FACTORS THAT RESULT IN SUSTAINABLE FOREST ECOSYSTEM DEVELOPMENT ON PADDED SITES IN PEATLANDS

PILOT STUDY

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EXECUTIVE SUMMARY

In 2018, the Petroleum Technology Alliance of Canada (PTAC) initiated a multi-stage project on the reclamation certification process for sites that were constructed using imported mineral soil pads in peatlands (padded sites). Stage 1 of the project has been completed and identified knowledge gaps for making decisions to accept or reject requests for a change in land use for padded sites during the reclamation certification process. Stage 2 is nearing completion and includes a decision framework and support tools for making decisions related to reclamation certification of padded sites; however, some of the factors that the framework and support tools are based upon, are knowledge gaps. Stage 3 is the field research component of the project to address the knowledge gaps. The pilot study described in this document is a component of Stage 3. The pilot study sought to provide preliminary results for one of the knowledge gaps from Stage 2: *factors that result in sustainable forest ecosystem development on padded sites in peatlands*. As a pilot study, it was also meant to verify methods and identify efficiencies for a large-scale study.

For the pilot study, eight padded sites were selected with the following characteristics:

- abandoned >25 years ago,
- received a reclamation certificate,
- located in the forested Green Area of Alberta,
- within a 100 km radius of Slave Lake, Alberta (for logistics and efficiency), and
- encompassing a range of vegetation characteristics, from sites where trees had infilled to those that remained grass dominated.

In September 2021, measurement of vegetation, soils and information related to pad characteristics were taken on the eight padded sites. Preliminary data analysis was completed to determine if a relationship existed between pad characteristics and vegetation. This relationship would then be used to predict the future vegetation composition and tree growth performance (outcome) based on pad characteristics.

Preliminary results from the pilot study indicated that vegetation which approximates a natural forest can establish on pads, but there are also pads where forest species are not the dominant vegetation cover. Characteristics that influence pad vegetation are predominately pad moisture conditions, cation concentrations in the pad material, and pad dimensions. The pilot study also identified that pads have zones with different vegetation and pad characteristics: pad centre, pad periphery and access road. It should be noted that these results are based on limited replication and results could differ in a large-scale study.

The pilot study validated the research questions, sampling design, measurement and data analysis methods developed for a large-scale study, with some minor amendments. In particular, sufficient replication is required to be able to correlate pad to vegetation characteristics. It is recommended that a large-scale study with a phased approach might be most efficient as this will avoid over-replication.

TABLE OF CONTENTS

ACRONYMS

ANOVA	Analysis of Variance
CCA	Canonical Correlation Analysis
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
EC	Electrical Conductivity
LiDAR	Light Detection and Ranging
NAIT	Northern Alberta Institute of Technology
NMDS	Non-metric Multidimensional Scaling
permANOVA	Permutational Analysis of Variance
PTAC	Petroleum Technology Alliance Canada
SAR	Sodium Adsorption Ratio

1.0 INTRODUCTION

1.1 Project Overview

In 2018, the Petroleum Technology Alliance of Canada (PTAC) initiated a multi-stage project on the reclamation certification process for sites that were constructed using imported mineral soil pads in peatlands, and upland sites with vegetation on a trajectory to approximate natural forest vegetation but with one or more reclamation deficiencies according to the applicable wellsite criteria. These sites cannot receive a reclamation certificate without additional scrutiny and professional justification under current regulatory criteria and policies. The goal of the project is to ensure that decisions made during the reclamation certification process result in the best possible ecological outcome (i.e., net environmental benefit) for these sites and surrounding region.

1.2 Stage 1 Literature Review & Identification of Knowledge Gaps

Stage 1 of the project was completed in 2019. It identified that there was limited guidance on how decisions were being made to accept or reject requests for a change in land use for sites constructed using imported mineral soil pads in peatlands (Tokay et al., 2019). Stage 1 also identified key factors to consider when assessing the ecological implications of a change in land use request (hydrology, cumulative effects and regional considerations, upland function, status of the borrow pit, site location, and land use considerations) and several knowledge gaps related to these key factors.

1.3 Stage 2 Draft Wellsite Certification Guidance Documents

The outcome of Stage 1 lead to the development of two (draft) decision framework and support tools (Stage 2):

- one focused on decisions and justifications for variances on upland sites (Tokay et al., 2019) and
- the other on decisions related to leaving mineral soil pads in place in peatlands (Drozdowski et al., 2020).

Both decision support documents will be updated with feedback from industry (energy companies and practitioners) and government (Alberta Environment and Parks and Alberta Energy Regulator).

1.4 Stage 3 Research Program

The overall goal of Stage 3 is to **address key priority areas for research and refine the draft decision framework and support tools based on results of the research program.**

Priority areas for research were identified from the knowledge gaps identified in Stages 1 and 2 for sites that were constructed using imported mineral soil pads in peatlands. A summary of these knowledge gaps is provided in Appendix A.

Based on the priority areas for research, the following research objectives were developed:

1. Determine factors that result in sustainable forest ecosystem development on padded sites, including access roads, in peatlands

2. Develop a mechanism for detecting and evaluating the effects of pads off-site
3. Determine factors that result in padded sites impacting surrounding peatland ecosystems in the long term and the extent and severity of these impacts
4. Evaluate the effectiveness of partial reclamation activities for alleviating off-site impacts resulting from pads left in place in peatlands

Other areas of research that **were not included as objectives** for this research program include:

- Likelihood of success for peatland recovery if the pad is removed and the factors that influence success (being addressed by work through NAIT)
- Cumulative effect threshold based on scientific and geographical approaches to allow a proportion of wetlands in a given area to be "lost" without significant degradation of function in the region

Specific research questions and the experimental approach associated with each research objective are provided in Appendix B.

1.4.1 *Inventory of Padded Sites*

To inform research objectives and knowledge gaps, a mapping initiative was executed to differentiate padded sites and non-padded sites in peatlands at a provincial scale and in a cost-effective manner (Caron et al., 2022). High-resolution LiDAR data combined with open-access optical imagery from Sentinel-2 were used to develop a supervised machine learning model that predicted mineral pad presence by exploiting the differences in elevation, texture, vegetation, and moisture characteristics on pads compared to adjacent landscapes. Approximately 7,000 padded sites in Alberta were identified. This inventory of padded sites will be used to select research locations for a large-scale study and provide statistics on padded sites in Alberta.

1.4.2 *Pilot Study*

A pilot study was initiated in 2021 to investigate the first research objective: *factors that result in sustainable forest ecosystem development on padded sites in peatlands*. The main research questions to be answered by this objective were:

- Do sustainable forest ecosystems develop on pads?
- What factors result in sustainable forest ecosystem establishment on pads? Factors investigated included:
    - o Reclamation practices: none, deep ripping, mounding, application of amendments (or salvaged topsoil), fertilization (depending on the availability of sites)
    - o Pad thickness and size
    - o Presence, type, and depth of liner (e.g., corduroy, geotextile)
    - o Physical and chemical properties of the pad material
    - o Water level within the pad material (i.e., pad water table; depth to water below the surface of the pad)
    - o Surrounding peatland size and proximity of the pad to off-site seed sources

The objectives of the pilot study were to:

- Verify the methods are appropriate for answering the research questions
- Provide preliminary results
- Identify efficiencies that can be applied to a large-scale study

Upon completion of a large-scale study for this research objective, it is anticipated that measurable pad characteristics will be identified that can be used to predict if a sustainable forest ecosystem will develop on a pad. This will in turn inform decisions on whether a pad could remain in place. The research can also be used to provide statistics on padded sites (e.g., estimate of the percentage of padded sites with geotextile, percentage of padded sites with forest ecosystem establishment, pad thickness, etc.).

2.0 METHODS

2.1 SITE SELECTION

The pilot study used continuous variables (rather than treatments) to determine the relationship between predictive factors (e.g., pad characteristics) and outcomes (e.g., vegetation characteristics that may indicate sustainable forest ecosystem development) on historically reclaimed pads. Sites were selected based only on remotely sensed information (e.g., aerial/satellite imagery and digital elevation models (DEM)) and wellsite databases (e.g., Abacus Datagraphics Ltd. (2022) and Alberta Energy Regulator (2022)). Sites were selected to represent a range of outcomes and not predictive factors; outcomes (vegetation) were observable with remotely sensed data whereas the predictive factors (pad characteristics) were generally not.

