We Have a Reclamation Certificate, But is it Good Enough?

Ecological Recovery Monitoring of Oil and Gas Wellsites 2012-13 Final Report for Alberta Upstream Petroleum Research Fund

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Executive Summary

There is uncertainty related to the long-term consequences of reconstructing landscapes on Alberta's specified lands. Alberta has over 100,000 wellsites that have been certified under evolving reclamation criteria over the past 50+ years. These wellsites are not currently revisited post-certification to evaluate their long-term ecological recovery. Ecological recovery is achieved when the biological, physical and chemical properties (e.g., vegetation community composition, soil properties) of a reclaimed site are similar to the properties of an undisturbed reference or pre-disturbance site. With the lack of long-term monitoring of wellsites post-certification in Alberta, there is currently no way of knowing if or when ecological recovery will be achieved on these reclaimed sites. The absence of this information is a potential liability that detracts from government's stewardship commitments, and from industry's social license to operate on public lands.

The Ecological Recovery Monitoring (ERM) Project Team was established in November 2012. The overarching goals of the ERM are to: i) undertake a field study to assess historical wellsites to address key knowledge gaps that currently constrain the assessment of ecological recovery after reclamation, and ii) create a scientifically-robust, transparent, and financially-sustainable long-term monitoring program to assess the ecological recovery of reclaimed wellsites. The initial focus on wellsites will provide a foundation for future work on other energy sector footprints.

In the first stage of the project (November 2012 – March 2013), three main project activities were completed. Using a series of workshops, the strengths and weaknesses of three programs that could potentially be used to develop integrated long-term monitoring protocols were evaluated. Workshop participants, who included members from research institutions, industry and government, selected a set of soil and vegetation indicators that could be used to monitor ecological recovery of certified sites. Integrated monitoring protocols that incorporated the selected indicators were developed for use in evaluating the long-term success of reclamation on certified reclaimed wellsites (ABMI 2013a). A governance and funding model to implement and sustain this project in the long-term was also recommended (ABMI 2013b). An extensive review of the literature and existing sources of pertinent data illustrated a lack of long-term monitoring data for certified sites in Alberta (ABMI 2013c).

In the most recent stage of the project (April 2013-March 2014), our project focused on two research areas: i) using the newly developed integrated monitoring protocols to assess ecological recovery of historical wellsites on a single common ecosite type in native grasslands (see Chapter 1), and ii) developing a framework to support implementing a long-term monitoring program to track ecological recovery of certified sites in Alberta (see Chapter 2).

The first objective for this year was to compare ecological recovery for a set of vegetation and soil properties (i.e., indicators of recovery) on certified reclaimed wellsites with adjacent reference locations (i.e.,sites without industrial disturbance) across a range of age classes post certification (~10, 20, and 30 yrs) in native grasslands in the Dry Mixedgrass Natural Subregion (see Chapter 1).

We measured vegetation (percent cover by species and strata, species richness, Shannon diversity, and Sørensen's similarity index) and soil (bulk density, electrical conductivity, LFH depth, pH, total nitrogen (TN), total organic carbon (TOC), TOC:TN) indicators for four soil depths (0-15 cm, 15-30 cm, 30-60 cm, and 60-100 cm), comparing them among 18 wellsites and adjacent reference locations. For each indicator we conducted two-way ANOVAs to test for differences among location (wellsite vs reference) and age class (10, 20, 30 yrs post certification). We also used non-metric multidimensional scaling (NMS) ordination and a multi-response permutation procedure to explore plant community composition patterns among sites.

Vegetation analyses highlighted differences among the wellsite and reference locations, including lower species richness, Shannon diversity, and total vegetation cover on the wellsites compared with the reference sites, regardless of age class. In contrast, wellsites had significantly higher cover of non-native

vegetation compared with the reference sites across age classes. Several vegetation indicators only showed significant differences for the wellsite and reference locations in some age classes (i.e., forb (including non-native), graminoid (including non-native), clubmoss, and lichen cover, and Sørensen's similarity index). There were no significant differences among wellsite and reference sites for shrub cover. The plant community composition ordination illustrated separation of the wellsite and reference locations among age classes, with the 10-yr wellsite community composition more similar to the composition of the reference sites compared with the 20- and 30-yr age classes. These differences among site locations and age classes were primarily correlated with the cover of plant species (e.g., crested wheatgrass in 20- and 30-yr wellsites).

For all soil indicators there were significant differences among the wellsite and reference locations for at least one soil depth. Bulk density (only measured for the two shallowest depths) and electrical conductivity were higher in the wellsites for all sampled depths. Compared with reference sites, wellsite pH was significantly higher at 15-30 cm depth and significantly lower at 60-100 cm depth. LFH depth was significantly deeper in the reference sites compared with the wellsites for the 20 and 30 yr age classes. Total nitrogen was significantly higher in the reference sites for the two shallowest depths and total organic carbon was significantly higher for the reference sites in the most shallow depth (0-15 cm). The ratio of total organic carbon: total nitrogen was significantly higher on wellsites in the deepest depth (60-100 cm).

Overall, it appears that for many vegetation and soil indicators, wellsites have not yet fully recovered to values similar to those found in adjacent reference locations. This lack of recovery was evident across the different age classes, although there was some support for increased recovery of plant communities in the youngest age class compared with the older age classes. We do not yet know how long it will take for these reclaimed wellsites to recover, and thus longer-term monitoring is needed to evaluate recovery trajectories over time.

Alberta is in the process of developing the Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA) with the goal of providing "accurate, trustworthy, and useful data and information to inform the work of policymakers, regulators, research organizations and others through the design, execution and supervision of environmental monitoring programs for air, land, water and biodiversity" (AEMP 2011, WGEM 2012). This over-arching provincial body could provide an administrative and regulatory framework for this long-term ecological recovery monitoring program several years down the road, however considerable work is required prior to this potential amalgamation to ensure that reclaimed sites are effectively monitored.

Thus, the second study objective was to begin development of a framework to support the inclusion of long-term monitoring of reclaimed wellsites in Alberta as part of AEMERA. Towards achieving this objective we investigated the following areas of research: i) we used the historical wellsite study (see Chapter 1) as a pilot of our long-term monitoring protocols, reviewing information from the field study to inform sampling effort in native grasslands for the long-term monitoring program, and ii) we identified potential criteria to aid in development of a framework for selection of a subset of wellsites for inclusion in the long-term monitoring program. We initially planned to develop an implementation plan for the long-term monitoring program, but with the uncertainty related to the governance of AEMERA, we decided it would be more relevant to wait until the governance structure of AEMERA is decided before pursuing this avenue of research so that our results are cohesive with the structure the government plans to implement.

The piloting of the long-term monitoring protocols in the field study described in Chapter 1 provided significant learnings; improvements in technology and use of trained reclamation field crews contributed to significant increases in efficiencies throughout the field season. Analysis of variability among vegetation and soil indicators illustrated high variability both within and between wellsite and reference locations within and among sites. However, the statistical design of our study with paired locations of wellsite and reference locations within individual sites provided the statistical power to detect treatment differences. The statistical design of our study also allowed us to detect differences with a smaller number of sample sites than we would need if we did not use blocking in our design. Our statistical design and the hands on learning experience we gained in the field can be applied when implementing the long-term monitoring program for certified wellsites in native grasslands, thus ensuring efficient and cost effective wellsite monitoring in the future.

ERM advisory group members identified criteria that could potentially be used to classify/categorize both the current pool of certified reclaimed wellsites (>100,000) and future certified wellsites that have not yet been certified (>300,000 and growing). There was also discussion about the scope of the monitoring network, with two different potential approaches identified: i) sampling wellsites from all possible combinations of classes/criteria, or ii) sampling wellsites from only a subset of classes/criteria. Group members highlighted the complexities associated with site selection and its implementation as part of a long-term monitoring program. No final decisions related to site selection for long-term monitoring were made, as these decisions will depend on both the scope of the program and the budget available for establishment of the plot network, and we also need more information on sampling in forested and cultivated lands to help inform site selection.

Overall, our findings from the activities in this project year provided novel insights into the sampling and assessment of recovery of wellsites post-certification in native grasslands in the Dry Mixedgrass natural subregion. These findings will aid in the development of an integrated, scientifically robust and financially sustainable monitoring program to enable the assessment of ecological recovery of physical, chemical, and biological indicators at certified reclaimed wellsites across Alberta. In the next stage of our project we will be assessing ecological recovery of historical wellsites in forested lands and continue to develop the framework for establishing the long-term monitoring program for certified reclaimed wellsites in Alberta.

General Introduction

The Ecological Recovery Monitoring (ERM) Project Team was established in November 2012. The overarching goals of the ERM are to: i) undertake a field study to assess historical wellsites to address key knowledge gaps that currently constrain the assessment of ecological recovery after reclamation, and ii) create a scientifically-robust, transparent, and financially-sustainable long-term monitoring program to assess the ecological recovery of reclaimed wellsites. The initial focus on wellsites during the first three stages of the project will provide a foundation for future work on other energy sector footprints.

In the first stage of the project (November 2012 – March 2013), three main project activities were completed. Using a series of workshops, the strengths and weaknesses of three programs that could potentially be used to develop integrated long-term monitoring protocols were evaluated. The workshop participants, who included members from research institutions, industry and government, selected a set of soil and vegetation indicators that could be used to monitor ecological recovery of certified sites. Integrated monitoring protocols that incorporated the selected indicators were developed for use in evaluating the long-term success of reclamation on certified reclaimed wellsites (ABMI 2013a). A governance and funding model to implement and sustain this project in the long-term was also recommended (ABMI 2013b). An extensive review of the literature and existing sources of pertinent data illustrated a lack of long-term monitoring data for certified sites in Alberta (ABMI 2013c).

In the most recent stage of the project (April 2013-March 2014), our project focused on two research areas: i) using the newly developed integrated monitoring protocols to assess ecological recovery of historical wellsites on a single common ecosite type in native grasslands (see Chapter 1), and ii) developing a framework to support implementing a long-term monitoring program to track ecological recovery of certified sites in Alberta (see Chapter 2).

In the next stage of the project (April 2014-March 2015), our project will again be focused on two research areas: i) using the integrated monitoring protocols to assess ecological recovery of historical wellsites in forested lands (Chapter 1), and ii) continuing to develop a framework to support implementing a long-term monitoring program to track ecological recovery of certified sites in Alberta (Chapter 2).

Chapter 1: Describing Recovery Trajectories

Background/Introduction

Under current regulations, after upstream oil and gas facilities or other industrial developments have been decommissioned on Alberta's specified lands[1], reclamation is directed through the Environmental Protection and Enhancement Act (EPEA). After specified lands have been deemed to have met the legislated requirements, a reclamation certificate is issued. However, the conservation and reclamation guidelines for certificate issuance have changed since the first Alberta reclamation guideline, the *Surface Reclamation Act*, was enacted in 1963. In 1993 the first formal criteria for wellsite certification that linked reclamation and remediation were established. Since 1993, there have been multiple updates to these conservation and reclamation criteria; criteria have shifted from focusing on removal of surface debris to an increasing push towards minimizing cumulative effects and returning ecological function (Powter et al. 2012).

Reclamation of specified lands is a complex process because it may be decades or longer before plant communities, soil properties (e.g., Avirmed et al. 2014), and other ecological functions recover on reclaimed sites. Ecological recovery will be achieved when the biological, physical and chemical properties (i.e., ecological functions) of reclaimed sites are similar to the properties of undisturbed reference or pre-disturbance sites. Published studies suggest that vegetation communities at reclaimed sites often differ from undisturbed areas (e.g. Desserud et al. 2010; Raab and Bayley 2012). In Alberta, there are over 100,000 upstream oil and gas wellsites that have been certified reclaimed, with hundreds of thousands more currently in production or abandoned that will eventually be decommissioned and apply to receive a reclamation certificate. However, the ecological recovery of these wellsites after they have been certified, and how their recovery success may differ based on the conservation and reclamation policies and practices in place when certificates were issued are not currently measured and are thus unknown.

The absence of information on the ecological condition of Alberta's certified industrial footprints that may not have fully recovered is a potential liability that detracts from government's stewardship commitments, and from industry's social license to operate on public lands. Thus, measurements of soil and vegetation ecological recovery indicators in reclaimed sites are needed to quantify recovery after certification. However, without long-term monitoring of wellsites in Alberta there is currently no way of knowing if or when ecological recovery will be achieved on them.

Therefore, the objective of this study was to compare ecological recovery of vegetation (percent cover by species and strata, species richness, Shannon diversity, and Sørensen's similarity index) and soil (bulk density, electrical conductivity, LFH depth, pH, total nitrogen (TN), total organic carbon (TOC), TOC:TN) properties (*recovery indicators*) on certified reclaimed wellsites and adjacent reference locations (without industrial disturbance) across a range of age classes (~10, 20, and 30 years) post certification, focusing on native grasslands in the Dry Mixedgrass Natural Subregion. Monitoring of soil and vegetation indicators at reclaimed sites in native grasslands across a range of age classes will provide novel insights into how recovery varies depending on the conservation and reclamation practices applied at a site and length of recovery (time). In addition, this study, as a pilot of our newly developed field protocols for monitoring ecological recovery on specified lands, also contributes to understanding the sensitivity and variability of indicators across reference vs wellsite locations in both individual sites and among age classes post-certification. This study also provides a foundation that supports development of an integrated, scientifically robust and financially sustainable monitoring program to enable the assessment of ecological recovery of physical, chemical, and biological indicators at certified reclaimed wellsites across Alberta.

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[1] land used for specified industrial disturbances – in this case oil and gas industrial disturbance

Methodology

Study Area

The Ecological Recovery Monitoring of Certified Wellsites (ERM) Advisory Group participated in a series of workshops in Spring 2013 to discuss the study sampling protocols and site selection strategies. Given the relatively small number of wellsites we could sample, the advisory group decided upon screening sites for inclusion in the study rather than randomly selecting wellsites. We felt it was important to select a group of sites with similar shared attributes to increase our ability to detect potential differences in recovery, rather than these recovery signals getting lost in the high degree of variability among sites had we not screened our samples. Recommendations from the group to narrow the scope of sampling to reduce variability and increase the power of our sampling included screening for: i) a particular natural subregion, the Dry Mixedgrass Natural Subregion, ii) a single common ecosite type representative of the subregion (i.e., sampling medium texture chernozemic profiles), iii) flat topography to avoid cut and fill soil disturbance that would greatly increase the degree of soil disturbance, iv) selecting reference locations adjacent to wellsites and using sites as blocking variables, and v) selecting only certain age classes of reclaimed wellsites. To evaluate how recovery differed across different ages post-certification, but recognizing that different age sites were confounded because they had different types of conservation and reclamation policies that were applied to them, the group decided to evaluate recovery patterns for 3 age classes: approximately 10, 20, and 30 years post certification.

The study was conducted from May-August 2013 in the Dry Mixedgrass Natural Subregion of Alberta (Natural Regions Committee 2006). There were a total of 18 sample units selected for inclusion in this study; they were located on loamy ecosites on public grazing leased lands (Fig. 1-1; see Appendix I for detailed information on the sites). In addition we used 15 reference sites with < 2% human footprint and >50% loamy soil sampled by ABMI's monitoring program (ABMI 2012) to compare our vascular plant species composition (presence/absence) with (Fig. 1-1).

Data Collection

Vegetation and soil indicator data and samples were collected as described in the Ecological Recovery Monitoring of Certified Reclaimed Wellsites in Alberta: Field Data Collection Protocols for Native Grasslands (ABMI 2013d) for both wellsite and reference locations within each of the 18 study sites. The same vascular plant census data collection protocols were used for the 15 ABMI 1 ha reference sites. (information on database and data fields can be found in Appendix III).

Statistical Analysis

We calculated plant species richness and alpha diversity (i.e., Shannon Index, Magurran 1988) per 0.25 m^2 quadrat as well as species richness at the site level (wellsite vs reference location) using the species census data. We also used species presence/absence data from the species census to measure Sørensen's similarity index (Sørensen 1948) to make pair-wise comparisons among the percent of species shared among vascular plant communities. Sørensen's index provides a measure of the similarity among two sites which ranges from 0 to 100 where 0 = totally dissimilar (i.e., the two sites have no species in common), and 100 = 100% similar (i.e., the two sites have all species in common, thus there are no unique species that are only present in one of the two sites). Sørensen's similarity index was calculated for i) wellsite vs reference location within individual age classes, and ii) to compare individual wellsite and reference locations with the 15 ABMI reference sites.

This study used a split-plot design with age class as the plot-level 'treatment' and the location (wellsite vs reference) as the subplot 'treatment'. For univariate analyses, we first determined whether each variable met the assumptions for analysis of variance (ANOVA) and transformed response variables when necessary. Two-way ANOVAs were used to test for significant ($\alpha=0.05$) differences in the response of individual variables (e.g., Shannon diversity, species richness, bulk density, electrical conductivity, pH, total organic carbon) to the age class (10, 20, and 30 yrs) and location (reference vs wellsite), as well as

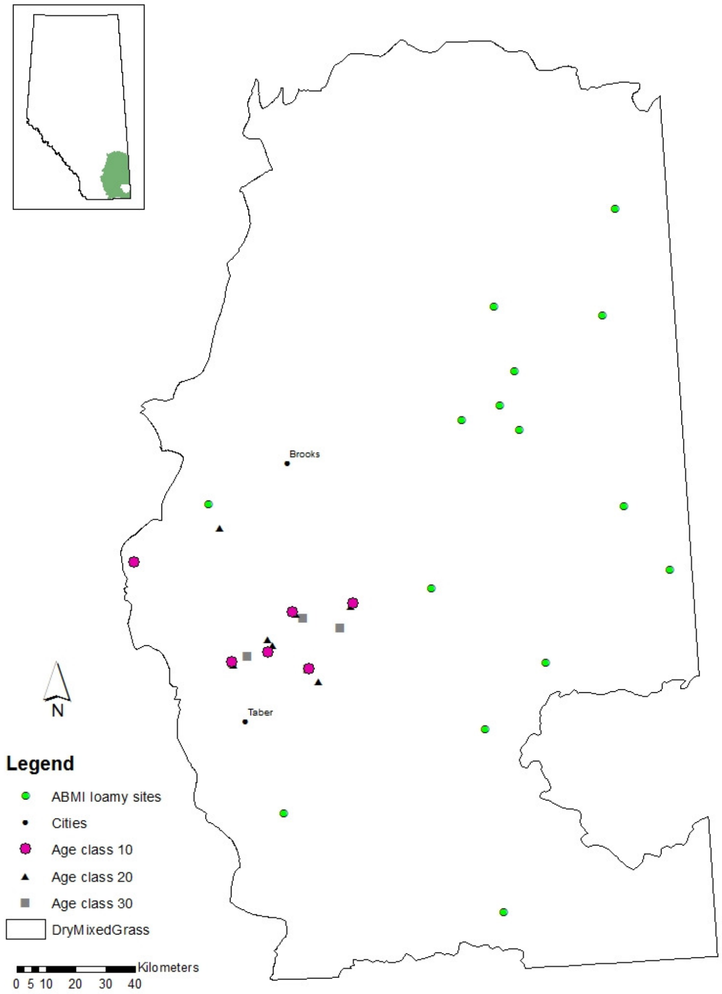

Fig. 1-1. Locations of the 18 study sites in the Dry Mixedgrass Natural Subregion delineated by post-certification age class, along with the location of the 15 ABMI monitoring sites that were compared with our 18 study sites.

for significant (α=0.10) interactions between age class and location, including site (n=18) as a random factor in the mixed model (Proc Mixed, SAS Institute, Version 9.2 (32-bit), Cary, NC, USA; SAS Institute 2008). When age class was significant but location was not significant we used post-hoc linear contrasts to compare among age classes, combining data for all locations within each age class. When there was a significant age-class by location interaction we compared among locations for each age class separately and among age classes for each location separately. For all of these post-hoc comparisons we used Bonferroni-adjusted α values (family-wise α = 0.05).

Multivariate plant community composition patterns among locations (wellsite vs reference) and age classes (10, 20, 30) were examined using nonmetric multidimensional scaling (NMS) ordination (McCune and Grace 2002). Ordinations used PC-ORD (Version 5; MjM Software Design, Gleneden Beach, OR), with Sørenson as the distance measure, 100 runs with real data and 100 Monte Carlo randomized runs, starting with a six-dimensional solution and stepping down to a one-dimensional solution. We omitted species that only occurred in two of the 324 quadrats. We determined the number of dimensions of our final solution by evaluating the scree plot and the reduction in stress with step-down in dimensionality of the preliminary runs (McCune and Grace 2002). Stability of the solution (stability criterion = 0.00005) was assessed by plotting stress versus iteration. After the preliminary runs we ran a final NMS with the optimal number of dimensions, using the starting configuration that worked best in our preliminary runs, and omitting the Monte Carlo test. We then calculated the Pearson correlation coefficients of the vegetation and soil indicators (e.g., bulk density and pH at each of the soil sampling depths, cover by growth form, Shannon index) with the NMS ordination axes and overlaid variables with correlation ($R^2 > 0.25$) on the ordination plots. We used the multiresponse permutation procedure (MRPP) to test for statistically significant differences in plant community profiles among the locations and age classes. MRPP is a nonparametric multivariate procedure for testing the null hypothesis of no difference between two or more groups of entities (Zimmerman et al. 1985). The initial MRPP was followed up by pairwise comparisons among locations and age classes; P-values were Bonferroni-adjusted so the family-wise Type I error rate remained 0.05.

Boxplots of indicators for individual sites are included in Chapter 2 to assess within site and between site variability of vegetation and soil indicators comparing among the wellsite and adjacent reference location for each site. Boxplots provide graphical displays that clearly represent the center, spread, and skewness of the distribution of the data by presenting a box that shows the middle 50% of datapoints from a dataset, with the tails of the boxplot representing the remainder of the data (Ramsay and Schafer 1997 – see Chapter 2 Fig. 2-2 for graphical display of a sample boxplot and the information it provides).

Results

Note that all graphs display results with locations (reference vs wellsite) separated out by individual age classes to display results at that fine scale. However, there was not always a significant interaction between location and age class (see Table 1-1 for which interactions were significant).

Vegetation

Species richness

Mean species richness for the number of species counted within both each (a) 0.25 m^2 quadrat and (b) within each site was consistently higher in the reference locations compared with the wellsite locations for each of the three age classes (Table 1-1; Fig. 1-2). There was no significant difference among non-native species in the wellsite vs reference locations (data not shown).

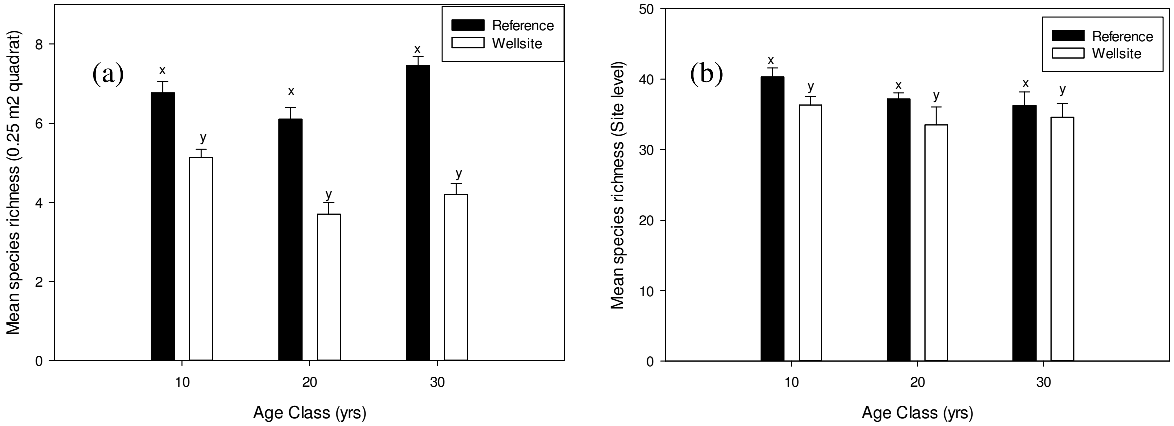

Fig. 1-2. Mean species richness (+ SE) by age class post-certification and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different.

