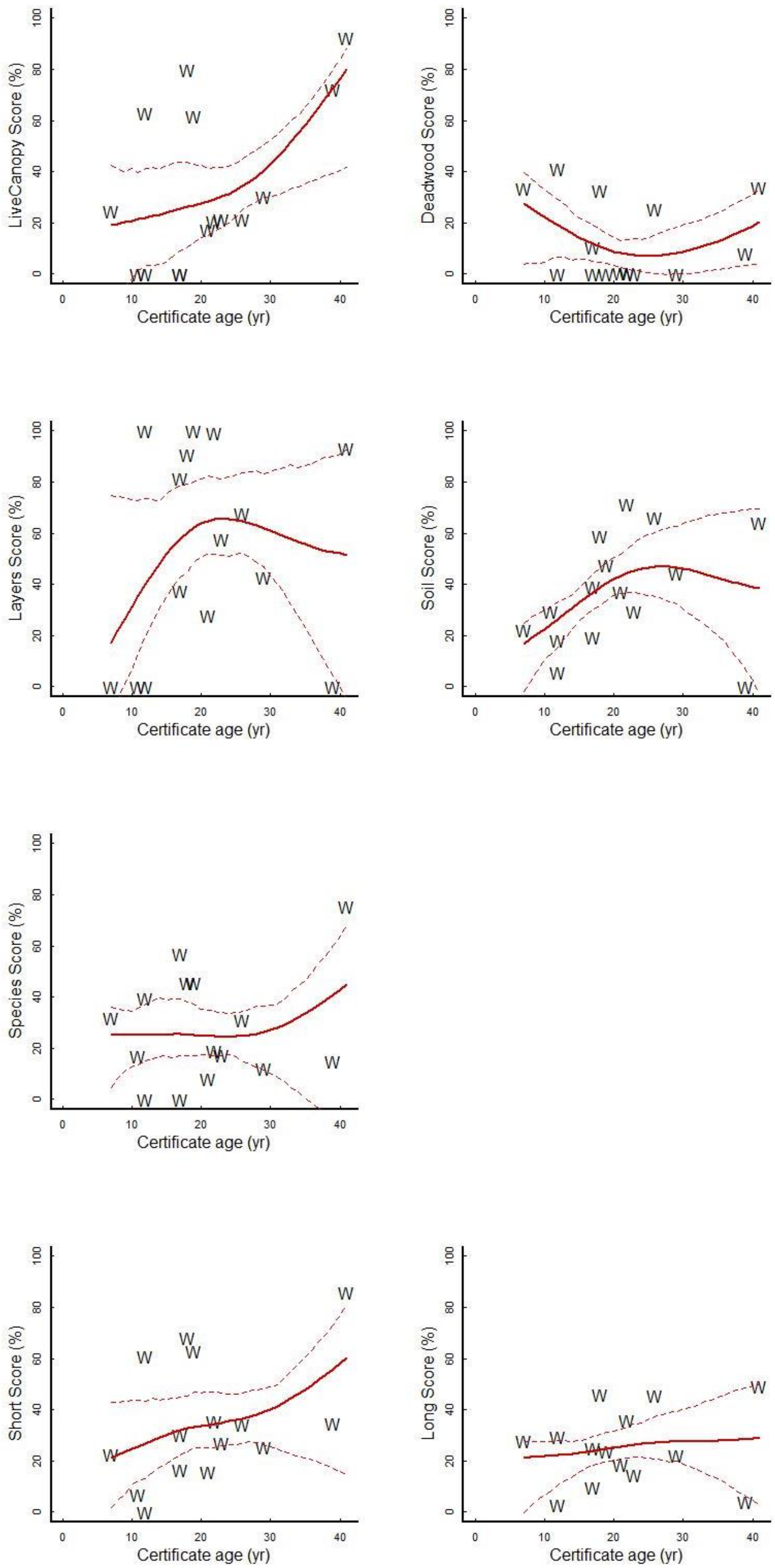

Figure 3. Composite recovery scores – LiveCanopy, Deadwood, Layers, Soil and Species – and summary recovery index scores – Short-term and Long-term – for reclaimed boreal wellsites. W = individual wellsite/control pair, solid red line = smooth spline, dotted lines = 90% confidence intervals on smooth spline.

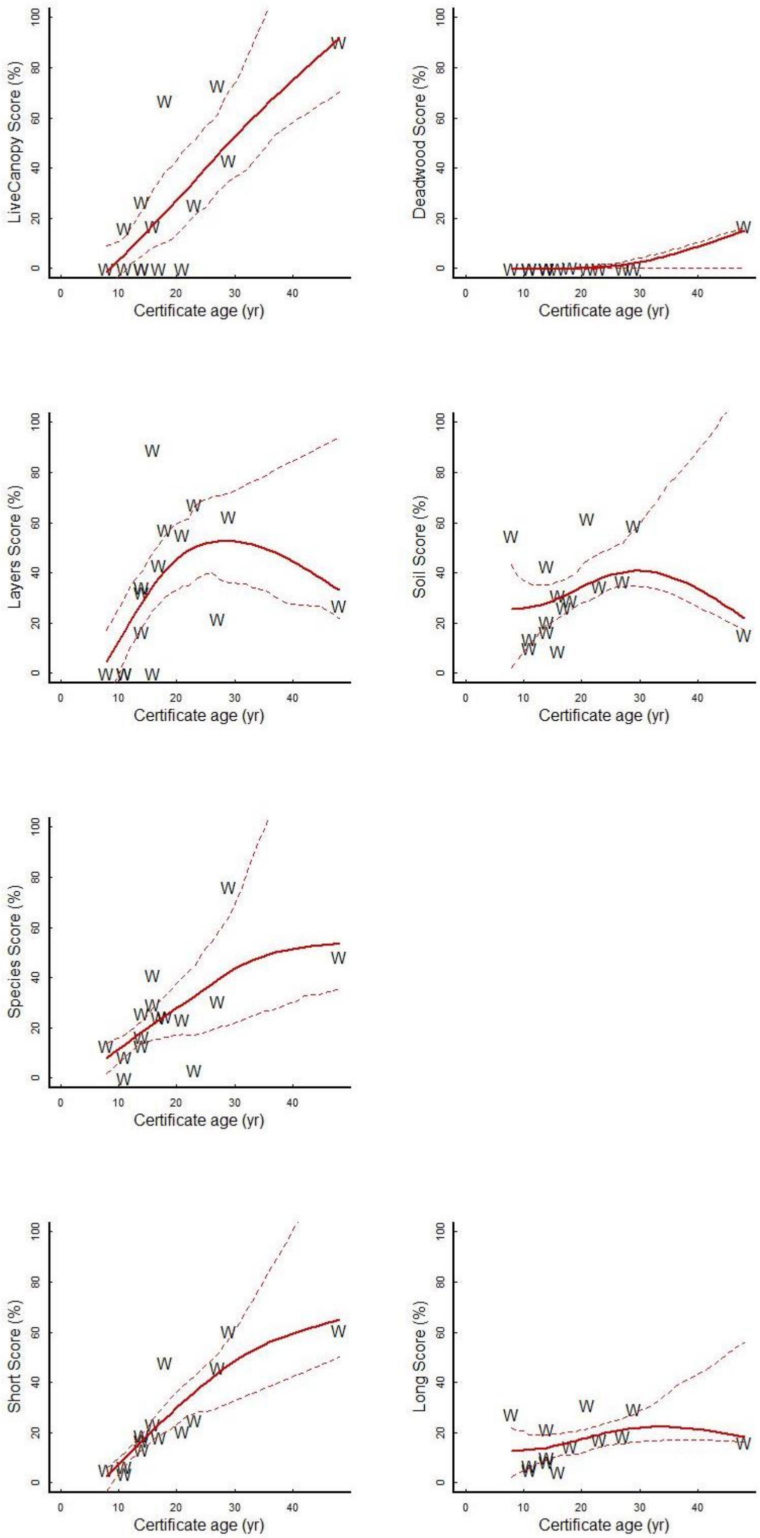

Figure 4. Composite recovery scores – LiveCanopy, Deadwood, Layers, Soil and Species – and summary recovery index scores – Short-term and Long-term – for reclaimed foothills wellsites. W = individual wellsite/control pair, solid red line = smooth spline, dotted lines = 90% confidence intervals on smooth spline.

7. Discussion

7.1. Sampling design and analysis approach

The sampling design of wellsites paired with adjacent controls is a powerful way to reduce problems of high site-to-site variability. There is likely no other way that individual wellsites could be assessed for recovery. Operational recovery assessments should continue to use the paired design.

Relying on the paired design means that baseline data from systematic ABMI sites does not have much use for individual wellsite assessments. There is simply too much variability among sites, even if the best models for systematic ABMI sites are used to try to account for effects of covariates (habitat type, soil type, geographic location). Additionally, some of the field protocols have a definite subjective element, including estimating cover and even individual differences in detecting different species. Some variables also potentially change with time of year and between year, such as species composition and soil variables. Direct comparisons of wellsites with paired controls greatly reduces complications from those factors, compared to trying to use systematic ABMI plots as controls for individual wellsites. Comparisons of wellsites with similar ages of natural (fire-origin) forest could be a useful additional source of information on whether wellsites were on a trajectory towards their original older forest conditions.

The use of four quadrants in the controls surrounding the wellsite is very helpful for estimating the uncertainty in the individual control values, and particularly for standardizing the percent similarity measures to account for the inherent plot-to-plot variability (producing the scaled percent similarity measure used here). That plot layout should be maintained for operational assessments. One consideration is that control plots should not be located in habitat that is clearly different from the habitat the wellsite was put in. For example, a control plot should not be put in a small patch of wet lowland if the wellsite is upland. An alternative upland location should be available for that control plot. With only 4 plots, it is more important to get comparable plots in the adjacent control than fully random sampling.

The likelihood approach used in the initial assessment of the 2014 grassland sites was not pursued this year, because it does not make use of the benefits of the paired wellsite-control design. Instead, that approach compared the pool of wellsites in a region to the pool of controls. It could be helpful for assessing a large number of similar wellsites as a group, but would not be so useful for individual wellsites. Additionally, the likelihood analysis needs a large number of samples to produce reliable results, particularly when there are many variables (different habitat and soil measurements, many species). The more direct approach used here, of summarizing and winnowing the variables based on pilot results and biology, then generating sensible composite indices, is simpler and more robust when datasets are not huge.

The inherent difficulty of confounding in chronosequence designs was highlighted in interpreting the age relationships in the grasslands. There is not much that can be done about that, assuming that all older wellsites were treated similarly. A priority for future sampling within the grassland might be shrubby habitats, which could have different recovery than the grass- and forb-dominated sites. Again, changes in management practices over time might confound that comparison.

It is possible that there are similar confounding issues with different management in the older sites in the boreal and foothills regions, but there was no clear sign of that. The limitation in those two regions is that there are only 2 or 1 site >30 years old. Those old sites play a big role in determining the relationship of individual variables and recovery scores to wellsite age. Increasing the number of older wellsites would be helpful, if it is important to verify how the recovery scores respond to age.

An additional problem in the boreal region was that at least a couple wellsites with young or moderate certification ages appeared to have been recovering for much longer – they had live basal areas that were too high for their age, and ended up with anomalously high short-term recovery scores. It might be worth checking if there is any way to find out if those sites were abandoned or rehabilitated long before certification was issued.

7.2. Field methods

The final recovery scores use a variety of different variables, including habitat elements and structures, soil measures and species composition. Each individual variable showed considerable variation and some "odd" sites, but the overall combination of variables provided a much more stable and sensitive index of recovery. That supports continuing the various protocols, rather than trying to find a single type of measurement that can index recovery.

Some comments on the specific field methods:

- Trees and snags. The tree and snag field plots work well. Stocking density (number of trees >3m tall) was examined as an alternative to basal area, because it is typically used in forestry cutblock assessments and it does not require measuring each tree's diameter. It produced similar information to basal area. However, it is probably worth continuing with the more intensive measurement of each tree in plots, because this will allow direct comparison with ABMI (and other) plots in forested areas. It will also track how trees on recovering wellsites survive and grow over time. Unlike plant surveys, there is little subjective difference in tree measurements, so the wellsite plots can also contribute to the larger ABMI database.
- CWD. There was high variability in the CWD values measured in each control site. This is a typical result with CWD transects, because a single large log on a short transect produces a big increase in estimated volume. That uncertainty is probably not important for assessing wellsite recovery, however, because CWD levels are going to be low or absent on wellsites for many decades.
- SWD. Percent cover was the best summary variable for small woody debris. This is best estimated as was done in this study – by recording the number of pieces along a transect in a few size classes, then calculating cover from those results. Direct estimates of SWD cover would be faster, but are almost impossible to do reliably in the field.
- Cover layers. The 2D cover estimates from the 5x5m plots provided better information on the broad cover layers (total forb cover, grass, shrub, mineral soil, litter, etc) than the measures from the small quadrat plant cover plots. On the other hand, the cover quadrats are needed for plant species assessments, so it probably does not hurt to continue recording the cover layer estimates from the small plots. For the 2D cover information, the percent similarity measure was the most useful summary variable, because it compares the overall structure of the layers. Canopy cover is also directly useful.
- Plant species. The cover quadrats were more useful for non-native plants than the vascular searches, because overall cover of non-natives is a basic measure of their ecological impact. There was much more difference between wellsites and controls using non-native cover than occurrence of non-native

species in searches. The cover results also better showed the lasting effects of seeding old wellsites with non-native agronomic species. In the boreal and foothills regions, community similarity based on the vascular plant searches and cover quadrats showed similar patterns with wellsite age. However, the vascular search values were higher, showing that that method is less sensitive to differences between wellsites and controls than the cover quadrats. Overall, the results favour the cover quadrats over the vascular searches. The vascular searches are more compatible with ABMI monitoring in the forested regions, but that may not be too important, because there are substantial subjective elements to the search results. If different crews are doing the wellsite monitoring than ABMI plots, it may be difficult to incorporate the wellsite search results into the larger ABMI dataset.
- Soils. It is not obvious why the wellsites show consistent differences from controls, and how long it will take for those differences to disappear in recovering wellsites. But soil variables clearly do show fundamental differences between wellsites and controls, and so are useful as long-term recovery indicators.

7.3. Recovery index

The short- and long-term recovery indices show sensible trends relative to certification age in the three regions, including the expected "non-intuitive" negative relationship with the known confounding in the grasslands. The short-term index showed considerable variation in the boreal, especially with some points having greater recovery than expected for their age. That may be due to certification age underrepresenting the actual time that those wellsites have been recovering.

A main challenge with a recovery index, especially if it is used for issuing certifications, is that the management expectation is not that a certified wellsite is completely recovered ecologically. Some processes, like deadwood creation and decay, will take many decades. Instead, the expectation is just that the wellsite is on a trajectory towards full recovery. The short-term index may be measuring that, but there is no guarantee that a site with a high or moderate score will continue to full recovery, and there is certainly no single threshold score that guarantees a good trajectory. Figuring out such a threshold would require a very long-term ecological recovery monitoring program that measured the recovery variables at various ages and tracked wellsites over decades to see which ones actually recovered fully. In the absence of that monitoring program, assumptions would just have to be made about a suitable score.

For individual wellsites, there is uncertainty even in the summary recovery index scores. In other words, two sites in similar conditions would receive somewhat different scores, just because of sampling error in measuring the wellsite, or the paired control that is equally integral to the recovery score. Confidence intervals could conceivably be put on the recovery scores, but that would be fairly difficult statistically, because the scores involve ratios with sampling error in both the numerator and denominator, and many individual variables contribute to the scores.

A related point is that the recovery index is not expected to ever reach 100% for a wellsite. Again, sampling error, and just inherent natural variability from point to point ensures that at least some of the contributing variables will never reach the exact levels found in the paired control (other variables may exceed the control values eventually, but those "overachievers" are truncated to 100%). Again, that is not too important in practice, because the management responsibility is not to have the wellsites 100% recovered to control conditions.

Continued sampling of wellsites for operational assessment should allow future refinements to the score. Further sampling of old wellsites would be particularly helpful for that purpose, particularly if they were reclaimed with techniques similar to modern ones.

Appendix 1. Results for individual variables

A1.1 Grassland

A1.1.1 Grassland Cover layers

- Shrub cover was very high on one grassland wellsite and its control, but absent in all but 2 other wellsites despite some shrub cover in controls.
- Vegetation cover on wellsites was often 10-20% lower than in the paired controls, and declined slightly with age, probably reflecting different reclamation practices on older wellsites (seeding with agronomic species).
- Litter cover was considerably higher on wellsites than controls in all but four cases, and showed no pattern with age.
- Mineral soil and rock cover was substantially higher on wellsites than controls in half the paired cases, but low and similar to controls in the other half, with no relationship to age.
- The ratio figures do not show any variables with clear recovery (=approaching a ratio of 1) with age. Vegetation cover goes the wrong way (wellsites and controls are less similar with older wellsites), while the others show no trend with age or high variability (for shrubs, which are rare in this habitat type).

→ The change in conservation and reclamation techniques over time makes it hard to derive any good recovery indicators here.

GRASSLAND

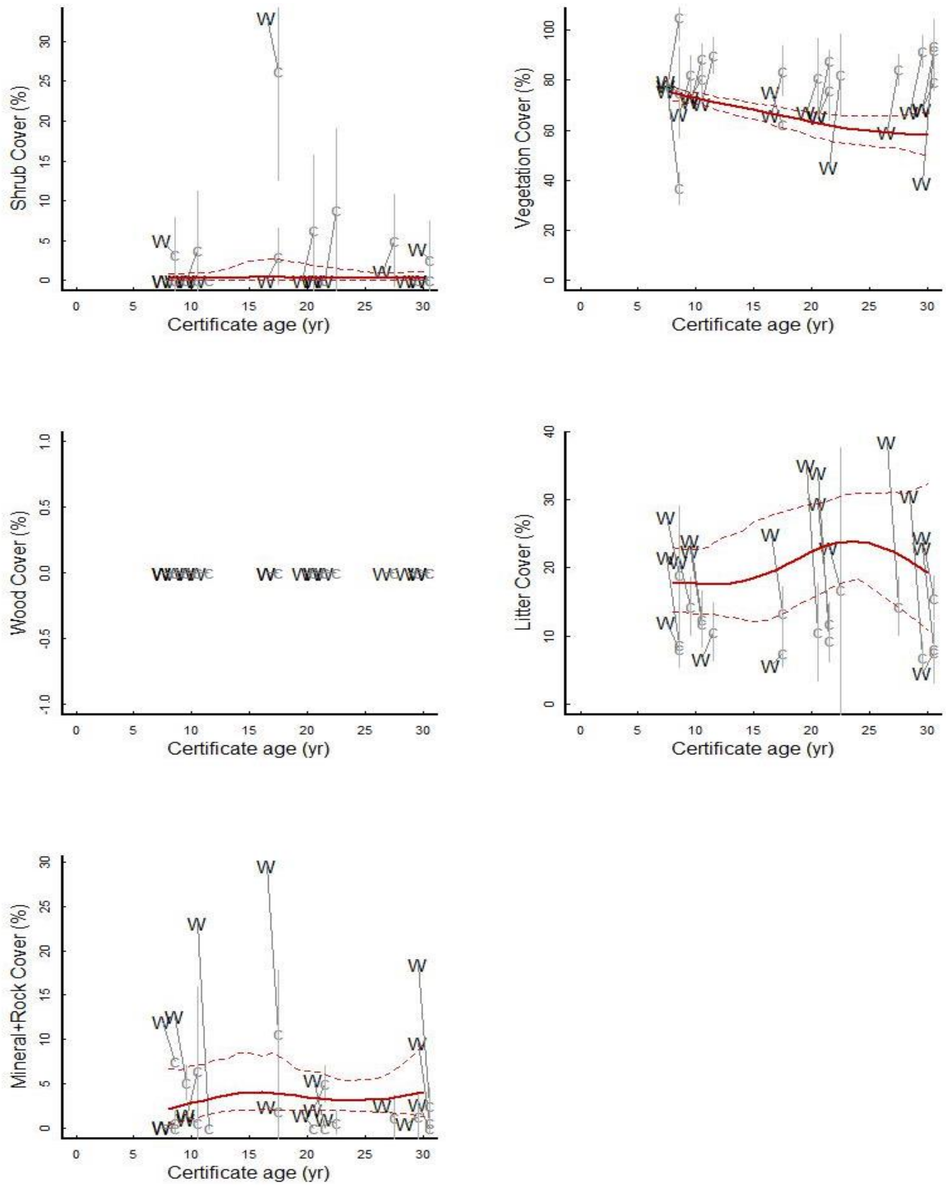

Figure A1.1. Grassland cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the 4 control quadrats.