Padded sites were selected from the inventory of padded sites (Caron et al., 2022), with the following characteristics:

- abandoned >25 years ago,
- received a reclamation certificate,
- located in the forested Green Area of Alberta,
- within a 100 km radius of Slave Lake, Alberta (for logistics and efficiency), and
- encompassing a range of vegetation characteristics, from sites where trees had infilled to those that remained grass dominated.

Eight sites were included in the pilot study and in some cases included padded access roads. A summary of the sites is included in Table 1 and locations are shown on Map 1.

Table 1. Characteristics of Selected Sites.

Unique Well Identifier	Construction (Spud) Date	Well Abandonment Date	Access Road – Padded in Peatland
100 / 02-22-069-03 W5 / 0*	1966-04-14	1995-10-31	Yes
100 / 08-19-081-08 W5 / 0	1980-09-07	1980-09-30	Yes
100 / 11-28-082-09 W5 / 0	1983-07-03	1983-07-16	Yes
100 / 12-07-077-07 W5 / 0	1979-02-22	1979-03-17	Yes
100 / 12-24-073-05 W5 / 0	1983-11-16	1986-11-25	Yes
100 / 13-07-073-03 W5 / 0	1994-01-22	1994-02-05	Yes
100 / 14-12-073-04 W5 / 0	1990-03-06	1990-03-22	No
100 / 16-32-078-08 W5 / 0	1984-12-29	1985-01-16	Yes

*May be only partially padded as it is in a transitional area between upland and peatland

2.2 SAMPLE DESIGN

The padded area of each site was stratified into three zones: (wellsite) pad centre, (wellsite) pad periphery and access road (if a padded access road is associated with the wellsite). Based on review of aerial imagery and experience, these zones generally have different vegetation communities; the pad centre often has fewer trees and shrubs, whereas the wellsite periphery has more trees and shrubs, and the access road typically has dense trees and shrubs.

Measurements were taken at three sample areas in each of these zones:

- Pad centre sample areas were located 10 m from the centre of the pad (generally well centre) at bearings of 45º, 135º and 225º (or 315º if one of the other directions could not be used)
- Pad periphery sample areas were located 10 m from the edge of the pad at bearings of 135º, 225º and 315º (or 45º if one of the other directions could not be used)
- Access road sample areas were equally distributed along the length of the padded portion(s) of the access road and in the middle of the access road's width. Due to timing constraints, measurements were taken on only 5 of the 7 padded access roads (i.e., 100 / 08-19-081-08 W5M / 0 and 100 / 13-07-073-03 W5M / 0 were not assessed)

Examples of the plot layouts are included on Maps 2a-h.

2.3 VEGETATION

Vegetation characteristics (outcome variables) were assessed at each of the sample areas in September 2021. Measurements of trees and shrubs were taken in a 10 m^2 circular plot, and measurements of understory vegetation were made in two 1 x 1 m plots at each sample area. Tree measurements in the 10 m^2 plot included a tally of tree stems by species and height class (<1.3 m, 1.3 m to 3.0 m, >3.0 m), and the height, diameter at breast height (DBH) and an estimate of tree age for up to three "site" trees of each species in the plot (three trees with the largest DBH). The percent canopy cover of both trees and shrubs was estimated in the 10 m^2 plot as well. Understory measurements in the 1 x 1 m plots included percent canopy cover by vegetation strata (tree and shrub, native forbs, and prostrate shrubs, native graminoids, agronomic species and weeds, non-vascular, total vegetation cover, bare ground, litter, and standing water) and by species. In addition, a 10-minute walkaround of the entire padded area was completed to identify all vegetation species present.

2.4 PAD CHARACTERISTICS

Pad material was characterized at each of the sample areas, in September 2021, by auguring through the pad until peat was encountered below the pad and measuring:

- pad thickness,
- depth to water,
- material texture,
- colour (gleying/mottling),
- moisture category (based on a field hand test), and
- presence or absence of geotextile or corduroy below the pad.

In a 30 cm deep pit at each sample area, the upper profile of the pad material was characterized in detail and included:

- texture,

- structure,
- consistence,
- coarse fragment content and
- rooting restrictions.

Samples of the pad material were collected and submitted for laboratory analysis of:

- bulk density,
- pH,
- electrical conductivity (EC),
- sodium adsorption ratio (SAR),
- percent saturation, and
- concentrations of
  - calcium,
  - magnesium,
  - potassium and
  - sodium.

The bulk density sample was collected from a 15-30 cm depth. The sample for all other parameters was collected from a 0-30 cm depth except at one sample area per stratification zone where samples were collected from 0-15 and 15-30 cm. Two sample depths were collected at these areas to determine if there were differences by depth to verify the pilot study methods and determine if there was any indication of soil development. Samples were analyzed by Element Materials Technology Inc.

Pad size, location within the landscape and historical construction and reclamation practices were documented in the field. These observations were verified with wellsite databases and remote sensing data (aerial imagery available from Google Earth and a DEM provided by Alberta Environment and Parks with 1 m resolution, position accuracy of approximately 0.3 m, and data acquired between 2006 and 2014). The following variables were then characterized:

- Dimensions of the pad and total padded area
- Elevation of the pad above the surrounding peatland and variation in pad elevation (standard deviation of pad elevation derived from a DEM with a 1 m resolution)
- Distance to upland areas to the west (direction of prevailing wind), minimum distance to upland (any direction) and percent land area occupied by upland (forested) land within a 250 m radius from the centre of the pad
- Predominant surrounding wetland type
- Years since wellsite construction (approximated based on well spud date) and well abandonment
- Reclamation practices – tree planting, surface roughening, etc.

2.5 Data Analysis

Statistical analysis was completed on the pilot study data to explore the preliminary results. Results were used to confirm that the statistical analysis approach was appropriate and verify sample design and methods for a large-scale study. However, due to the limited number of sites in the pilot study, statistical analysis results must be considered preliminary; results obtained from a future large-scale study may differ.

To provide initial information on the forest ecosystem on pads, the vegetation and pad characteristics between sites were compared using non-metric multidimensional scaling (NMDS) analysis. NMDS considers the influence of all the measurements and not just a single measurement and is a useful way to examine data with multiple variables. NMDS results were plotted to examine differences between sites in an ordination space; the distance between the sites on the graph generally represents the magnitude of the difference between sites. Only pad centre measurements were used in the analysis. Separate NMDS graphs were prepared for the vegetation and pad characteristics. Redundant variables were removed from the analysis (i.e., for total tree stems and total tree stems by species, only the tree stems by species were included), and only cover by vegetation strata was used (i.e., not cover by species). Simple dot plots for each measurement were also prepared for visual interpretation.

To examine factors that result in forest vegetation establishment on pads, correlations between vegetation and pad characteristics were analyzed. For the pilot study, two statistical approaches were explored to examine the relationship: separate correlations between each vegetation measurement and pad characteristics and canonical correlation analysis (CCA). CCA is a multivariate approach to determine which vegetation measurements and pad measurements have the maximum correlation with each other. Spearman's rank correlation, a non-parametric test, was used for the separate correlation analysis as the data were generally not normally distributed. Only pad centre measurements were used in the analysis and only cover by vegetation strata was used (not cover by species). An alpha value of 0.05 was used to determine significance and only significant correlation with a correlation coefficient (R) value greater than 0.5 are presented in the results. For the CCA, variables to be included in the CCA were first narrowed down using a step-wise selection process.

As a method to verify the sample design, vegetation and pad characteristics of the different stratification zones were compared to each other. A permutational analysis of variance (permANOVA) approach was utilized as the data were not normally distributed. Non-normally distributed data (data residuals) should not be analysed with an analysis of variance (ANOVA) test, whereas a permANOVA can be applied to non-normally distributed data. ANOVA results are presented along with the permANOVA results for comparison purposes. An alpha value of 0.05 was used to determine significance and no post-hoc tests were completed. Each site was considered a blocked replicate.

To verify the pad material sampling method, where samples were collected from two depths, the characteristics of the 0-15 cm and 15-30 cm depth increment samples of the pad material were compared. A non-parametric Wilcoxon test was utilized as the data were not normally distributed. The samples from each pit were treated as paired samples in the analysis and each pit was considered a replicate. An alpha value of 0.05 was used to determine significance.

Methods used to prepare the data for analysis are summarized in Appendix C.