Shannon diversity index

Mean Shannon diversity for each 0.25 m^2 quadrat was consistently higher in the reference locations compared with the wellsite locations for each of the three age classes (Table 1-1; Fig. 1-3).

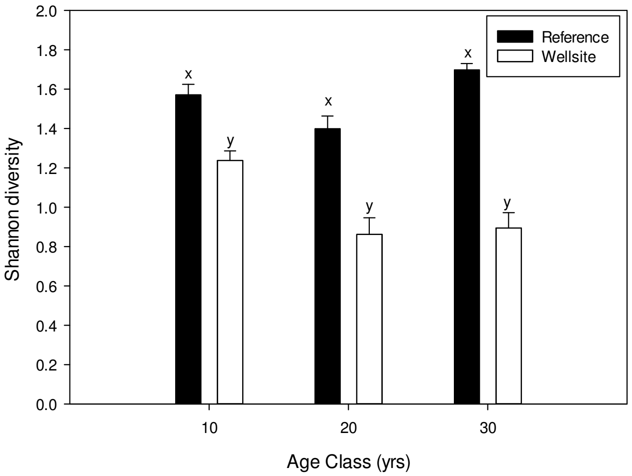

Fig. 1-3. Mean Shannon diversity (+ SE) by age class post-certification and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different.

Vegetation cover by growth form – all species combined

Mean percent cover of total vegetation and clubmoss cover were consistently higher in the reference compared with the wellsite locations for each of the three age classes (Table 1-1; Fig. 1-4a,e). Shrub cover did not differ between wellsite and reference locations across age classes (Table 1-1; Fig. 1-4b). Forb cover was only higher in the 10 yr age class on the wellsite compared with the reference locations (Table 1-1; Fig. 1-4c). Graminoid cover was significantly higher in the 30 yr age class reference location compared with the wellsite location (Table 1-1; Fig. 1-4d). Lichen cover was only higher in the 10 yr age class on the reference compared with the wellsite locations (Table 1-1; Fig. 1-4f).

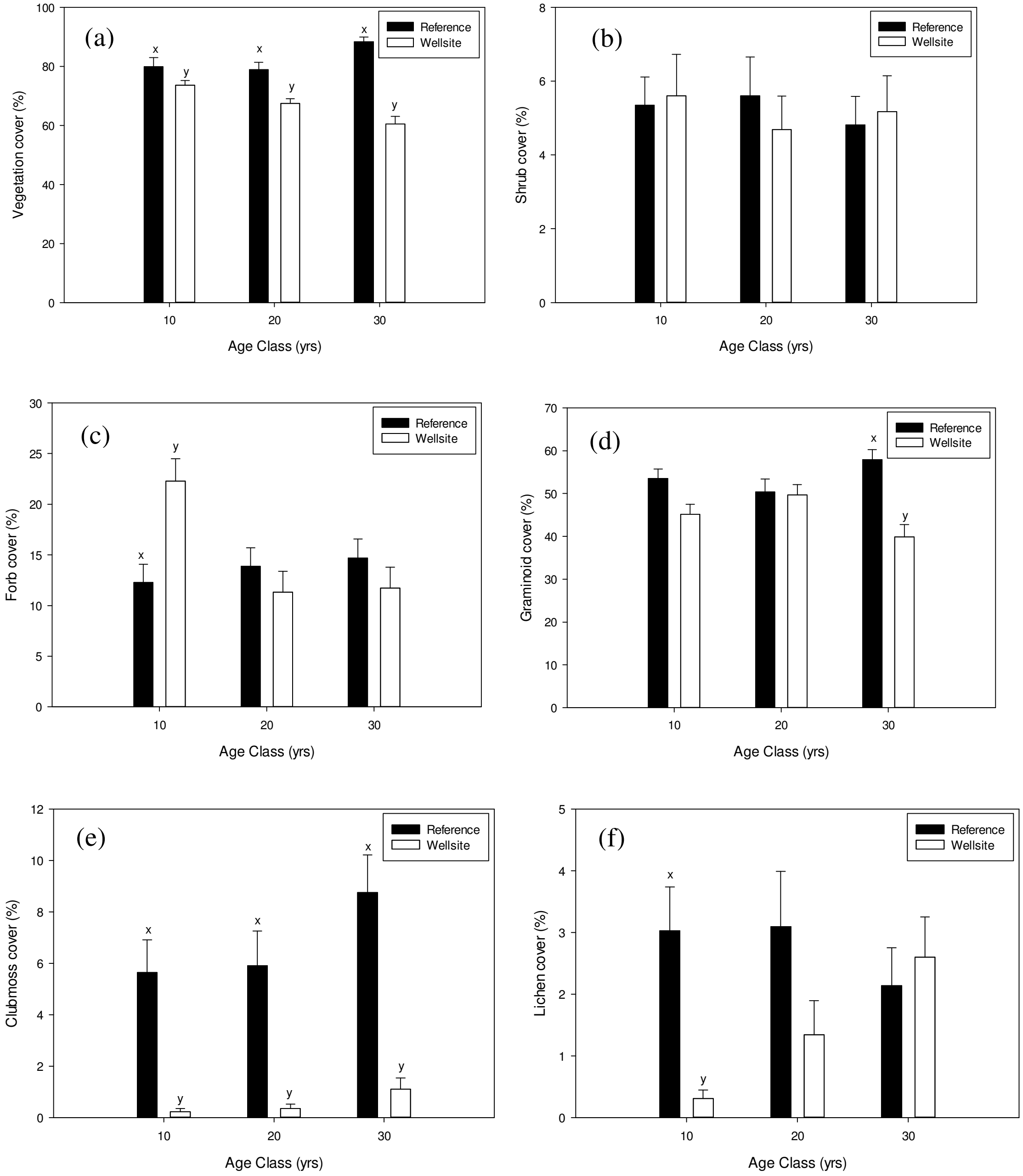

Fig. 1-4. Mean percent cover (+ SE) of (a) total vegetation, (b) shrubs (c) forbs (d) graminoids (e) clubmoss and (f) lichens by age class post-certification and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different.

Vegetation cover by growth form – non-native species

Mean percent cover of total non-native vegetation was significantly higher on the wellsites compared with the reference locations regardless of age class (Table 1-1, Fig. 1-5a). For non-native forb cover wellsites had significantly higher cover than reference locations in the 10 yr age class (Table 1-1, Fig. 1-5b). For graminoid cover, 20- and 30-yr age classes of wellsites were significantly higher than reference locations (Table 1-1, Fig. 1-5c).

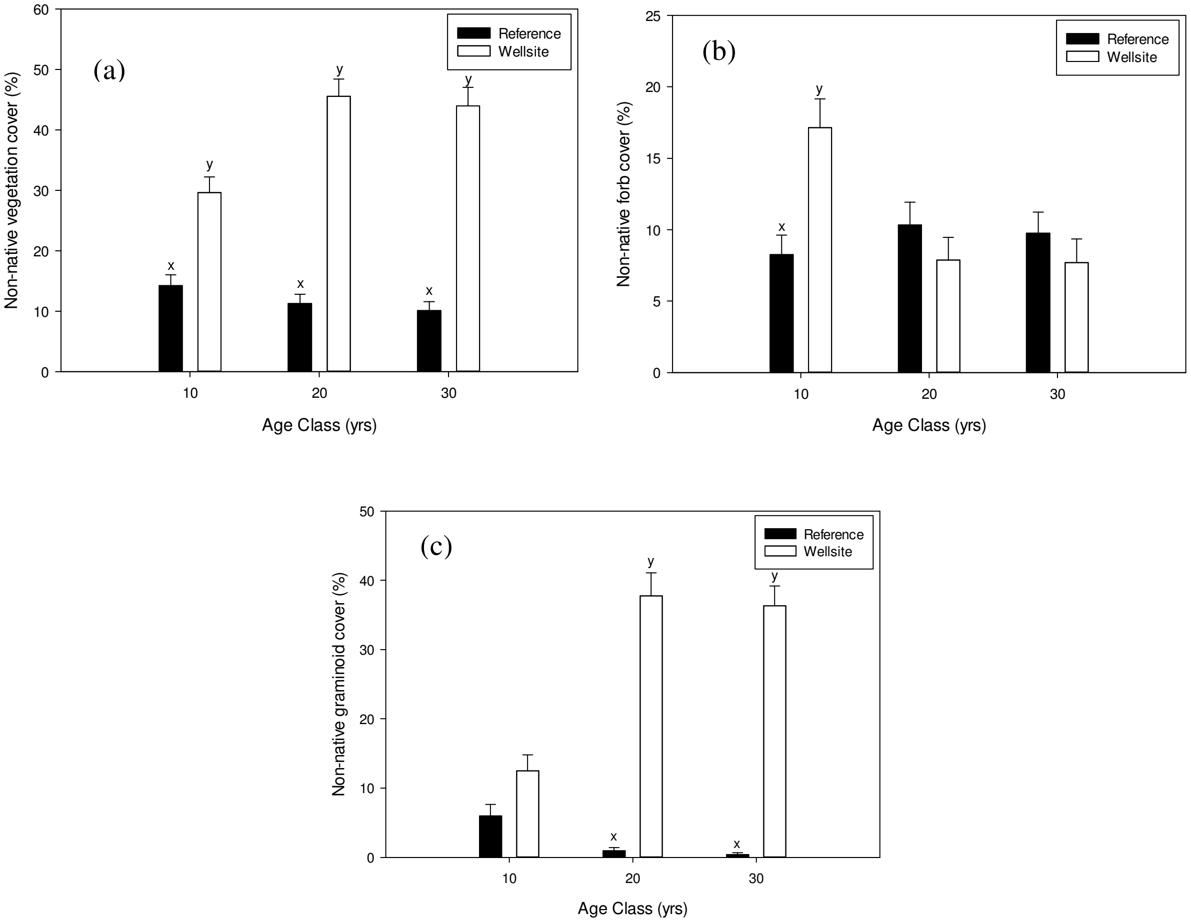

Fig. 1-5. Mean percent cover (+ SE) of non-native (a) total vegetation, (b) forbs and (c) graminoids. Locations with different letters (x, y) within individual age classes were significantly different.

Sørensen's similarity index

Mean Sørensen's similarity index varied among age classes, with the 10 and 30 yr age class wellsite vs reference locations being more similar than for the 20 yr age class (Table 1-1, Fig. 1-6).

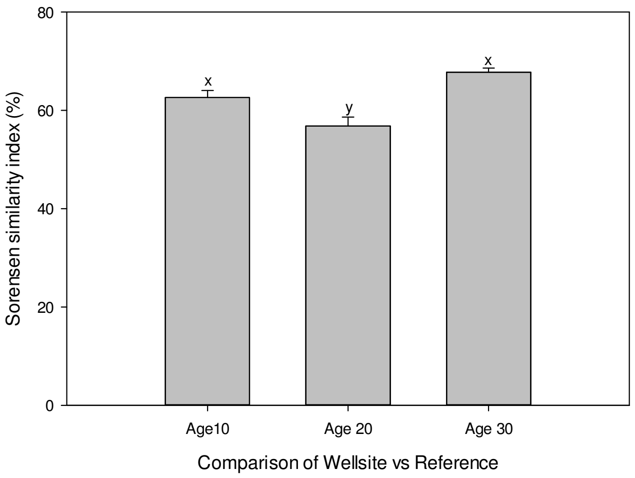

Fig. 1-6. Sørensen's similarity comparing among the presence/absence of vegetation data for wellsite and reference condition locations for 10 yr age class (Age10mix), 20 yr age class (Age20mix), 30 yr age class (Age30mix), combining all age classes (Mix), and all reference locations compared with each other (Ref) and all wellsite locations compared with each other (Well).

Comparing the mean Sørensen's similarity index of the ABMI, wellsite, and reference sites, while the reference and ABMI sites had similar percent similarity to each other, the wellsites were significantly less similar to the ABMI sites (Table 1-1, Fig. 1-7).

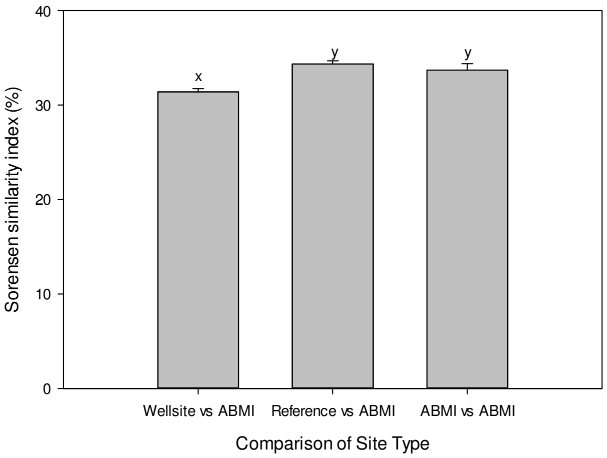

Fig. 1-7. Sørensen's similarity using presence/absence of vascular plant species data comparing among ABMI sites and ABMI (ABMI), reference (Ref vs ABMI), and wellsite (Well vs ABMI) site types.

Plant community composition ordination

The NMS three-dimensional solution (final stress = 10.4 after 34 iterations) explained 90.7% of the variation in the plant community; overlaying the vegetation and soil descriptive variables on the NMS ordination of the plant community showed correlations of several plant and soil variables with the three ordination axes (Fig. 1-8; Table 1-2). The 20 and 30 yr wellsite classes grouped together and based on their locations in the ordination plot they showed positive correlations with cover of *Agropyron cristatum* (crested wheatgrass), and cover of litter. The 10 yr old wellsites grouped together and based on their locations showed positive correlations with cover of *Taraxacum officinale* (dandelion), *Pascopyrum smithii* (western wheat grass), and forb cover. The reference locations overlapped for the three age classes and were positively correlated with Shannon diversity, total vegetation cover, cover of *Bouteloua gracilis* (blue grama grass), *Hesperostipa comata* (needle and thread grass), *Lycopodium annotinum* (stiff club-moss), and *Tragopogon dubius* (goat's-beard), and TOC and N in the 15-30 cm depth, and negatively correlated with bulk density in the two shallowest depths, as well as cover of *Heterotheca villosa* (golden aster) and *Thermopsis rhombifolia* (golden bean). MRPP analysis of plant communities showed significant differences among the locations among the age classes post-certification (A=0.18, P=0.000008); post-hoc pairwise comparisons also highlighted the differences between the wellsite and reference locations across age classes.

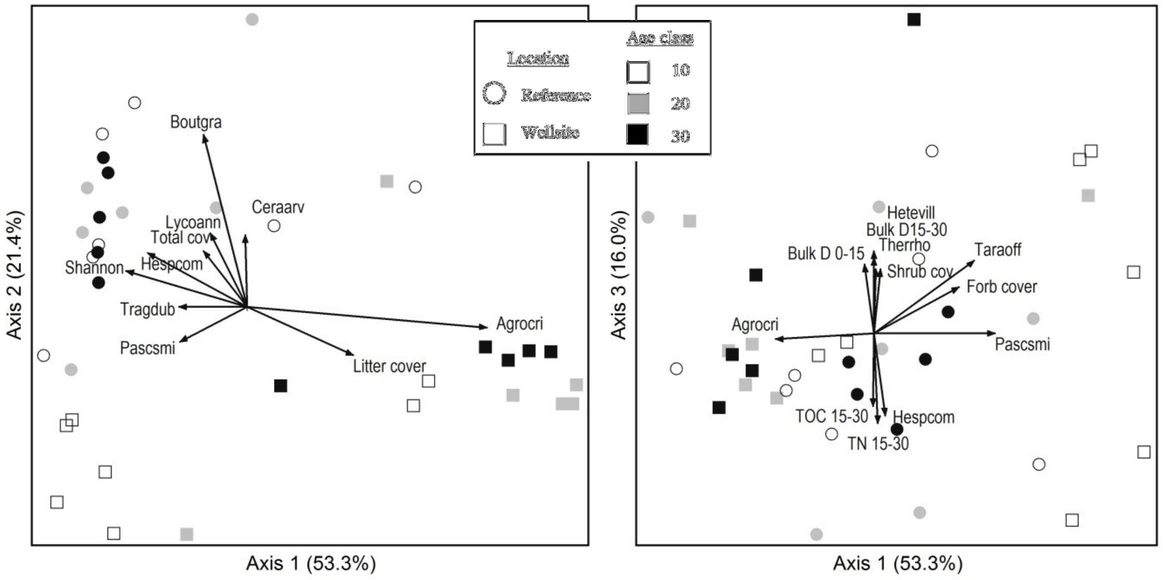

Fig. 1-8. Results of nonmetric multidimensional scaling (NMS) ordination of plant community composition. The final ordinations were 3-D solutions, so two plots are presented. Each symbol in the plots is a location and each color is an age class within an individual site. The amount of variation explained by each axis is included in parentheses. The angles and lengths of the vectors for the individual variables overlain on the ordination indicate direction and strength of associations of them with the ordination axes. Seven letter codes are species codes (See Appendix II). The cutoffs for display was $R^2 > 0.25$.

Soils

Bulk density

Bulk density was higher on the wellsites compared with the reference locations for each of the three age classes for both the 0-15 cm and 15-30 cm depths (Table 1-1; Fig. 1-9).

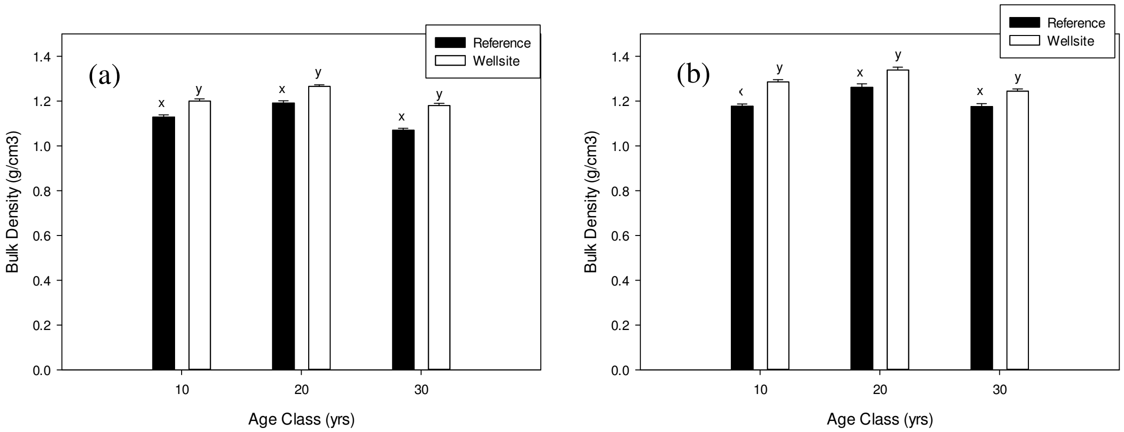

Fig. 1-9. Mean bulk density (+ SE) for (a) 0-15 cm depth and (b) 15-30 cm soil by age class post-certification and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different.

Electrical conductivity

Electrical conductivity (saturated paste) in the shallowest soil depth (0-15 cm) was higher on the wellsite compared with the reference condition location across age classes (Fig. 1-10a; Table 1-1). For the three deeper soil depths (15-30 cm, 30-60 cm, and 60-100 cm), electrical conductivity was also higher on the wellsite compared with adjacent reference condition site, independent of age class (Fig. 1-10b-d; Table 1-1).

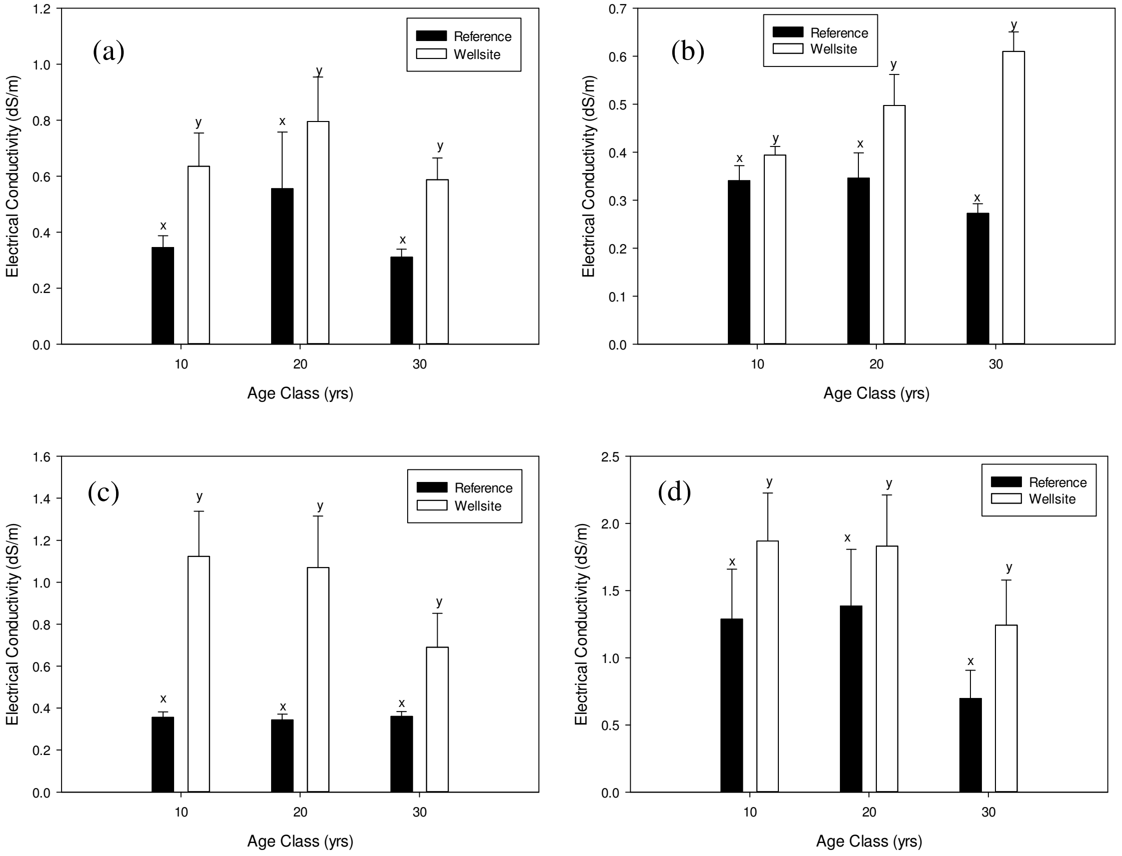

Fig. 1-10. Mean electrical conductivity (+ SE) for (a) 0-15 cm, (b) 15-30 cm, (c) 30-60 cm, and (d) 60-100 cm depth soil by post-certification age class and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different. Electrical conductivity was log transformed for analysis. Note the difference in scale across graphs.

LFH depth

For the 20 and 30 yr age classes, LFH depth was significantly larger in the reference locations compared with the wellsite locations (Fig. 1-11; Table 1-1).