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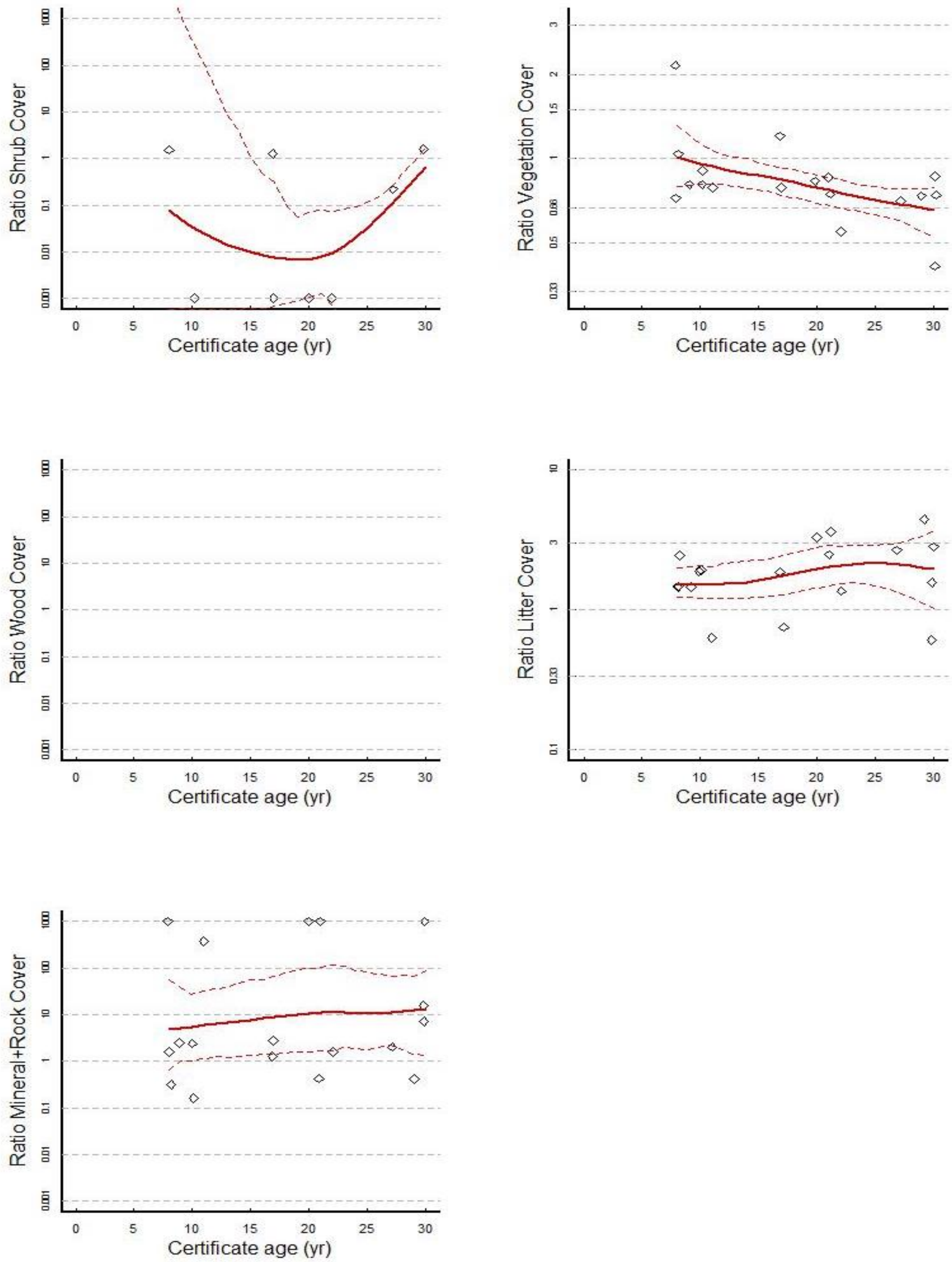


Figure A1.2. For Grassland cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.1.2 Grassland 2D Cover layers

- The 2D cover plots similarly showed higher shrub cover on 3 wellsites, and little or no shrub cover on the rest, despite some shrubs in the controls. No shrubs were >2m and few were >0.5m tall.
- Forb cover on wellsites was variable compared to paired controls, ranging from substantially higher to moderately lower. Forb cover decreased with age of wellsites, possibly reflecting grass seeding on older wellsites.
- Grass cover was typically lower on wellsites than in controls for younger wells, increasing slightly to more similar levels in older wellsites, which again may reflect different seeding practices.
- Moss cover was mainly negligible in wellsites and controls in the grasslands.
- Lichen cover was near zero in all but two wellsites, despite moderate amounts in about half the controls. Two of the older wellsites had more lichens, but still less than the controls.
- The 2D cover plots also showed the higher litter layers in most wellsites compared to controls, and similarly little trend with wellsite age.
- Bare ground was also high in about half the wellsites in the 2D cover plots, and almost always higher than the controls, with no trend with age.
- Two of the ratio figures show some hint of recovery for 2D cover: 1) Grass on wellsites increases towards control levels over time, although it does not start much lower than controls even at age 10. 2) Lichen cover increases from low ratios to about 1 in the oldest grassland wellsite-control pairs, but there is wide variation among individual sites (including cases of no lichens in one or the other of the wellsite or its control).
- Combining the layers into the percent similarity metric did not produce any relationship with wellsite age. The scaled similarity values were all quite high, meaning that the layer structure of the wellsites was not very different from the controls.

→ 2D cover results do not suggest any strong indicators of recovery in the grasslands. Lichen cover is possible, but it is highly variable between sites (wellsites and controls). Grass cover is probably too general to use as a reliable indicator.

GRASSLAND

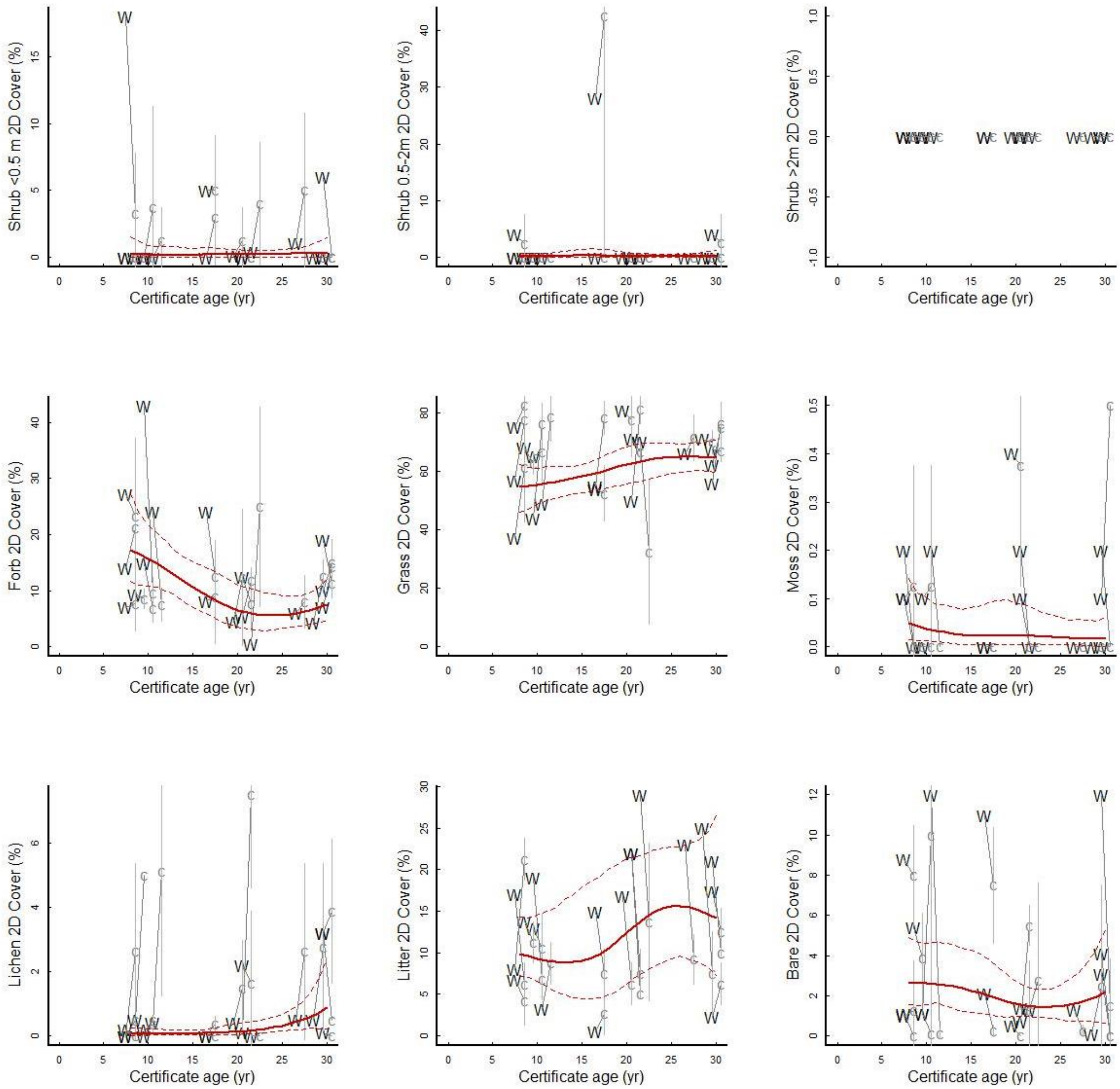


Figure A1.3. Grassland 2D cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

GRASSLAND

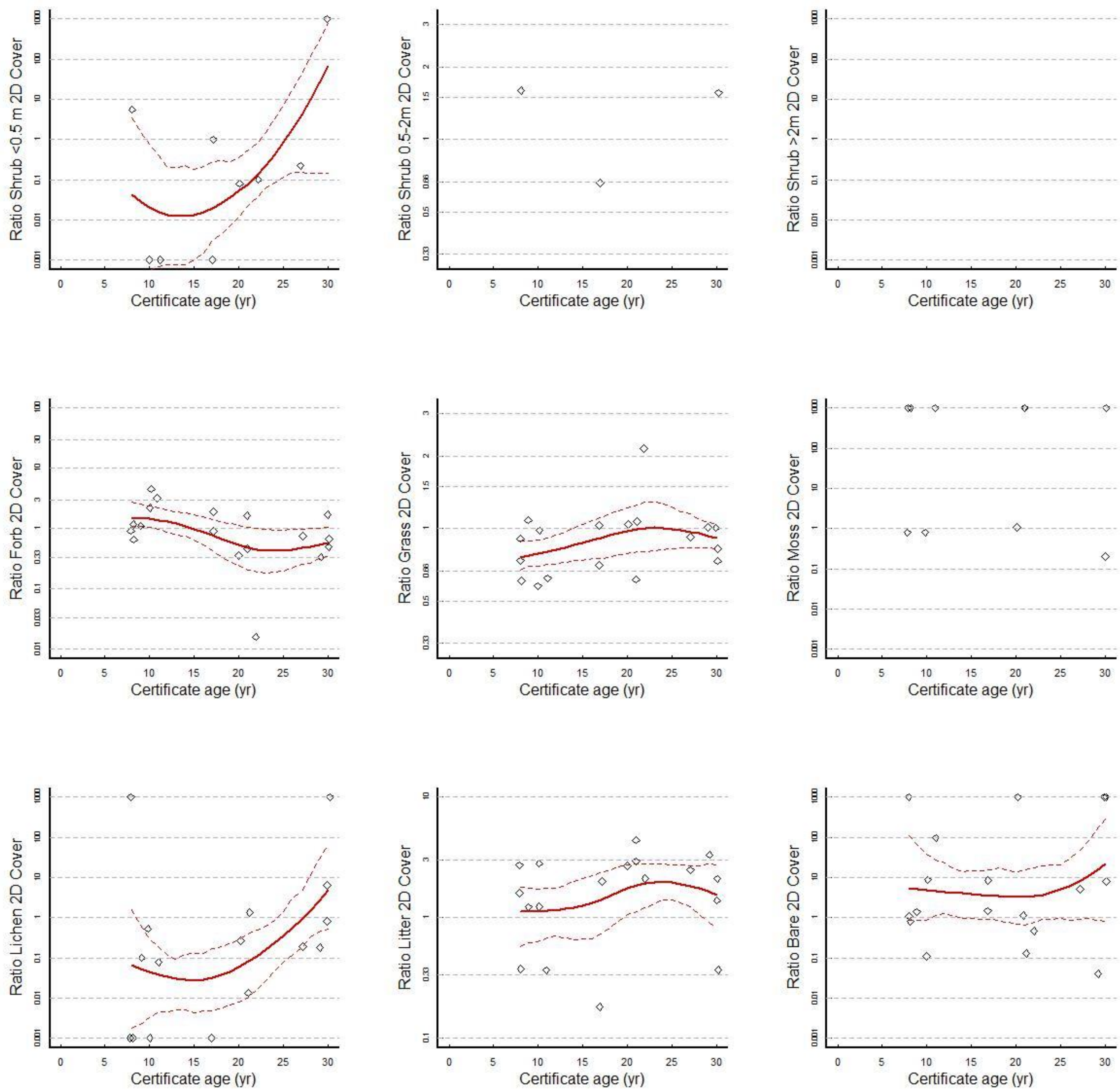


Figure A1.4. For Grassland 2D cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

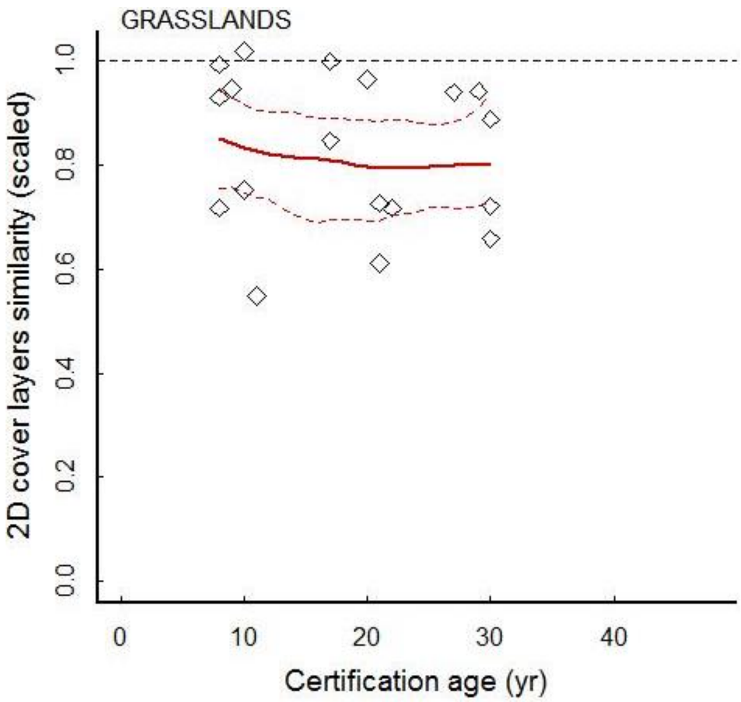


Figure A1.5. Percent similarity of 2D cover layers between wellsites and paired controls for Grassland sites, versus certification age of wellsite. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).

A1.1.3. Grassland Non-native plants

- Cover quadrats showed increasing cover of non-native (NN) plants in older wellsites (one exception), but little change in number of non-native species. That is consistent with older sites having been seeded with a few persistent non-native species.
- The vascular searches found a much higher number of non-native species overall, with slightly decreasing numbers in older sites.
- Control values were scattered among the wellsite values using the vascular searches, while controls were consistently lower than wellsites with the cover quadrats, especially for non-native cover. The vascular searches do not indicate how prevalent or important the non-native species are, because a single occurrence in one spot is counted the same as extensive cover.
- Note: Figures of wellsite:control ratios were not plotted because of the many zero or very low values in the controls.

→ Overall, total non-native cover makes more sense as an indicator, because it should have more direct effect on loss of native species. Total number of non-native species, however measured, is a coarser indicator.

COVER QUADRATS

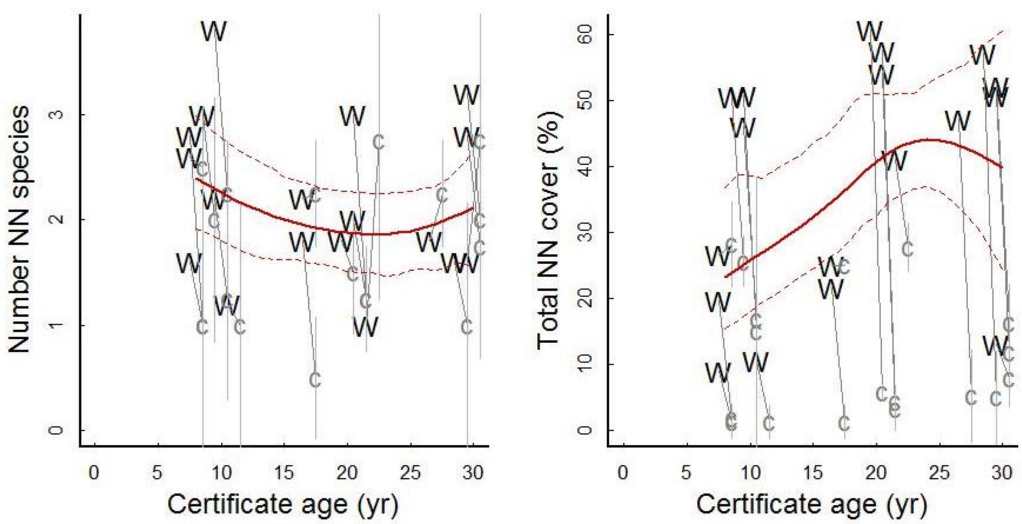


Figure A1.6. Number of non-native plant species in Grassland <u>cover quadrats</u> on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

VASCULAR SEARCHES

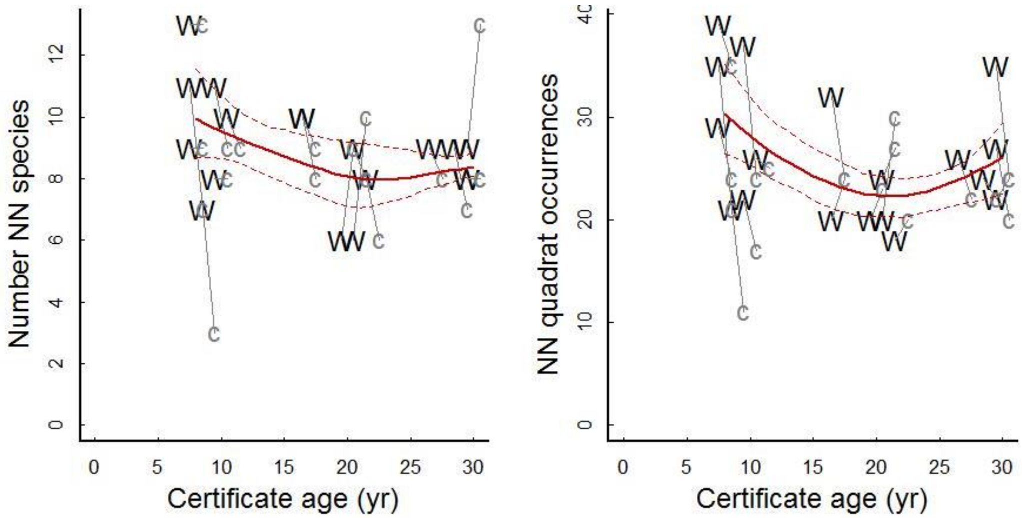


Figure A1.7. Number of non-native plant species in Grassland <u>vascular plants searches</u> on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

A1.1.4. Grassland Soils

- None of the soil variables on wellsites in the grasslands showed consistent trends with age of wellsite. For some variables, there was high variability among wellsites, and for others (bulk density, pH, Carbon/Nitrogen) there was little variability (note the limited range of the y-axis on the Carbon/Nitrogen figure).
- The ratio figures show that bulk density was almost always slightly higher on the wellsites than in the adjacent control, electrical conductivity was considerably higher on the wellsites, and nitrogen was usually lower (and hence carbon/nitrogen was slightly higher on wellsites).