3.0 RESULTS

3.1 Vegetation

The vegetation measurements in the pilot study do not specifically address the sustainability of the forest ecosystem on pads but do characterize the forest ecosystem and could be used to infer sustainability. Vegetation at the (wellsite) pad centres in the pilot study had the following characteristics:

- Tree stem density at the centre of pads varied by site and ranged from 0 to approximately 6 stems/plot (or 6,000 stems/ha). Populus balsamifera was the most observed tree species, however, Populus tremuloides, Picea glauca and Larix laricina were observed on some sites at pad centre (Figure 1a)
- The height growth rate of Populus balsamifera varied by site, from approximately 0.25 to 0.5 m/year (Figure 1b)
- Canopy cover of trees, shrubs, native forbs and prostrate shrubs, native graminoids and non-vascular species varied by site and ranged from <1% to 100% (when all vegetation strata categories are combined). Agronomic species and weeds also varied between sites from 0% to nearly 80% (Figure 1c)
- Between 10 and 45 native species were found on each site and Shannon's Diversity (H) ranged from 1 to greater than 2.5 (Figure 1d)

Interpretation of the NMDS graph suggests three groupings of sites: five of the eight sites were associated with a high cover of agronomic species and weeds, two sites were associated with a high tree and shrub cover and stem density of balsam poplar in the >3 m height class, and one site was associated with a high native graminoid cover and non-vascular cover. The NMDS from the pilot study should be interpreted with caution as there was insufficient replication (Figure 2). While not indicated by the NMDS, 100/12-24-073-05 W5/0, the site associated with a higher native graminoid cover and non-vascular cover, had saturated soils and ponding as the pad surface was below the water level in several locations.

3.2 Pad Characteristics

At pad centre, the following characteristics were observed:

- Pad thickness ranged from approximately 0.8 to 1.8 m and pad surface elevation ranged from 0.3 to 0.8 m above the surrounding peatland surface elevation. The pad surface was generally level and smooth; however, small anomalies with higher and lower surface elevation were present (e.g., holes and mounds; Figure 3a)
- Pad material texture varied from sand to clay. Generally, the texture was uniform throughout the profile except for two sites. These two sites had organic material mixed in with the pad material (Figure 3b)
- Pad material had a neutral pH (except 100/12-24-073-04 W4/0 which had saturated soils and ponding), was non-saline and non-sodic. Sodium and potassium concentrations were less than 10 mg/kg, magnesium was less than 30 mg/kg and calcium varied from nearly 0 to approximately 200 mg/kg (Figure 3c)

- Bulk density ranged from approximately 0.8 to 1.3 g/cm^3 and rooting restrictions were observed at one site (Figure 3d)
- Pad material moisture varied from saturated to dry with depth to water ranging from approximately 0.4 to 1.6 m (Figure 3e)
- The percent of upland area within a 250 m radius of the site ranged from 0% to 35% and the distance to nearest upland area varied from 0 to 600 m
- No evidence of geotextile or corduroy beneath the pad was observed at any of the sites
- No evidence of reclamation activities, surface preparation or tree planting was observed at any of the sites. Swales were dug through the access road pad on two of seven sites with padded access roads

Interpretation of the NMDS graph, does not suggest any distinct groupings of sites; however, sites exhibited differences in pad characteristics. Texture, saturation, sodium concentrations of the upper 30 cm of pad material, depth to anaerobic conditions and distance to upland areas in the west were differentiating factors. The NMDS from the pilot study should be interpreted with caution as the low stress results indicates insufficient replication (Figure 4).

3.3 INFLUENCE OF PAD CHARACTERISTICS ON VEGETATION

There were several significant correlations between pad characteristics and vegetation measurements at pad centre in the pilot study:

- There was a positive correlation between calcium and potassium concentrations in the upper 30 cm of the pad material with tree stem density in the 1.3 to 3 m height class and, to a lesser extent, tree canopy cover (Figure 5a)
- Depth to anoxic conditions, pad size and dimensions were positively correlated with shrub cover (Figure 5b)
- Variation in pad elevation was positively correlated with native forb (including prostrate shrubs) and, to a lesser extent, native graminoid cover (Figure 5c)
- Distance to upland areas to the west was positively correlated with Shannon's Diversity Index (including all species) and, to a lesser extent, native graminoid cover (Figure 5c)

The CCA indicated that bulk density, maximum wellsite pad dimension, variation in pad elevation, pad moisture rating, depth to anoxic conditions and sodium concentrations had the greatest influence on vegetation characteristics at pad centre. Higher sodium concentrations were associated with greater tree cover and shrub cover and stem density in the >3 m height class, whereas a higher bulk density was associated with agronomic species and weeds and higher density of trees in the <1.3 m and 1 to 3 m height classes. The CCA from the pilot study should be interpreted with caution due to low replication (Figure 6).

3.4 PAD ZONES

Padded areas were stratified into three zones: pad centre, pad periphery and access road (if padded) in the pilot study. Vegetation and pad characteristics varied between these zones. For vegetation, statistically significant differences were observed for agronomic species and weed canopy cover, tree cover and the Shannon Diversity Index. Pad centres had greater agronomic species and weed canopy cover, and pad periphery and access road had greater tree cover and species diversity than other zones. While not statistically different, the pad periphery and access road typically had a greater density of trees and diversity of tree species. Trees at the centre of the pads were mostly limited to *Populus balsamifera* whereas *Populus tremuloides*, *Larix laricina* and *Betula papyrifera* were common on the pad periphery and access roads (Figures 7a-c).

For pad characteristics, a statistically significant difference was only observed for depth to anoxic conditions. On the access road, the depth to anoxic conditions was shallower and, while not statistically significant, the access roads also tended to have thinner pads and a higher moisture content than other zones. The periphery of pads also tended to have a greater concentration of cations (calcium, magnesium, potassium, and sodium) and higher EC and SAR than other zones, but the differences were not statistically significant (Figures 8a-d).

3.5 Pad Material Sample Depth

Pad material was sampled at two depth increments at select sample areas to determine if there was a change in pad characteristics with depth and verify sampling methods in the pilot study. SAR was statistically higher in the 15-30 cm sample interval compared to the 0-15 cm interval; however, concentrations of calcium, magnesium, and sodium, used in the calculation of SAR, were not statistically different between the intervals but tended to be higher in the 0-15 cm interval (Figures 9a-b).

4.0 DISCUSSION AND RECOMMENDATIONS

4.1 VEGETATION

One of the research questions was to determine if sustainable forest ecosystems can develop on pads. The pilot study did not collect data to directly answer this question; however, vegetation characteristics on pads can be compared to reclamation criteria and biodiversity and growth performance thresholds documented in literature to make an inference about sustainability. The following documents can be used as sources for thresholds:

- The *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands* (Alberta Environment and Sustainable Resource Development, 2013) is recommended as a primary source of thresholds
- Species diversity thresholds can be derived from the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Alberta Environment, 2010) and peer-reviewed literature from studies conducted in Alberta (e.g., Macdonald and Fenniak, 2007)
- Growth performance of trees can be compared using site index to expected targets in the *Field Guide to Ecosites of North America* (Beckingham and Archibald, 1996) and/or timber productivity ratings in Appendix II of the *Alberta Vegetation Inventory Standards* (Alberta Agriculture, Forestry and Rural Economic Development, 2022) and/or mean annual increment per the *Reforestation Standard of Alberta* (Alberta Agriculture and Forestry, 2018)

For the pilot study, vegetation characteristics were only compared to the *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands* (referred to as "criteria"; Alberta Environment and Sustainable Resource Development, 2013). Additional comparisons to thresholds were not made for the pilot study, but they are recommended for a large-scale study. At pad centre, three of eight sites had greater than 5 tree stems/10 m^2 plot (5,000 stems/ha), two of eight sites had greater than 25% woody vegetation cover (trees and non-prostrate shrubs) and four of eight sites had greater than 25% native herbaceous vegetation cover. Two of eight sites (100/14-12-073-04 W5 / 0 and 100/11-28-082-09 W5 / 0) met criteria for all three of the parameters.

The pilot study verified vegetation that approximates a forest ecosystem can establish on pads and there is a variety of vegetation outcomes that are likely driven by various factors. These driving factors can be used as predictive factors and guide pad reclamation. These findings confirm that there is a rationale for a large-scale study, however, it is recommended that the research question, "Do sustainable forest ecosystems develop on pads?", be amended to "Does the vegetation community on pads meet expected thresholds for composition and tree growth performance of forest ecosystems?" to be better aligned with the study design.