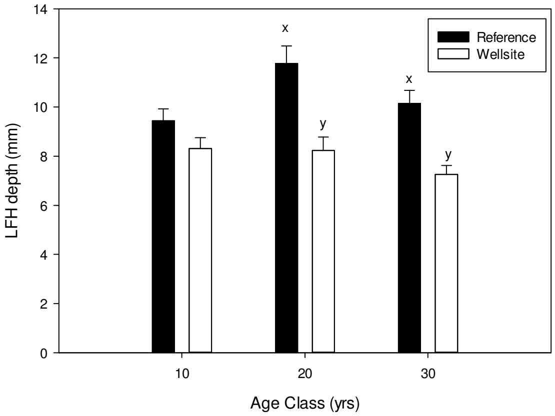

Fig. 1-11. Mean LFH depth (+ SE) by post-certification age class and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different.

pH

For the shallowest soil depth (0-15 cm), pH was higher on the wellsite compared with the reference condition for the 20 and 30 yr age classes, but not the 10 yr age class (Fig. 1-12a; Table 1-1). For the 15-30 cm soil depth, pH was significantly higher on the wellsite compared with adjacent reference condition site, independent of age class (Fig. 1-12b, Table 1-1). For the 30-60 cm depth there was no significant difference in pH (Fig. 1-12c, Table 1-1). For the 60-100 cm depth, the pH was significantly lower on the wellsite compared with the reference location site, independent of age class (Fig. 1-12d; Table 1-1).

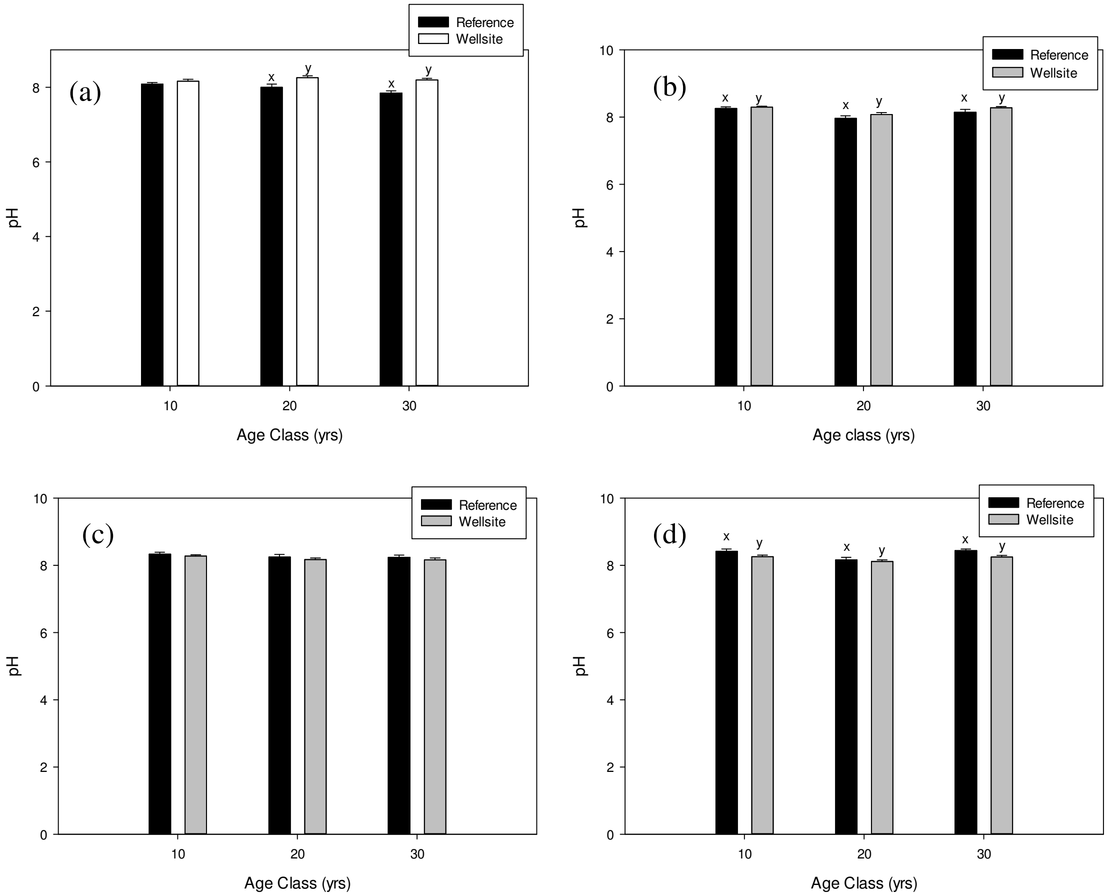

Fig. 1-12. Mean pH (+ SE) for (a) 0-15 cm, (b) 15-30 cm, (c) 30-60 cm, and (d) 60-100 cm depth soil by post-certification age class and location (reference vs wellsite). Locations in (a) with different letters (x, y) within individual age classes were significantly different. Locations in (b), (c), and (d) with different letters (x, y) among locations were significantly different.

Total nitrogen (TN)

Across all age classes, total nitrogen was lower on the wellsite compared with the reference site locations for the upper three depths (0-15 cm, 15-30 cm, 30-60 cm), whereas there was no difference in the deepest soil sample (60-100 cm)(Fig. 1-13; Table 1-1).

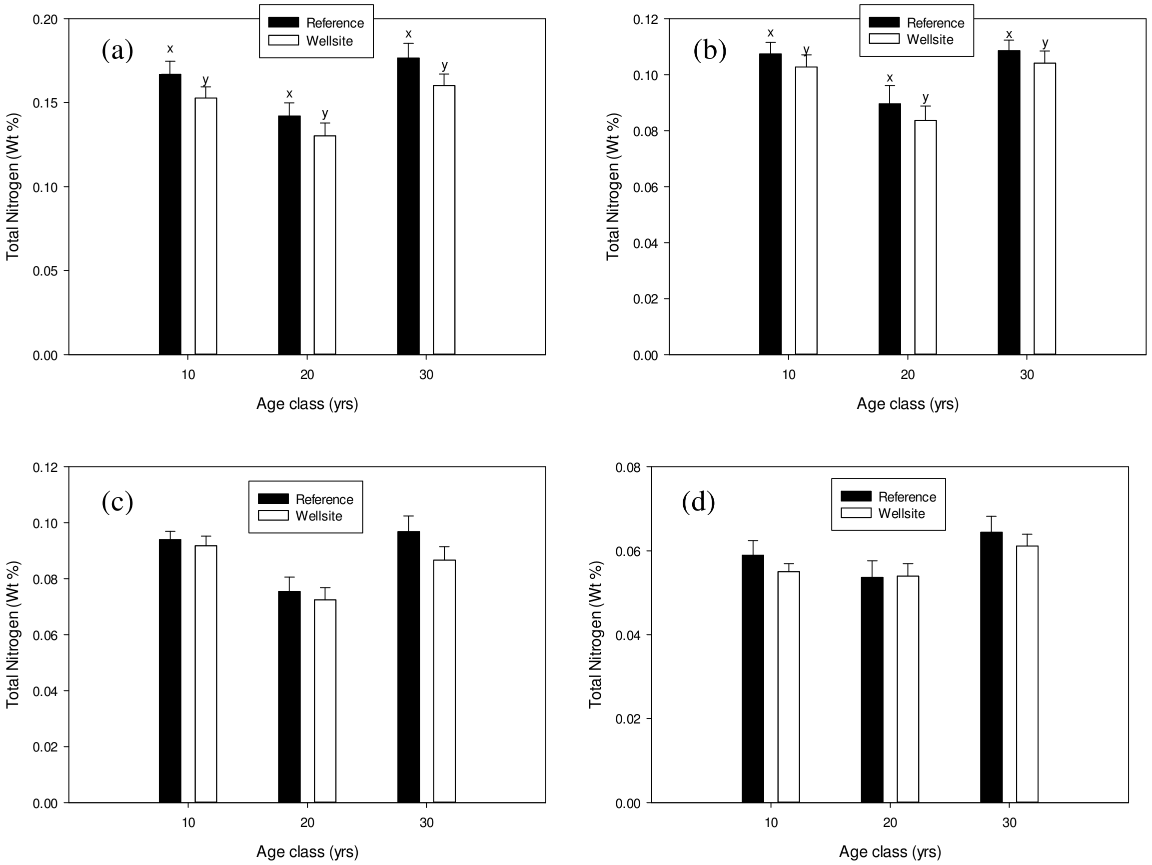

Fig. 1-13. Mean total nitrogen (+ SE) for (a) 0-15 cm, (b) 15-30 cm, (c) 30-60 cm, and (d) 60-100 cm depth soil by post-certification age class and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different. Total nitrogen for 60 cm depth was log transformed for analysis. Note the difference in scale across graphs.

Total organic carbon (TOC)

Across age classes for the shallowest soil depth (0-15 cm), total organic carbon (TOC) was lower on the wellsites compared with the reference site locations (Fig. 1-14a; Table 1-1). However, there were no differences in TOC among reference and wellsite locations for the three deepest depths (15-30 cm, 30-60 cm, 60-100 cm) (Fig. 1-14b-d, Table 1-1).

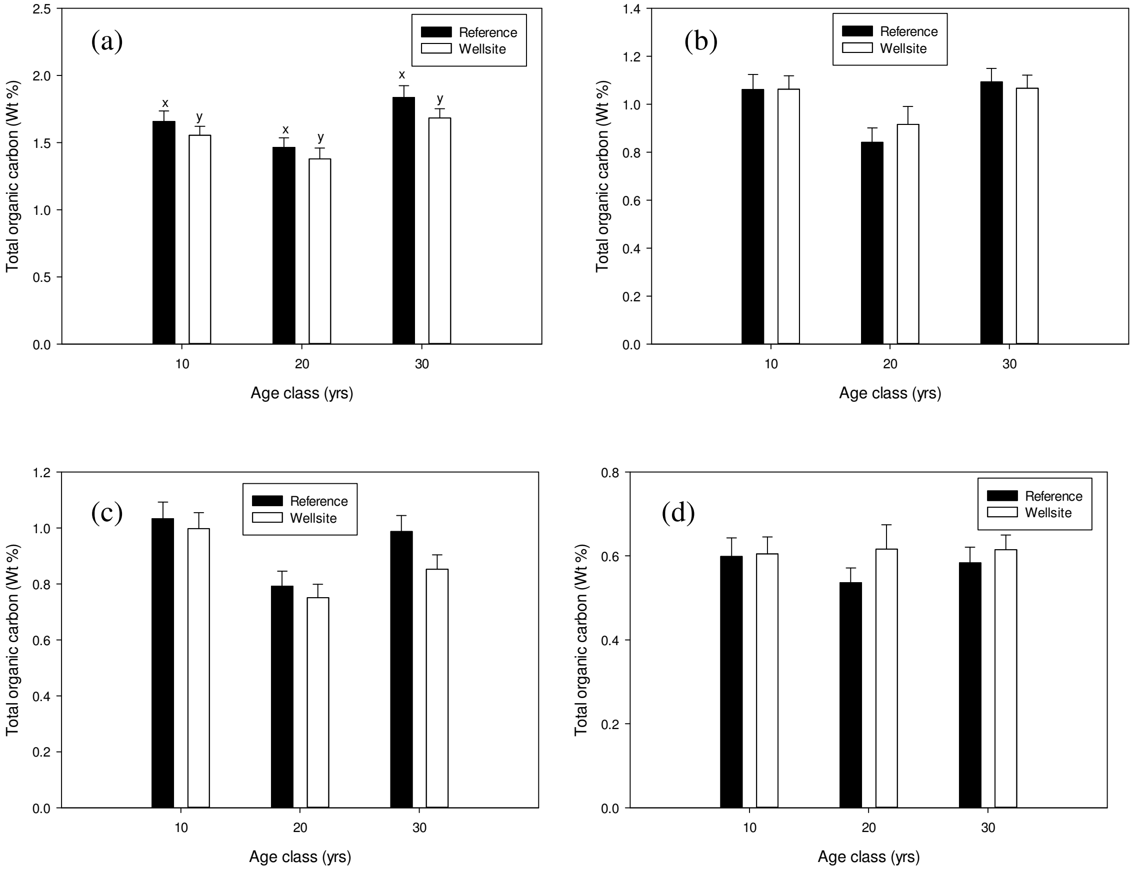

Fig. 1-14. Mean total organic carbon (+ SE) for (a) 0-15 cm, (b) 15-30 cm, (c) 30-60 cm, and (d) 60-100 cm depth soil by post-certification age class and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different. Note the difference in scale across graphs.

Total organic carbon : total nitrogen (TOC:N)

Across age classes, there was no difference in TOC:N for 0-15 cm and 30-60 cm depths (Fig. 1-15a,c, Table 1-1). For the 15-30 cm soil depth the 20 yr old wellsites had higher TOC:N ratios than the reference sites (Fig. 1-15b, Table 1-1). For the 60-100 cm depth, wellsites also had higher TOC:N ratios than the reference sites (Fig 15d, Table 1-1).

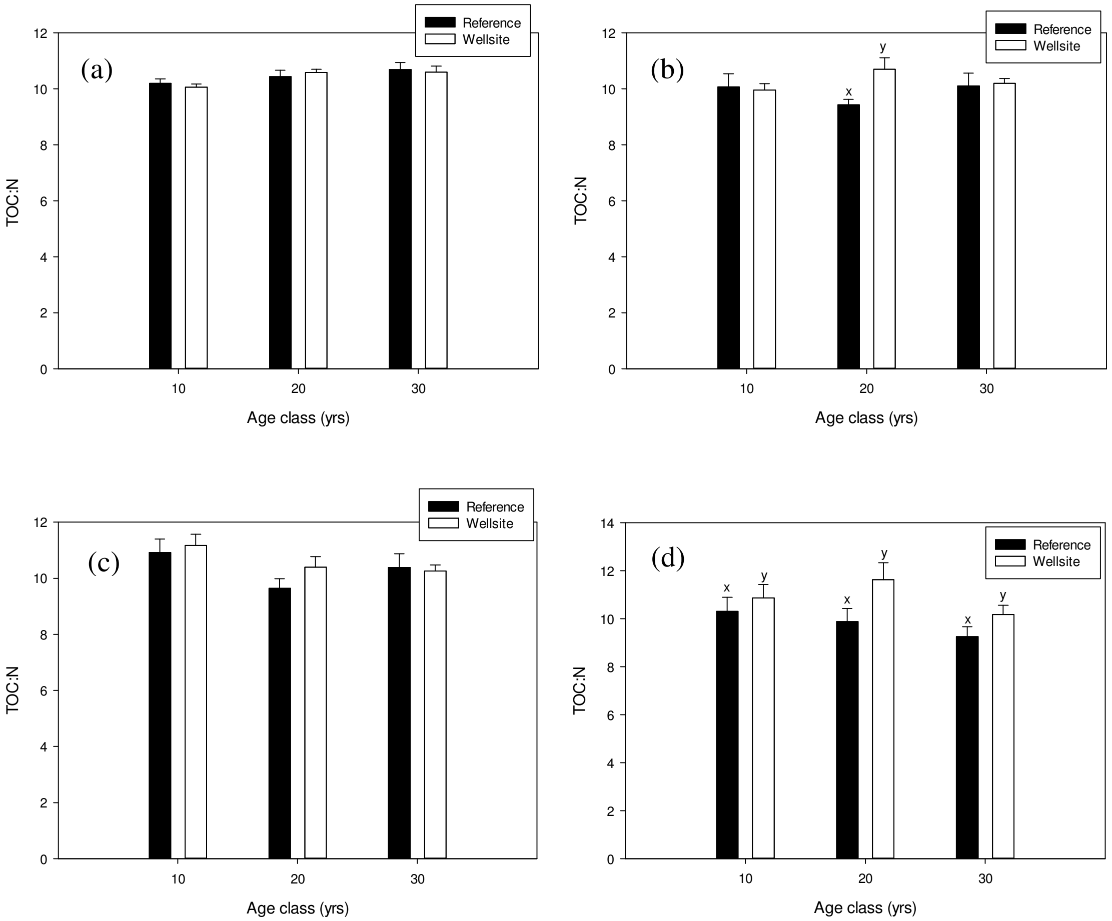

Fig. 1-15. Mean ratio of total organic carbon (TOC) to total nitrogen (+ SE) for (a) 0-15 cm, (b) 15-30 cm, (c) 30-60 cm, and (d) 60-100 cm depth soil by post-certification age class and location (reference vs wellsite). Locations with different letters (x, y) within individual age classes were significantly different. Note the difference in scale across graphs.

Table 1-1. Results (P values) for two-way ANOVAs testing for the effects of age class, location (reference vs wellsite), and the interaction between age class and location for vegetation and soil indicators in 18 loamy ecosite Dry Mixedgrass study units. Significant P-values highlighted in bold.

Variable	Age class	Location	Age class X Location
VEGETATION			
Species Richness			
Quadrat level	0.18	**<0.0001**	**0.03**
Site level	0.22	**0.02**	0.67
Shannon diversity	0.16	**<0.0001**	**0.007**
Total vegetation cover	0.60	**<0.0001**	**0.0003**
Shrub cover	0.97	0.91	0.78
Forb cover	0.59	0.41	**0.003**
Graminoid cover	0.91	**0.0003**	**0.03**
Clubmoss cover	0.38	**<0.0001**	0.36
Lichen cover	0.86	**0.01**	**0.06**
Total non-native cover[3]	0.69	**<0.0001**	**0.0009**
Non-native forb cover[3]	0.77	0.95	**0.0001**
Non-native graminoid cover[3]	0.41	**<0.0001**	**<0.0001**
Sørenson similarity index			
Age classes – well vs ref	n/a	**<0.0001**	n/a
Well vs ref vs ABMI	n/a	**<0.0001**	n/a
SOILS			
Bulk density			
0-15 cm depth	0.12	**<0.0001**	**0.02**
15-30 cm depth	0.26	**<0.0001**	**0.06**
Electrical conductivity			
0-15 cm depth	0.39	**<0.0001**	**<0.0001**
15-30 cm depth	0.97	**<0.0001**	0.55
30-60 cm depth	0.84	**<0.0001**	0.31
60-100 cm depth	0.59	**0.03**	0.96
LFH depth	0.86	**<0.0001**	**0.0044**
pH			
0-15 cm depth	0.61	**<0.0001**	**0.02**
15-30 cm depth	0.17	**0.02**	0.55
30-60 cm depth	0.44	0.06	0.97
60-100 cm depth	**0.03**[1]	**0.002**	0.38
Total nitrogen			
0-15 cm depth	0.26	**0.04**	0.74
15-30 cm depth	0.22	**0.04**	0.96
30-60 cm depth	0.054	0.06	0.54
60-100 cm depth	0.23	0.31	0.72
Total organic carbon (TOC)			
0-15 cm depth	0.29	**0.0004**	0.69
15-30 cm depth	0.43	0.68	0.30
30-60 cm depth	0.09	0.06	0.41
60-100 cm depth	0.92	0.26	0.60
TOC:N			
0-15 cm depth	0.27	0.83	0.53
15-30 cm depth	0.97	**0.009**	**0.03**
30-60 cm depth	0.43	0.19	0.43
60-100 cm depth	0.60	**0.01**	0.46

[1] Pairwise comparisons among age classes were not statistically significant.
[2] Log transformed prior to analysis.
[3] Square root transformed prior to analysis.

Table 1-2. NMS ordination Pearson, R-square, and tau correlations of variables with each of the 3 axes ordered from highest to lowest R-square for axis 1. Seven letter species codes refer to species described in Appendix II.

					Axis				
		1			2			3	
Variable	r	R^2	tau	r	R^2	tau	r	R^2	tau
Agrocri	0.95	0.91	0.77	-0.13	0.02	-0.05	-0.15	0.02	-0.08
Shannon diversity	-0.69	0.48	-0.32	0.27	0.07	0.18	0.19	0.04	0.12
Litter cover	0.65	0.42	0.38	-0.33	0.11	-0.25	-0.01	0.00	0.08
Hespcom	-0.63	0.40	-0.56	0.36	0.13	0.34	-0.57	0.32	-0.37
Tragdub	-0.50	0.25	-0.43	-0.11	0.01	-0.03	0.33	0.11	0.11
Pascsmi	-0.47	0.22	-0.46	-0.45	0.20	-0.23	-0.04	0.00	0.13
Boutgra	-0.45	0.21	-0.25	0.76	0.57	0.59	0.15	0.02	0.12
pH 0-15 cm	0.44	0.20	0.25	-0.29	0.08	-0.21	-0.16	0.03	-0.12
Forb cover	-0.44	0.20	-0.22	-0.33	0.11	-0.17	0.42	0.18	0.28
Electrical conductivity 0-15 cm	0.44	0.19	0.21	-0.27	0.08	-0.23	-0.12	0.02	-0.12
Total vegetation cover	-0.43	0.19	-0.37	0.40	0.16	0.31	-0.05	0.00	-0.01
Club-moss cover	-0.40	0.16	-0.22	0.48	0.23	0.41	-0.20	0.04	-0.18
Lycoann	-0.40	0.16	-0.22	0.48	0.23	0.41	-0.20	0.04	-0.18
Medisat	0.38	0.15	0.27	-0.13	0.02	-0.15	-0.15	0.02	-0.29
C:N ratio 15-30 cm	0.38	0.14	0.17	-0.03	0.00	-0.05	-0.18	0.03	-0.18
C:N ratio 60-100 cm	0.36	0.13	0.10	-0.15	0.02	-0.14	-0.17	0.03	-0.16
Taraoff	-0.34	0.12	-0.13	-0.50	0.25	-0.40	0.53	0.28	0.33
Bulk density 0-15 cm	0.34	0.11	0.29	-0.08	0.01	-0.11	0.52	0.27	0.38
TOC 60-100 cm	0.32	0.10	0.06	-0.10	0.01	-0.11	-0.17	0.03	-0.06
pH 60-100 cm	-0.31	0.09	-0.18	0.07	0.00	0.12	-0.12	0.01	-0.09
Electrical conductivity 15-30 cm	0.30	0.09	0.18	-0.23	0.05	-0.25	-0.18	0.03	-0.08
Elyminn	0.30	0.09	0.22	-0.09	0.01	-0.09	-0.08	0.01	-0.09
LFH depth	-0.30	0.09	-0.18	-0.06	0.00	-0.08	-0.01	0.00	0.00
Bromine	0.30	0.09	0.29	0.03	0.00	-0.11	0.40	0.16	0.26
Anteapr	0.28	0.08	0.28	-0.08	0.01	-0.15	0.34	0.12	0.18
Age of certification	0.28	0.08	0.19	0.20	0.04	0.16	-0.01	0.00	-0.02
Koelmac	-0.27	0.07	-0.25	0.36	0.13	0.31	-0.32	0.10	-0.14
Trifhyb	0.24	0.06	0.16	-0.04	0.00	-0.03	-0.06	0.00	-0.06
Achimill	-0.23	0.05	-0.15	-0.03	0.00	-0.15	-0.07	0.00	0.13
Descpin	-0.23	0.05	-0.16	-0.16	0.02	-0.13	-0.13	0.02	-0.08
Poasan	-0.23	0.05	-0.13	0.01	0.00	0.12	-0.17	0.03	0.00
Agrosca	-0.23	0.05	-0.30	-0.31	0.10	-0.24	-0.26	0.07	-0.26
Shrubs (less than 0.5 m tall)	-0.23	0.05	-0.07	0.01	0.00	0.15	0.50	0.25	0.30
Carespp	-0.22	0.05	-0.06	0.38	0.15	0.21	-0.19	0.04	-0.07
Descsop	-0.22	0.05	-0.17	-0.27	0.07	-0.17	0.33	0.11	0.16
Sphacoc	-0.21	0.04	-0.12	0.45	0.20	0.33	-0.24	0.06	-0.07
Festsax	-0.20	0.04	-0.13	0.06	0.00	-0.06	0.31	0.10	0.32