→ None of the soil variables showed recovery trends with wellsite age, although again confounding of age and rehabilitation treatment confuses the issue. Changes toward control values in variables that are consistently different on wellsites and controls could be useful indicators of recovery (e.g., bulk density, electrical conductivity).

GRASSLAND

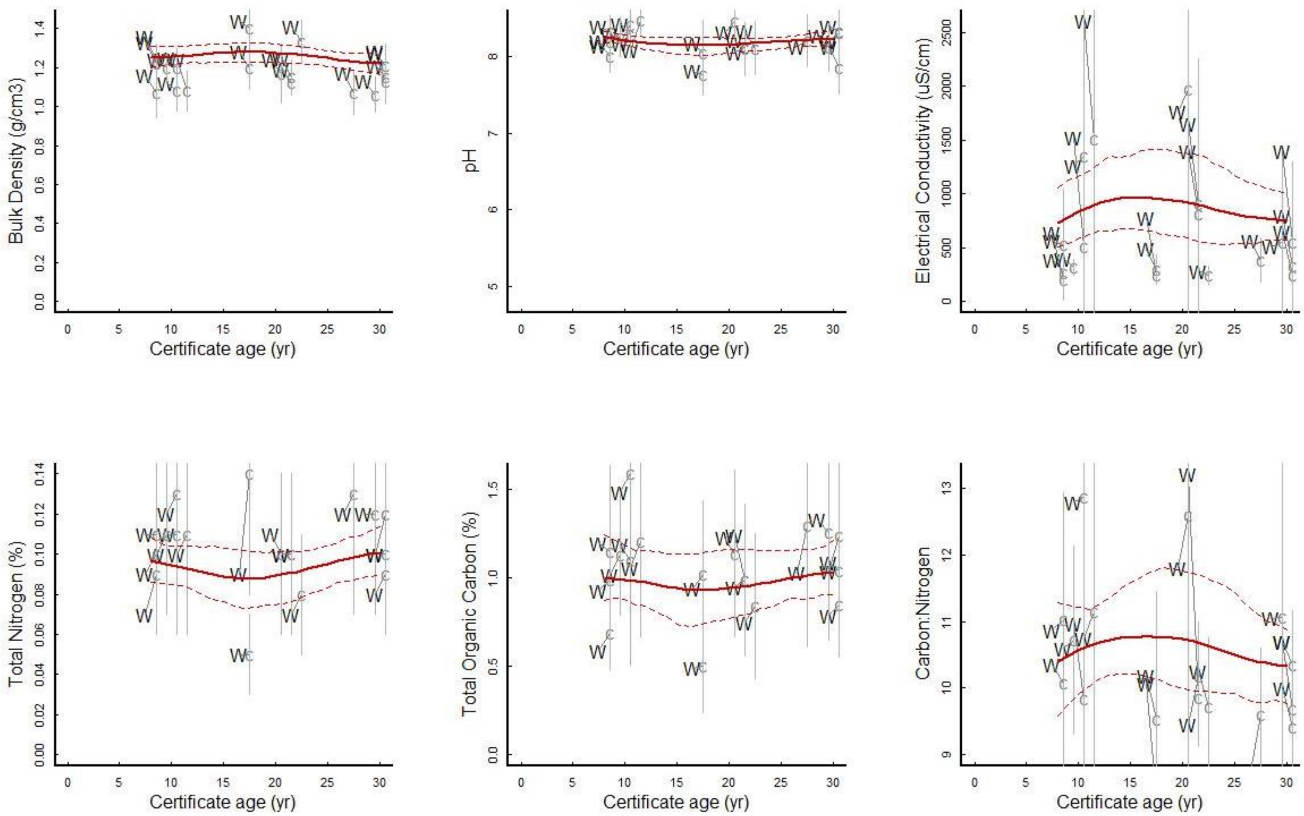


Figure A1.8. Grassland soil variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

GRASSLAND

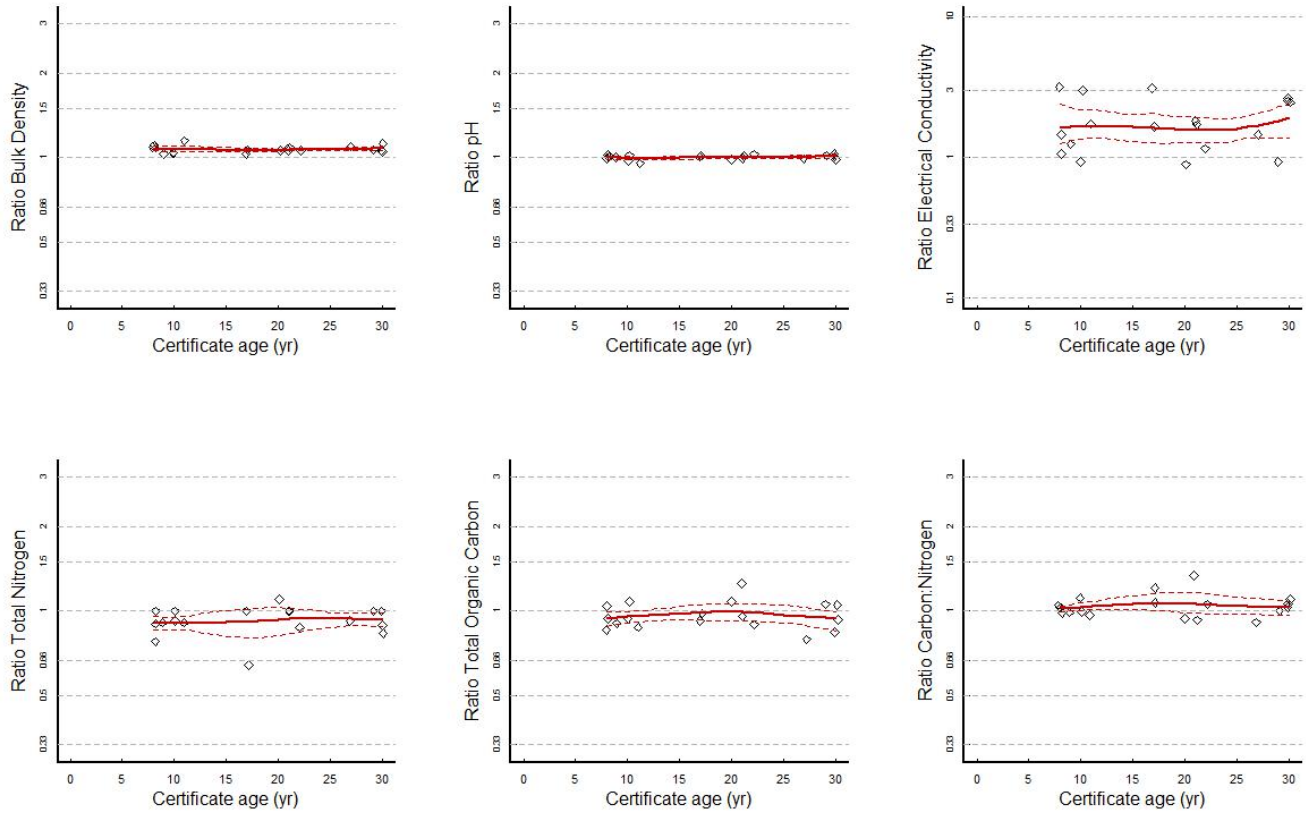


Figure A1.9. For Grassland soil variables, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.1.5. Grassland Community similarity

- Similarity of the species composition of plants on the cover quadrats wellsites and adjacent controls decreased sharply with age of wellsites. This must reflect the persistent effects of the different management of the older sites, including seeding with agronomic species.
- The plants from the vascular searches showed no real decline with age. Similarity of wellsites and controls was also almost as high as the similarity among controls (the scaled similarity is near 1). Remember that for the vascular searches, the control benchmark was based on the similarity among the different control sites, not the similarity among control plots within each site. Site-to-site differences would lower that within-control similarity, and hence raise the scaled values reported here. However, the main reason for the high similarity with the vascular search is probably just that that technique is only providing a crude presence/absence of species on 4 quadrats, not the actual cover estimates provided by the quadrat cover technique. So species could differ hugely in percent cover between wellsites and controls, but if they are still present, the similarity from the vascular searches would be high. Some colonization of adjacent controls by species seeded onto wellsites would also raise the presence/absence based similarity.
- There were too few shrubs on these sites to look at similarity of shrub communities.

→ Plant cover similarity assessed with quadrats should be helpful for indicating recovery, assuming that communities on older wellsites are less recovered because of persistent effects of non-native seeding. There are too few shrubs in these habitat types to make shrub species similarity worthwhile.

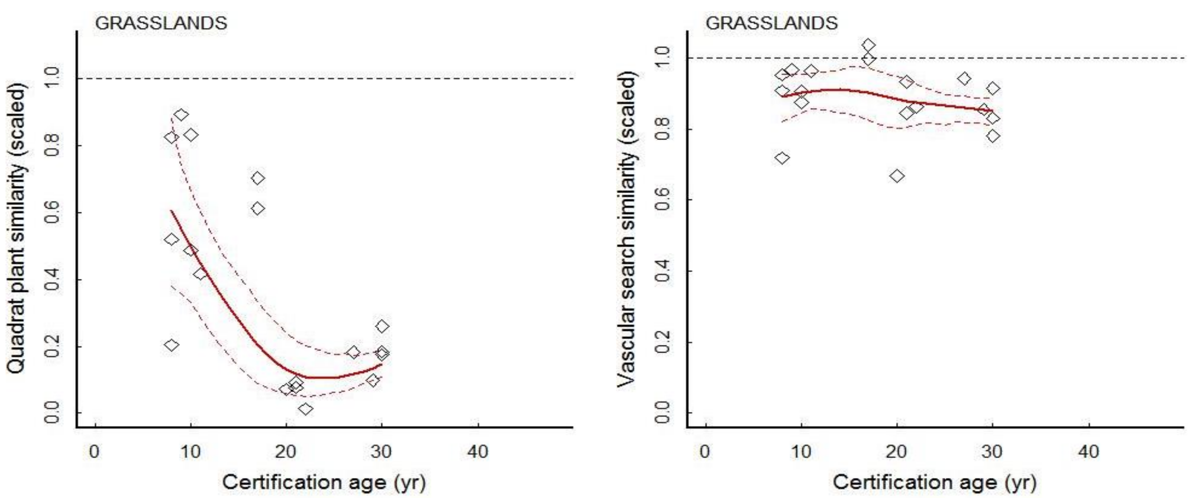


Figure A1.10. Percent similarity of vascular plant species composition between wellsites and paired controls for Grassland sites, versus certification age of wellsite. Left = similarity based on small quadrat cover; right = similarity based on vascular searches. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).

A1.2. Boreal

A1.2.1. Boreal Trees, snags and coarse woody debris

- There was relatively little basal area (BA) of conifers on the sampled boreal wellsites, even though some of the paired controls were conifer-dominated. The slight increase in conifer BA with age was due to one site (which actually had little conifer in its paired control).
- Deciduous trees dominated the wellsites, so the increasing trend of deciduous BA with wellsite age was the same as the trend for total BA. Two (apparently?) younger wellsites also had large deciduous and total BA's (more than would be expected at that age, suggesting that those wellsites may have been abandoned some time before their certification ticket was issued).
- The ratio figures show total BA steadily recovering to a ratio of 1 (wellsite=control) by the oldest age sampled (40 years), but there was much variability in the ratios for younger wellsites (again, perhaps because of uncertainty in their 'real' ages?). The ratio for conifer BA showed similar recovery, but was a weak relationship, because many wellsites had no conifers. Deciduous BA also showed the increase to or past 1, but with wide confidence intervals. A main source of variability for the conifer and deciduous BA curves was that one old site with conifer controls became deciduous dominated, while the opposite happened in the other one. Those composition changes were not detected by total BA.
- Stocking density showed largely the same results as BA, for conifers, deciduous and all species combined. It was therefore redundant with BA, but it might be an easier to measure option in the field, because it only requires counts of trees above 3m, not DBH measurements.
- With the exception of 2 sites, snags density was much lower on the wellsites than their paired controls, as expected. Because one of the wellsites happened to be old, snags showed an increase with age, but with very wide confidence intervals.
- Coarse woody debris (CWD) and soft CWD were absent on most wellsites (and highly variable with the relatively short measurement transects in the controls). That is expected, given the time it takes trees to grow to a meaningful size and die. CWD would not make a good indicator of recovery for wellsites in this age range, other than to serve as a reminder that some ecological attributes take a long time to recover.

→ Tree BA (or stocking density) is a clear indicator of recovery. This might be modified by conifer versus deciduous BA, to account for sites where the forest type is changed.

→ In the long-term, snag BA, and in the even longer-term CWD volume, are also indicators that forest structure used by many species are also recovering.

BOREAL

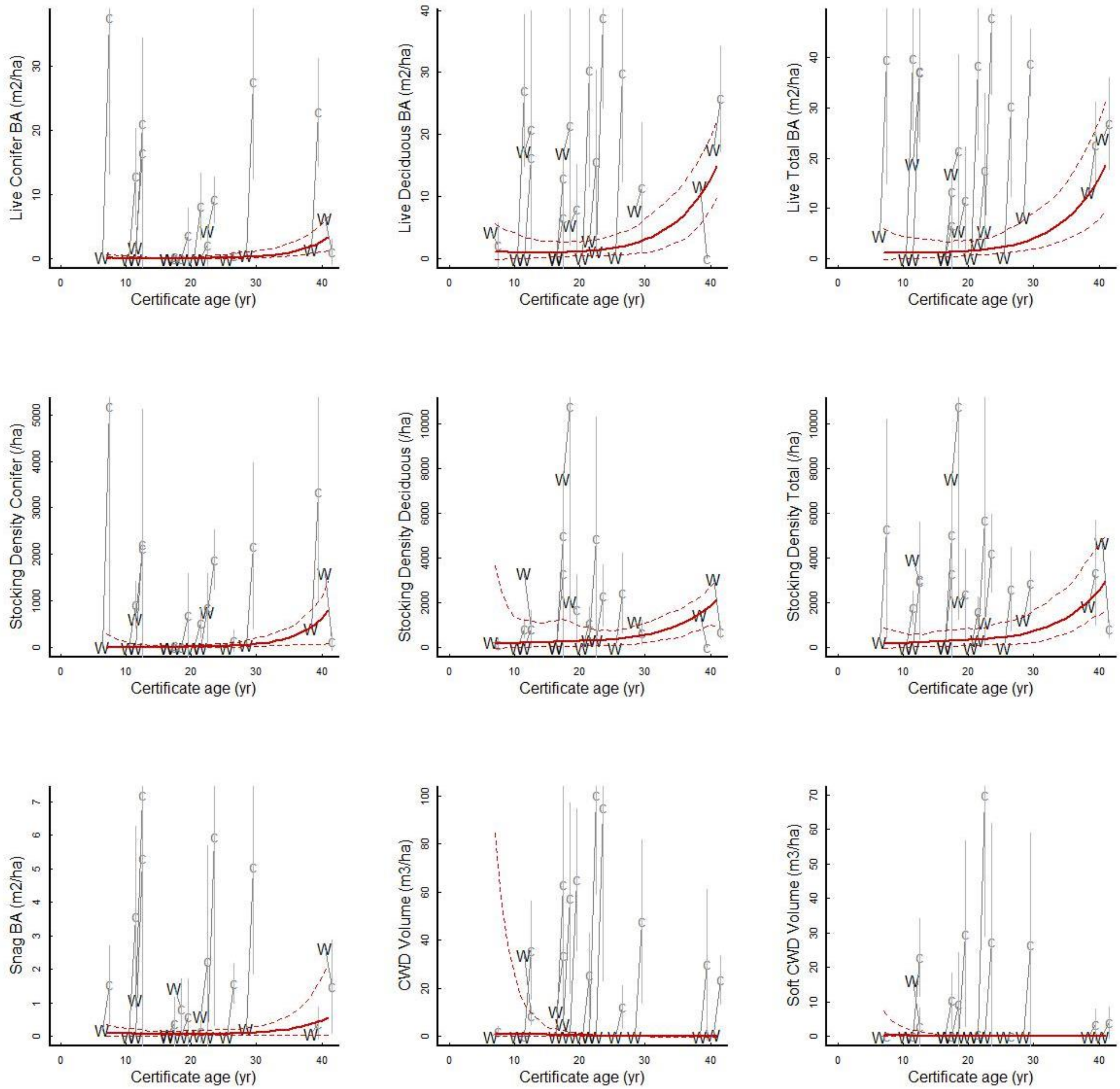


Figure A1.11. Boreal tree, snag and coarse woody debris (CWD) variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

BOREAL

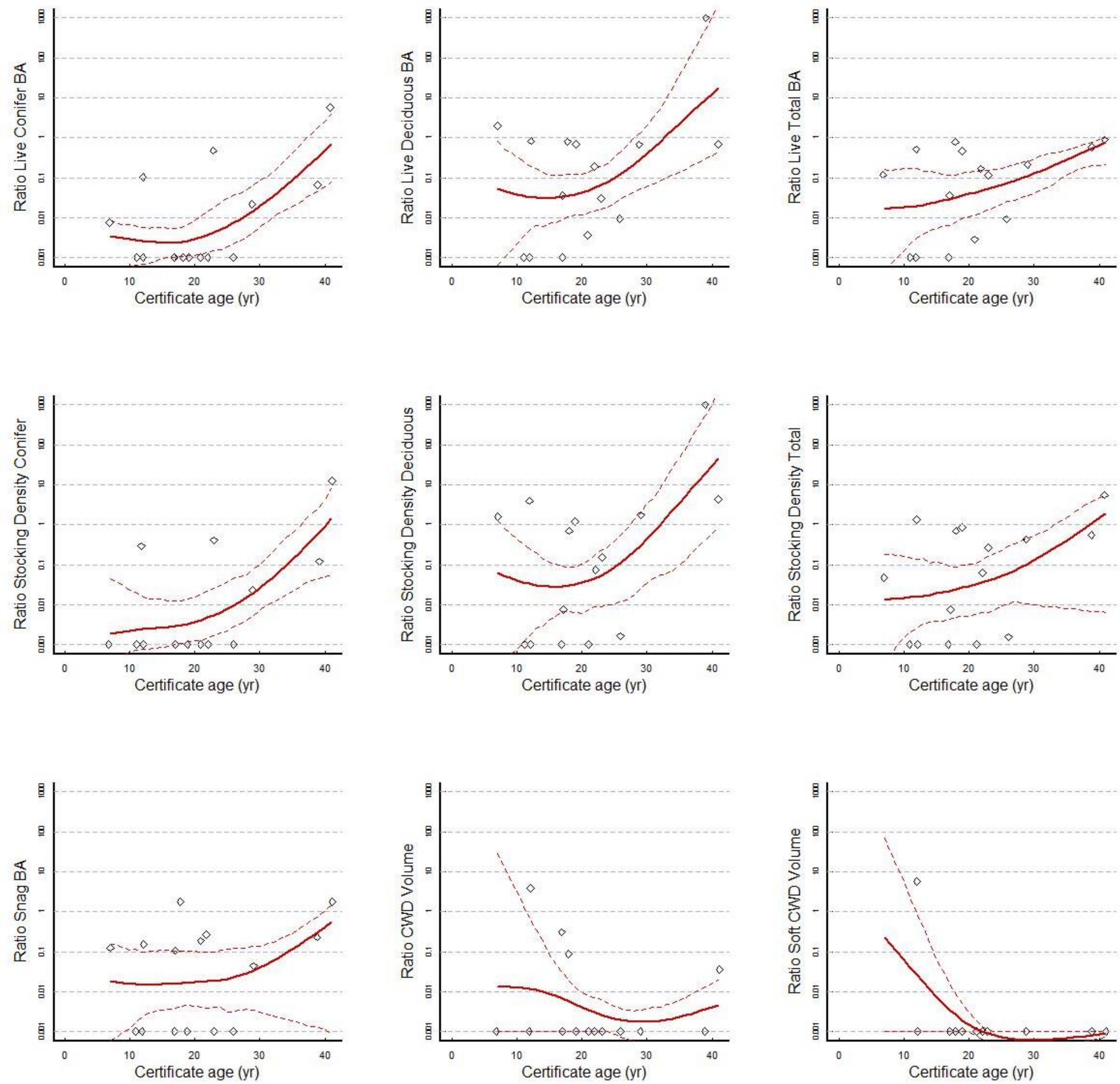


Figure A1.12. For Boreal trees, snags and coarse woody debris (CWD), the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.2.2. Boreal Small woody debris

- Overall cover of small woody debris (SWD) and amounts in the smaller two size classes increased slightly with age, although they were also a bit higher in young wellsites, and particularly high in two wellsites in the middle of the age range.
- The ratio figures showed recovery towards a ratio of 1 in the oldest ages for the smaller two classes of SWD and total SWD cover, but ratios were also high in the younger ages and for some individual mid-range wellsites.