4.2 INFLUENCE OF PAD CHARACTERISTICS ON VEGETATION

The second research question focused on determining factors that result in sustainable forest ecosystem establishment on pads. The pilot study examined the influence of various pad characteristics on vegetation composition and growth. Due to the limited amount of replication in the pilot study and as only two sites had vegetation that approximated a forest ecosystem, results are preliminary and should be interpreted with caution. Statistical analysis and general observations during the pilot study indicate that pad moisture conditions, cation concentrations in the pad material, and pad dimensions are likely factors that affect vegetation composition and growth on pads. Variation in pad elevation may be a factor as well, but the elevational difference between pads in the pilot study was minimal. Pad moisture is hypothesized as being one of the key factors in vegetation community development. For example, dry pad areas had fewer trees and more agronomic species, moist conditions resulted in vegetation more comparable to a forest ecosystem, and wet conditions resulted in swamp or marsh vegetation. Nutrients may also be a key driver of the vegetation characteristics; the pad material of the sites in the pilot study often had low concentrations of calcium, magnesium, potassium, and sodium which could limit plant growth. Other nutrients were not analyzed as, during planning of the pilot study, it was thought it may be difficult to determine the source of the nutrients (inherent pad material characteristic or because of deposition and decomposition of plant litter). However, these measurements may help predict outcomes and would be recommended to include in the large-scale study. Pad size may also be useful in predicting outcomes. It was expected that smaller pad dimensions would result in vegetation comparable to a forest ecosystem as there is less interior area and mostly edge area, and pad periphery (edge) tended to have vegetation that more closely approximates a forest ecosystem. However, results from the pilot study suggest an opposite trend for pad centres (Figures 7a-c).

For a large-scale study, it is recommended that the research question, “What factors result in sustainable forest ecosystem establishment on pads?”, be amended to “Which pad characteristics result in a vegetation composition and tree growth performance that meet expected thresholds for a forest ecosystem?”. This question would be the main focus of a large-scale study for research objective 1 (refer to Section 1.4 for the original list of research objectives).

The pilot study verified the sample design and methods. Considerations for a large-scale study include:

- Increased detail or quantitative measurements of pad moisture content
- Measurements of water levels in the surrounding peatland as they could influence the moisture content of the pad material
- Sampling of soil nutrients and organic carbon
- Sampling entire thickness of the pad material (refer to Section 4.3)

A large-scale study should also include sufficient replication to answer the research questions for this objective. Due to the high number of pad characteristics being examined as predictive factors, there needs to be enough replicates to make conclusions. As it is only feasible to select sites based on outcomes (vegetation) and not predictive factors (as this would require fully measuring all the pad characteristics first), it is difficult to accurately predict the number of sites needed to fully answer the research question. It is recommend starting initially with approximately 40 sites, analysing the data, and using the results to assess whether additional replication is needed to address the research questions. One approach could be to conduct a large-scale study in phases and add sites in each phase until there is sufficient data to make conclusions.

4.3 AMENDMENTS TO SAMPLE DESIGN

An objective of this pilot study was to verify that the methods will be appropriate in a large-scale study and identify additional efficiencies. Recommended amendments are discussed below.

4.3.1 *Pad Zones*

The pilot study stratified the pad to determine if it was beneficial to sample multiple zones (pad centre, pad periphery and access road). Differences were found between the zones, validating the stratification approach. Data from the (wellsite) periphery and access road zones was not used in analysis in the pilot study when examining the influence of pad characteristics on vegetation but could be used in a large-scale study. However, the periphery and access road are also influenced by edge effects and the periphery of wellsites may experience a different degree of disturbance than the pad centre and the access road. These factors are hard to differentiate from the effect of the pad characteristics. To collect data during a large-scale study, it might be prudent to focus mainly on pad (wellsite) centres and exclude the periphery; pad centres generally occupy a larger portion of the pad than the periphery (60% to 80% of the pad area) and are the most limiting area of the pad. Access roads should be included as a separate zone as they can occupy a significant area and have different pad and vegetation characteristics than pad centres. To off-set the loss of periphery measurements, the number of sample areas at pad centre would be increased to a minimum of four.

4.3.2 *Pad Material Sample Interval*

The pilot study examined pad material sample intervals to determine if the upper 30 cm of the pad material could be sampled as a single interval or if it should be split into two 15 cm intervals. There was minimal difference between the 0-15 cm and 15-30 cm sample intervals and a single sample interval of 0-30 cm could be used in a large-scale study. The pilot study did not sample material below 30 cm as it was hypothesized that the upper 30 cm of the material would have the greatest effect on vegetation. However, a deeper soil sample may also better represent the original pad material quality, whereas the 0-30 cm interval may be more modified by vegetation and weathering processes. It is recommended that samples be taken from a minimum of two intervals: a 0-30 cm interval and 30 cm to maximum thickness of pad. The lower interval could be one composite sample per zone.

4.3.3 *Vegetation Measurements*

The pilot study required a significant amount of time to complete the vegetation measurements. While the effort resulted in detailed data, the level of detail was not required for comparison to the proposed thresholds. For a large-scale study, the following is recommended:

1. In 2 x 2 m or larger plot at each sample area, estimate canopy cover by vegetation strata using the strata documented in the pilot study (not by species)
2. For each pad zone, complete a walkaround and record vegetation species and assign a cover class rating to each species and vegetation strata
3. At each sample area, complete a stem count by height class in a 10 m^2 plot following the methods used in the pilot study

4. For each stratification zone, select three site index trees of each of the species present and record their height, DBH and age.

It is anticipated that these changes to the methods will reduce the time required for vegetation measurements by 15% to 25%. In addition, these changes will provide data that better represent the site and allow for the research question to be addressed.

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APPENDIX A: SUMMARY OF KNOWLEDEGE GAPS

	Knowledge Gaps
Local and Regional Impacts	Relationship between peatland type (e.g., bog vs. fen), feature type (e.g., pad vs. road) and direction of water flow relative to the feature on the occurrence of off-site impacts
	Impacts of pads and roads left in place on groundwater, wildlife habitat, wildlife movement and use of the landscape
	Methods that can be used to measure the occurrence and extent of current pad impacts to hydrology, as well as the potential for future impacts
	Cumulative impacts of multiple pads and roads on local and regional peatland hydrology, chemistry, vegetation and greenhouse gas fluxes and the threshold at which cumulative impacts degrade overall ecological function of the region
	Magnitude of carbon emissions released during pad removal (including site access) and associated net environmental "benefit" associated with pad removal vs. leaving the pad in place
	Success rate of pad removal in achieving peatland ecosystem function, ecological land classification and the factors and reclamation practices that contribute to success or failure. Specifically: • Extent of peat compression under the pad, and impact of overall thickness and weight of the pad • Extent of peat rebound after pad removal and impact from duration of pad being in place and thickness/weight of the pad • Potential for and risk of minimal peat rebound and the creation of an open water body instead of a site on a trajectory to a functional peatland • Impacts to underlying peat chemistry resulting from the pad material, and how those changes may impact a developing plant community after pad removal
	Cumulative effect threshold based on scientific and geographical approaches to allow a proportion of wetland in a given area to be "lost" without significant degradation of function of the region
Site Specific Considerations	Factors that result in padded sites impacting the surrounding peatland ecosystems in the long term and affect the extent and severity of these impacts
	Effectiveness of partial reclamation activities for alleviating impacts resulting from pads (wellsite and/or access roads) in peatlands
	Likelihood of success for peatland recovery if the pad is removed
	Success rate of pads left in place that achieve and maintain upland ecosystem function and ELC in the long term. Specifically: • Relative importance of factors that influence successful reforestation of pads (e.g., soil quality, topsoil depth, compaction, dispersal vectors, historical revegetation efforts, time, surrounding peatland type, water quality and levels, etc.) • Potential for water table to rise into the root zone over time • Resiliency of upland ecosystems developed on pads left in place
	Factors that result in sustainable forest ecosystem development on padded sites

APPENDIX B: RESEARCH OBJECTIVES, QUESTIONS AND EXPERIMENTAL APPROACHES

Objective 1) <u>Investigate the factors that result in sustainable forest ecosystem development on padded sites in peatlands</u>

Rationale

One factor in the decision to leave a pad in place in a peatland is the sustainability of the ecosystem that has developed on the pad; this must be demonstrated to justify/approve reclamation certification. Additional understanding of the factors that encourage the development of sustainable forest ecosystems on padded sites is required to optimize reclamation practices to achieve this goal.

Research Questions

Objective 1 will specifically focus on the following research questions:

- Does the vegetation community on pads meet expected thresholds for composition and tree growth performance of forest ecosystems?
- Which pad characteristics result in a vegetation composition and tree growth performance that meet expected thresholds for a forest ecosystem?