					Axis				
		1			2			3	
Variable	r	R^2	tau	r	R^2	tau	r	R^2	tau
Poapra	-0.20	0.04	-0.17	0.12	0.02	0.19	0.32	0.10	0.13
Elymtra	-0.19	0.04	-0.15	-0.25	0.06	-0.19	0.35	0.12	0.32
Mammviv	0.20	0.04	0.24	0.08	0.01	0.06	0.23	0.05	0.01
Non-native richness	-0.19	0.04	-0.18	-0.41	0.17	-0.25	0.01	0.00	0.05
TOC 15-30 cm	0.19	0.04	0.05	-0.10	0.01	-0.02	-0.53	0.28	-0.35
Carepen	-0.17	0.03	-0.10	0.12	0.02	0.10	0.30	0.09	0.26
Gaurcoc	-0.17	0.03	-0.15	0.11	0.01	0.09	-0.07	0.01	0.03
Melioff	0.17	0.03	0.15	-0.19	0.04	-0.29	-0.14	0.02	0.03
Electrical conductivity 30-60 cm	0.17	0.03	0.09	-0.28	0.08	-0.24	-0.29	0.08	-0.09
Lappsqu	-0.16	0.03	-0.22	0.18	0.03	0.02	-0.04	0.00	0.02
Soncasp	0.16	0.03	0.11	-0.11	0.01	-0.16	-0.01	0.00	0.06
Festcam	-0.15	0.02	-0.22	0.08	0.01	0.07	-0.27	0.07	-0.21
Lichspp	0.15	0.02	0.12	0.31	0.10	0.34	-0.42	0.17	-0.32
TN 30-60 cm	-0.15	0.02	-0.11	-0.23	0.05	-0.09	-0.20	0.04	-0.11
Convarv	-0.15	0.02	-0.20	-0.30	0.09	-0.21	-0.18	0.03	-0.18
Viciame	-0.15	0.02	-0.12	-0.18	0.03	-0.04	-0.04	0.00	0.03
Water cover	-0.15	0.02	-0.16	-0.18	0.03	-0.17	-0.28	0.08	-0.22
Careste	-0.14	0.02	-0.11	0.05	0.00	0.09	0.28	0.08	0.27
Medilup	-0.14	0.02	-0.10	0.10	0.01	0.09	-0.14	0.02	-0.16
Seladen	-0.14	0.02	-0.11	0.05	0.00	0.03	0.27	0.08	0.21
Chenalb	-0.14	0.02	0.01	0.19	0.04	0.14	-0.02	0.00	0.19
Hordjub	-0.14	0.02	-0.07	0.07	0.00	0.06	0.11	0.01	0.13
Allitex	-0.13	0.02	-0.07	0.12	0.01	0.12	0.20	0.04	0.22
Bulkd density 15-30 cm	0.13	0.02	0.15	-0.16	0.03	-0.26	0.54	0.30	0.39
Phlohoo	-0.13	0.02	-0.14	0.25	0.06	0.20	-0.02	0.00	0.03
Planpat	-0.13	0.02	0.08	-0.22	0.05	0.19	0.10	0.01	0.09
Creptec	-0.12	0.02	-0.18	-0.37	0.14	-0.17	0.07	0.00	-0.06
Therrho	-0.12	0.02	-0.05	0.00	0.00	0.00	0.50	0.25	0.36
Arabhol	-0.12	0.01	-0.03	0.11	0.01	0.10	0.19	0.04	0.17
Astrcra	-0.12	0.01	-0.03	0.11	0.01	0.10	0.19	0.04	0.17
Carefil	-0.12	0.01	-0.03	0.11	0.01	0.10	0.19	0.04	0.17
Linavul	-0.12	0.01	-0.03	0.11	0.01	0.10	0.19	0.04	0.17
Stelspp	-0.12	0.01	-0.03	0.11	0.01	0.10	0.19	0.04	0.17
Thlaarv	-0.12	0.01	-0.02	0.27	0.07	0.22	-0.09	0.01	-0.10
pH 15-30 cm	0.12	0.01	0.05	-0.30	0.09	-0.13	-0.03	0.00	0.02
Bromtec	-0.11	0.01	-0.05	-0.25	0.06	-0.10	0.28	0.08	0.25
Ceraarv	-0.11	0.01	0.01	0.52	0.27	0.36	0.27	0.07	0.22
Grinsqu	-0.11	0.01	-0.10	-0.35	0.12	-0.29	0.07	0.00	-0.07
Lactsca	-0.11	0.01	-0.01	-0.25	0.06	-0.20	0.28	0.08	0.22
Wood cover	0.11	0.01	0.10	0.22	0.05	0.30	0.18	0.03	0.21

					Axis				
		1			2			3	
Variable	r	R^2	tau	r	R^2	tau	r	R^2	tau
pH 30-60 cm	-0.11	0.01	-0.11	-0.10	0.01	0.00	-0.10	0.01	0.03
Liatpun	0.10	0.01	0.10	0.44	0.19	0.25	0.16	0.03	0.02
Raticol	-0.10	0.01	0.01	-0.34	0.11	-0.24	0.09	0.01	0.11
Soncarv	-0.10	0.01	0.02	-0.41	0.17	-0.30	0.34	0.12	0.28
Nassvir	0.10	0.01	-0.10	0.48	0.23	0.39	0.11	0.01	-0.04
TOC 30-60 cm	-0.09	0.01	-0.17	-0.22	0.05	-0.09	-0.26	0.07	-0.15
Fungi cover	0.09	0.01	-0.03	-0.01	0.00	0.00	-0.15	0.02	-0.09
TN 0-15 cm	-0.09	0.01	-0.07	-0.16	0.03	-0.09	-0.36	0.13	-0.19
TN 60-100 cm	-0.08	0.01	0.05	0.07	0.00	0.05	-0.11	0.01	-0.07
TOC 0-15 cm	-0.07	0.00	-0.08	-0.14	0.02	-0.03	-0.32	0.11	-0.20
C:N ratio 0-15 cm	0.07	0.00	0.08	0.01	0.00	-0.02	0.05	0.00	0.05
Hetevill	0.07	0.00	0.13	-0.11	0.01	0.07	0.57	0.32	0.31
Elymlan	-0.05	0.00	-0.02	-0.34	0.12	-0.26	0.21	0.04	0.16
Animal waste cover	-0.06	0.00	0.05	0.04	0.00	0.12	-0.17	0.03	-0.12
Artecan	-0.04	0.00	-0.07	0.47	0.22	0.24	0.30	0.09	0.22
Artefri	-0.04	0.00	0.15	-0.42	0.17	-0.17	0.08	0.01	0.19
Electrical conductivity 60-100 cm	0.04	0.00	0.02	-0.13	0.02	-0.16	-0.33	0.11	-0.16
Elymrep	-0.04	0.00	0.02	0.13	0.02	0.13	-0.30	0.09	-0.24
Andrsep	-0.03	0.00	0.03	-0.33	0.11	-0.22	0.21	0.04	0.18
Astrdas	-0.03	0.00	0.07	0.03	0.00	-0.02	0.15	0.02	0.01
Cirsflo	0.04	0.00	0.07	-0.11	0.01	-0.13	0.47	0.22	0.24
Psorlan	0.04	0.00	-0.04	-0.02	0.00	-0.13	0.24	0.06	0.27
Rosaaci	-0.02	0.00	0.05	0.40	0.16	0.24	0.18	0.03	0.16
Grass cover	-0.04	0.00	-0.22	0.21	0.04	0.12	-0.42	0.18	-0.26
Lichen cover	-0.03	0.00	-0.02	0.35	0.13	0.33	-0.48	0.23	-0.42
Mineral soil cover	0.03	0.00	0.15	0.10	0.01	0.06	0.16	0.03	0.03
Rock cover	-0.04	0.00	0.23	-0.12	0.01	0.06	-0.31	0.10	-0.21
TN 15-30 cm	-0.01	0.00	-0.14	-0.16	0.03	-0.05	-0.59	0.35	-0.40
C:N ratio 30-60 cm	0.00	0.00	-0.05	-0.06	0.00	-0.06	-0.27	0.07	-0.15
Shrub cover 0.5-2 m	0.01	0.00	-0.07	0.44	0.20	0.16	0.30	0.09	0.38
Moss cover	0.01	0.00	-0.07	-0.26	0.07	-0.32	-0.18	0.03	-0.09

Discussion

The patterns in vegetation differences among the wellsite and reference locations we saw in this study were generally consistent with what was expected based on the conservation and reclamation guidelines in place when the sites were certified (see Table 2 - Alberta Environment 2010). For example, the observed differences in the 20 and 30 yr age classes were consistent with reclamation practices in place at the time; compatible species including both native and non-native varieties suitable for grazing purposes were used for sites reclaimed prior to 1993. While non-native vegetation was consistently higher for wellsites across all age classes, non-native forbs (e.g., dandelion, yellow sweet clover) rather than graminoids (i.e., crested wheatgrass) contributed to higher non-native cover in the 10 yr age class compared with the 20 and 30 yr classes post certification. This is also consistent with the shift in reclamation practices; for sites abandoned and/or reclaimed from 1993-2001 vegetation cover was required to be dominated by native species, but with the caveat that sites could be certified with whatever introduced forages came up from the seedbank. The proximity of the 10 yr wellsite plant communities to the reference plant communities in the NMS ordination suggests that the plant community composition of the younger wellsites reclaimed under more recent reclamation criteria are recovering more quickly than are the older age class wellsites.

Interestingly, despite the lack of support for vegetation recovery of the wellsites for most indicators, the Sørensen similarity index of both age 10 and age 30 sites were more similar to reference sites than were age 20 sites post certification. This result suggests that in addition to the 10 yr sites, the 30 year old sites are also recovering in terms of the species present on site, although the relative proportions of cover of the species present are still very different than reference locations. We still do not know how long it will take for the plant composition of these sites to recover and have similar distribution of percent cover among species as is found in the reference locations. Given the still very high abundance of crested wheatgrass, which is now recognized as a problem introduced forage, on these sites 30 yrs after certification, it is unclear when (if ever) sites reclaimed under the pre-1993 historic reclamation criteria will ever recover plant communities that are similar to reference conditions.

The patterns in soil properties comparing among wellsite and reference locations across age classes showed a lack of recovery of wellsites for most indicators for at least one soil depth. However, LFH depth did not significantly differ among wellsite and reference locations for the 10 yr age class, suggesting that more recent reclamation practices may be recovering LFH depths more quickly than prior reclamation practices. This could be a function of the different plant community composition in the 10 yr age class compared with the older age classes post certification. In addition, the surface depth of soil pH did not differ between the wellsite and reference condition, also suggesting that pH recovery of the top soil layer (0-15 cm) could be occurring more quickly in more recently reclaimed wellsites compared with older reclaimed sites. The findings of differences between wellsite and reference locations for most soil indicators across age classes suggests that ecological recovery of these soil indicators will take longer periods of time than were evaluated in this study.

The study findings provide novel insights into the recovery of reclaimed native grassland wellsites, highlighting some differences in patterns of recovery among the different reclamation criteria and management practices that have occurred over the past 30+ years since the first reclamation guidelines were developed. Given that we still do not know how long it will take for the vegetation and soil indicators of these reclaimed wellsites to recover to those found on reference locations, further study is needed. A long-term monitoring program would enable Alberta to better evaluate ecological recovery for reclaimed sites, addressing key knowledge gaps that currently constrain the assessment of ecological recovery after reclamation.

Chapter 2: Long-term Monitoring Framework to Track Ecological Recovery of Certified Sites in Alberta

Background/Introduction

Recovery of ecological conditions (e.g., soil properties, vegetation community composition) at wellsites, pipelines, and other oil and gas infrastructure in Alberta may continue long after a reclamation certificate is issued, but this ecological recovery, or lack thereof, is not currently tracked or documented. Alberta's growing inventory of certified industrial footprints that may not have fully recovered to the intended objective of equivalent land capability is perceived as a potential liability that detracts from government's stewardship commitments, and from industry's social license to operate on public and private land. The long-term effectiveness of reclamation practices after site certification in Alberta's cropland, native prairie and forest land is not presently monitored, and published studies suggest that ecological functions (e.g., vegetation communities, soil properties) at reclaimed sites often differ from undisturbed areas (e.g. Desserud et al. 2010; Avirmed et al. 2014).

In keeping with Alberta's history of "continuously adapting its industrial land conservation and reclamation program and related legislation in response to changing public expectations and improvements in reclamation science" (Powter et al. 2012), an overarching goal of the Ecological Recovery Monitoring (ERM) program is to create a scientifically-robust, transparent, and financially-sustainable long-term monitoring program to track the ecological recovery of reclaimed wellsites. The initial focus on wellsites will provide a foundation for further work on other energy sector footprints (e.g., seismic lines, pipelines). A scientifically-robust, transparent, long-term reclamation monitoring program will support the Alberta Government's monitoring mandate and industry's social license to operate on public and private land. Stakeholders expect the best available knowledge to be applied to environmental problems; there will be considerable uncertainty in the ability of operators to achieve meaningful reclamation (e.g. Lemphers et al. 2010) without credible, reliable data on the progression of recovery on reclaimed land. Development of a long-term monitoring program to assess ecological recovery on reclaimed lands would aid in understanding recovery of ecological functions on reclaimed sites.

Alberta Environment and Sustainable Resource Development's current business plan (ESRD 2013) has identified broad policy goals related to ecological recovery of wellsites, including the goals of achieving desired environmental outcomes for air, land, water, and biodiversity, and having sustainable natural resource development. Priority initiatives related to these goals include: i) advancing an integrated resource system for cumulative effects management; ii) developing a world-class scientifically rigorous monitoring system that provides transparent reliable information for environmental outcomes; and iii) addressing regulatory framework policy issues and gaps related to remediation, reclamation, and abandoned energy infrastructure through a land reclamation framework.

Many of AESRD's priority initiatives are likely to be advanced through the Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA), which aims to provide "accurate, trustworthy, and useful data and information to inform the work of policymakers, regulators, research organizations and others through the design, execution and supervision of environmental monitoring programs for air, land, water and biodiversity" (AEMP 2011, WGEM 2012). Legislation for the creation of this arms-length agency was put forth by Minister of ESRD Diana McQueen in Bill 31 on October 2013. In tabling the bill, McQueen said "We're building a monitoring system to understand environmental impacts and help us manage responsible development. The new arm's-length agency will ensure this work remains open, transparent and underpinned by science and facts". This over-arching provincial body could provide an administrative and regulatory framework for a new long-term ecological recovery monitoring program for wellsites (and potentially other specified lands) in the next few years as AEMERA launches, however considerable work is required to ensure that reclaimed sites are effectively monitored.

To provide support towards the inclusion of long-term monitoring of reclaimed wellsites in Alberta as part of AEMERA, we investigated the following area of research: i) we used the historical wellsite study (see Chapter 1) as a pilot of our long-term monitoring protocols, reviewing information from the field study to inform sampling effort in native grasslands for the long-term monitoring program, and ii) we identified potential criteria to aid in development of a framework for selection of a subset of wellsites for inclusion in the long-term monitoring program. We initially planned to develop an implementation plan for the long-term monitoring program, but with the uncertainty related to the governance of AEMERA, we decided it would be more relevant to wait until the governance structure of AEMERA is decided before pursuing this avenue of research so that our results are cohesive with the structure the government plans to implement.

Methodology

Field Protocol Review

We used the data collected during the Dry Mixedgrass sampling season (see Chapter 1) to i) evaluate the sampling effort (time, cost) required for sampling of individual sites, and ii) evaluate the sensitivity and variability of individual vegetation and soil indicators. To evaluate the sampling effort we compiled information on the number of staff and field sampling days it took to sample each of the 18 sites and also recorded anecdotal information on sampling efficiencies based on feedback from field crew members. To assess the sensitivity and variability of individual vegetation and soil indicators we used boxplots, comparing among the wellsite and adjacent reference locations for each site. Boxplots provide graphical displays that clearly represent the center, spread, and skewness of the distribution of the data by presenting a box that shows the middle 50% of datapoints from a dataset, with the tails of the boxplot representing the remainder of the data (Ramsay and Schafer 1997 – see Fig. 2-1 for graphical display of a sample boxplot and the information it provides).

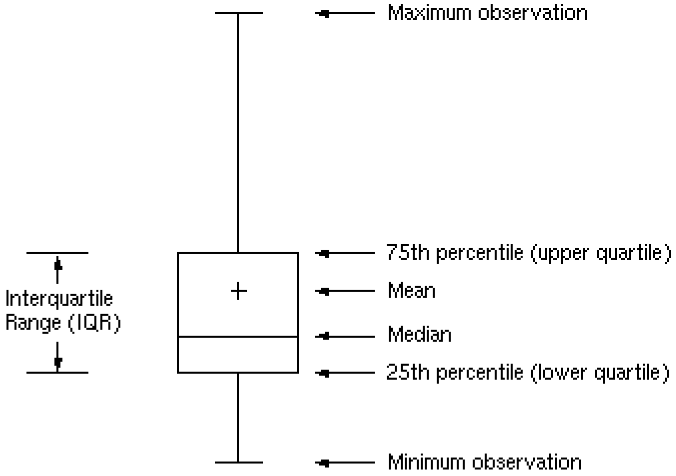

Fig. 2-1. Interpretation of boxplot labeling that is used for all of the boxplots included in the remainder of Chapter 2.

Site Selection Framework

During two workshops in February and March 2014, ERM Advisory Group members brainstormed to identify potential selection criteria that could be used to select a subset of wellsites for inclusion in the long-term monitoring program.

Results and Discussion

Field Protocol Review

Sampling effort

We spent eight weeks in June and July 2013 collecting vegetation and soil indicator data on 18 wellsites and adjacent reference locations in the Dry Mixedgrass Natural Subregion. During the field season there was variability in the number of sites sampled. In the first week two sites were sampled with a four member crew, and in the following weeks the two person crew only averaged one-two sites per five day field shift. A few weeks into the project we brought on an additional senior crew member so that we had a three person field crew to help complete field work in a timely fashion for the remainder of the season, which increased sampling to 2-3 sites per week. In the last week of the field season we had five staff in the field and averaged almost two sites per day in the field.

Throughout the season we continually sought out opportunities to make sampling faster. With half of the sites (n=9) sampled in the last two weeks of the field season, our sampling efficiencies greatly increased during the season. The following list highlights ways that efficiency sampling increased:

- Initially we used integrated monitoring protocols that also included additional information that was not relevant to sampling grasslands (e.g., forest structure and downed woody material data) – we created a separate set of grasslands protocols to help to clarify protocols and reduce non-relevant information (ABMI 2013d) and we updated datasheets for clarity.
- As staff became familiar with the protocols their pace of sampling increased – for example as our plant technician became familiar with plant species and using seven letter codes to identify plant species on datasheets her efficiency increased.
- Making sure to remove all equipment from sites each day turned out to be critical – for example, early in the season some curious cows visited a site overnight and destroyed a lot of our equipment (e.g., measuring tapes) which slowed sampling progress.
- Early in the season the field crew had difficulties locating sites. Therefore, the lead ecologist went on a reconnaissance trip and visited all of the remaining sites to ensure that directions were clear and sites were readily accessible by the crew to reduce delays in sampling.
- Adding a senior technician in the field during the last half of the season helped to ensure quality assurance and efficient use of time and keep junior technicians focused on the tasks at hand.
- In the future, we recommend having a senior technician in the field for a minimum of one 10 day shift at the start of the field season to make sure that any logistical and sampling challenges are worked out right away at the beginning of the season.
- Early in the season there were problems with sampling of highly compacted sites. The soil corer would get jammed, requiring that sample cores be dug out – a very slow tedious labor intensive process. On one particularly compacted site both the primary and back-up soil corers broke, resulting in the crew returning early from their field shift. Innovations with the soil corer equipment greatly improved our efficiencies. Senior reclamation technician, Andrew Underwood, modified the design of the bulk corer during the last shift, such that cores from the second sample depth (15-30 cm) could be quickly removed without having to dig them out – this more than halved the amount of time spent collecting individual cores.
- An important caveat is that vegetation sampling is limited in the time of year when it can be sampled, so there will always be a limitation in terms of how many sites an individual crew can sample during the summer, because the plant sampling needs to be done when the vegetation are mature during the active growing season.

The cost of sampling the 18 sites in this study was ~$100,000. Dividing our field season budget by the number of sites sampled results in an average of $5000.00 cost per site. However, with the application of the increases in efficiencies of sampling, moving forward we would expect costs for field work to be closer to half of that per site for future sampling in native grasslands if the entire core set of vegetation and soil indicators are measured. Another important consideration moving forward will be to assess the sampling frequency for individual indicators in the context of a long-term monitoring program. Several of the soil indicators measured in Chapter 1 (e.g., bulk density, pH) were similar in their differences with reference locations across age classes, which suggests that they may not have to be measured very frequently, or perhaps they may only need to be measured during the initial visit to a site established as a long-term monitoring site to provide baseline information on it; this would also decrease the costs of processing and analysis of the soil samples. Overall, we expect that sampling in native grasslands will be more efficient and cost effective in the future.

Indicator variability

There was a high degree of variation in both vegetation (Figs. 2-2 - 2-14) and soil indicators (Figs. 2-15 - 2-21) when comparing both within and between wellsite and reference locations within sites and among sites. The variation within individual sites highlights the need to collect a large number of samples/data within individual sites to capture within-site variability. What these data also show is that if we just pooled our data among sites and didn't partition out the between-site variability by blocking the data by individual site, then we would lose the ability to detect differences in our 'treatment' effects of location (wellsite vs reference) and age class post-certification (10, 20, 30 yrs) because these treatment effects would be lost in the large degree of variability among sites. However, the statistical design of our study with paired locations of wellsite and reference location within individual sites provided the statistical power to detect treatment differences, thus decreasing the potential for a Type 2 error (i.e., rejecting the null hypothesis of no difference when the null hypothesis is false). The statistical design of our study also allowed us to detect differences with a smaller number of sample sites than we would need if we did not use blocking in our design. From the perspective of picking appropriate indicators, given that we have detected differences among wellsite and reference locations supports that the indicators we measured in this study are relevant and effective indicators that can also be used long-term monitoring program.