→ Total SWD cover might be a medium-term indicator of recovery of some habitat structures.

BOREAL

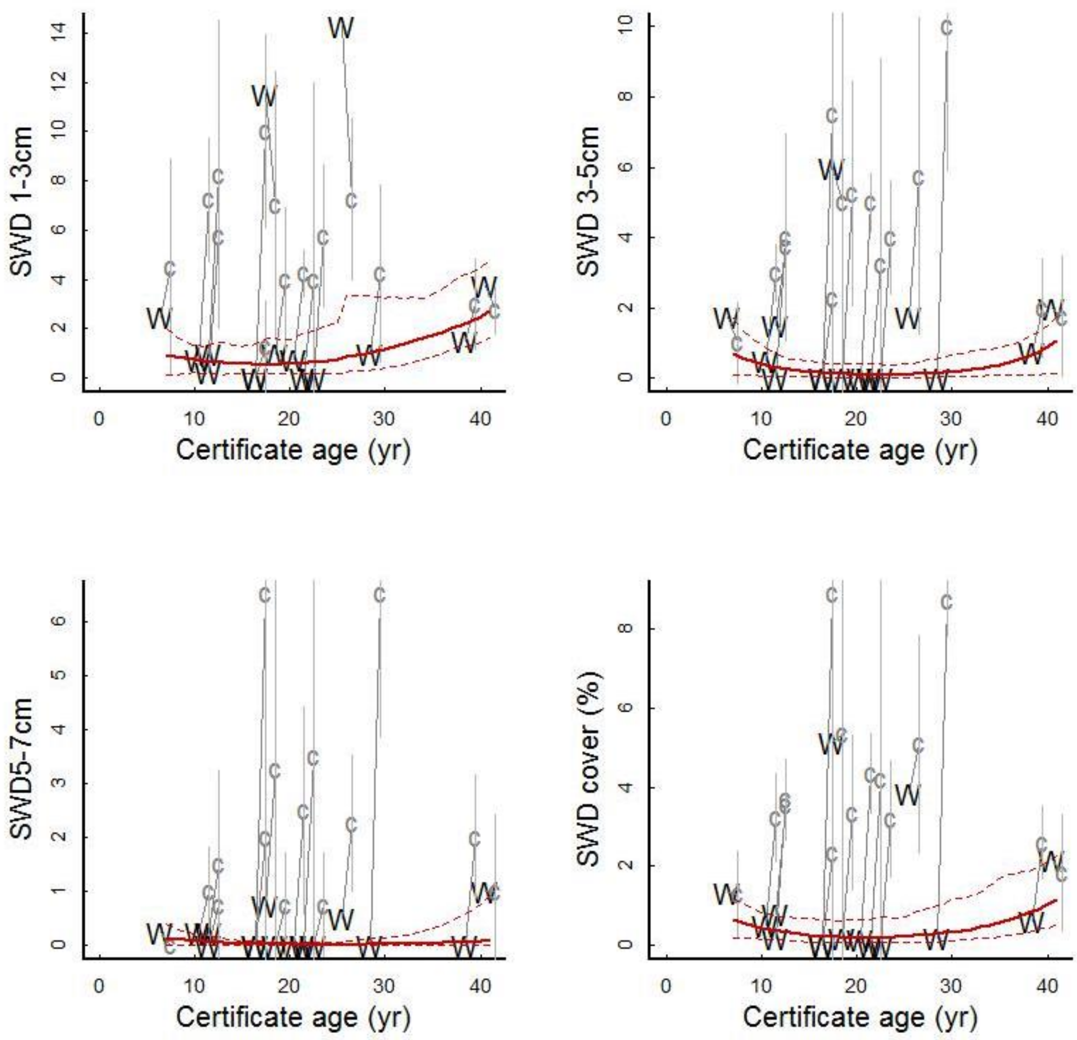


Figure A1.13. Boreal small woody debris (SWD) variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

BOREAL

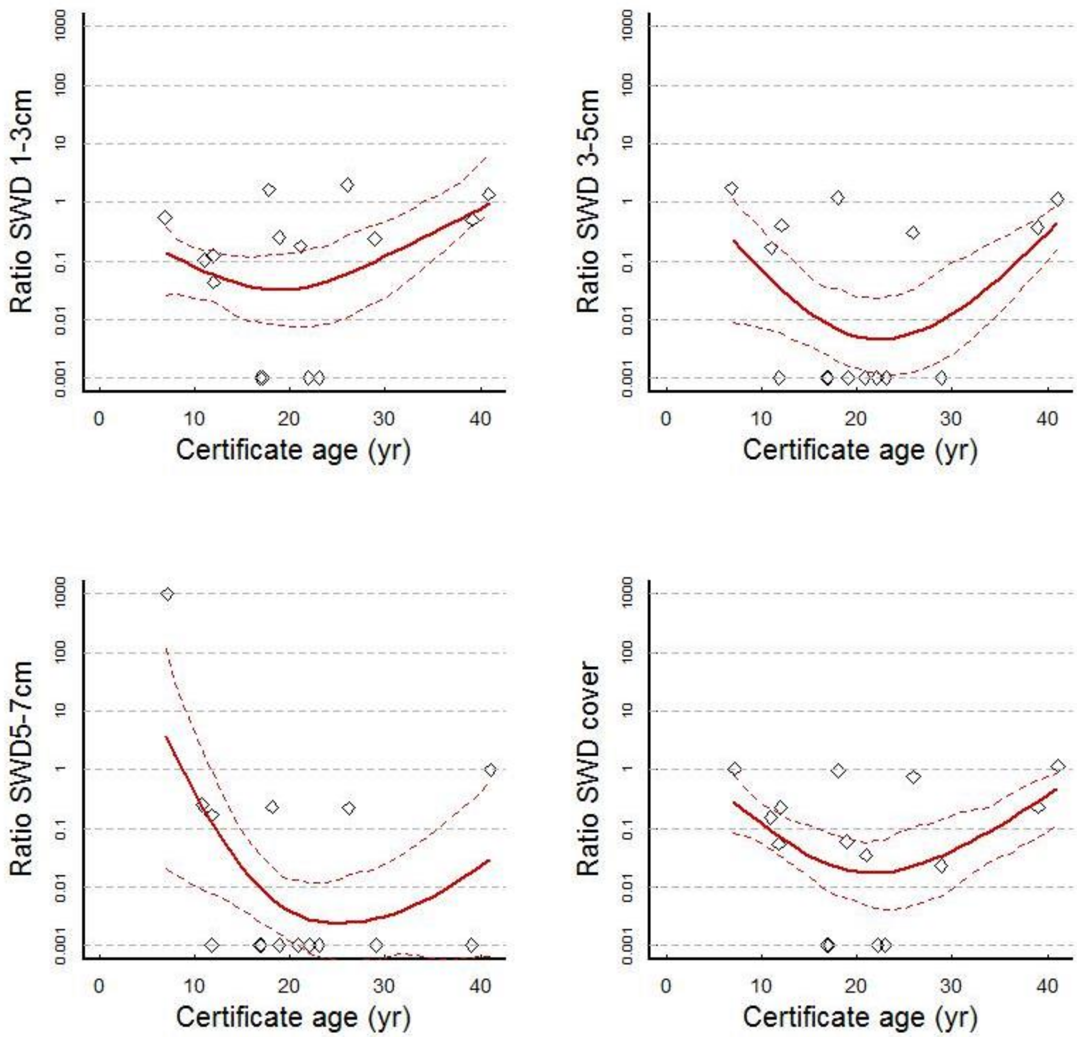


Figure A1.14. For Boreal small woody debris (SWD), the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.2.3. Boreal Cover layers

- Canopy cover was high in the two oldest wellsites in the boreal, and low in some of the young ones, leading to a strong increase with age.
- Shrub cover also increased with age, while total vegetation cover decreased moderately.
- Litter cover in the boreal wellsites was highly variable, with little apparent relationship with age.
- Wood cover was only present at a few wellsites.
- Mineral soil or rock were only common at one wellsite and present at all at only 5 sites.
- The ratio figures showed recovery towards a ratio of 1 in the oldest sites, although some of the youngest sites also had ratios near 1.
- Shrubs also recovered to or past a ratio of 1 with age, but many sites at all ages had similar shrub cover on the wellsite and in the paired controls (=ratios near 1).
- Vegetation cover started out at a higher level on the wellsites (ratio > 1), and recovered down towards a ratio of 1 with age.
- Litter cover showed no trend in the ratio with age, and the other cover layers were too rare to produce useful relationships with age.

→ Canopy cover is a good indicator of recovery, with some possible consideration about changing the measurement to exclude lower cover (<3m).

→ Other cover layers are less reliable indicators, either because they are rare or patchy, or because they change little.

BOREAL

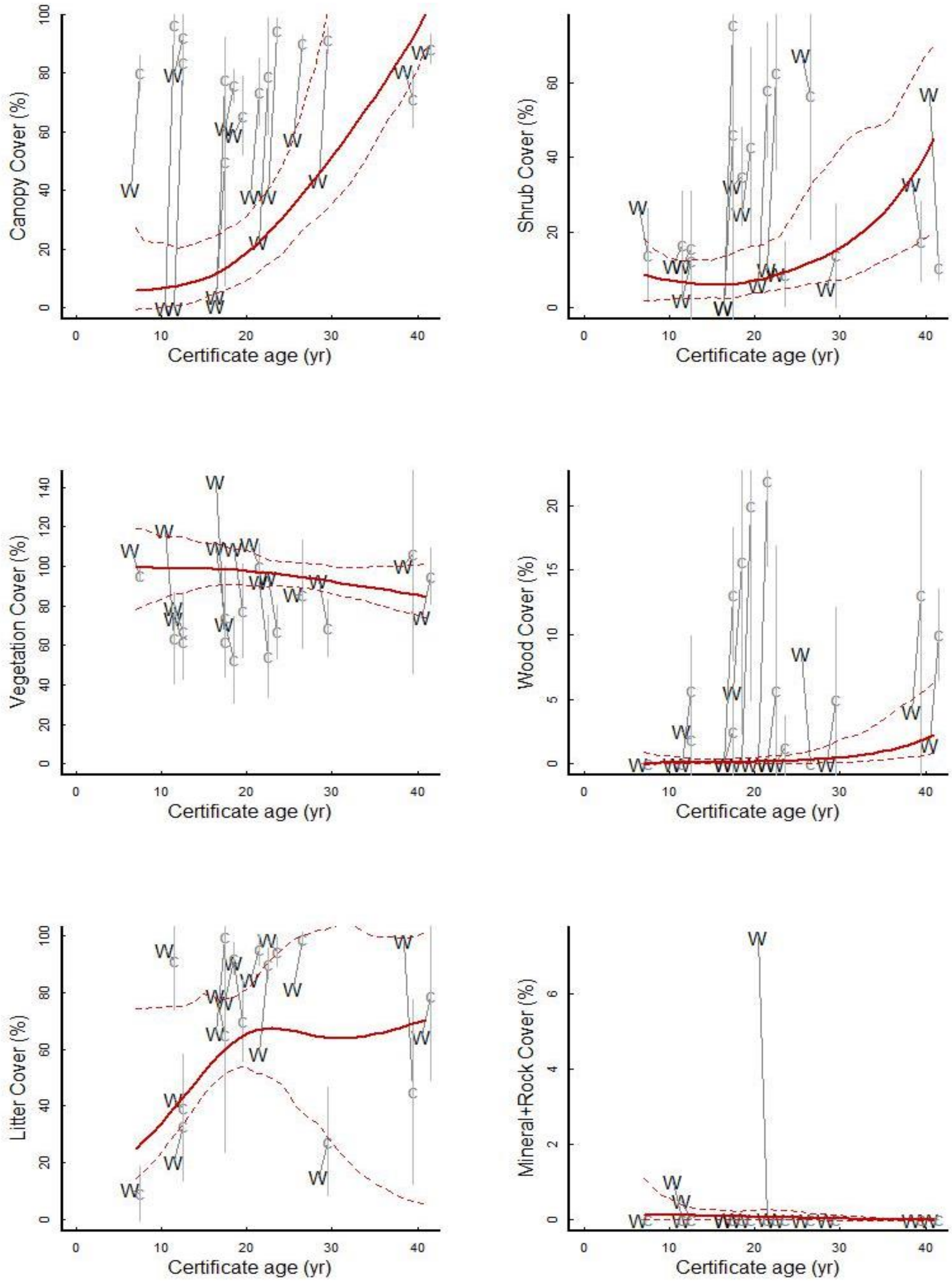


Figure A1.15. Boreal cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

BOREAL

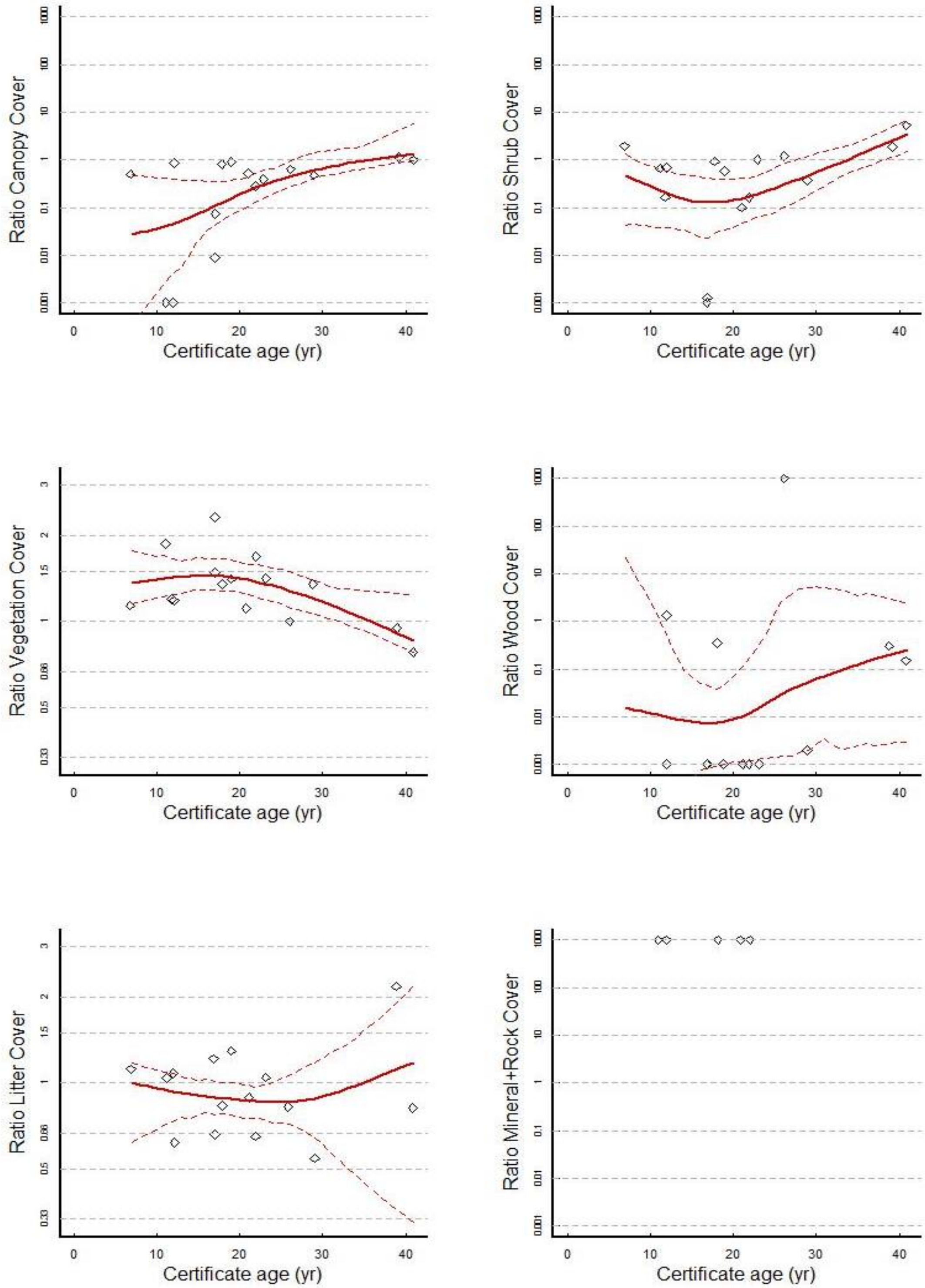


Figure A1.16. For Boreal cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.2.4. Boreal 2D cover layers

- Shrub cover in the different heights from the 2D plots showed high variability with age in the boreal sites, and no consistent trends in recovery in the ratio figures.
- About half the wellsites in the boreal had moderately low forb cover and the other half had high forb cover, and showed no real trend with age.
- Grass cover dropped in the oldest two boreal sellsites. However, one of the paired controls had no grass and the other had more, so there was no trend in the wellsite:control ratio with age.
- Moss and lichen cover were both uncommon on most boreal wellsites, and they were also uncommon in many paired controls. Both cover types showed trends towards recovery (wellsite:control ratio of 1) with age in the ratio figures, but wide confidence intervals on those relationships.
- Litter cover was often either near 0 or near 100% on the boreal wellsites (perhaps reflecting some variation in how this was assessed?)
- Combining the layers into the percent similarity index showed a general increase with wellsite age, with the exception of one anomalous old wellsite, and a scaled value >1 for a younger wellsite (meaning that the layers on the wellsite were more similar to the controls, on average, than the control plots were to each other).
- Bare ground was present at high levels on 4 of the wellsites, with no apparent trend with age.

→ Moss and lichen 2D covers show some value as recovery indicators in boreal wellsites, but both are patchy in controls, so may not be useful in all situations. I.e, they would only be useful where the paired controls have substantial levels of the cover type. Using percent similarity with the layers could provide a more informative recovery index, although still with considerable variability.