Experimental Approach

To determine if sustainable forest ecosystems develop on pads and what factors result in development of sustainable forest ecosystems, reclaimed pads with different vegetation compositions will be selected. Sites will be stratified into groups or treatment levels based on their vegetation composition:

- Closed or nearly closed tree and shrub canopy
- Open canopy of trees and shrubs
- No/minimal tree and shrub canopy.

Differences between the pad characteristics and local surroundings of pads of the treatment levels will be used to determine which factors affect development of a sustainable forest ecosystem on pads. To determine if pads support sustainable forest ecosystem, a fourth treatment level will be upland (forested) wellsites that have met the natural recovery or planted requirements of the Forested Reclamation Criteria and have received a reclamation certificate. These upland wellsites will be compared to pads with closed or nearly close tree and shrub canopy.

Effect of time will be controlled by selection sites that have been reclaimed between 15 and 20 years previous (this age range may change depending on availability of sites).

Factors that will be measured to compare pads in the different treatment groups and determine what contributes to sustainable forest ecosystem development on pads will include:

- Reclamation practices: none, deep ripping, mounding, application of amendments (or salvaged topsoil), fertilization (depending on the availability of sites)
- Pad thickness and size
- Presence, type and depth of liner (e.g., corduroy, geotextile)

- Physical and chemical properties of the pad material
- Water level within the pad material (i.e., pad water table; depth to water below the surface of the pad)
- Surrounding peatland size and proximity of the pad to off-site seed sources for upland or mineral wetland ecosystems
- Surrounding peatland type: bog, poor fen, moderate-rich fen, extreme-rich fen

Measurements that will be used to compare forest ecosystems on pads to upland wellsites will include:

- Vegetation cover, composition and structure
- Tree density, height, diameter at breast height, age, mean annual increment
- Litter accumulation and decomposition
- Density and diversity of propagules in the soil seedbank

Application

Results from this objective will be used to refine the site-specific decision support tool in the Decision Framework and Support Tool. It will provide measurable characteristics that can be used to determine if a sustainable forest ecosystem is likely to develop on the pad and the pad could be left in place or if the pad should be removed.

Objective 2) <u>Develop a mechanism for detecting and evaluating the effects of pads off-site</u>

Rationale

To make decisions about leaving a pad in place in a peatland, or to justify/approve reclamation certification for a pad left in place in a peatland, appropriate metrics, and an accurate methodology to assess the metrics, are needed to verify that there are acceptable to the surrounding peatlands. There are many options for metrics and methodologies that could be used to indicate that pads left in place are not having impacts on the surrounding peatland. The value of these different methods needs to be evaluated to ensure that we are using the appropriate measurements to have certainty about the occurrence of impacts within the peatland ecosystem overall, while also avoiding measuring unnecessary parameters that do not provide additional benefits in terms of decision making.

Research Questions

Objective 2 will focus specifically on the following research questions:

- What is the effectiveness of remote sensing as a method to detect impacts of pads left in place in peatlands and can remote sensing accurately detect different kinds of impacts?
- Are measurements of water chemistry, water levels or sedimentation required to detect impacts or are impacts to water chemistry or water levels reflected in the vegetation?
- When should impacts be detected or evaluated (I.e. how many years after pad construction or reclamation does it take for impacts reach their maximum or steady-state, if they reach a steady-state)?

Identifying ecological thresholds that define an impact was identified as an important question for this objective; however, determining thresholds needs to consider various factors include land uses, ecological role/function and risk tolerance of regulatory bodies and land users and would be beyond the scope of this research proposal. For this research objective, impact[1] will be defined as a statistical difference, at an alpha value of 0.05, between the peatland surrounding the site and an appropriate reference area(s).

Experimental Approach

To answer the research questions, sites will be stratified into groups based on visual indicators of off-site impacts:

- No visual impact
- Visual impact – difference in vegetation or ponded water as observed on an aerial image

Sites will also be stratified by time since construction of the pad:

- 5 to 10 years since construction
- 10 to 20 years since construction
- >20 years since construction

Field measurements of water levels, water chemistry, sedimentation and vegetation composition, cover and density of the peatland adjacent to the pad will be taken and compared to an appropriate reference area. Similarly, remote sensing will be utilized to characterize the peatland adjacent to the pad and the remote sensing data will be compared to an appropriate reference area.

Data will be analyzed as follows:

1. To determine if remote sensing can be used to identify impacts, outcomes of field-based measurements (impact or no-impact based on differences between peatland adjacent to the pad and a reference area) will be compared to remote-sensing based outcomes to determine if there is a correlation. The effectiveness of remote sensing to identify vegetation impacts compared to water and sedimentation impacts as well as the ability to detect less severe impacts will be evaluated.
2. To determine if water chemistry, water levels or sedimentation measurements are needed to identify impacts or just vegetation measurements, measurements will be compared to reference areas, if there is a difference in water chemistry, water levels or sedimentation but not vegetation, it could suggest that vegetation measurements are not sufficient. However, if vegetation, water chemistry, water levels and sedimentation are all different, vegetation measurements may suffice. These outcomes may be related to time since construction of pad as vegetation may take longer to respond than the other parameters. Hence, including different ages of pads in the comparison may determine when (years since pad construction/reclamation) vegetation measurements alone can

[1] *The definition for impact is subject to change based on site selection.*

be used to identify impacts and when water chemistry, water levels or sedimentation measurements also required to identify impacts.

3. To determine when impacts should be detected or evaluated and when they reach their maximum or steady state will utilize remote sensing. Historical remote sensing data will be utilized and learnings from analysis 1 and 2 will be incorporated. Changes in impacts will be tracked over time to determine when a maximum or steady-state has been achieved. The field measurements and outcomes from analysis 2 will also be used to verify the results.

Application

Results from this objective will be used to develop standardized methods for measuring site impacts which can be used to guide decisions in the local and regional impacts decision support tool.

Objective 3) Investigate the factors that result in padded sites having off-site impacts to their surrounding peatland ecosystems in the long-term and affect the extent and severity of these impacts

Rationale

The occurrence, or the potential for the occurrence, of impacts to the surrounding peatland as a result of a pad left in place is a major factor in justifying/approving reclamation certification for pads left in place in peatlands. Current and short-term off-site impacts can be directly measured (through work to address Objective 1), but prediction of future impacts is also a critical component of the decision. In the absence of long-term monitoring, there is a need to understand the factors that result in off-site impacts, to use these as predictors of long-term impacts.

Research Questions

Objective 3 will focus specifically on pads, including both padded wellsites and access roads, that have been reclaimed for 20 years or greater and the following research questions:

- What characteristics of pads result in impacts to the long-term health and function of the surrounding peatland ecosystem?
- What characteristics of peatland ecosystems and the location and orientation of the wellpad/access road within a peatland result in the pad having a long-term impact on the ecosystem?

Experimental Approach

To answer the research questions, sites will be stratified into groups based on visual indicators of off-site impacts:

- No visual impact
- Visual impact – difference in vegetation or ponded water as observed on an aerial image

Post data analysis, sites may be reclassified as impacted and not impacted based on the definition of impacts; however, this will ensure that sites with and without impacts are included.

Sites will also be stratified by peatland type:

- Bog
- Fen
- Marsh

Effect of time will be controlled by selection sites that have been reclaimed >20 years previous (this age range may change depending on availability of sites and assuming that impacts have reached a steady state). As explanatory factors for pad impacts, measurements of the following characteristics will be made in the field and using remote sensing data/aerial imagery. Data collected from Objective 1 and 2 will be utilized:

- Facility type: padded wellsite without a padded access road, padded wellsite with a padded access road, padded access road only
- Pad size
- Pad thickness
- Physical and chemical properties of the pad material.
- Location of the pad within the peatland
- Erosion and run-off potential of the pad; inferred from vegetation cover, slope and evidence of past erosion
- Peat thickness
- Texture of the substrate below the peat.
- Size of the peatland
- Heterogeneity of the peatland

To determine the characteristics of pads and peatlands that result in impacts to the long-term health and function of the surrounding peatland ecosystem, pads with impacts in the surrounding peatland will be compared to pads without impacts to determine if there are certain characteristics associated with pads with or without impacts. If there are associated characteristics, these characteristics can be used as predictions for impacts.

Application

Results from this objective will be used to refine the local and regional impacts decision support tool in the Decision Framework and Support Tool. It will provide measurable characteristics that can be used to determine if a pad could be left in place or if the pad should be removed.