Species Richness Single Site Variability – Wellsite vs Reference

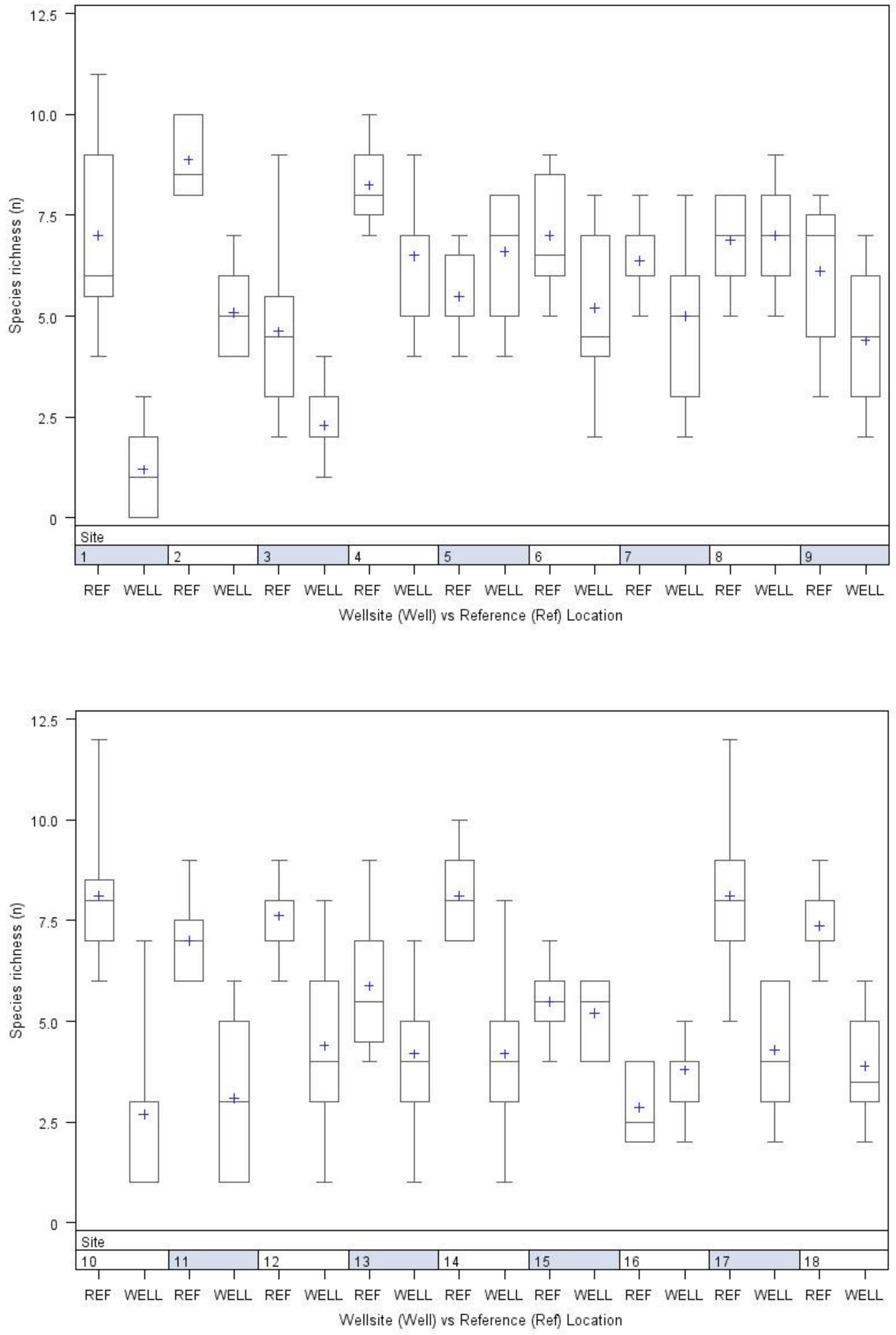

Fig. 2-2. Boxplots of species richness per 0.25 m^2 quadrat of reference (ref) vs wellsite (well) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Shannon Diversity Single Site Variability – Wellsite vs Reference

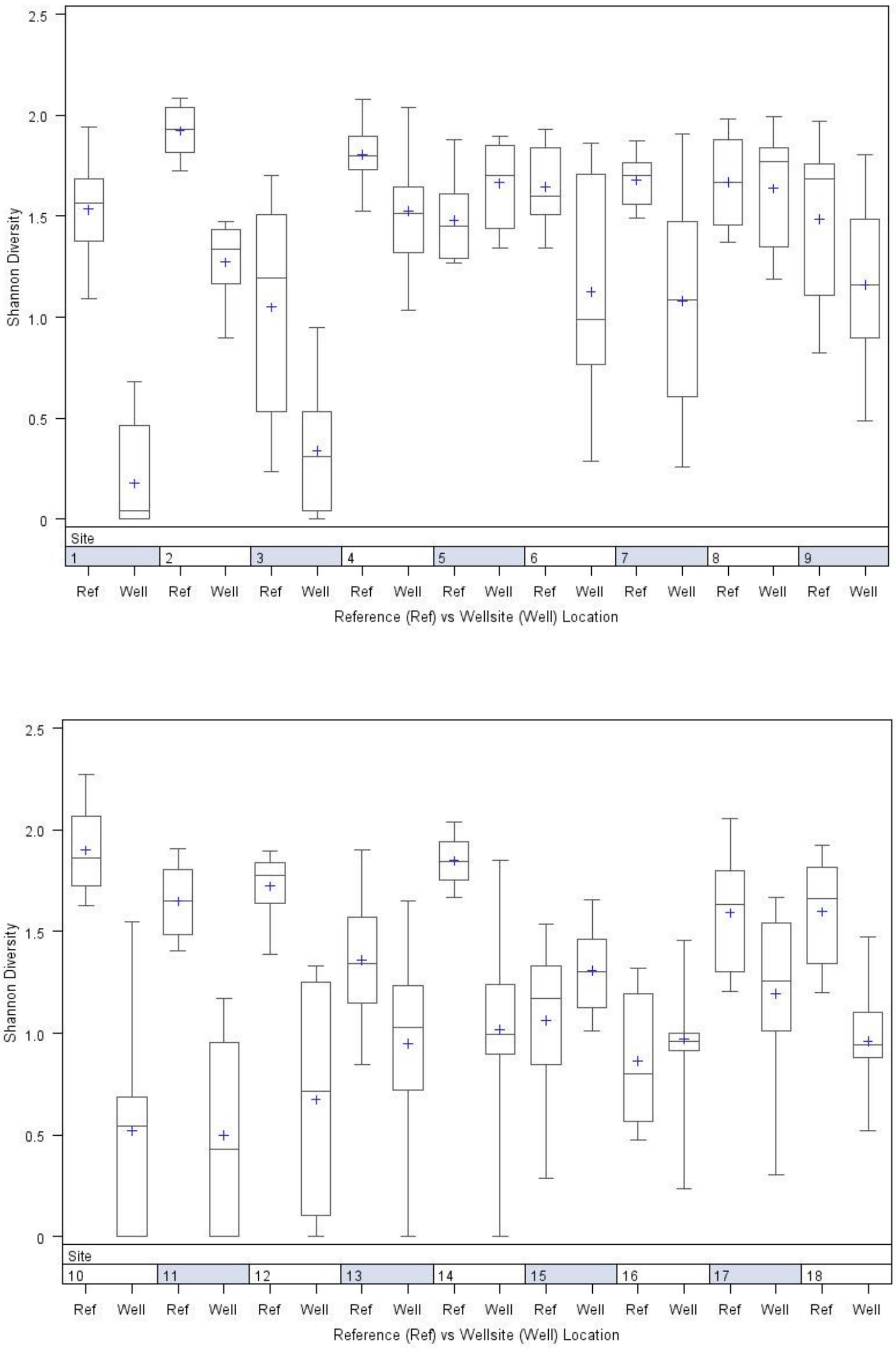

Fig. 2-3. Boxplots of Shannon diversity of reference (ref) vs wellsite (well) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Total Vegetation Cover Single Site Variability – Wellsite vs Reference

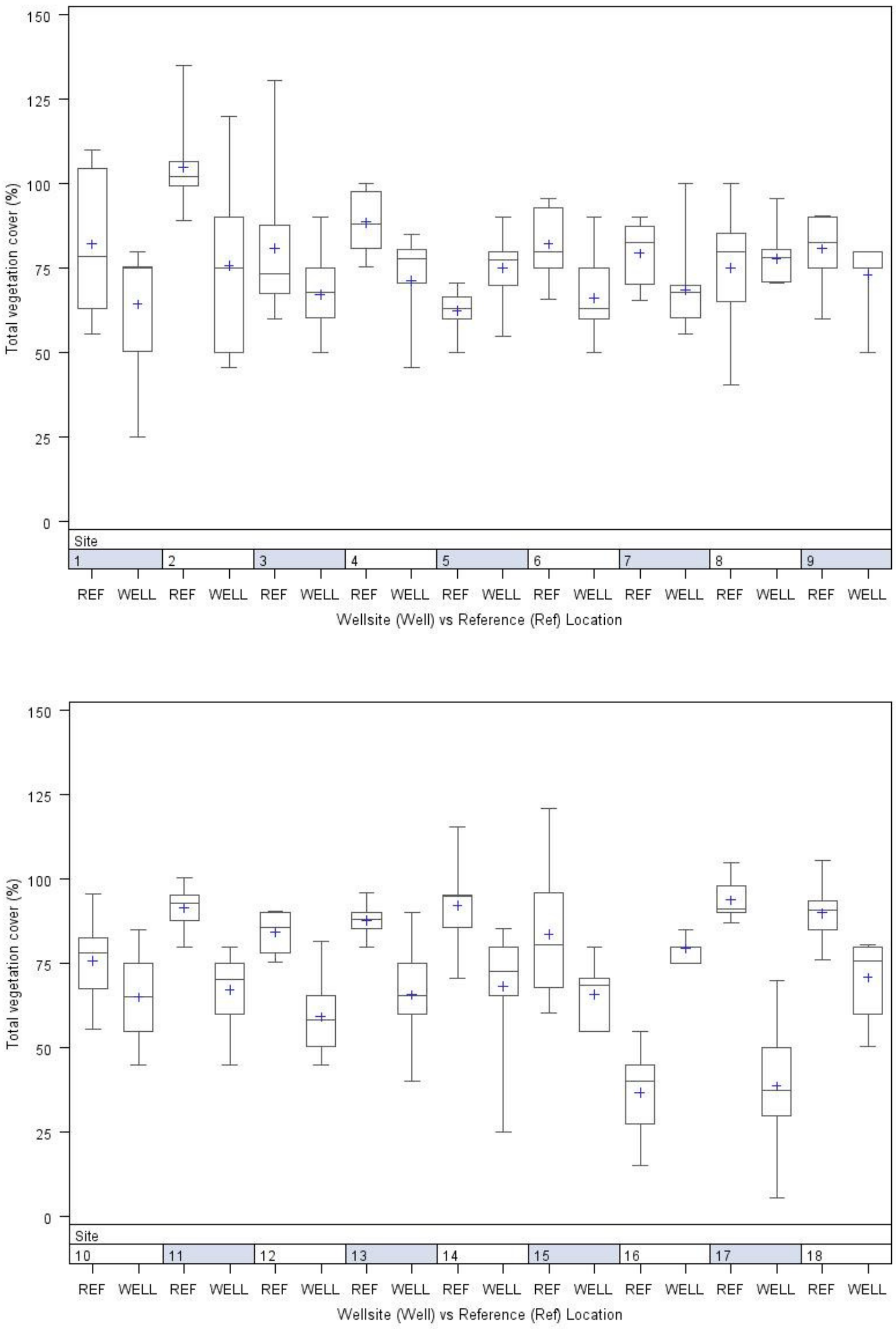

Fig. 2-4. Boxplots of total vegetation cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Total Non-native Vegetation Cover Single Site Variability – Wellsite vs Reference

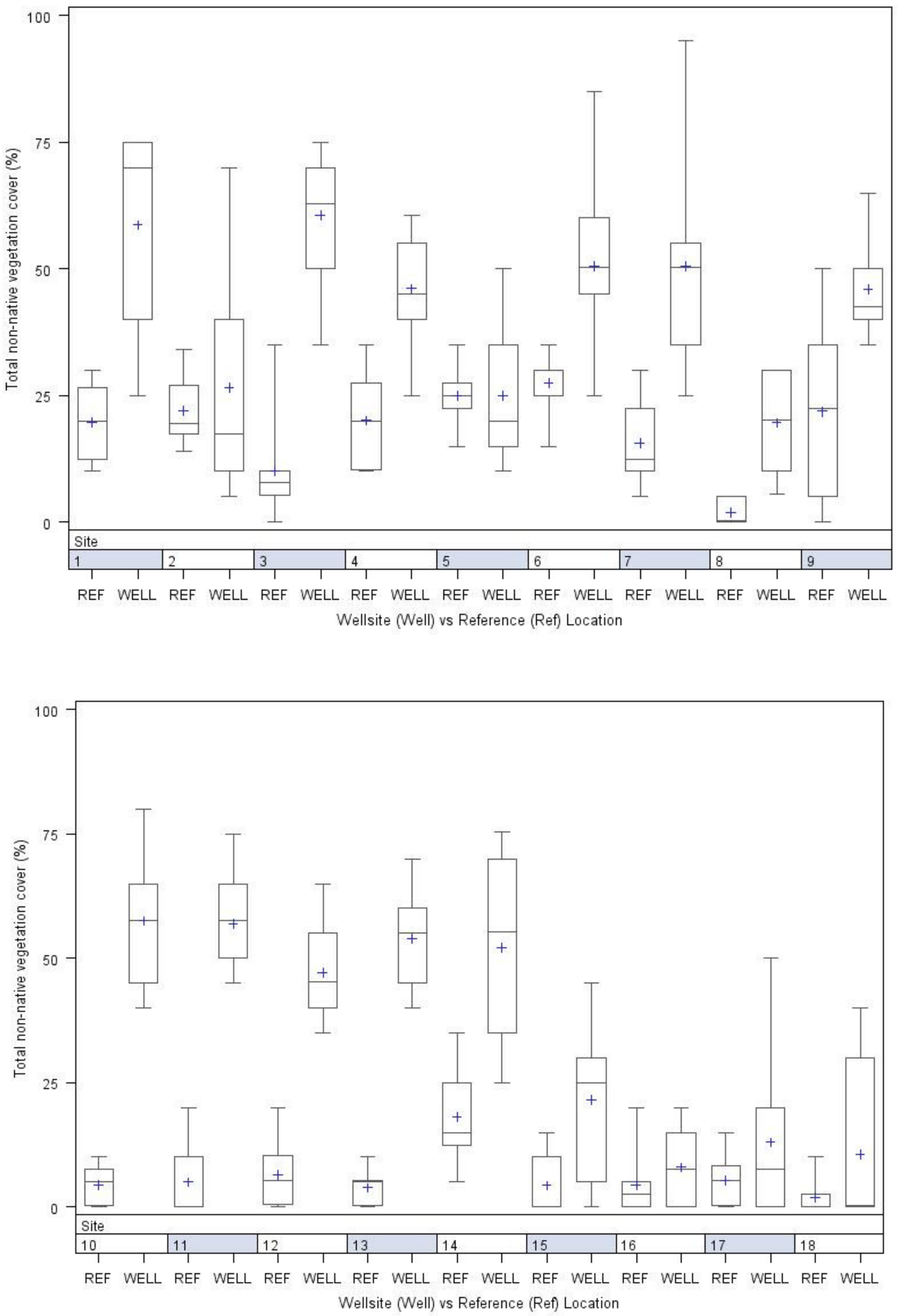

Fig. 2-5. Boxplots of non-native total vegetation cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Shrub Cover Single Site Variability – Wellsite vs Reference

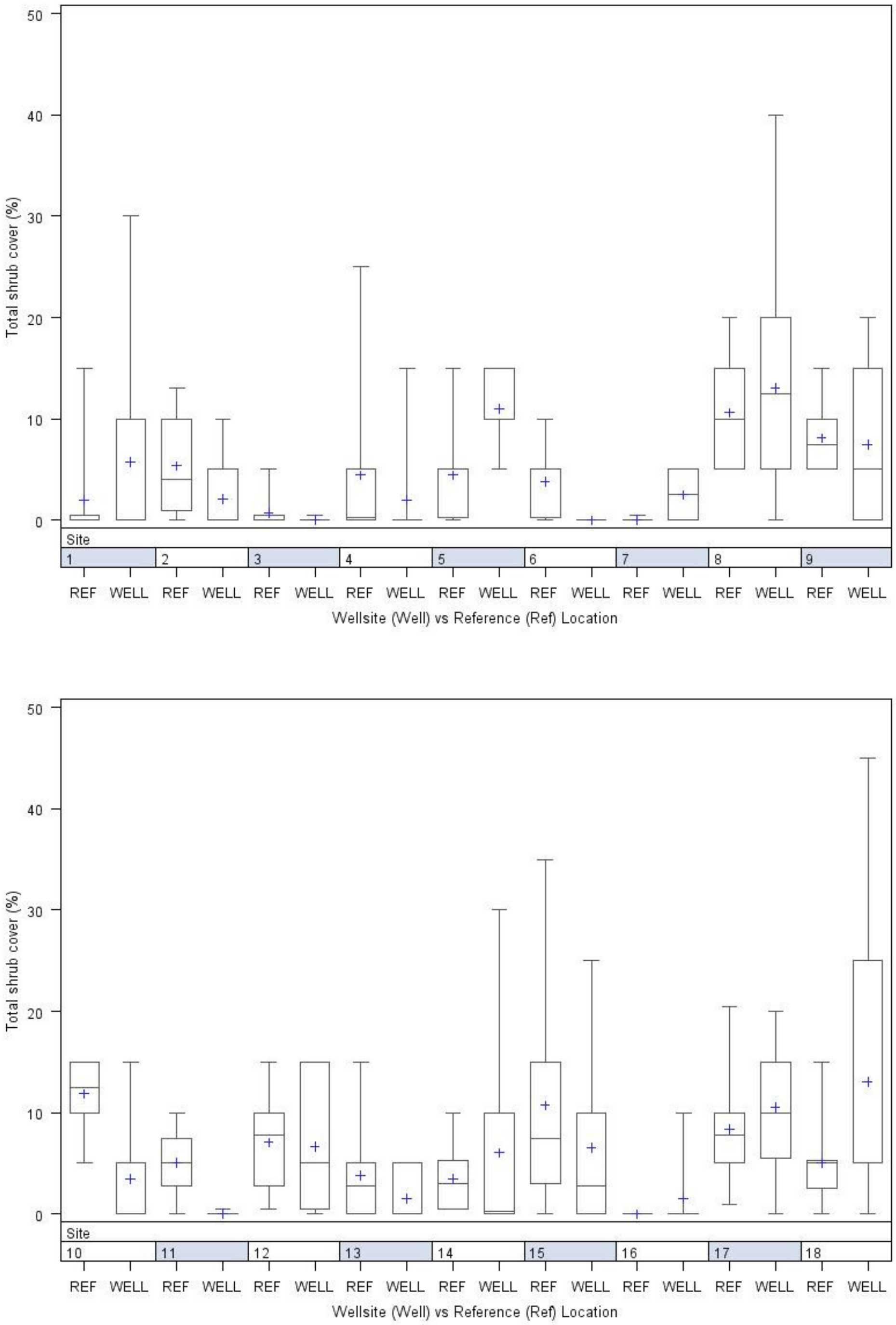

Fig. 2-6. Boxplots of shrub cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Forb Cover Single Site Variability – Wellsite vs Reference

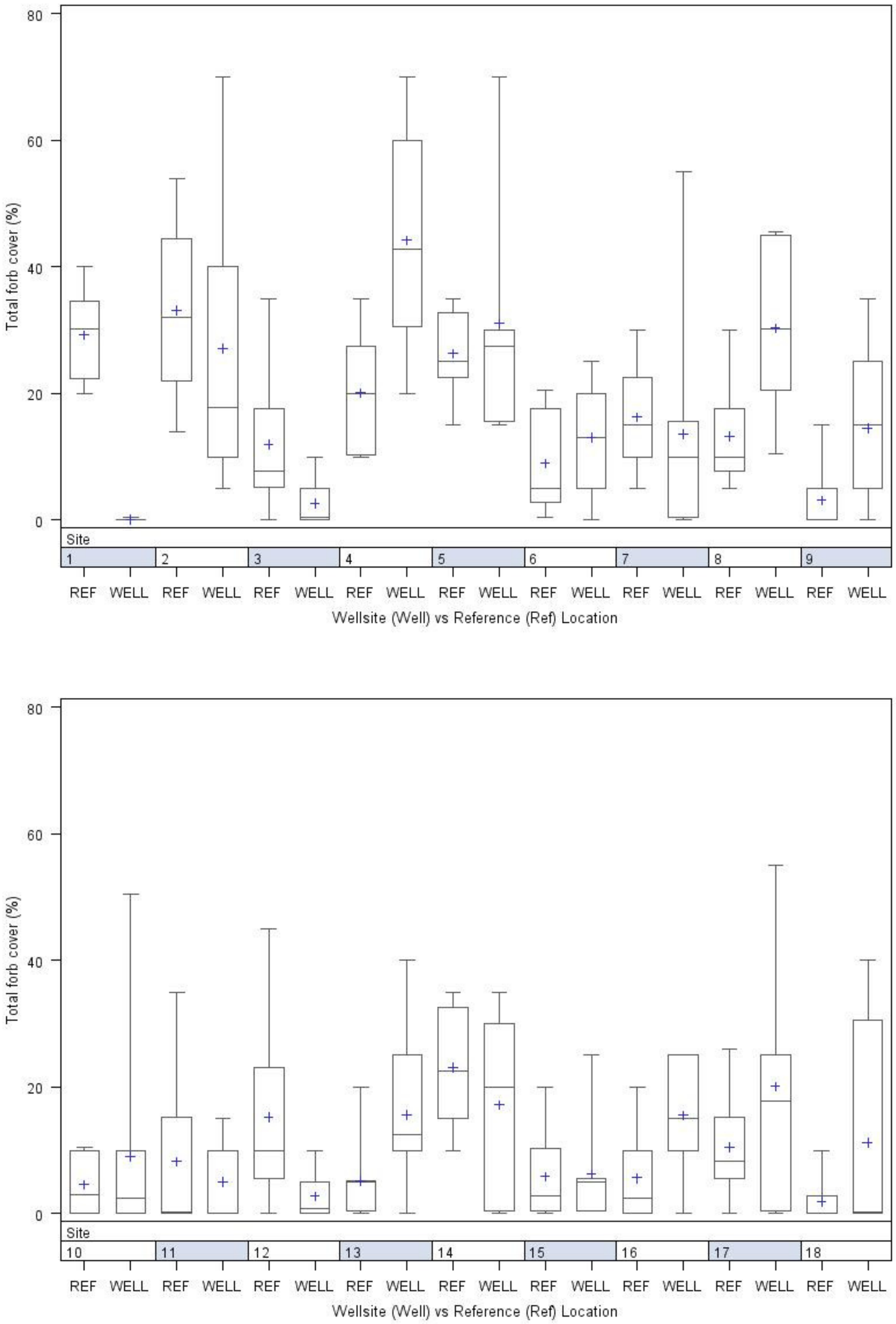

Fig. 2-7. Boxplots of forb cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Total Non-native Forb Cover Single Site Variability – Wellsite vs Reference

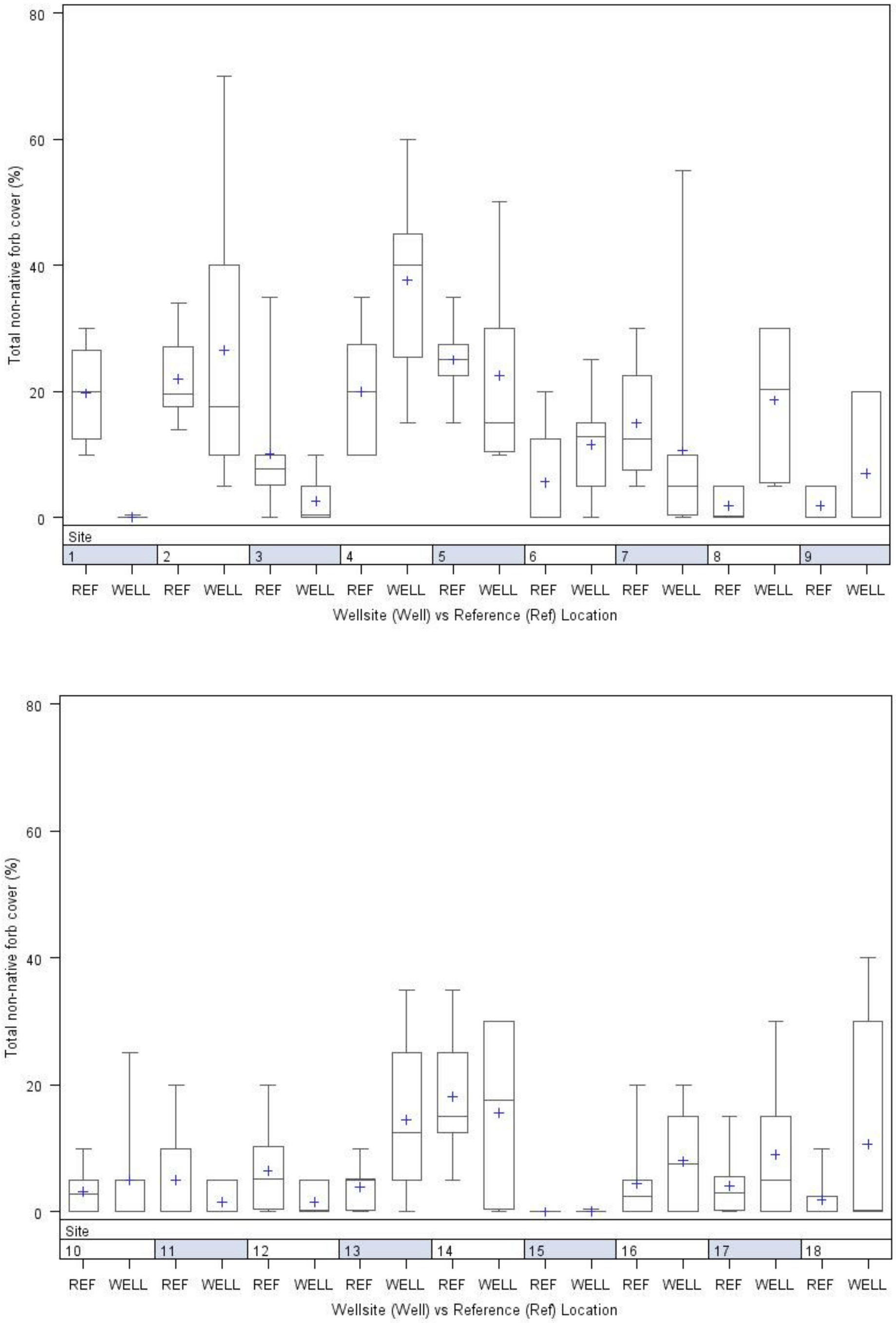

Fig. 2-8. Boxplots of non-native forb cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Graminoid Cover Single Site Variability – Wellsite vs Reference