BOREAL

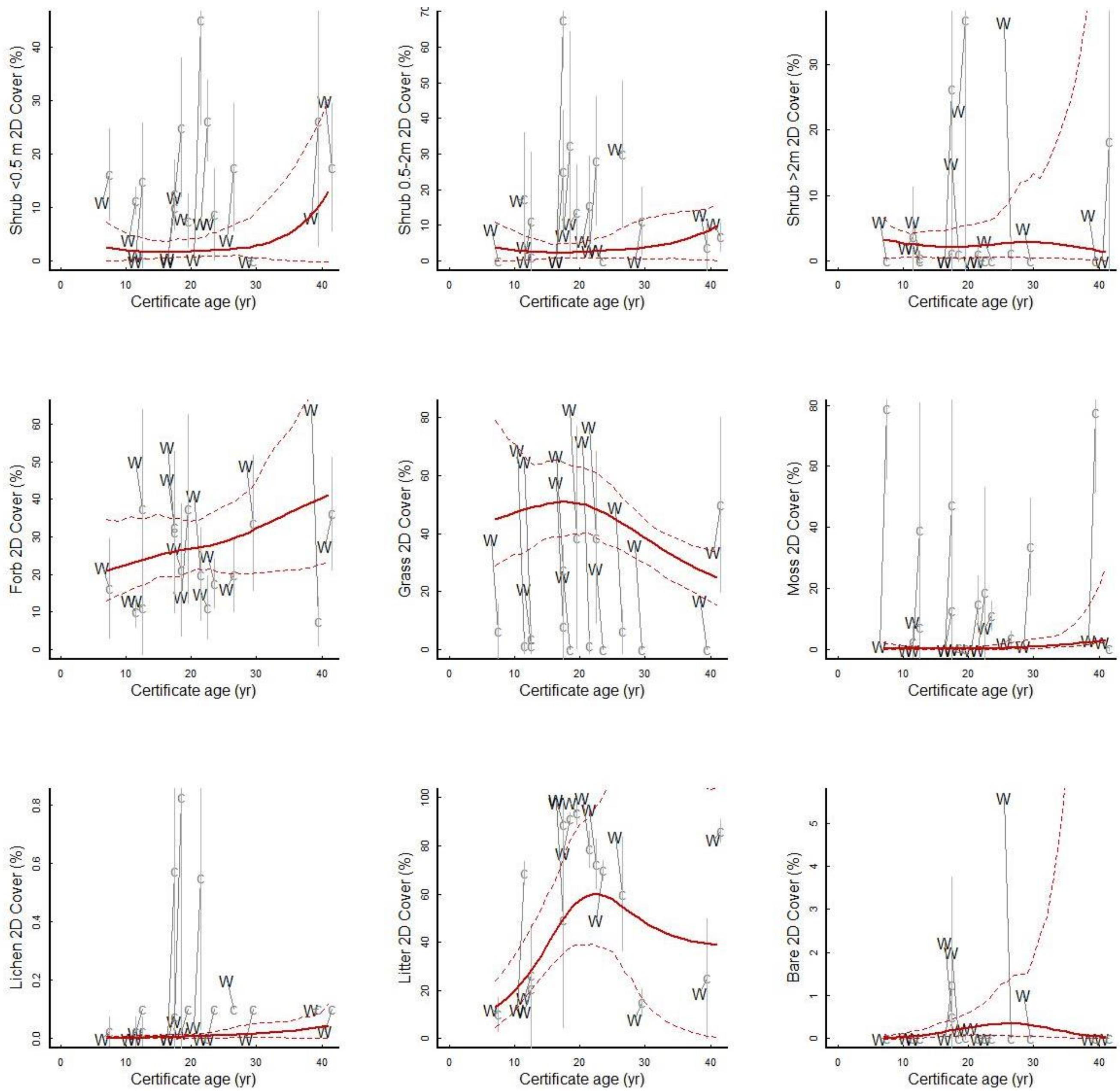


Figure A1.17. Boreal 2D cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

BOREAL

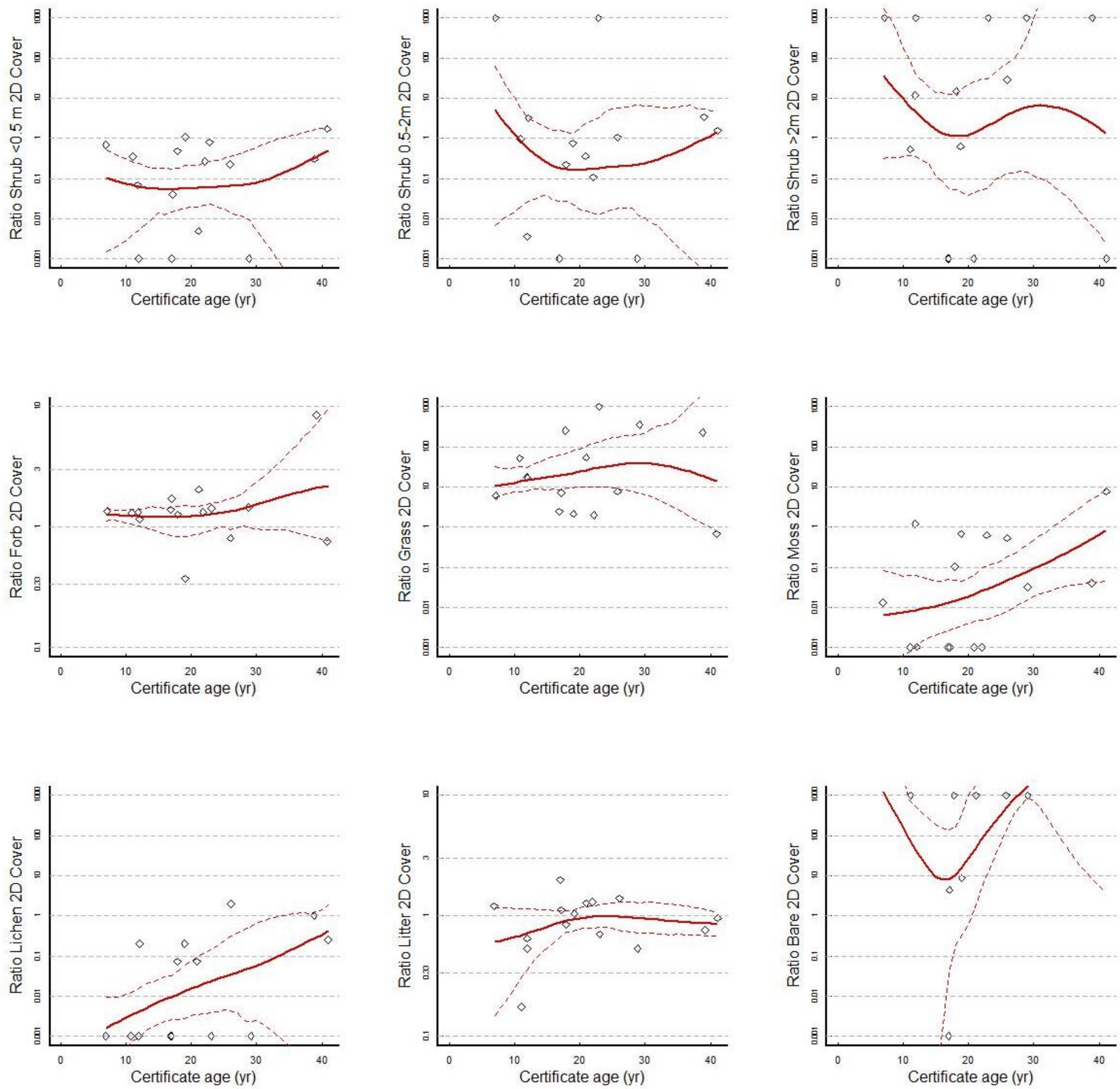


Figure A1.18. For Boreal 2D cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

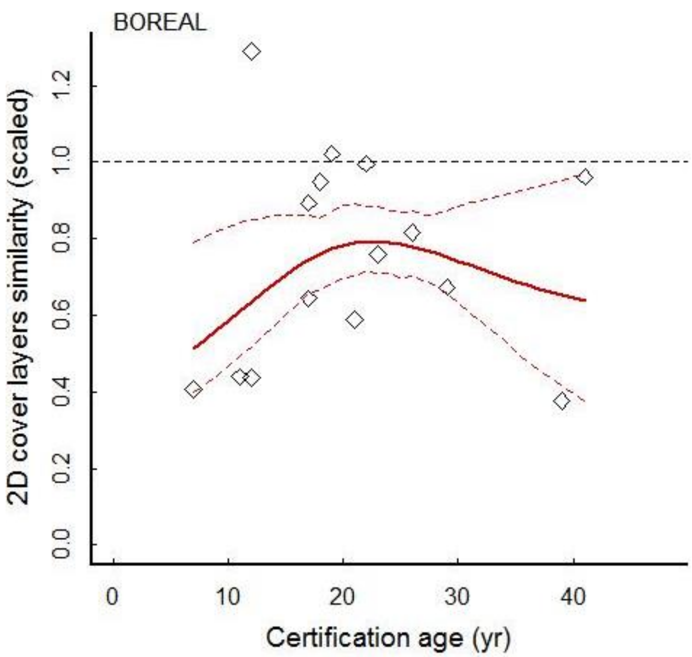


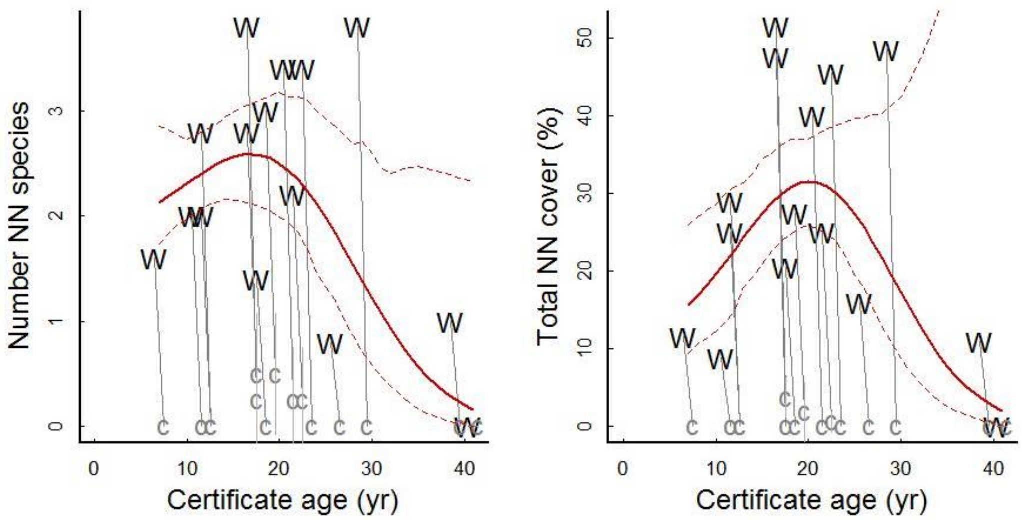
Figure A1.19. Percent similarity of 2D cover layers between wellsites and paired controls for Boreal sites, versus certification age of wellsite. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).

A1.2.5. Boreal Nonnative plants

- Both measures for both field methods showed a peak in non-native species in wellsites in the middle of the age range, although with wide uncertainty at either end of the gradient.
- Control values were much lower, especially using the cover quadrats.
- It is unclear whether the peaked curve represents colonization then reduction of non-native species over time, or whether it is just coincidence or confounding with some other variable (management changes over time, location of the sites). However, the controls associated with the mid-aged wellsites did tend to have more non-native species than other sites, supporting the possibility of confounding.
- Note: Figures of wellsite:control ratios were not plotted because of the many zero or very low values in the controls.

→ Although there are no clear trends with wellsite age, non-native cover from cover quadrats is probably the best indicator, and it shows the strongest distinction between wellsites and controls.

COVER QUADRATS



VASCULAR SEARCHES

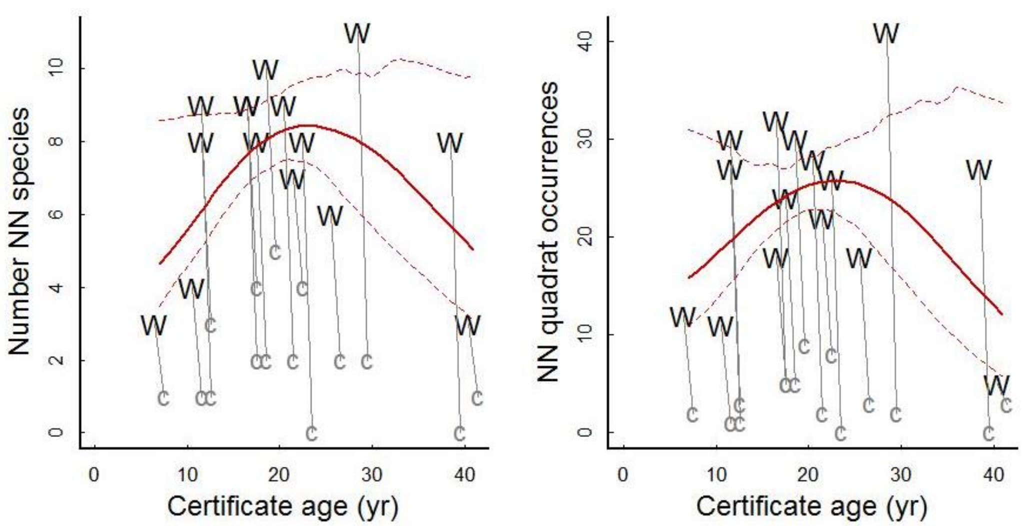


Figure A1.20. Number of non-native plants on Boreal wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

A1.2.6. Boreal Soils

- Soil parameters did not show any trend with certification age for the boreal wellsites.
- Bulk density was always higher on the wellsites than paired controls, pH and electrical conductivity were almost always higher, while total nitrogen, organic carbon and LFH depth were almost always or always lower on wellsites.
- In the ratio figures, the youngest boreal wellsites may have had lower ratios of the latter 3 variables – total nitrogen, organic carbon and LFH depth – but there were not any strong relationships with age showing recovery in soil variables.

→ None of the soil variables show recovery over the age range sampled, but changes towards control conditions in the variables that are consistently higher or lower on wellsites might be useful in the long-term.

BOREAL

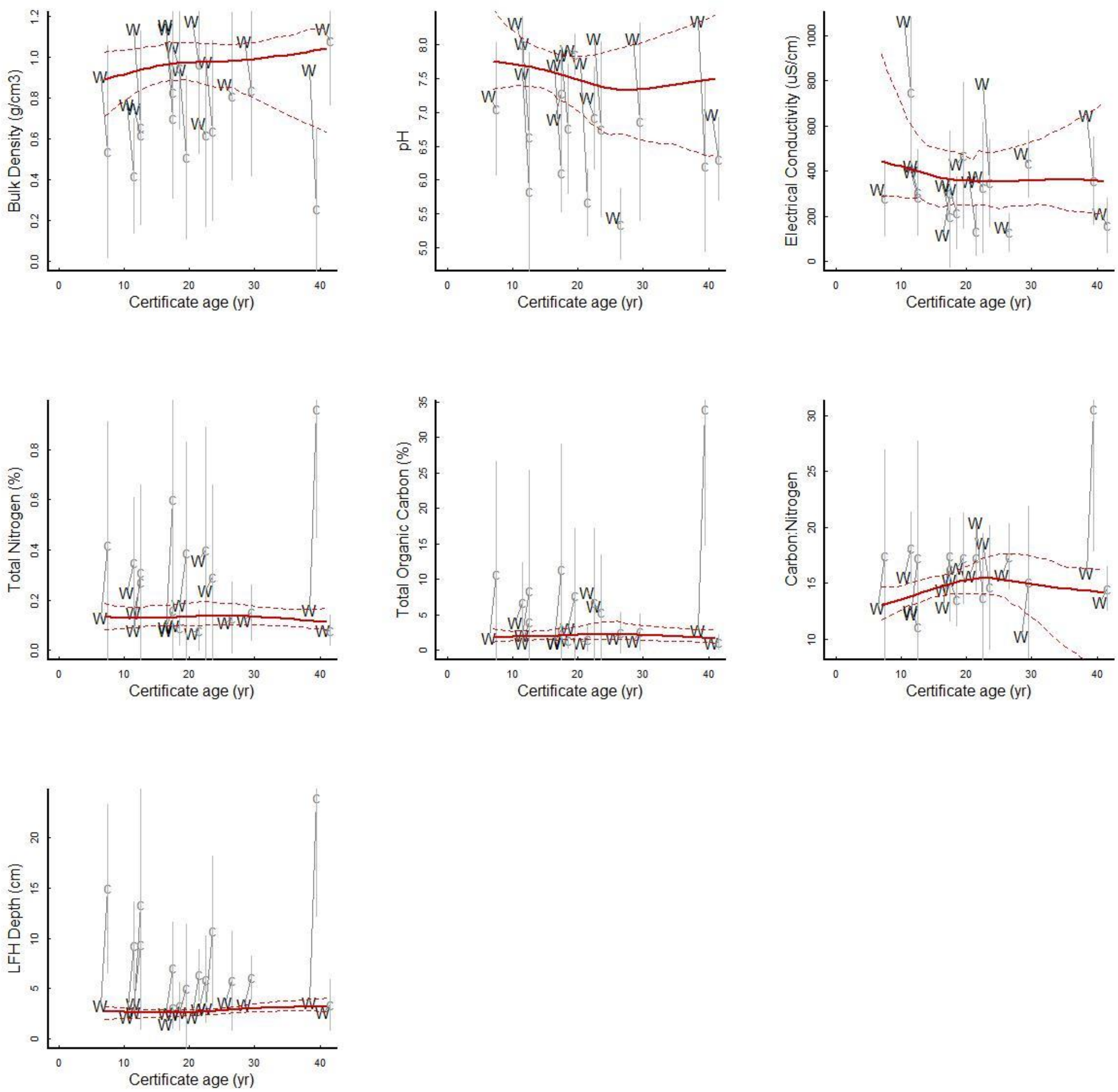


Figure A1.21. Boreal soil variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

BOREAL

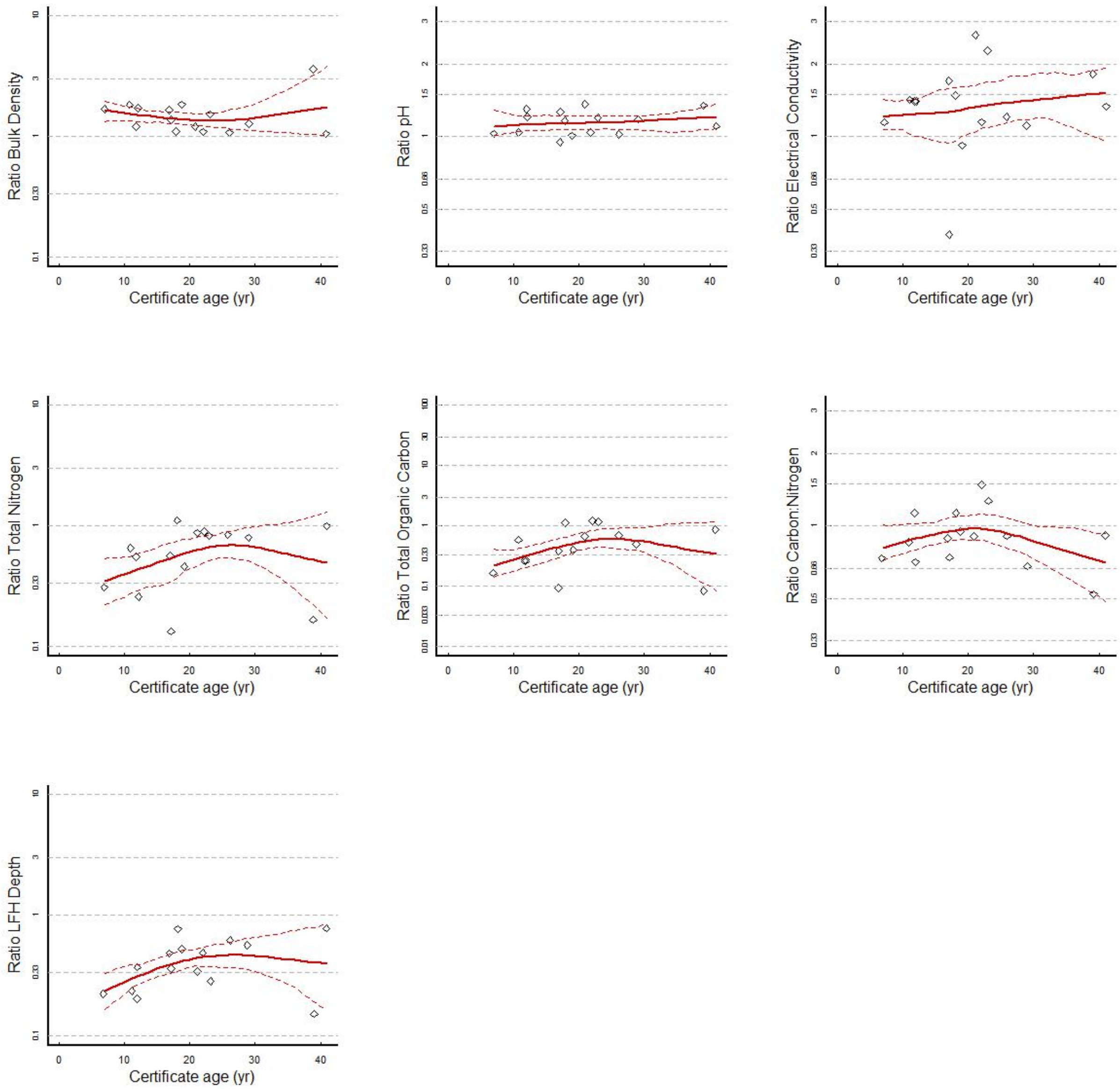


Figure A1.22. For Boreal soil variables, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.2.7. Boreal Community similarity

- Similarity of plant communities in wellsites and control from the cover quadrats showed no relationship with certification age in the boreal. Oddly, there seemed to be two groups of sites, both found across the edge range – one with moderately high similarity of wellsites and their paired controls, and the other with very low similarity.
- Shrub cover similarity showed a general increase with age, especially if one anomalously low site at 39 years of age was excluded. However, there is considerable variability, including four sites with reliatvely high similarity at about 20 years of age.
- Similarity based on the vascular plant searches was higher than for the cover quadrats (for reasons discussed in the section A1.1.4), but showed no trend with certification age. There was also the same tendency towards only relatively high or relatively low values, with the intermediate values lacking.