Objective 4) Evaluate the effectiveness of partial reclamation activities for alleviating off-site impacts resulting from pads left in place in peatlands

Rationale

Instead of complete pad removal, alleviating adverse effects to surrounding peatlands caused by pads left in place may be achieved through partial reclamation. Whether or not partial reclamation activities are successful at alleviating these off-site impacts is one of several factors that is considered in justifying/approving reclamation certification for pads left in place in peatlands.

For the purposes of this project, the partial reclamation options that will be studied are those that mitigate off-site impacts and may include:

- Partial removal of pad material to create drainage channels (e.g., swales), allowing water flow across/through the padded feature
- Partial removal of pad material from a vertical perspective to reduce the thickness of the pad and lower the elevation of the pad surface to match the surrounding peatland (on all or portions of the site)

Installation of culverts was not included as a potential partial reclamation option that will be studied because culverts cannot be left in place for reclamation certification. Partial reclamation options targeted at alleviating or improving soil conditions on the pad itself (e.g., deep ripping) are also not included in the project.

Research Questions

This project will specifically focus on the following research questions:

- Are partial reclamation methods effective in reducing off-site impacts caused by pads left in place in peatlands?
- What characteristics of the pads affect the success of partial reclamation?
- What characteristics of peatland ecosystems and the location and orientation of the pads within a peatland affect the success of partial reclamation?

Experimental Approach

Objective 4 will not include application of partial reclamation treatments to unreclaimed sites, instead sites where partial pad removal has already been conducted will be located and these pads will be utilized to answer the research questions. Sites will be stratified into groups or treatment levels based on reclamation treatment:

- Partial pad removal: swales
- Partial pad removal: vertical
- No pad removal
- Full pad removal

Sites will also be stratified by facility type:

- Access Road
- Wellsite

And sites will be stratified by peatland type:

- Bog
- Fen
- Marsh

Remote sensing will be utilized (incorporating the learnings from the use of remote sensing in Objective 2), to evaluate historical impacts in the peatlands surrounding the pads prior to application of the reclamation treatment. This will be compared to conditions of the peatland after application of the reclamation treatment and over several years (if possible) to determine how the peatland changes due to the partial reclamation. Field measurements of water levels, quality and vegetation composition and cover of the surrounding peatland will also be taken and compared to an appropriate reference area to verify the presence or absence of impacts.

In addition to the treatments, the following field measurements will also be taken on pads with partial reclamation to determine where partial reclamation is successful:

- Pad size and shape
- Pad thickness and size
- Physical and chemical properties of the pad road material
- Length of time the pad road has been present
- Location of the pad road within the peatland and distance to edge of the peatland
- Peat depth
- Permeability of the substrate below the peat
- Peatland size
- Peatland heterogeneity
- Peatland water level and hydrology

Application

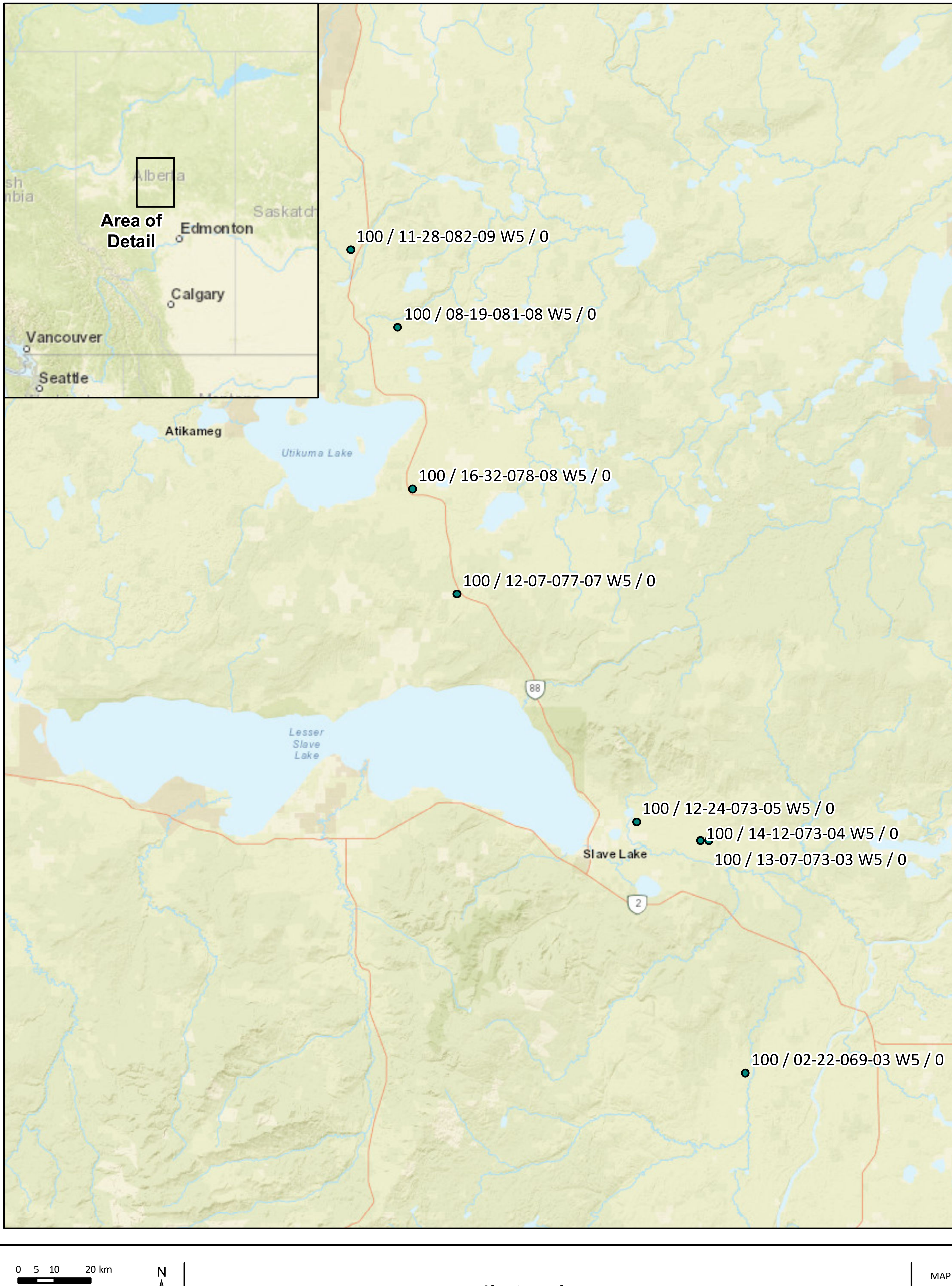
Results from this objective will be used to help determine when partial reclamation can be applied to alleviate off-site impacts.

APPENDIX C: DATA PREPERATION

To prepare the field data for data analysis:

- The mean of the three sample areas per stratification zone was calculated for use in statistical analysis and is shown on figures
- Select variables were excluded from analysis due to insufficient replication or lack of data (e.g., if a tree species was not present on a site, annual tree height growth could not be determined for that site)
- No sites were excluded from analysis despite outlying characteristics due to limited replication (e.g., 100 / 02-22-069-03 W5 / 0 was not excluded even though it may have been located in a transitional area and not a peatland); however, sites may be excluded in a large-scale study
- Tree height and age data were used to determine mean annual tree height growth (height divided by age). This calculation was used in the pilot study for simplicity, but in a large-scale study a standardized method such as site index should be used
- Data from the two understory vegetation plots at each sample area were averaged and the species cover data were used to calculate the Shannon Diversity Index. Shannon Diversity Index was calculated using all species as well as using only species native to the boreal forest ecosystem
- The total number of native species present on the site (wellsite and access road) was determined by counting number of entries in the list of species generated during the 10-minute walkaround
- Uniformity of the pad texture was rated as uniform (entire depth profile had a similar texture) or variable (two or more layers with different textures)
- Organic matter presence in the profile (excluding the litter layer) was rated as present or absent
- Changes in pad material colour (gleying or mottling) were used to determine a depth to anoxic conditions
- Percent sand, silt and clay were analyzed rather than soil texture categories (e.g., loam, clay loam)
- A numerical rating system was applied to categorical data (e.g., texture, consistence, structure)
- For sample areas where soil samples were collected from 0-15 and 15-30 cm depth intervals, an average of these two depths was calculated to allow comparison to other sample areas where only a 0-30 cm depth interval sample was collected.