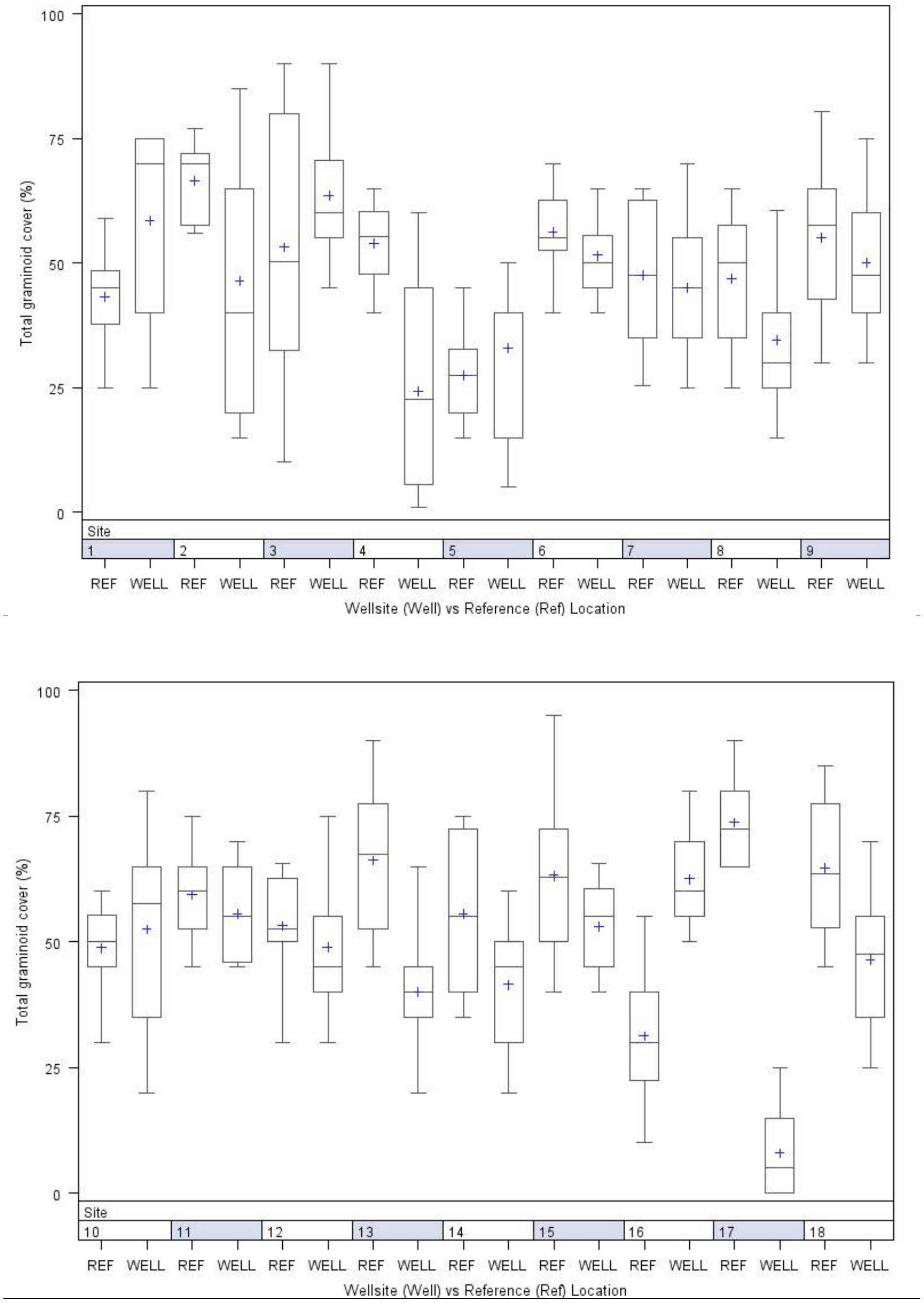

Fig. 2-9. Boxplots of graminoid cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Non-native Graminoid Cover Single Site Variability – Wellsite vs Reference

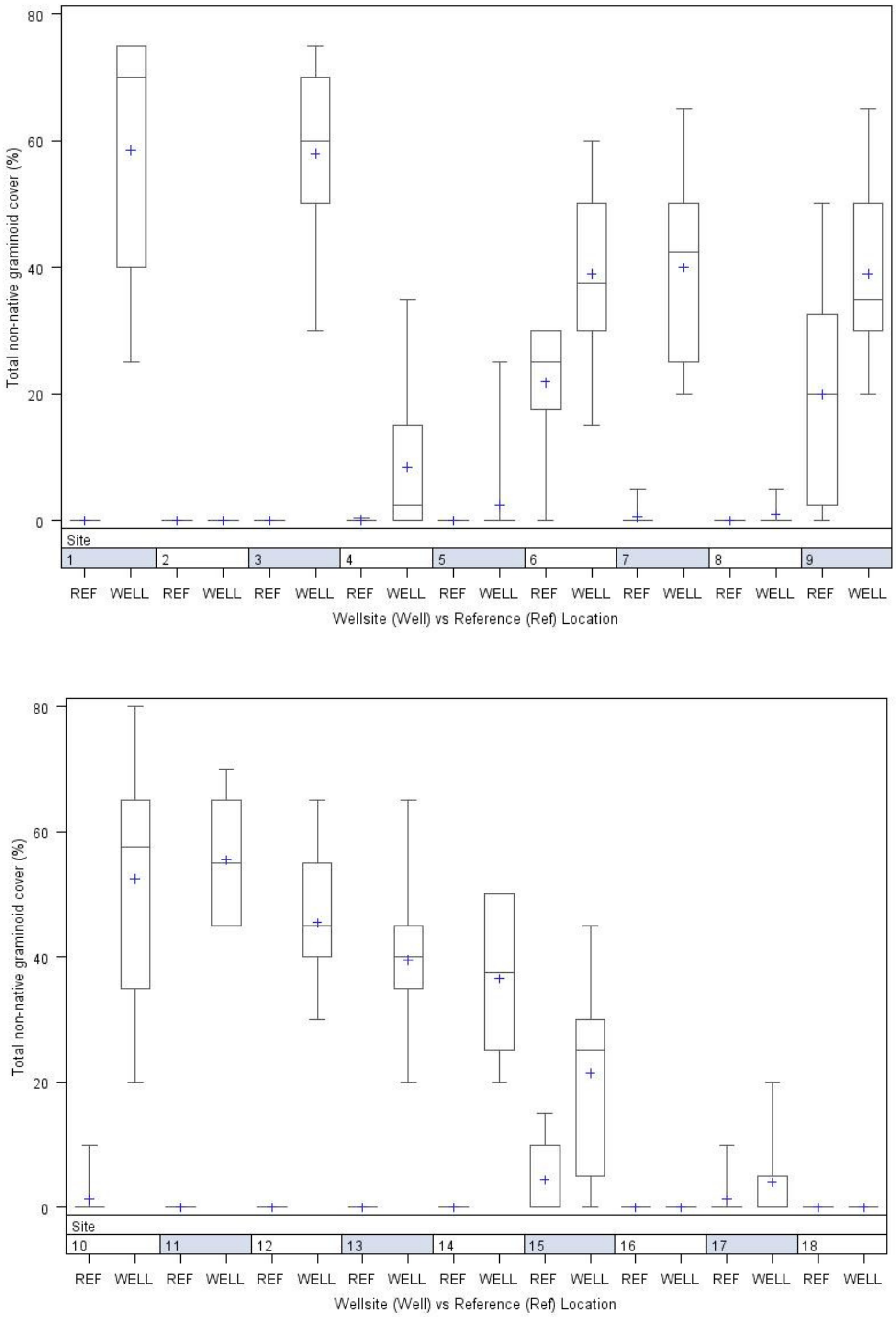

Fig. 2-10. Boxplots of non-native graminoid cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Clubmoss Cover Single Site Variability – Wellsite vs Reference

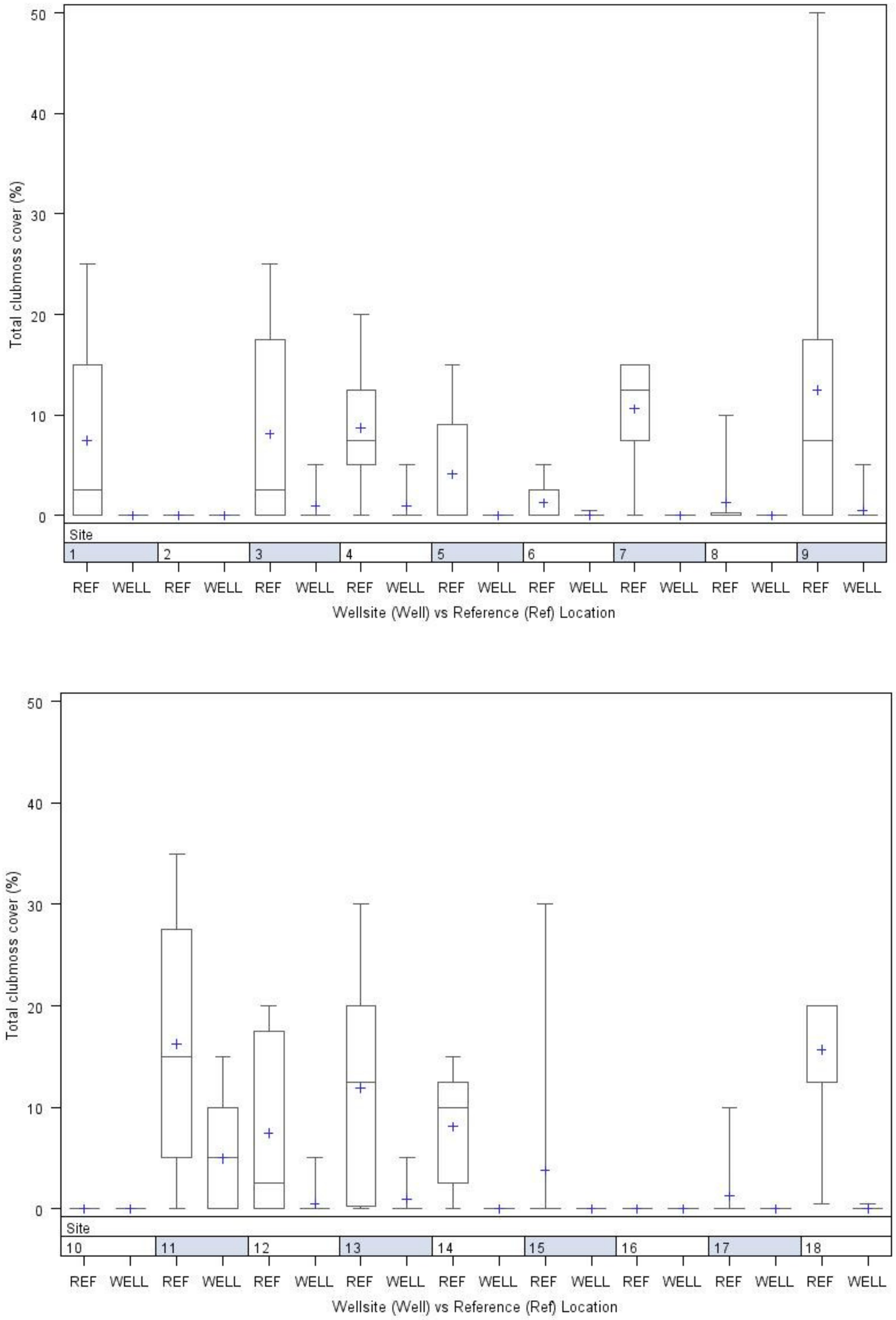

Fig. 2-11. Boxplots of clubmoss cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Lichen Cover Single Site Variability – Wellsite vs Reference

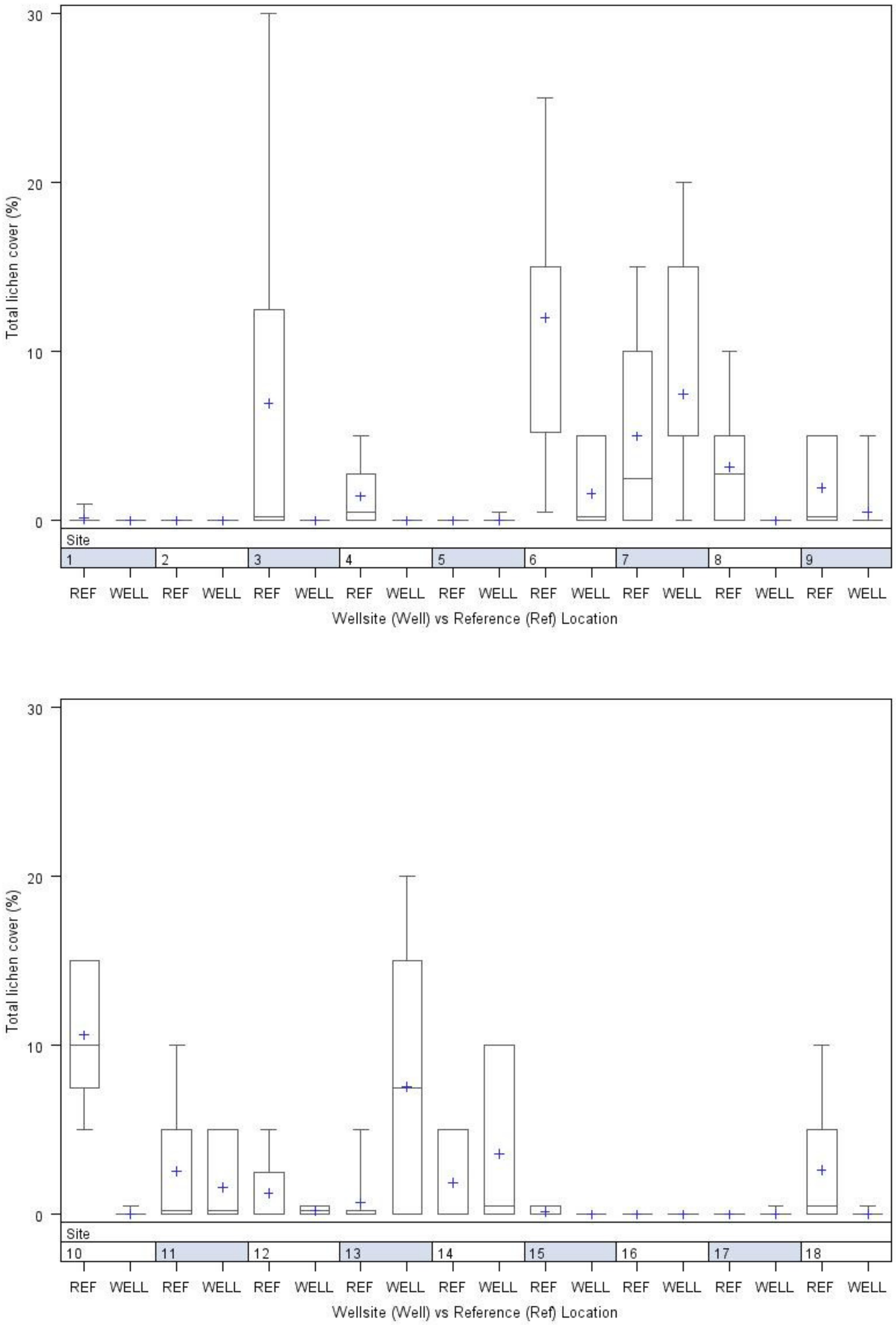

Fig. 2-12. Boxplots of lichen cover (%) of wellsite (well) vs reference (ref) location for individual sites. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Sørensen's Similarity Variability – Comparison Among Wellsite Locations

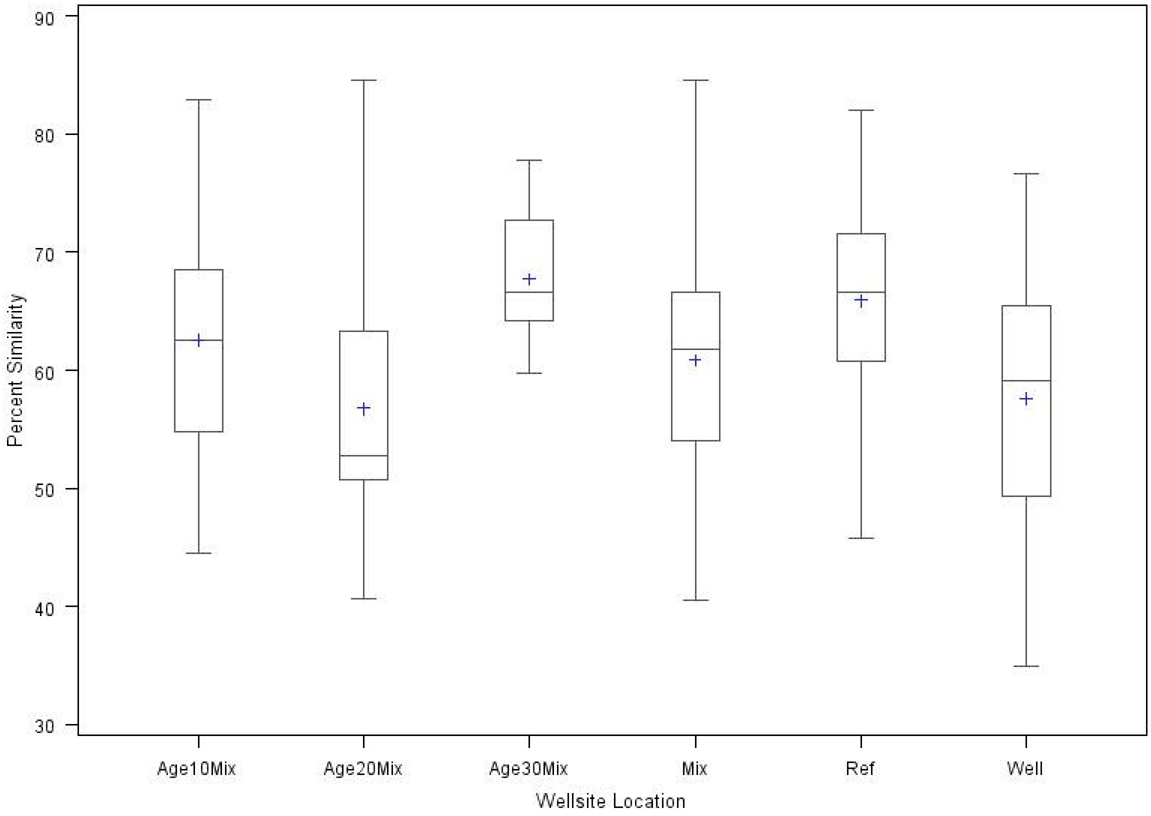

Fig. 2-13. Boxplot of Sørensen's similarity comparing among the presence/absence of vegetation data for wellsite and reference condition locations for 10 yr age class (Age10mix), 20 yr age class (Age20mix), 30 yr age class (Age30mix), combining all age classes (Mix), and all reference locations compared with each other (Ref) and all wellsite locations compared with each other (Well).

Sørensen's Similarity Variability – Comparison with ABMI sites

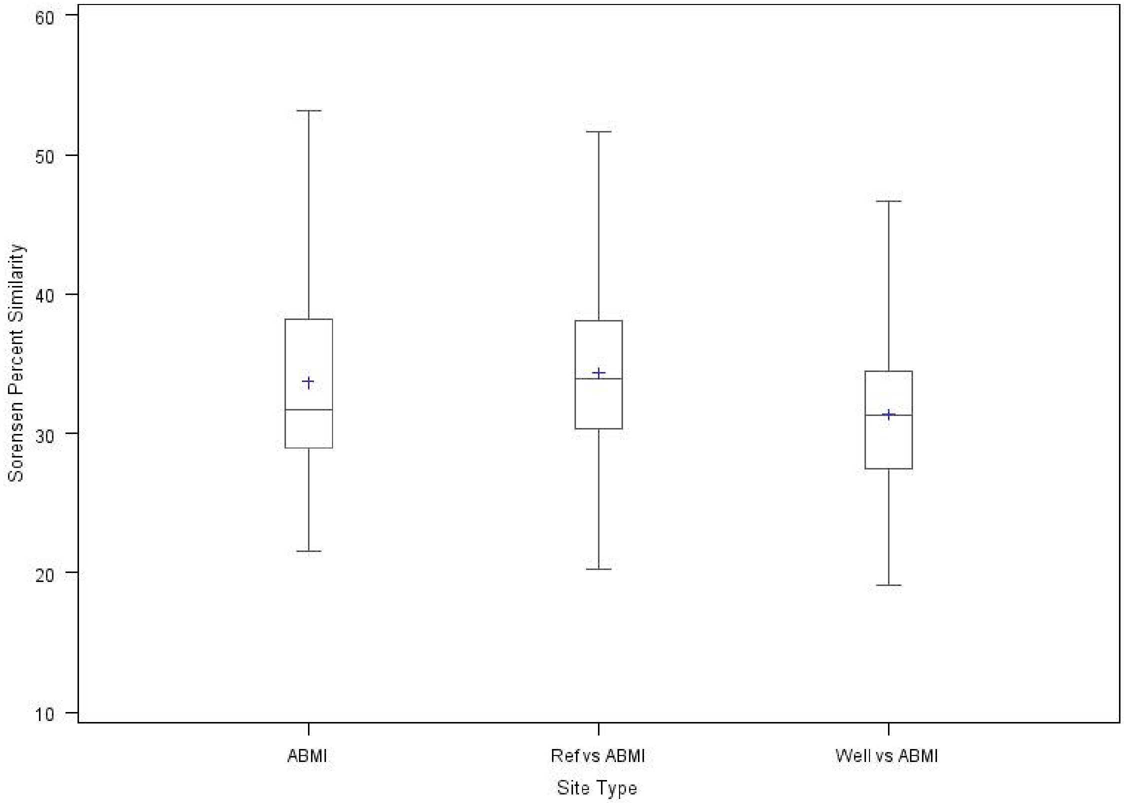

Fig. 2-14. Boxplot of Sørensen's similarity comparing among the presence/absence of vascular plant species data for ABMI (ABMI), reference (Ref vs ABMI), and wellsite (Well vs ABMI) site types.