→ Although the community similarity values should be useful indicators of recovery, they did not show patterns with age of wellsites in the boreal study area.

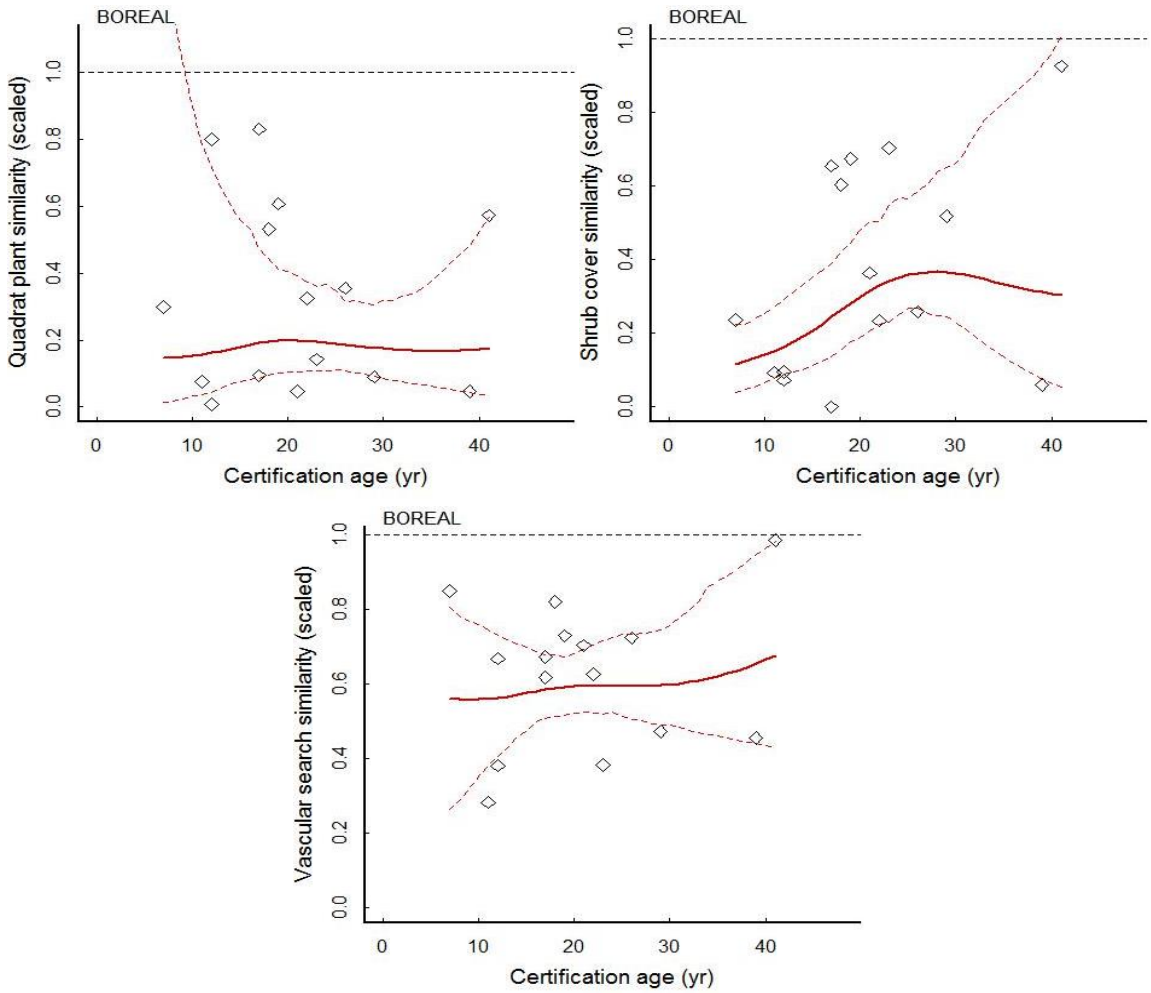


Figure A1.23. Percent similarity of plant species composition between wellsites and paired controls for Boreal sites, versus certification age of wellsite. Top left = vascular plants similarity based on small quadrat cover; top right = shrub species similairt; bottom = vascular plant similarity based on vascular searches. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).

A1.3. Foothills

[Note: A single site with certification age of 48 years has a large effect on the upper end of the plotted curves in the foothills. With the flexible curve-fitting, this one point should not affect the curve at young and intermediate ages. Readers should not focus excessively on the upper end of the curve.]

A1.3.1. Foothills Trees, snags and coarse woody debris

- Total BA increased with age, as many wellsites <15 years old had almost no tree basal area, while older sites had some (including a very high value for one 26-year old wellsite). There was a mix of deciduous and conifer regeneration among sites. All three ratio figures for BA show recovery towards a ratio of 1 (wellsite=control), with narrower confidence intervals on the curve for total BA.
- For stocking density, the oldest wellsite and one intermediate site showed very high stocking levels, while other sites had moderate or low stocking. The ratio figures for stocking density showed the wellsites “overshooting” the ratio of 1, because the oldest wellsite had much higher stocking than its paired control. However, confidence intervals are wide.
- Because of the one oldest site, snags on wellsites recovered to control levels with age. However, only 3 other wellsites had any snags at all.
- Only one wellsite had any CWD, compared to moderately low to very high levels in the paired controls.

→ Similarly to the boreal area, total BA is a good recovery indicator, with possibly some modification by conifer and deciduous BA to account for changes in stand type. Snags and CWD could be longer-term indicators of recovery of forest structures.

FOOTHILLS

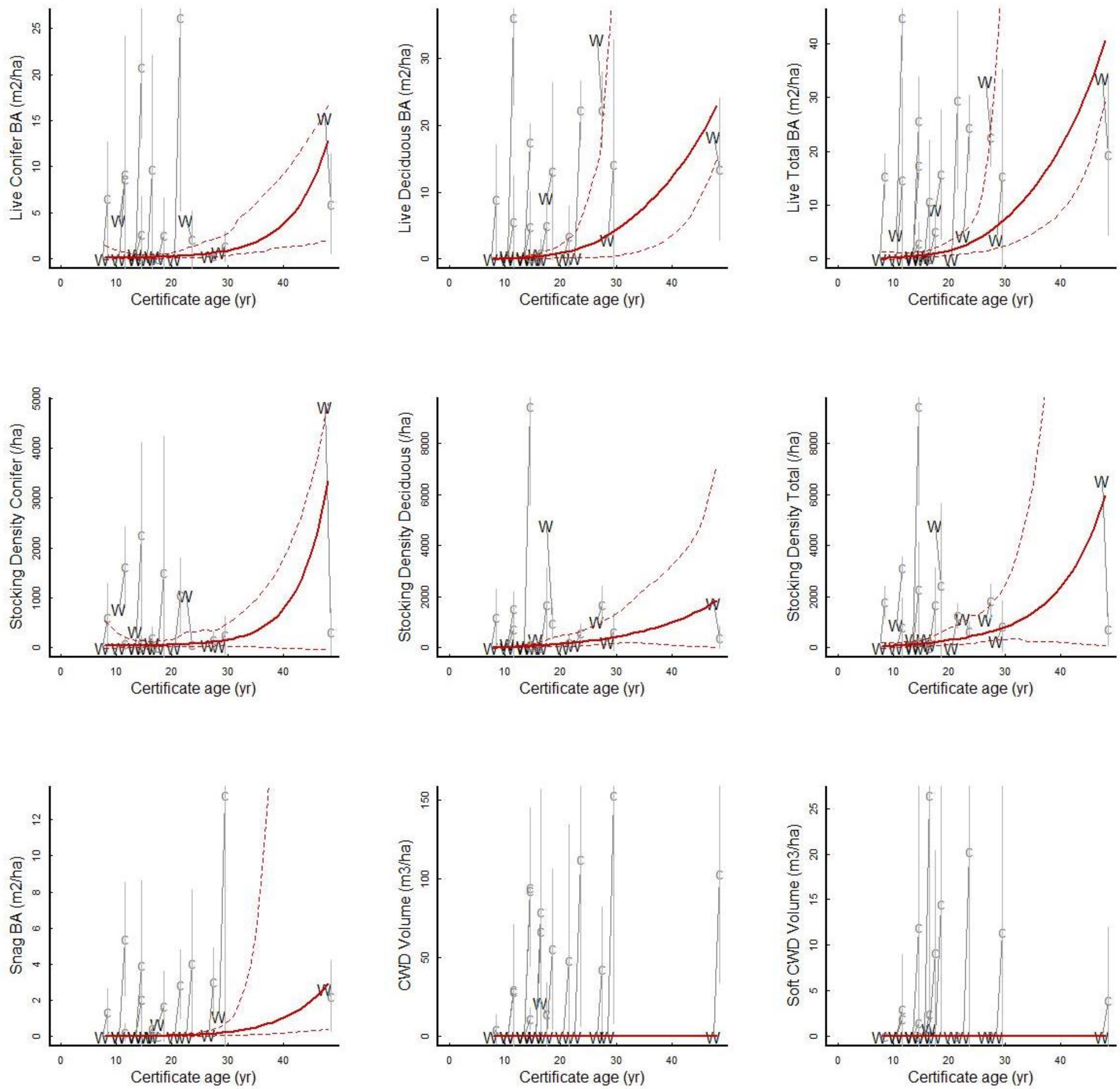


Figure A1.24. Foothills tree, snag and coarse woody debris (CWD) variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

FOOTHILLS

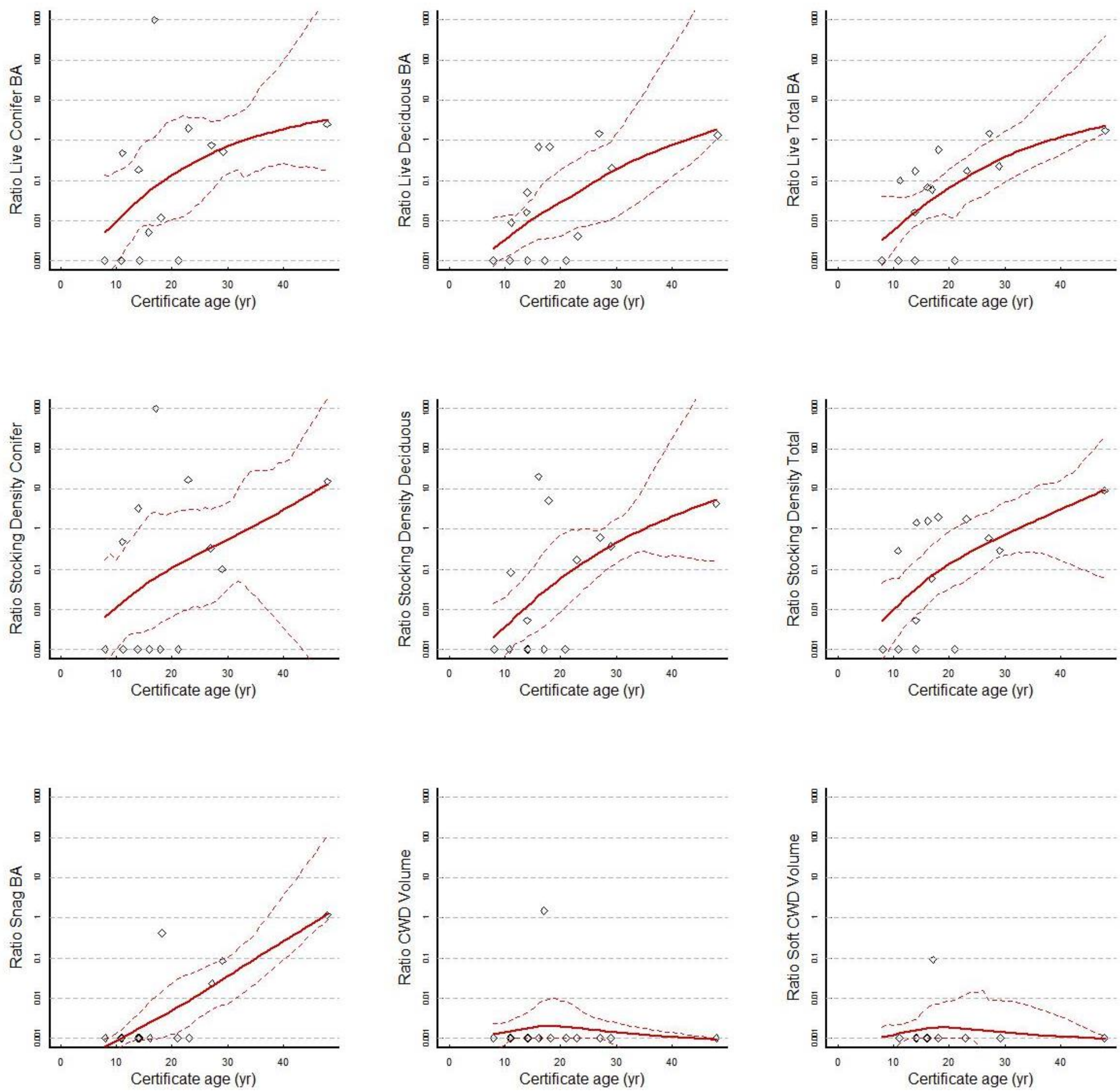


Figure A1.25. For Foothills trees, snags and coarse woody debris (CWD), the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.3.2. Foothills Small woody debris

- Small woody debris (SWD) was mostly at very low levels on wellsites, except for the one very old wellsite. That one site pulled up the ratio figure to near a value of 1 at 40+ years, but younger sites showed much less recovery (to about 1/10 the SWD levels found in controls).

→ Cover of SWD might have some value as an indicator of recovery of forest habitat.

FOOTHILLS

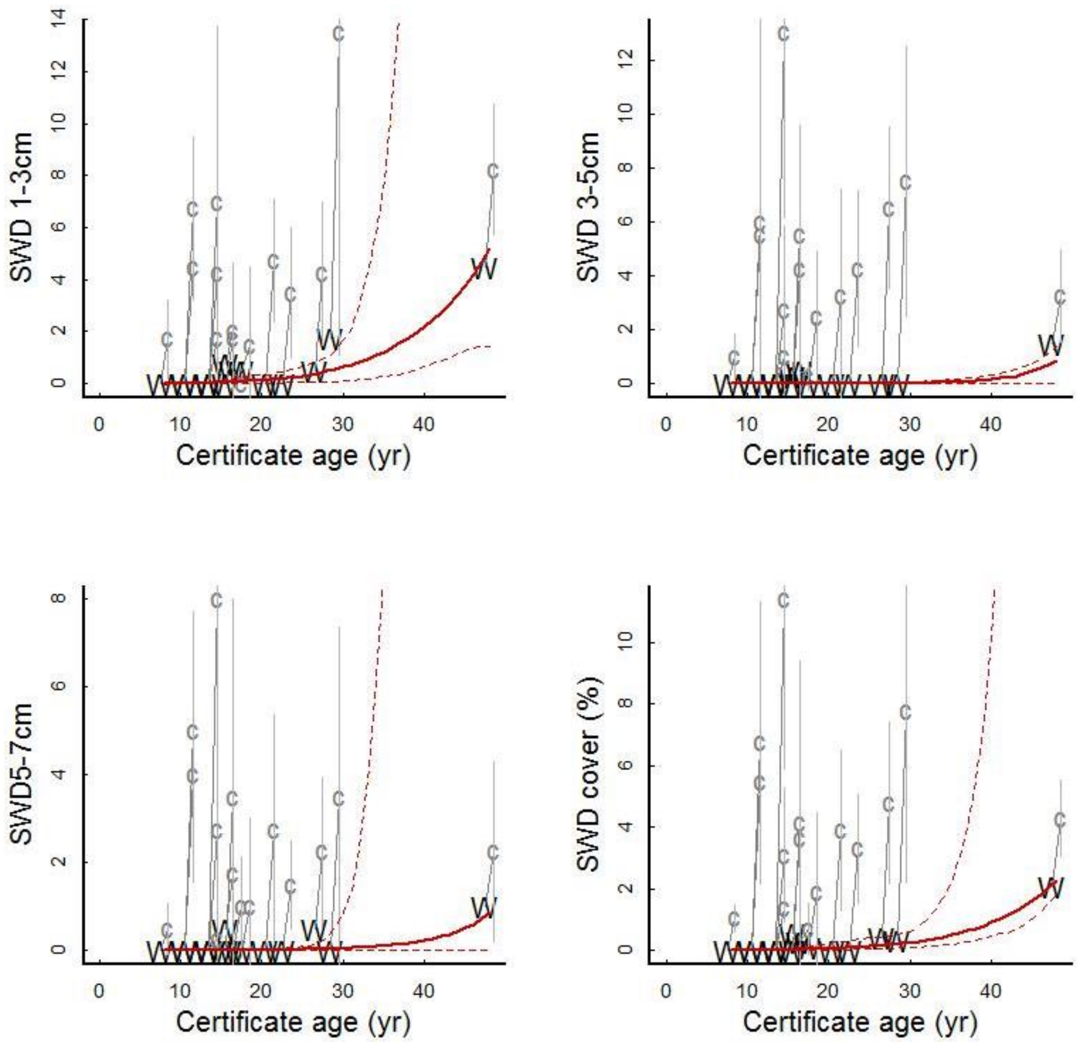


Figure A1.26. Foothills small woody debris (SWD) variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