APPENDIX D: MAPS



WGS 1984 World Mercator
Date: Feb 23/22

Site Locations

MAP: **1**

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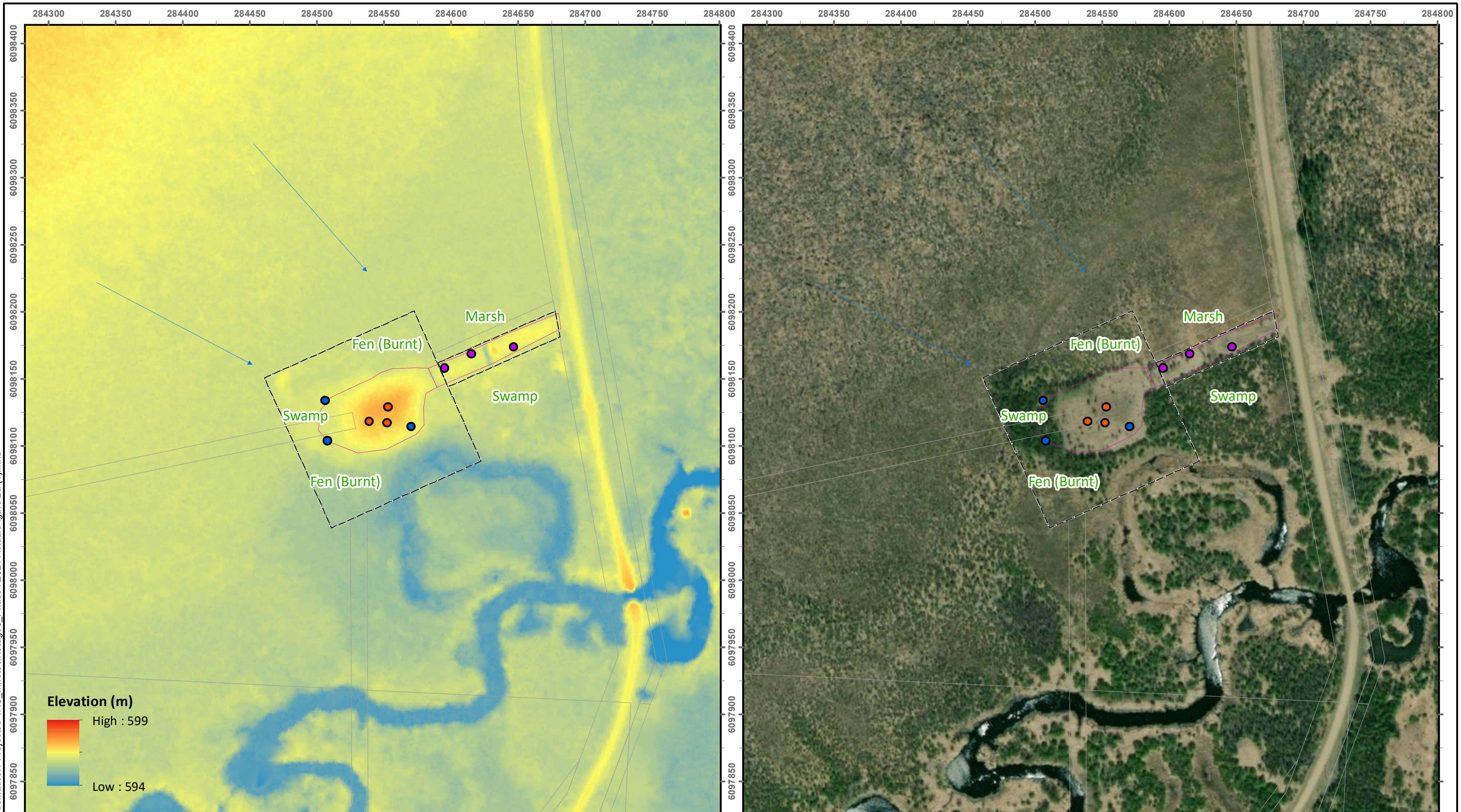

Access Road Sample Area
Pad Centre Sample Area
Pad Periphery Sample Area
Water Flow
Surveyed Site Boundary
Pad
Disposition

0 12.5 25 50 75 100 125 m

NAD 1983 UTM Zone 12N

Date: Mar 17/22

N

100 / 02-22-069-03 W5 / 0

Digital Elevation Model and Aerial Imagery

MAP:

2a

Geospatial data presented in this figure may be derived from external sources and Vertex does not assume any liability for inaccuracies. This figure is intended for reference use only and is not certified for legal, survey, or engineering purposes.

Note:

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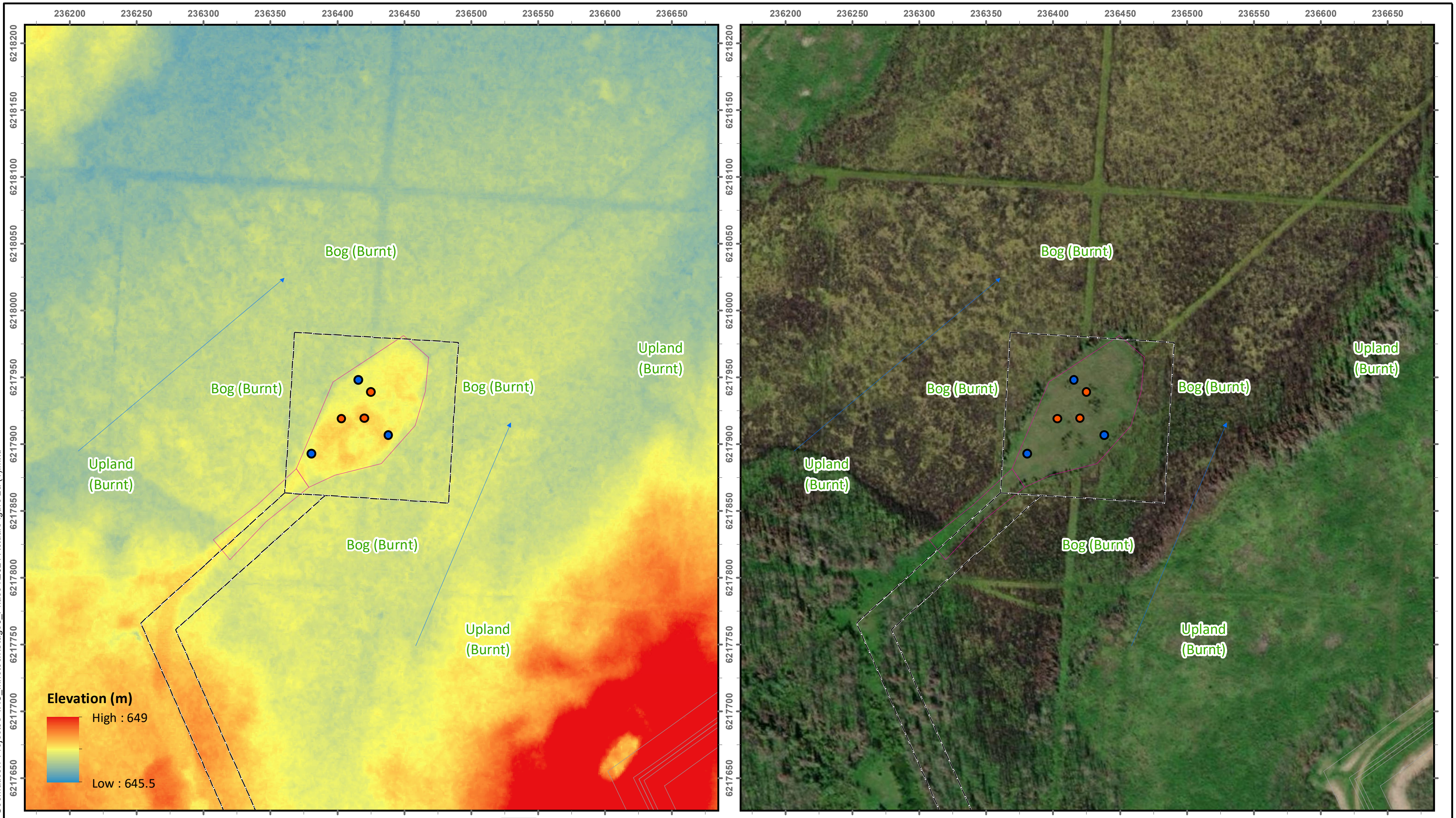