Bulk Density Single Site Variability – Wellsite vs Reference

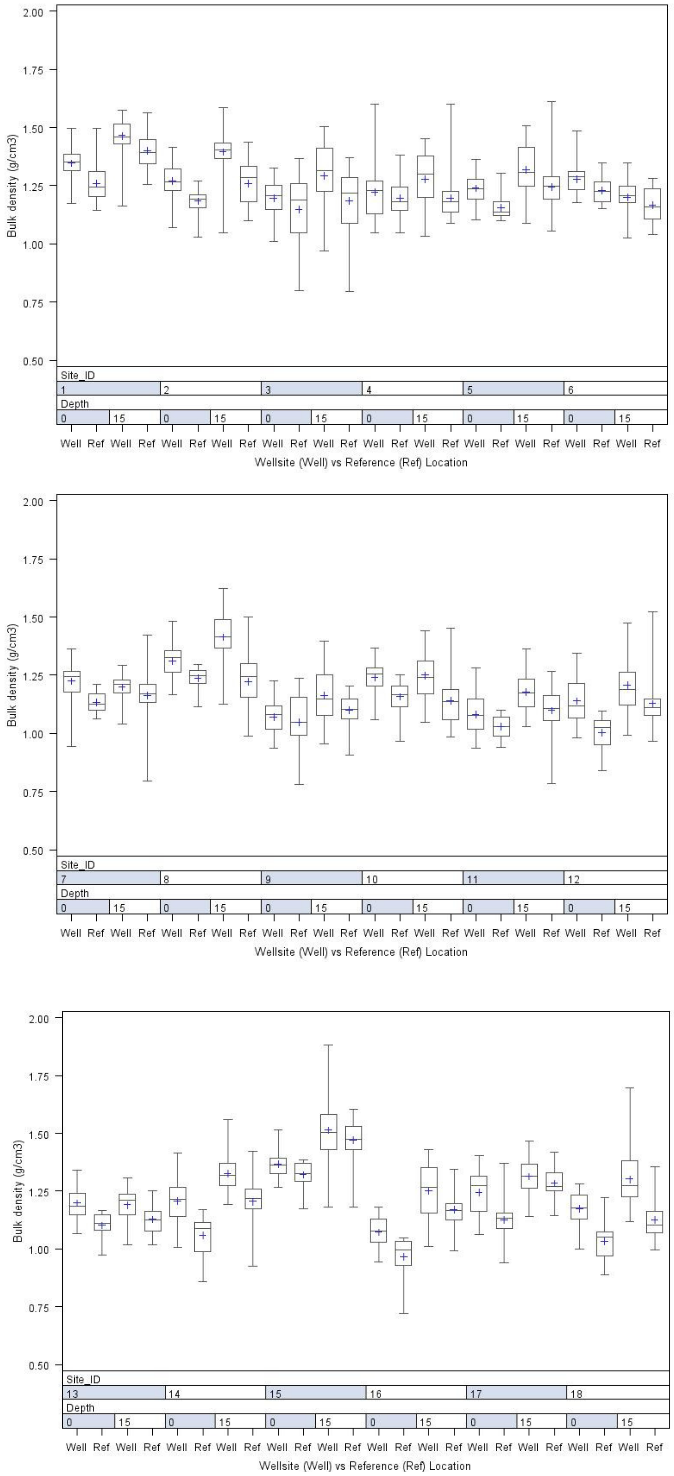

Fig. 2-15. Boxplots of bulk density of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm). Note that the figure consists of 3 panels containing data on 6 sites in each panel.

Electrical Conductivity Single Site Variability – Wellsite vs Reference

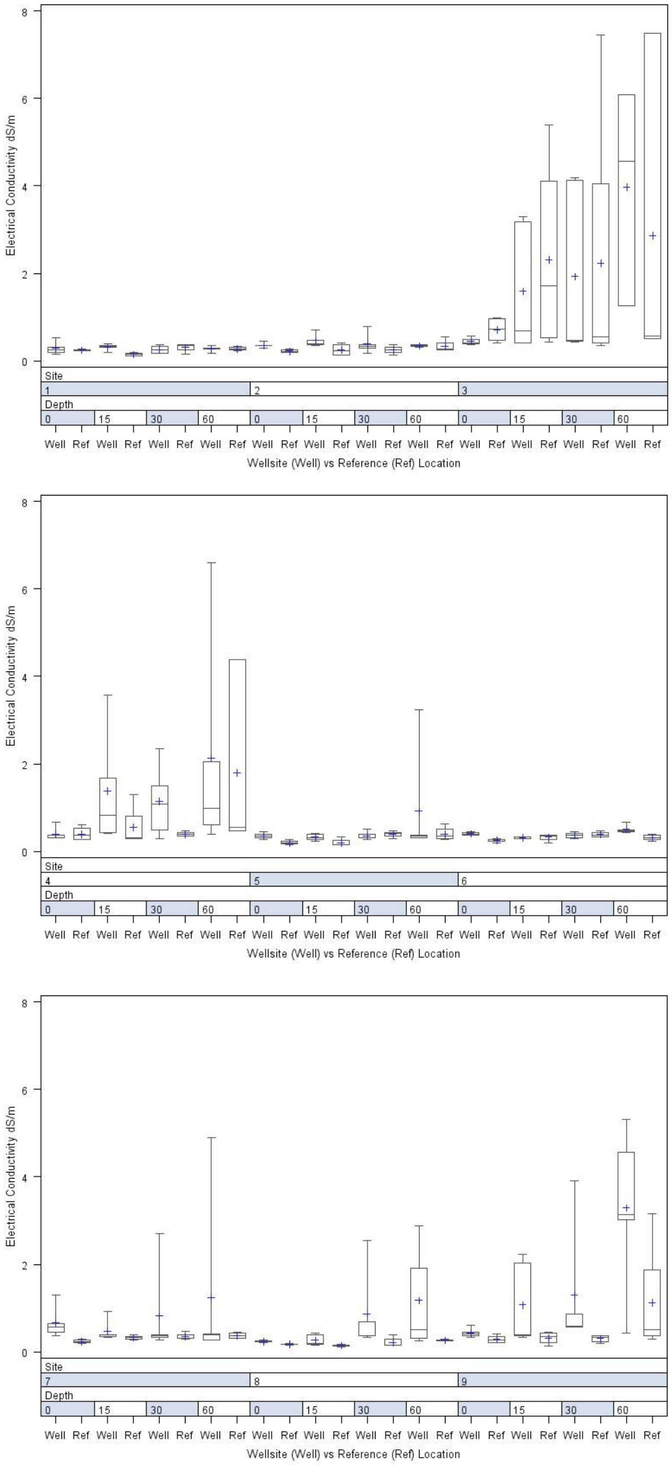

Fig. 2-16. Boxplots of electrical conductivity using saturated paste of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm, 30=30-60 cm, 60=60-100 cm). Note figure consists of 6 panels containing data on 3 sites in each panel.

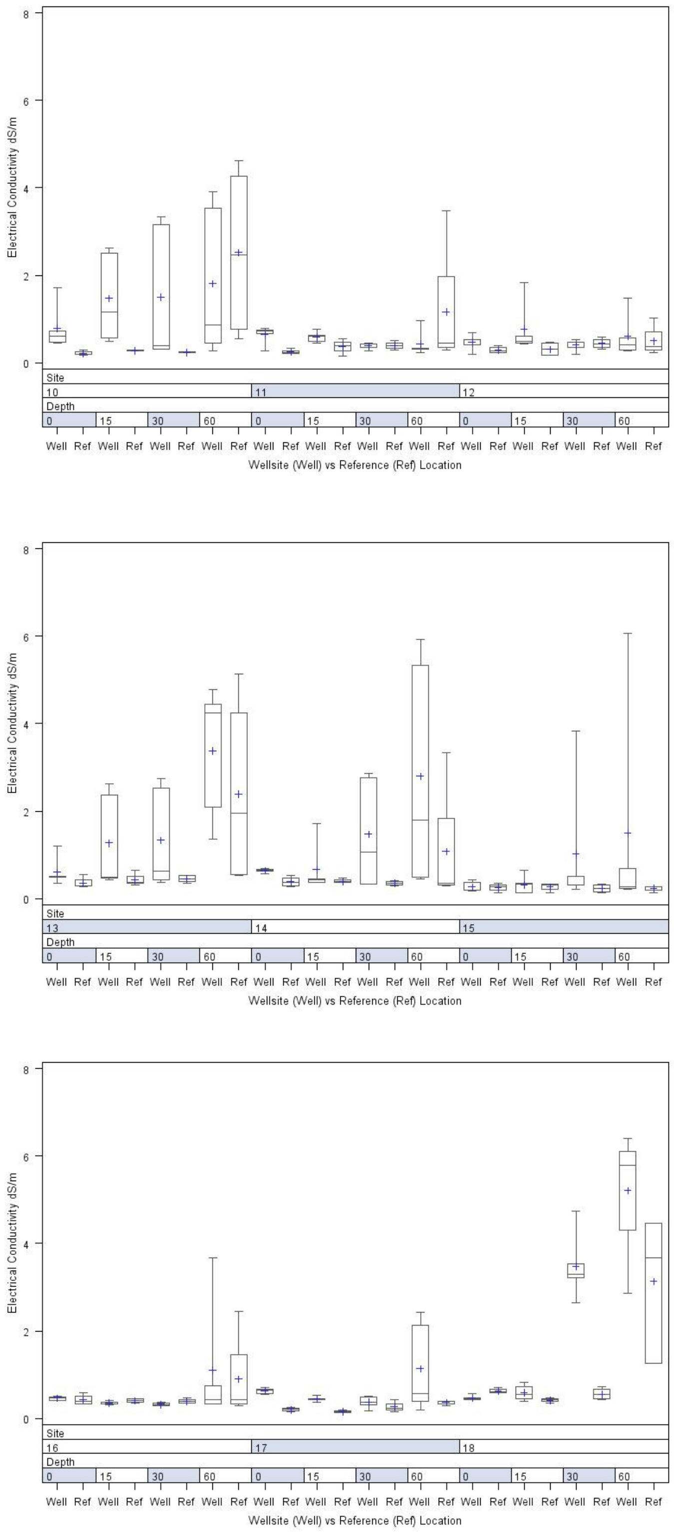

Fig. 2-16. Cont’d.

LFH Depth Single Site Variability – Wellsite vs Reference

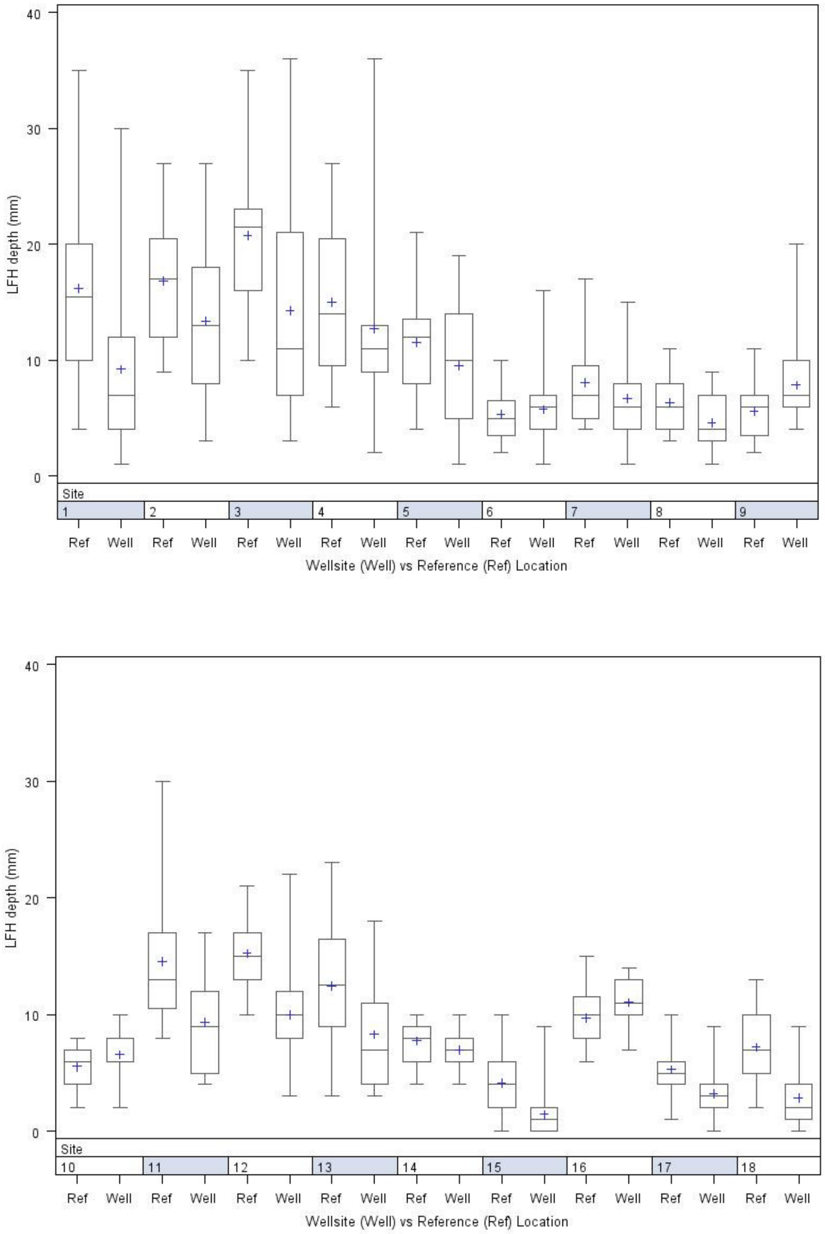

Fig. 2-17. Boxplots of LFH depth of wellsite (well) vs reference (ref) location for individual sites within each site. Note that the figure consists of 2 panels containing data on 9 sites in each panel.

Soil pH Single Site Variability – Wellsite vs Reference

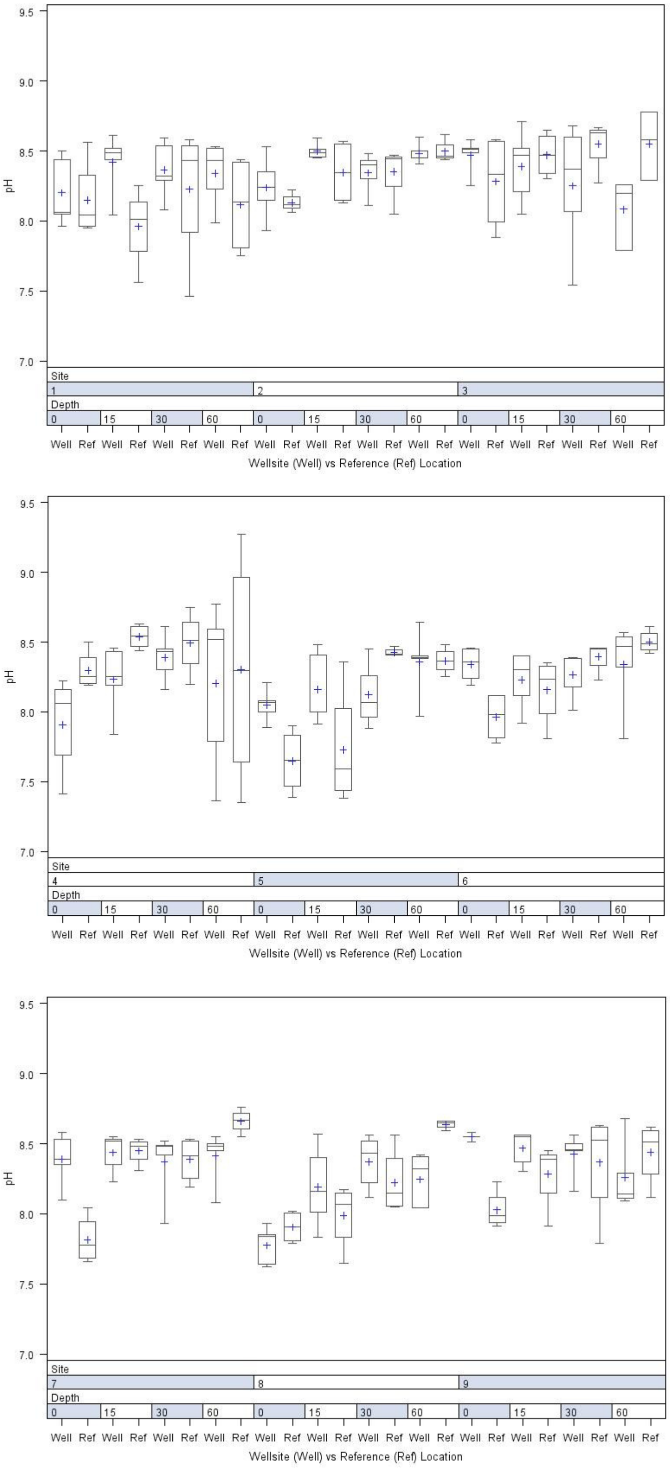

Fig. 2-18. Soil pH of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm, 30=30-60 cm, 60=60-100 cm). Note that the figure consists of 6 panels containing data on 3 sites in each panel.

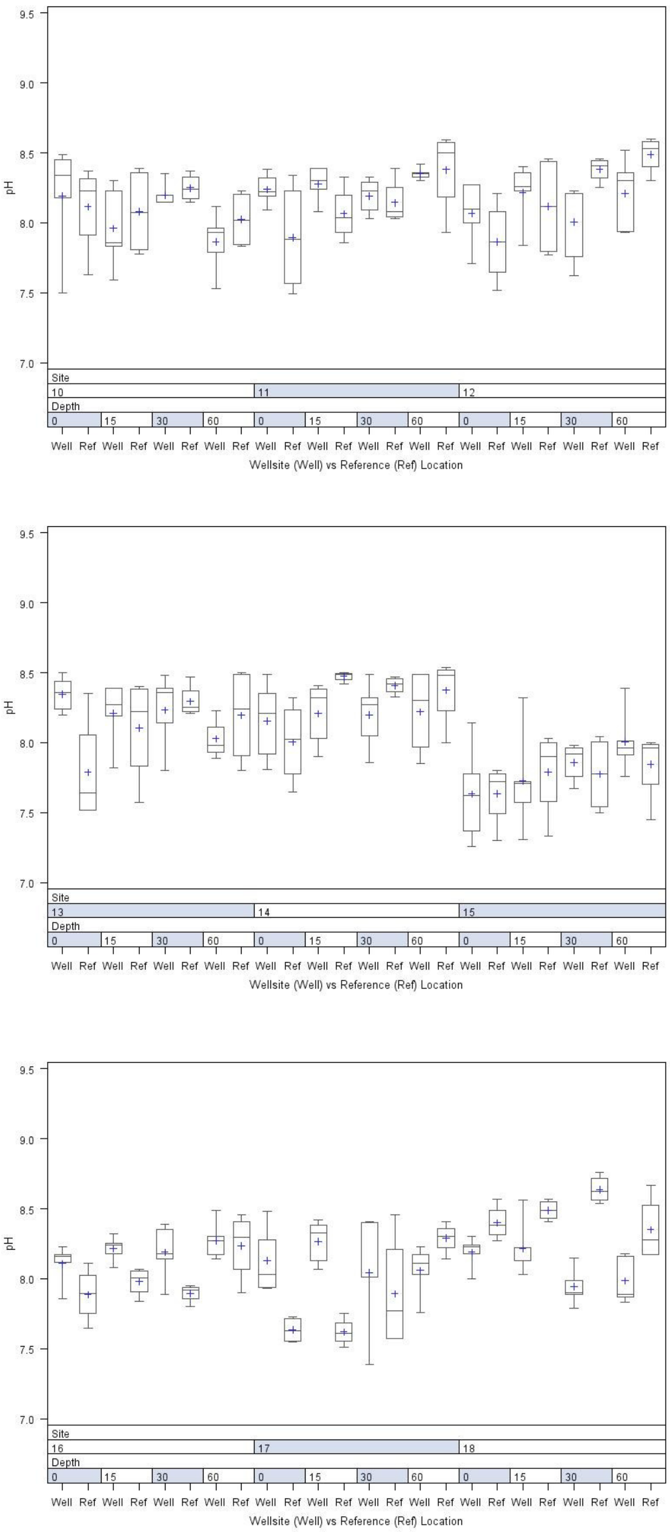

Fig. 2-18. Cont’d.

Total Nitrogen Single Site Variability – Wellsite vs Reference

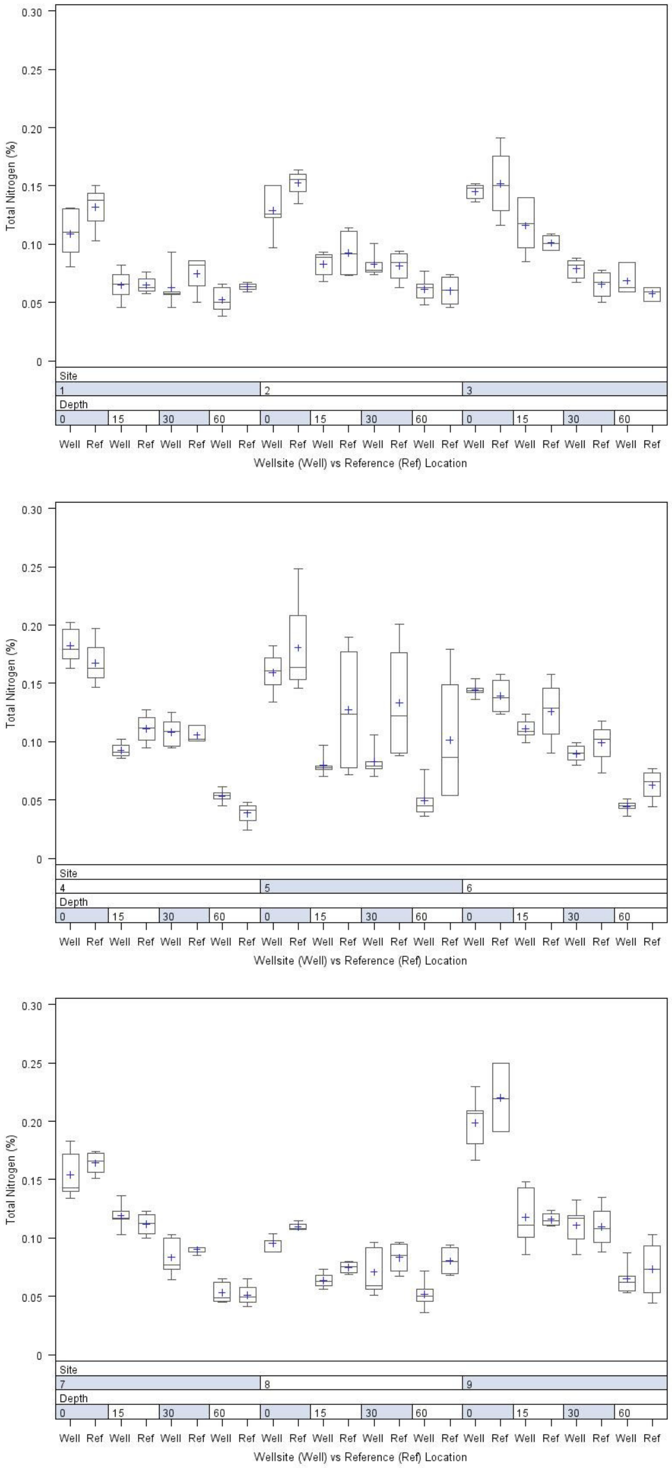

Fig. 2-19. Box plots of total nitrogen of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm, 30=30-60 cm, 60=60-100 cm). Note that the figure consists of 6 panels containing data on 3 sites in each panel.