FOOTHILLS

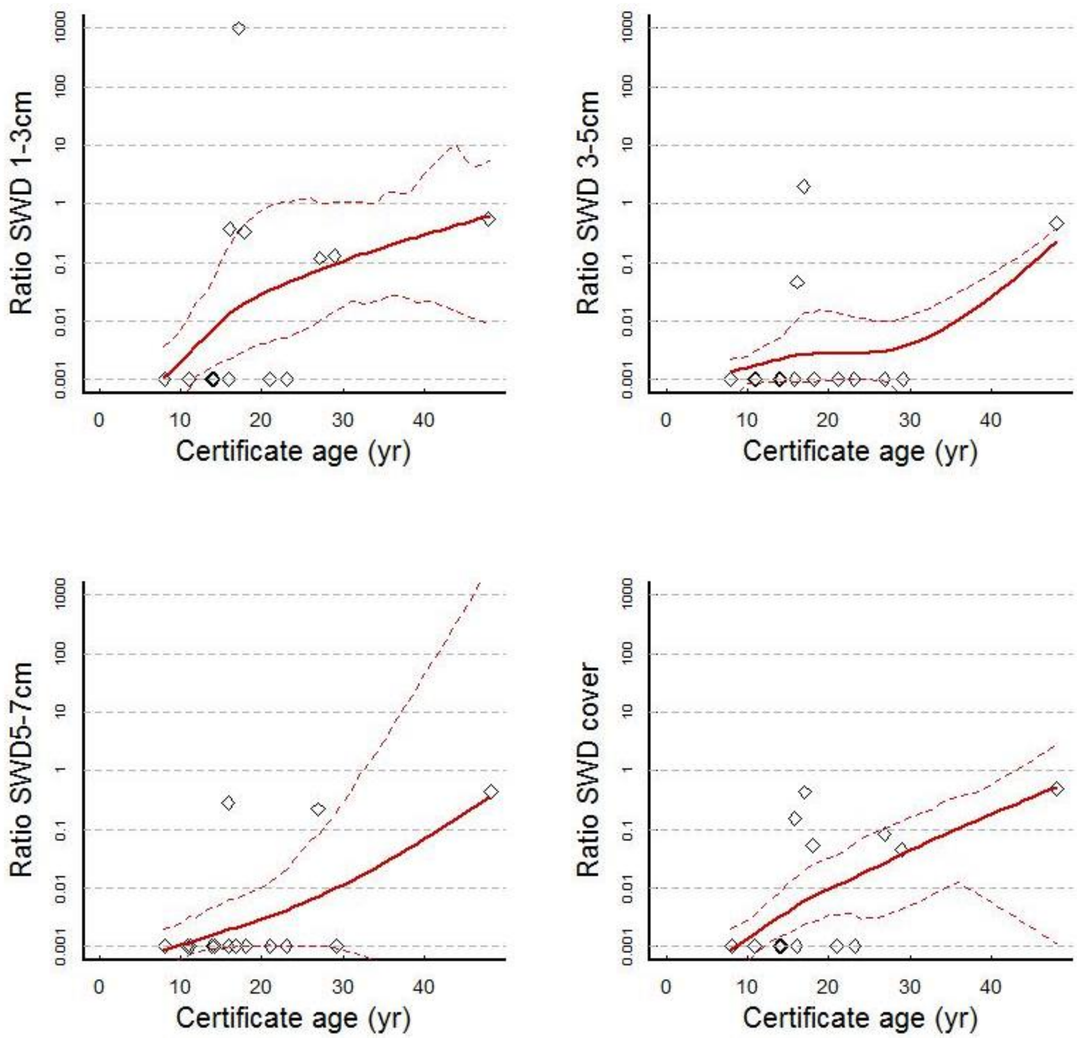


Figure A1.27. For Foothills small woody debris (SWD), the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.3.3. Foothills Cover layers

- Canopy cover in younger wellsites was either very low or moderately high. The oldest site had fairly low canopy cover, but its paired control plots also had low canopy cover, which means that the wellsite:control ratio figure showed recovery to a ratio of 1 at the old ages. However, about half of the younger wellsites also showed values near 1.
- Shrub cover and total vegetation cover were mostly unchanged by wellsite age, with shrub cover staying well below control levels, and total vegetation cover staying slightly higher.
- There was little wood cover on the wellsites, except for the one oldest site.
- Litter cover showed high variation, with no consistent pattern with wellsite age.
- Mineral soil and rock cover occurred on 5 wellsites, none of them >20 years old. Mineral soil and rock also occurred in scattered control sites, leading to no relationship between the wellsite:control ratio and wellsite age.

→ Canopy cover is the main potential indicator of recovery here, again possibly with some consideration for eliminating cover under 3m tall in the measurement. Other cover values were highly variable among sites, including controls.

FOOTHILLS

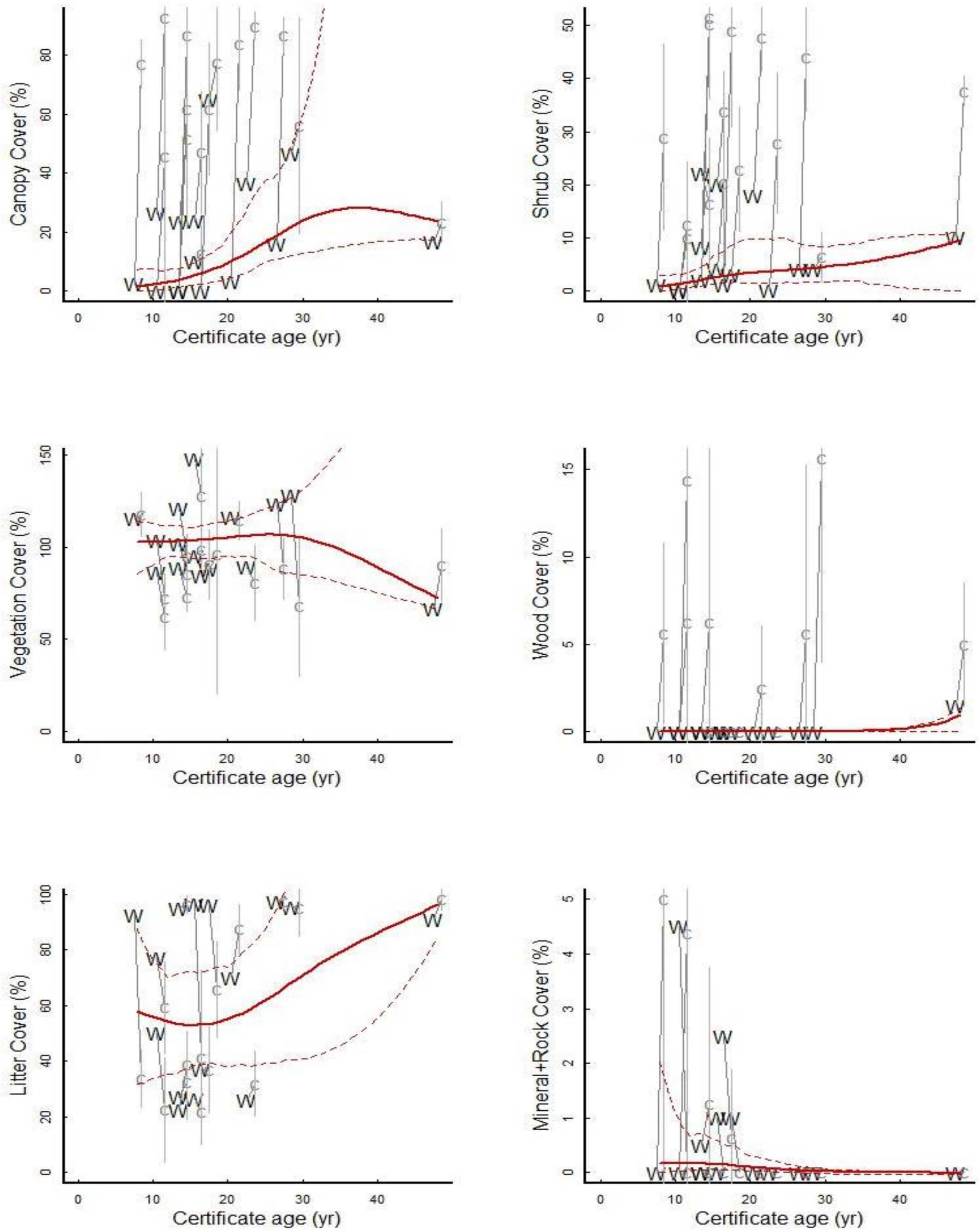


Figure A1.28. Foothills cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

FOOTHILLS

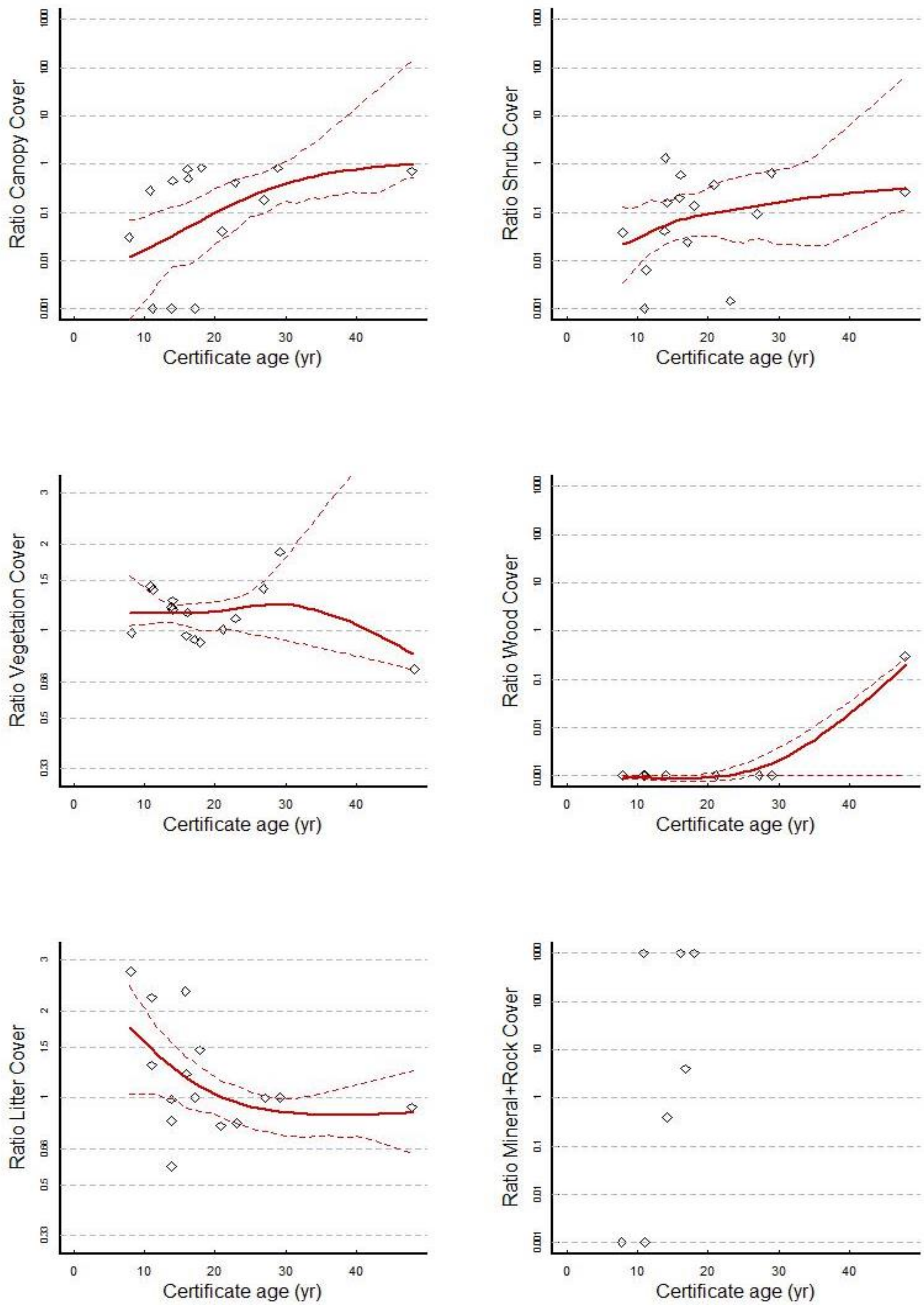


Figure A1.29. For Foothills cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.3.4. Foothills 2D cover layers

- In the 2D cover plots, shrubs <0.5m increased with age, while taller shrubs did not show clear patterns. The ratio figures showed recovery towards a ratio of 1 with age for shrubs <0.5m tall, but no patterns for taller shrubs (all with wide confidence intervals).
- Forb cover increased with wellsite age, except for the one oldest wellsite. The wellsite values were similar to or above the paired controls.
- Grass cover declined with wellsite age, although with considerable variability among sites. The ratio figure shows recovery from higher-than-control levels in young wellsites down to a ratio near 1 for the older sites.
- Moss cover was rare on wellsites, although with some tendency to increase with age. Moss in the controls was variable. As a result, moss on wellsites shows some recovery towards control levels with age, but the relationship is highly uncertain (wide confidence intervals at both ends).
- Lichen cover was absent in the youngest wellsites, and variably present in older ones. The ratio figure for lichen cover shows a steep recovery curve to a ratio near 1 at about 20 years, then a levelling off (but with very wide confidence intervals due to few older wellsites).
- Litter cover was either moderate on wellsites or very high, with no relationship to wellsite age.
- Bare ground cover was highest in a few intermediate-age wellsites, and also occurred in a few control sites. The relationship with age on the resulting ratio figure is probably not very reliable.
- Combining the layers into the percent similarity measure showed increasing similarity of wellsites and controls with increasing wellsite age, with the exception of the one oldest wellsite.

→ The 2D cover variables individually do not show strong indicators of recovery. Moss and lichens tend towards recovery with age, but are highly variable among sites, including controls, so may only be appropriate in some sites (those with substantial amounts of these layers in the controls). However, combing the layers in the percent similarity measure reduced some of that variability, producing a better potential metric of recovery.

FOOTHILLS

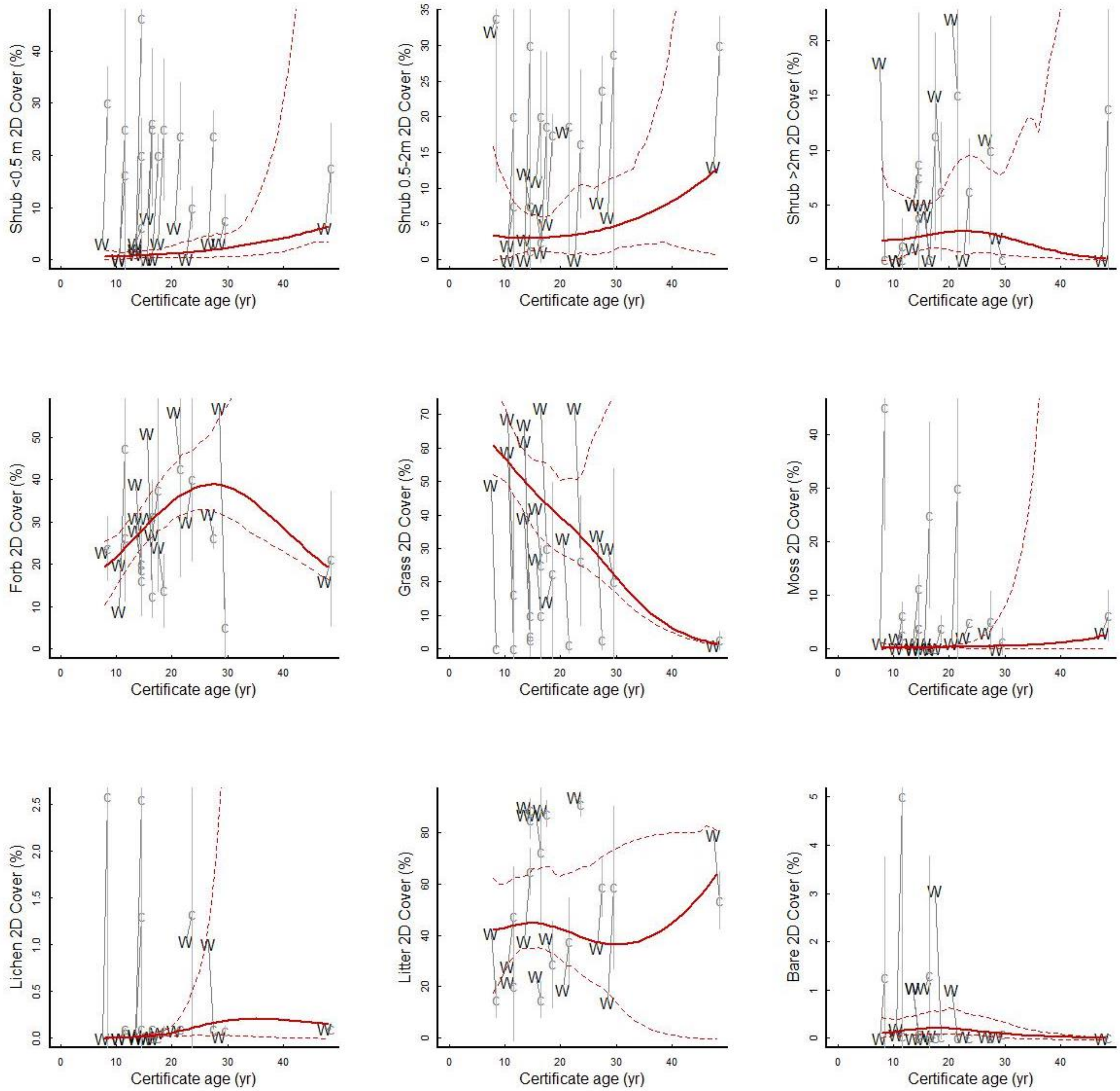


Figure A1.30. Foothills 2D cover layers on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

FOOTHILLS

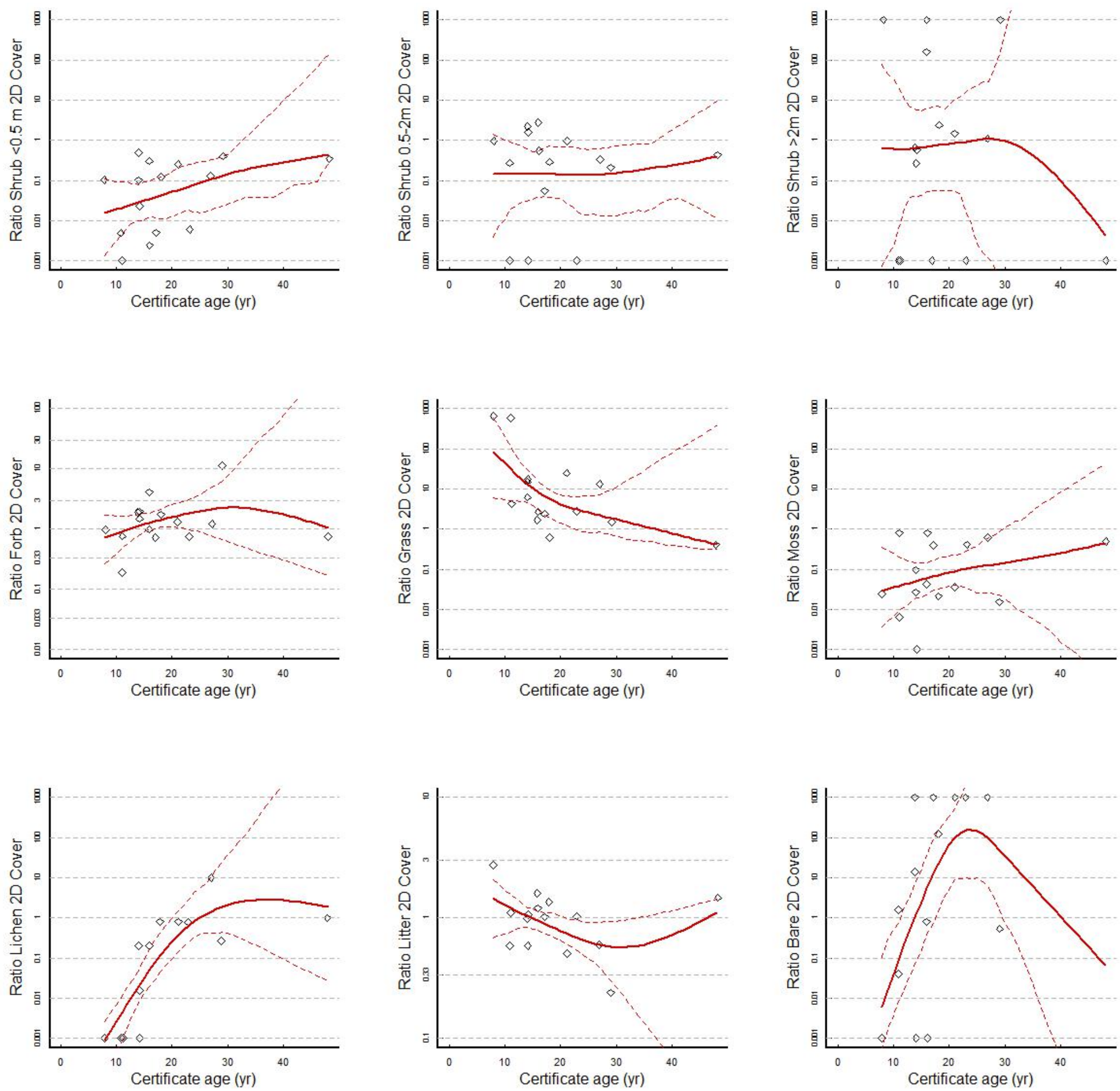


Figure A1.31. For Foothills 2D cover layers, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

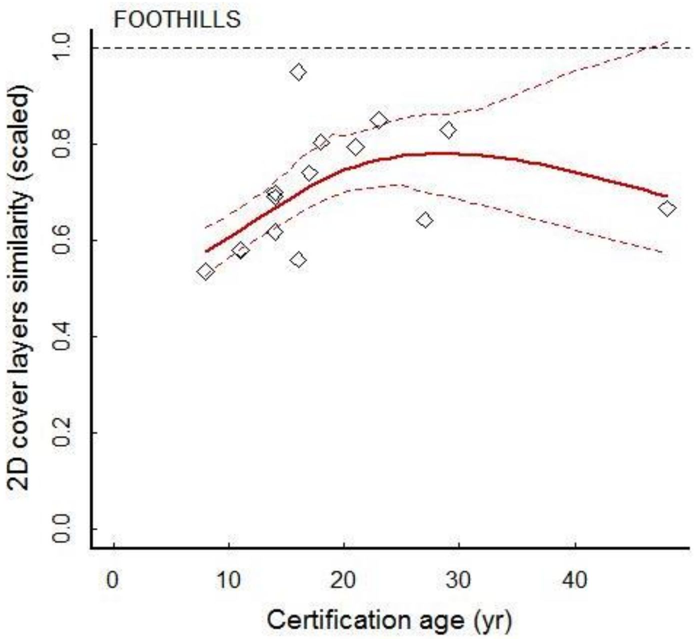


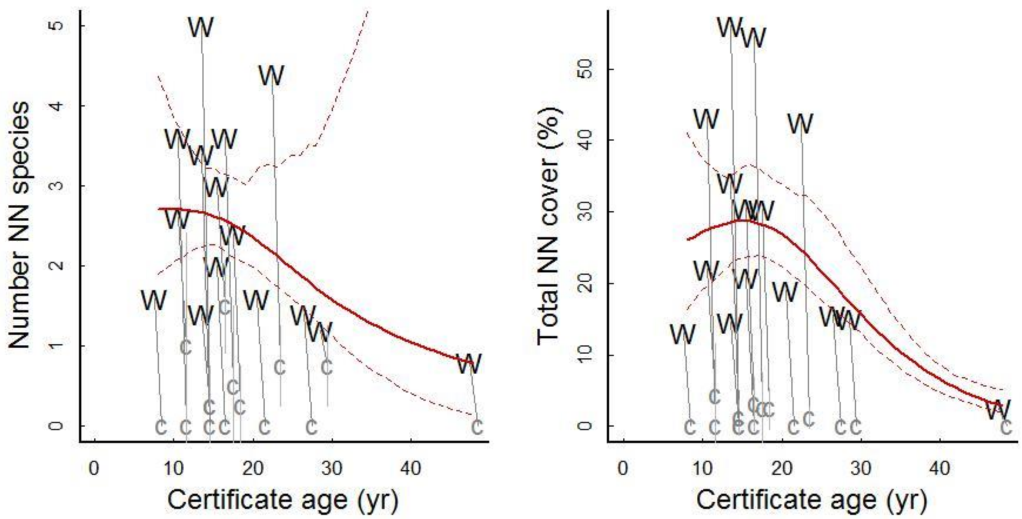
Figure A1.32. Percent similarity of 2D cover layers between wellsites and paired controls for Foothills sites, versus certification age of wellsite. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).

A1.3.5. Foothills Non-native plants

- Non-native species declined with age of wellsites in the foothills (although the one oldest site with few non-native plants had a large influence). Total non-native cover from the cover quadrats showed the strongest relationship with wellsite age, and the best distinction from the control sites.
- Note: Figures of wellsite:control ratios were not plotted because of the many zero or very low values in the controls.

→ Non-native cover from the cover quadrats is probably the most useful indicator of recovery using non-native plants.

COVER QUADRATS



VASCULAR SEARCHES

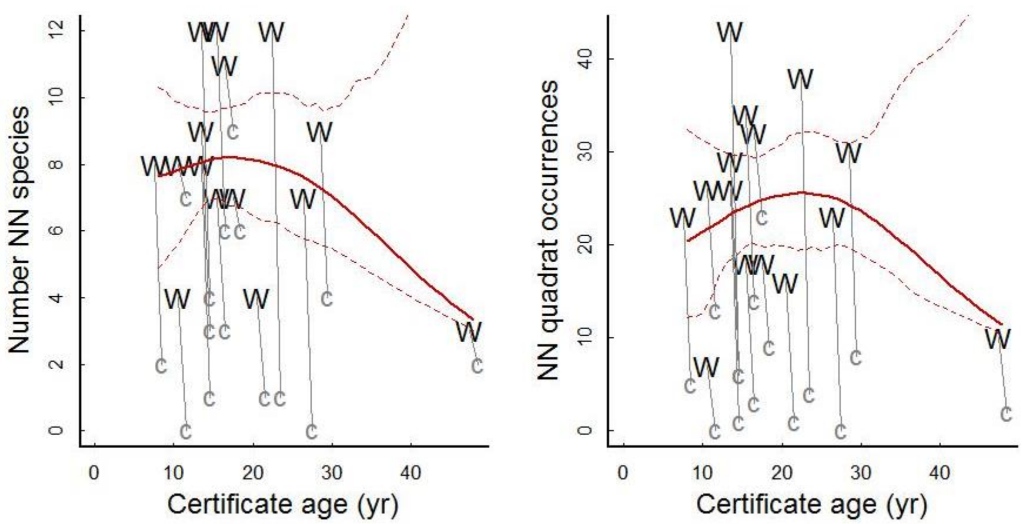


Figure A1.33. Number of non-native plants species in Foothills wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

A1.3.6. Foothills Soils

- Bulk density in the foothills wellsites showed no relationship to age, and remained somewhat higher than paired controls at all ages.
- pH and electrical conductivity declined considerably with age of wellsites, except for the one oldest wellsite. Both values tended to be higher than controls at young wellsite ages, so the ratio figure showed recovery down towards a ratio of 1 with age.
- Total nitrogen and organic carbon did not change with wellsite age, and both remained somewhat below the control levels (but two controls sites had very elevated levels of the two nutrients). The carbon:nitrogen ratio was the same, on average, in wellsites and controls across the range of wellsite ages.
- LFH depth increased with wellsite age, but remained well below control levels at all ages (partly because the controls for the oldest wellsite had LFH layers more than twice as deep as any other foothills site).

→ pH and electrical conductivity may be useful as recovery indicators. Otherwise, changes towards control values could be used for the variables where wellsites remain different from controls – bulk density, nitrogen, organic carbon and LFH depth.

FOOTHILLS

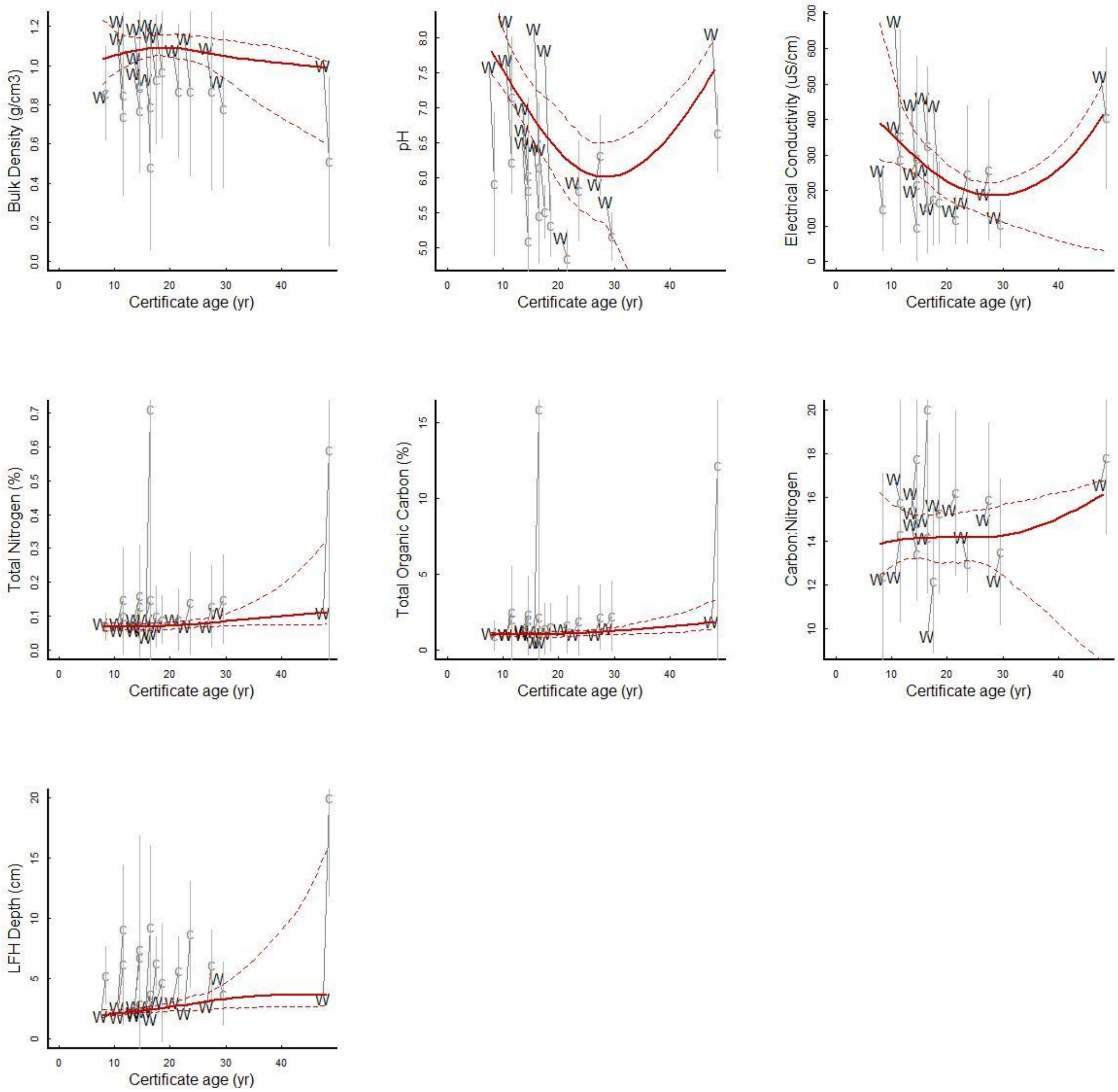


Figure A1.34. Foothills soil variables on wellsites (W) and paired control sites (C, connected with a line to the paired wellsite) versus certification age of the wellsite. Red line = smooth spline fit to the wellsite versus age data (dotted lines = 90% CI on the relationship). Error bars on the control points are ±1 SD, based on the control quadrats.

FOOTHILLS

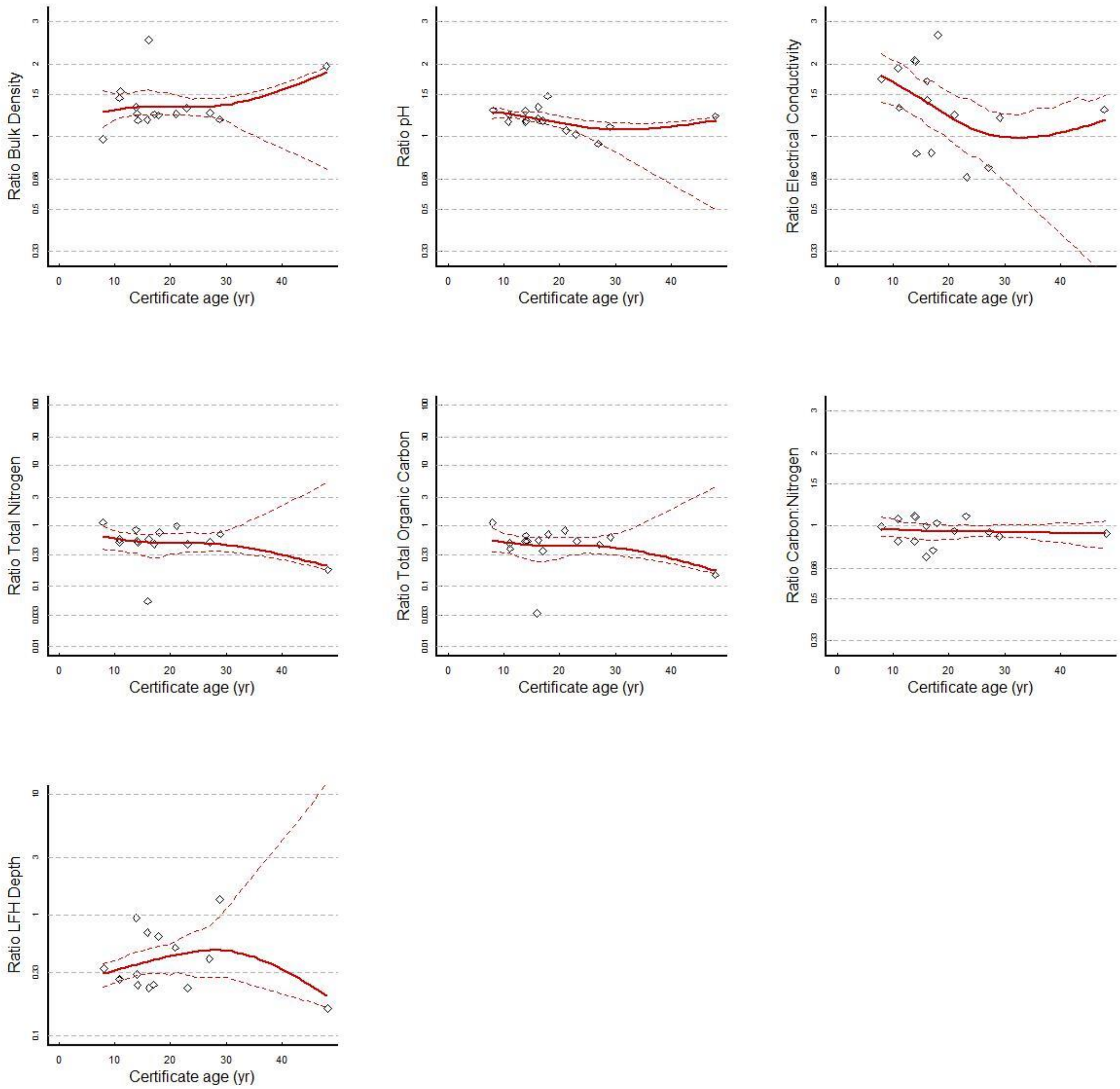


Figure A1.35. For Foothills soil variables, the ratio of the value on wellsites to the value on paired controls. Ratios >1000 are truncated to 1000; ratios <0.001 are truncated to 0.001. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship). Note that sites where the value on both the wellsite and control are 0 cannot be plotted (0/0 is undefined).

A1.3.7. Foothills Community similarity

- Plant species similarity from the cover quadrats increased with wellsite age, with the exception of the one oldest site.
- Shrub species similarity also increased with wellsite age, and the oldest wellsite continued the trend for that variable.
- Plant species similarity based on the vascular plant searches also increased consistently with wellsite age.

→ In contrast to the boreal, community similarity using all three measures – plant cover quadrats, shrub cover quadrats and vascular searches – all showed consistent recovery with age of foothills wellsites. The relationship was strongest for the vascular searches, although the single oldest wellsite had a strong influence on the upper half of the relationship.

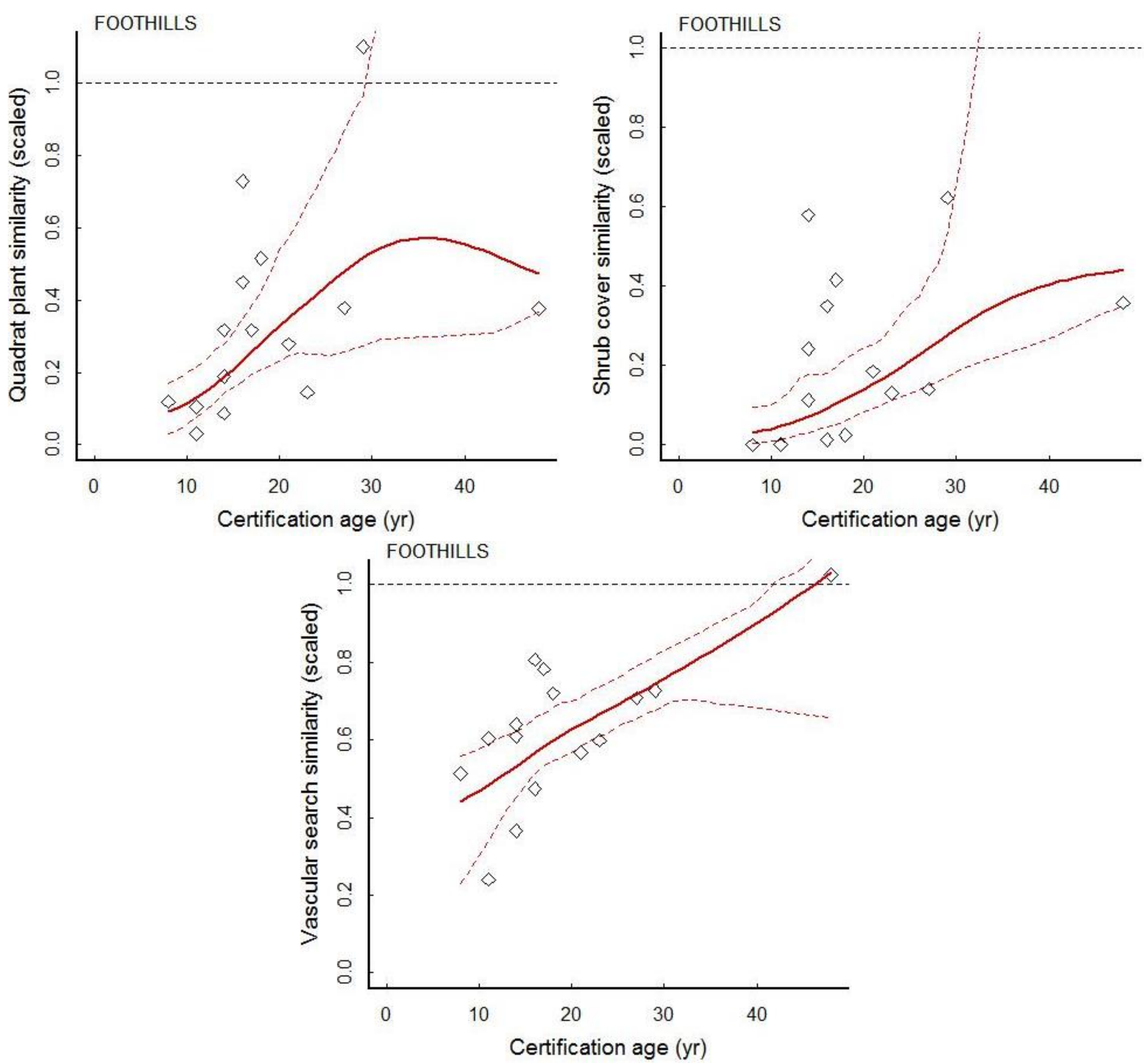


Figure A1.36. Percent similarity of plant species composition between wellsites and paired controls for Foothill sites, versus certification age of wellsite. Top left = vascular plants similarity based on small quadrat

cover; top right = shrub species similairt; bottom = vascular plant similarity based on vascular searches. Red line = smooth spline fit to the ratio versus age results (dotted lines = 90% CI on the relationship).