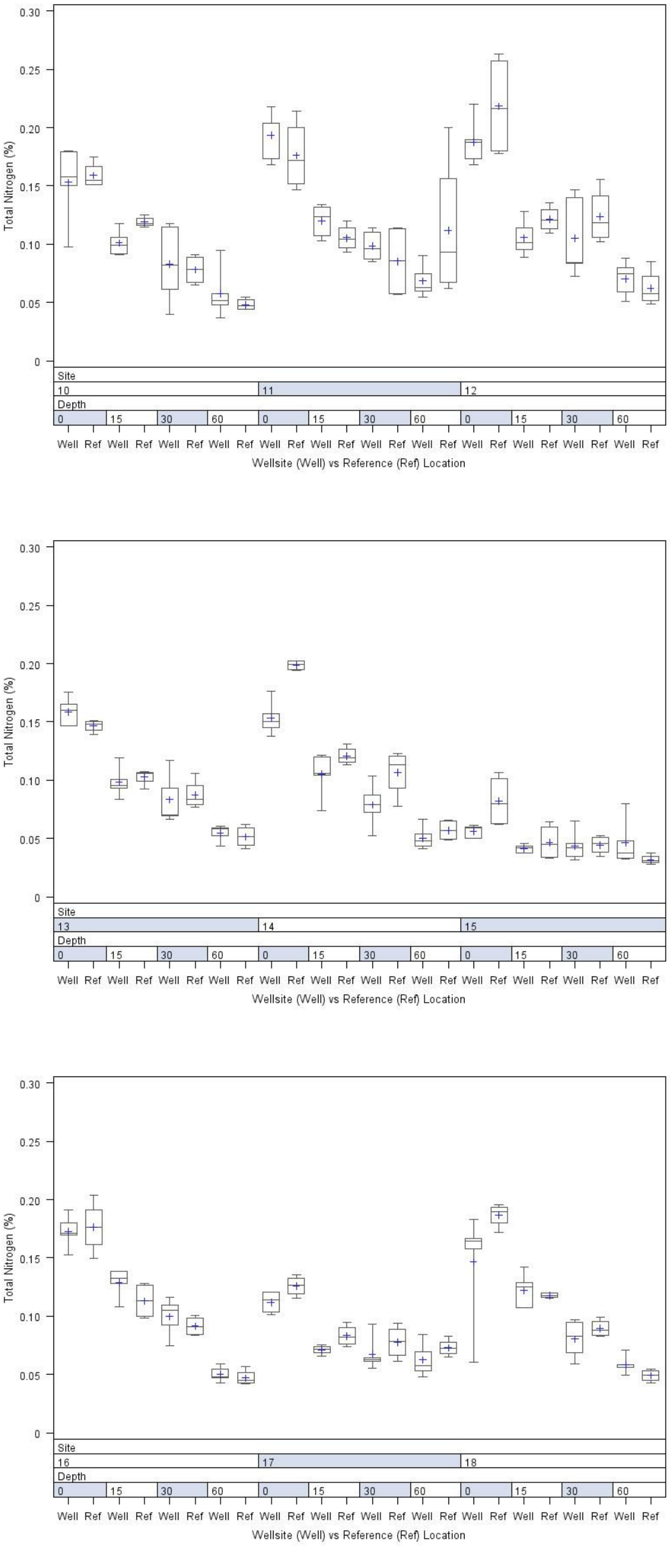

Fig. 2-19. Cont’d.

Total Organic Carbon Single Site Variability – Wellsite vs Reference

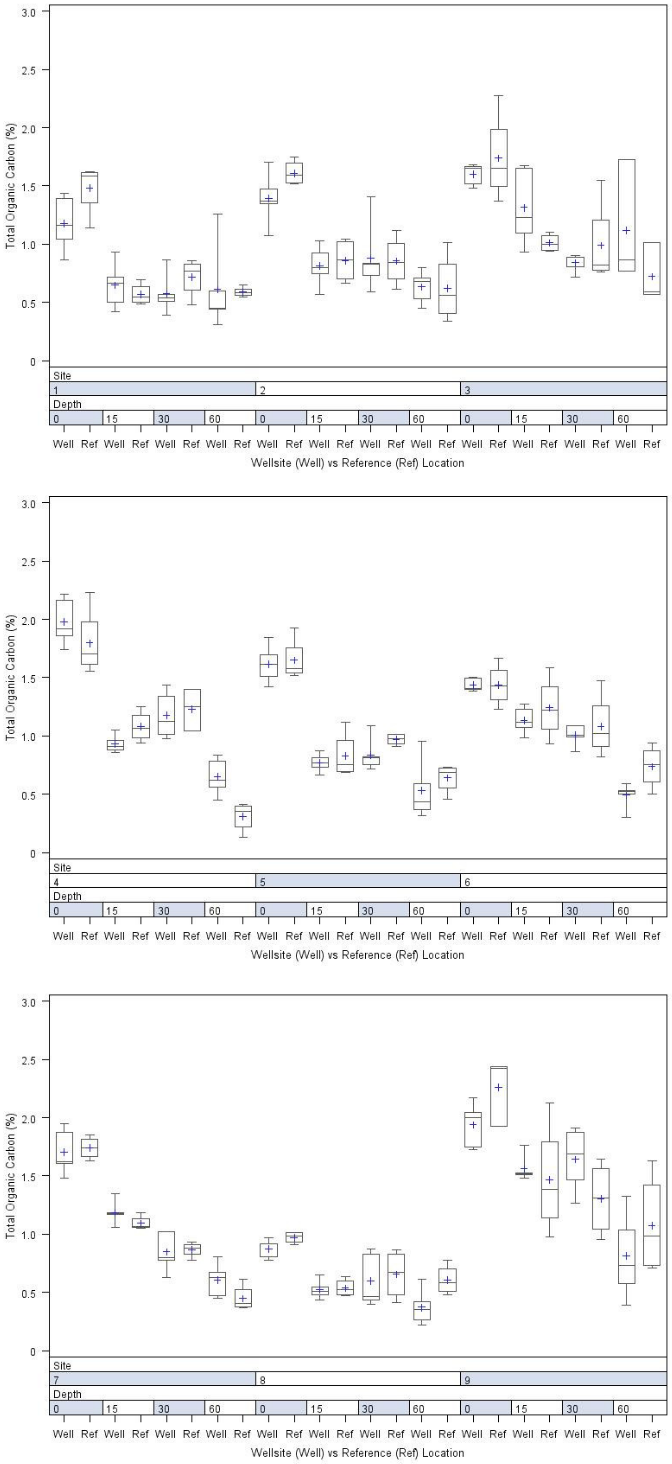

Fig. 2-20. Boxplots of total organic carbon of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm, 30=30-60 cm, 60=60-100 cm). Note that the figure consists of 6 panels containing data on 3 sites in each panel.

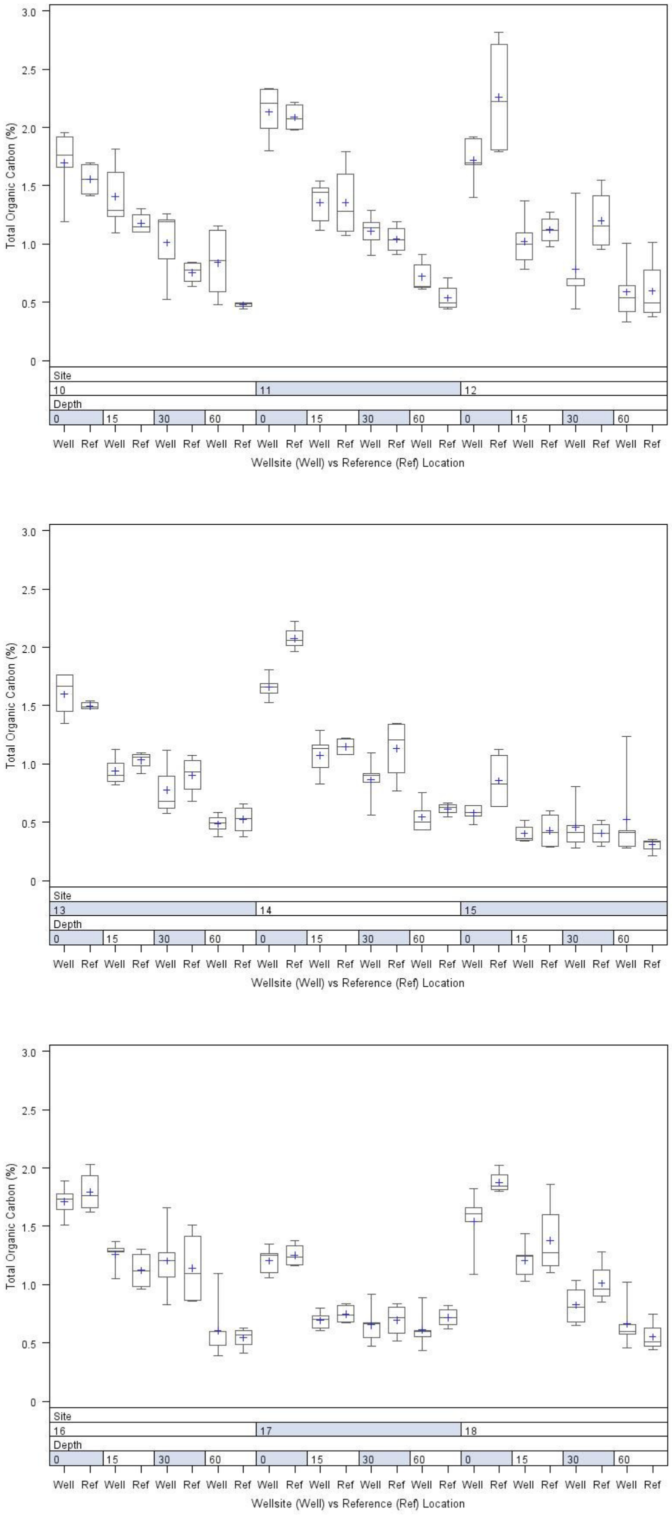

Fig. 2-20. Cont'd.

Total Organic Carbon : Total Nitrogen Single Site Variability Wellsite vs Reference

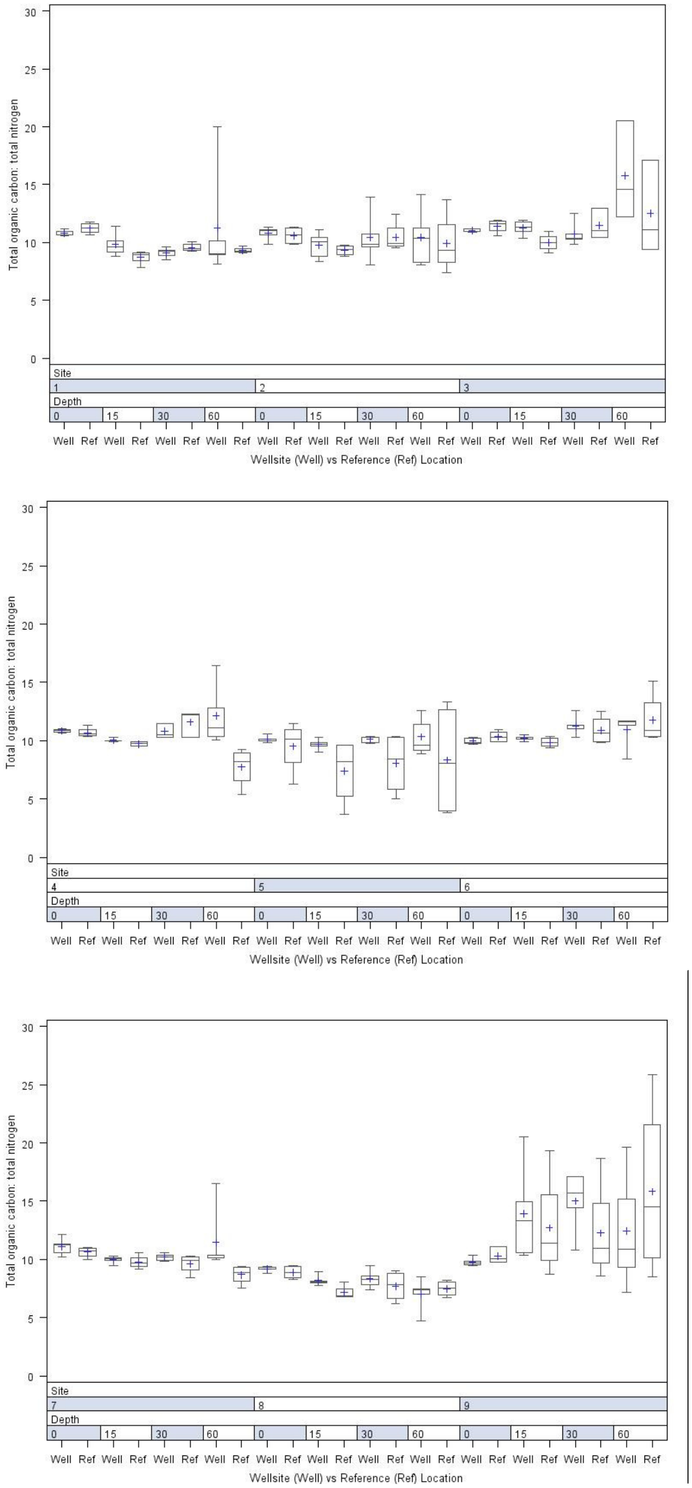

Fig. 2-21. Boxplots of total organic carbon: total nitrogen of wellsite (well) vs reference (ref) location for individual sites separated out by soil depth within each site (0=0-15 cm, 15=15-30 cm, 30=30-60 cm, 60=60-100 cm). Note that the figure consists of 6 panels containing data on 3 sites in each panel.

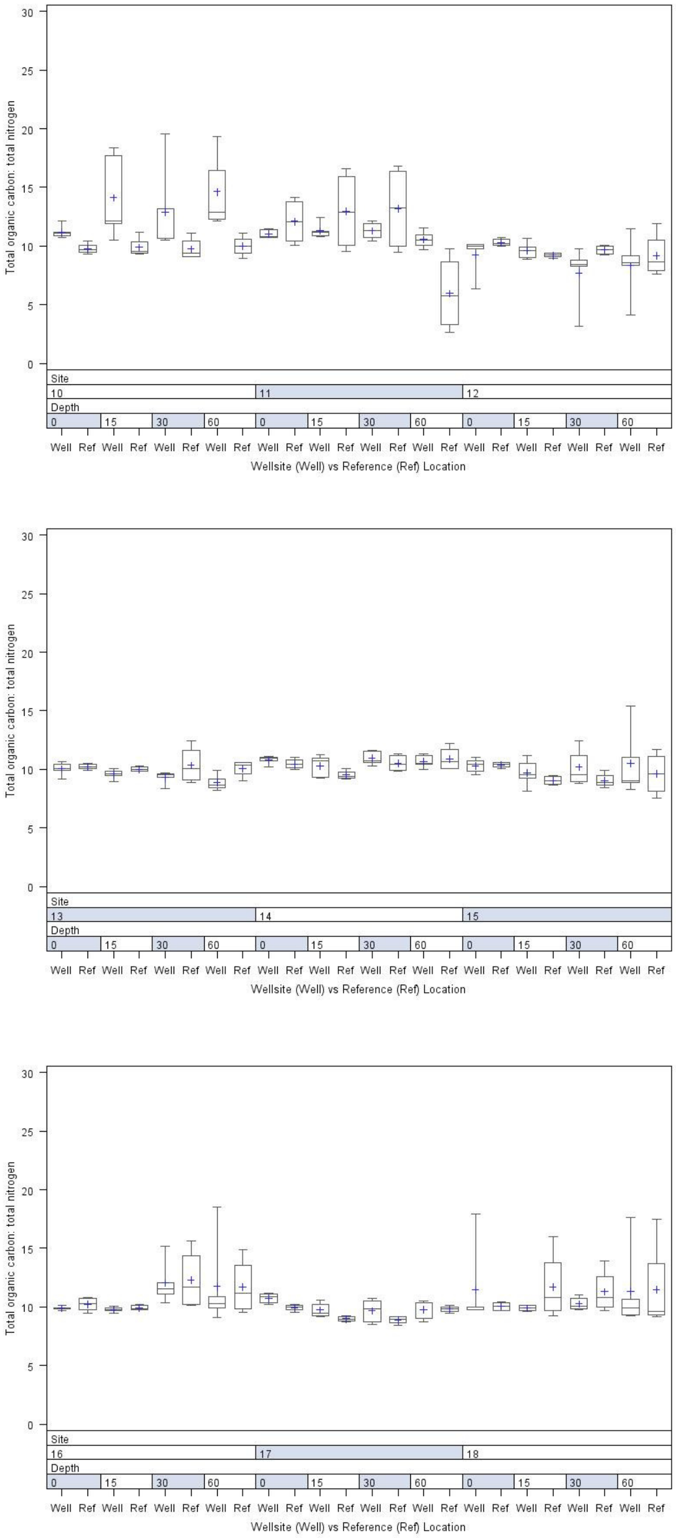

Fig. 2-21. Cont'd.

Site Selection Framework

Development of a framework to select wellsites for inclusion in a long-term monitoring program for certified wellsites was initiated during a set workshops with ERM advisory group members in Winter 2014. Given the goal of the long-term monitoring program evaluating trajectories of ecological recovery for reclaimed wellsites across the province, the site selection process should be inclusive of both the current pool of certified reclaimed wellsites (>100,000) and future reclaimed wellsites that have not yet been certified (>300,000). ERM advisory group members came up with a list of classes/criteria of factors that could potentially be used to categorize certified reclaimed wellsites that included the following:

- The focus of the long-term monitoring program is on upland oil and gas wellsites – recognizing that practices and recovery success are very different between upland and lowland oil and gas wellsites, we are not including lowland wellsites in the current monitoring program.
- Conservation and reclamation guidelines and criteria have shifted since their initiation in 1963 and will continue to change as more information on recovery becomes available, so that also has to be taken into consideration when selecting sites. For example –shifts in conservation and reclamation practices occurred in 1994, 2004, and 2010. Therefore, one way to categorize sites is based on the management practices in place when they were certified (i.e., pre-1995, 1995 - 2004, 2005-2009, 2010- present) recognizing that new categories will have to be added when future changes in practices and guidelines occur. It is important to recognize that we cannot substitute space for time and just sample across a range of age classes of reclaimed wellsites to identify patterns in wellsite recovery. This is because the conservation and reclamation practices have changed significantly over time (e.g., historically non-native crested wheatgrass was seeded to reclaim wellsites in native grasslands, but current regulations require use of native seed mixes). Therefore we are limited in understanding early recovery trajectories for older sites reclaimed under historical policies, but we can follow these sites forward to monitor their recovery over the longer term. Given this limitation for older sites, an emphasis on having site selection weighted more heavily towards younger sites that have been reclaimed under the current guidelines (compared with older sites reclaimed under previous guidelines) in order to help provide insights into early stages of recovery was proposed.
- Stratification of sampling by natural subregion and/or ecosite type within subregion would help us to better understand patterns of ecological recovery that are specific to particular regions and how patterns in recovery vary across regions.
- A more hands-on approach to site selection would be to ensure that the sites in the monitoring program capture a range of reclamation 'success' to ensure that extremes are also captured in the program – i.e., select sites that appear to have recovered very poorly (e.g., lots of bare exposed mineral soil) and also those that have been very 'successful'(e.g., no bare exposed mineral soil). However, there would be challenges associated with identifying these sites without actually sampling them – for example a site may seem that it is successful because it doesn't have exposed mineral soil and has high degree of cover – but if the cover of the species is non-native then this is not likely to recover at the same rate as sites seeded with native mixes. It may be easier to identify sites with poor recovery than sites with good recovery, for example using remotely sensed data. However, until we actually collect data on sites – we will lack detailed information that will aid in assessing where on the scale of recovery sites are with respect to soil indicators, as these data are not available for most reclaimed wellsites.
- The type of reclamation practices that were employed on site (e.g., cut and fill) would also be important factors to categorize the sites – but often this information will be hard to find – especially for sites certified a long time ago that do not have detailed documentation available.
- The type of development (drilled and abandoned, drilled and produced) and type of well (oil, gas) on the site may influence the recovery of ecological functions on the site and therefore sites could be separated among combinations of these categories.

- We do not know if the time of construction or abandonment or reclamation and the time between each stage alter recovery trajectories – so this would also be worth exploring.
- Ecological recovery of sites with additional disturbance post-certification will be confounded and therefore we would like to avoid sites with additional disturbance – e.g., commonly used for off-highway vehicle recreation.
- Sites should be selected to avoid other wellpads, roads, dugouts, gravel pits, buildings, cut lines, and other readily visible disturbances within 100 meter of the wellsites.
- Specific to grasslands, there are also differences in the grazing practices among land managers and therefore in order to control for variability in grazing pressure and its potential impact on recovery, site selection may be influenced by the level of grazing pressure. In the Dry Mixedgrass study we selected native grasslands only on public grazing lands to try to reduce variability in grazing practices influencing our results.

An additional consideration is deciding on the scope of the long-term monitoring sampling network. While the network could be comprised of wellsites from all possible combinations of categories described above (or a subset of these categories), another potential solution would be to limit sampling to only a subset of the classes within these categories. For example, for ecosite type, given that some ecosite types are uncommon on the landscape, instead focus sampling more on wellsites on common ecosite types and excluding the rare ecosite types rather than sampling fewer wellsites within each individual ecosite type. There is more discussion needed to address the merits of these alternative approaches and which categories to focus on, and what framework would provide the most value for the long-term monitoring program. Once categories for classification of sites and the scope of the monitoring network are identified, the selection of wellsites for inclusion in the monitoring program could be stratified by these categories/critera to capture a number of sites that are representative of the distribution of wellsites across them.

Overall, ERM workshop participants highlighted the complexities associated with scope and site selection and therefore, while there were a lot of ideas generated, no final decisions related to site selection for long-term monitoring were made. Final decisions for development of a framework for the long-term monitoring network will need to be based on the scope of the program (sample to capture all reclaimed wellsites or only some sets of wellsites?) and also the budget available for the network. In addition, more information on sampling effort and variability of indicators in other land types (boreal and cultivated lands) are needed to inform these decisions too.

Conclusions

In this stage of the project (April 2013-March 2014), our project focused on two main research areas: i) assessing ecological recovery of historical wellsites on a single common ecosite type in native grasslands (see Chapter 1), and ii) developing a framework to support implementing a long-term monitoring program to track ecological recovery of certified sites in Alberta (see Chapter 2). This project specifically addressed “The effectiveness of industrial footprint reclamation or functional restoration” ecological knowledge gap as identified in PTAC’s Policy Issues and Knowledge Gaps – Ecological Issues by directly addressing the following issues:

•Reclamation effectiveness of native prairie
•How long does it take for reclaimed areas to meet equivalent land capability?

By addressing these knowledge gaps, this project is greatly enhancing the ability of key industry and government stakeholders to evaluate the efficacy of reclamation practices on ecological recovery and provide assurances to the public that Alberta’s public lands are being responsibly managed for both today and into the future. In the future this program can be expanded beyond wellsites to explore ecological recovery of other specified lands too.

Overall, the results from our research showed that for many vegetation and soil indicators wellsites had not yet fully recovered to values similar to those found in adjacent reference locations. This lack of recovery was evident across the different age classes, although there was some evidence for increased recovery of plant communities in the youngest age class compared with the older age classes post-certification, suggesting that newer reclamation practices may be more effective at recovering native prairie plant communities more quickly. We do not yet know how long it will take for these reclaimed wellsites to recover, and thus longer-term monitoring is needed to evaluate recovery trajectories over time. We have begun development of a framework to support the inclusion of long-term monitoring of reclaimed wellsites in Alberta as part of AEMERA.

In the next stage of the project (2014/2015), the focus will be on describing ecological recovery in example ecosite types in forested lands in the Boreal Region, including the application of unmanned aerial vehicles (UAVs) and automated recording units (ARUs) in monitoring ecological recovery of reclaimed wellsites. We will use this information to continue to build the framework for development of an integrated, scientifically robust and financially sustainable monitoring program to enable the assessment of ecological recovery of physical, chemical, and biological indicators at certified reclaimed wellsites across Alberta. However, a key consideration to advancing this program will be to ensure that the long-term monitoring framework will fit within the governance structure that the Alberta government develops for AEMERA.

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