- Access Road Sample Area
- Pad Centre Sample Area
- Pad Periphery Sample Area
- Water Flow
- Surveyed Site Boundary
- Pad
- Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N

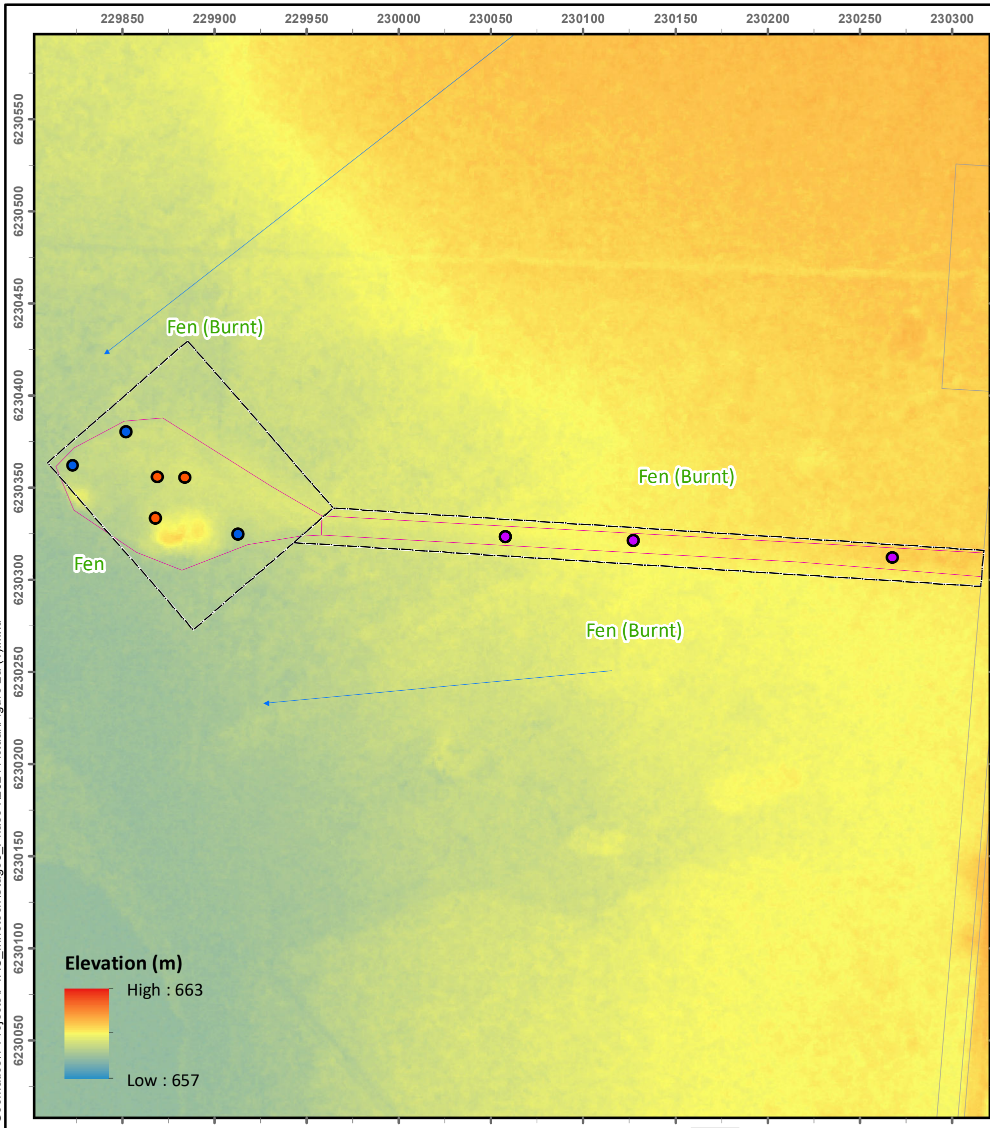
Date: Mar 17/22

N

100 / 08-19-081-08 W5 / 0
Digital Elevation Model and Aerial Imagery

MAP: **2b**

Note:



Access Road Sample Area	Water Flow	Disposition
Pad Centre Sample Area	Surveyed Site Boundary	
Pad Periphery Sample Area	Pad	

0 12.5 25 50 75 100 125 m

NAD 1983 UTM Zone 12N

Date: Mar 17/22

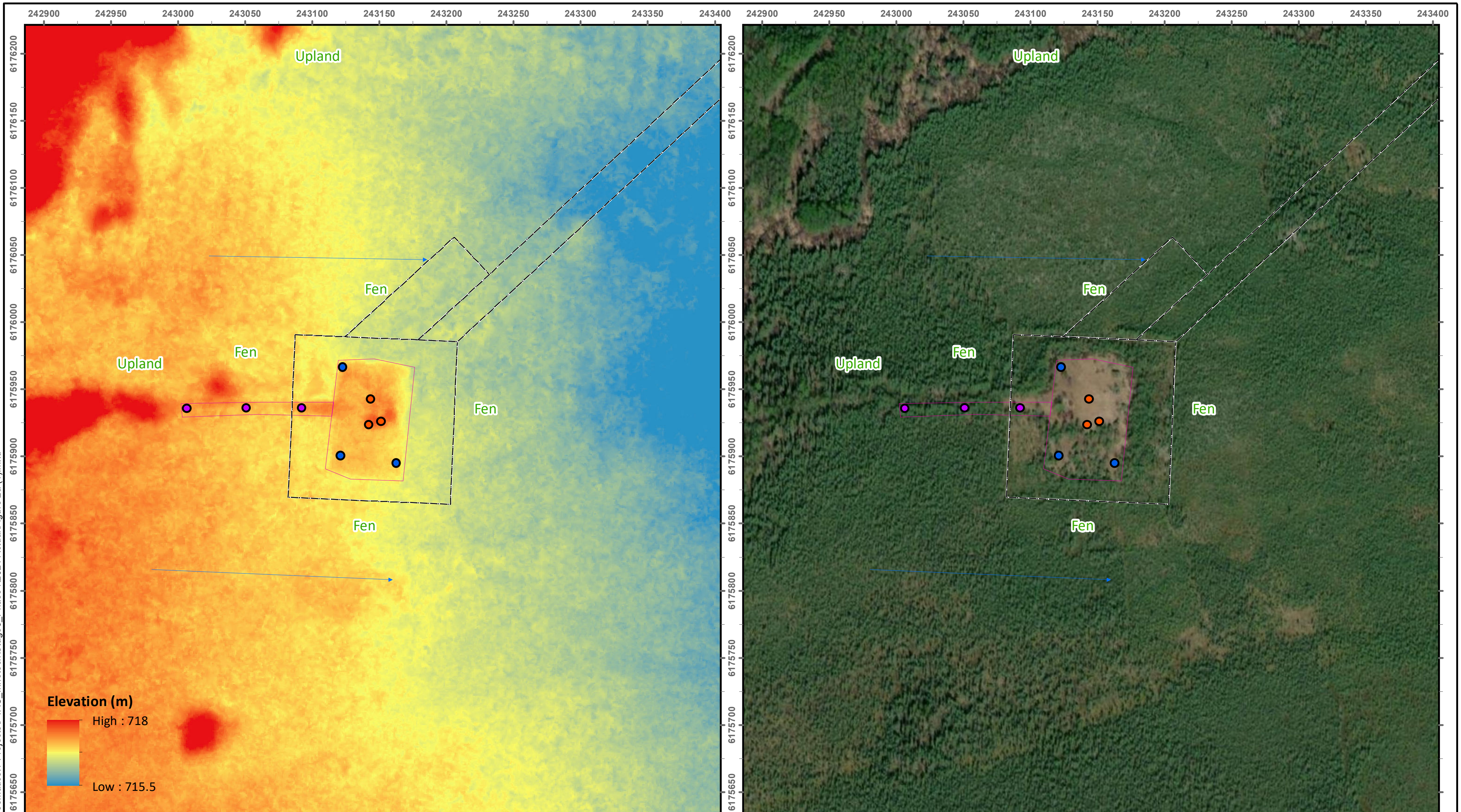
N

100 / 11-28-082-09 W5 / 0

Digital Elevation Model and Aerial Imagery

MAP: **2c**

Note:



Access Road Sample Area

Pad Centre Sample Area

Pad Periphery Sample Area

Water Flow

Surveyed Site Boundary

Pad

Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N

Date: Mar 17/22

N

100 / 12-07-077-07 W5 / 0

Digital Elevation Model and Aerial Imagery

MAP:

2d

Note:

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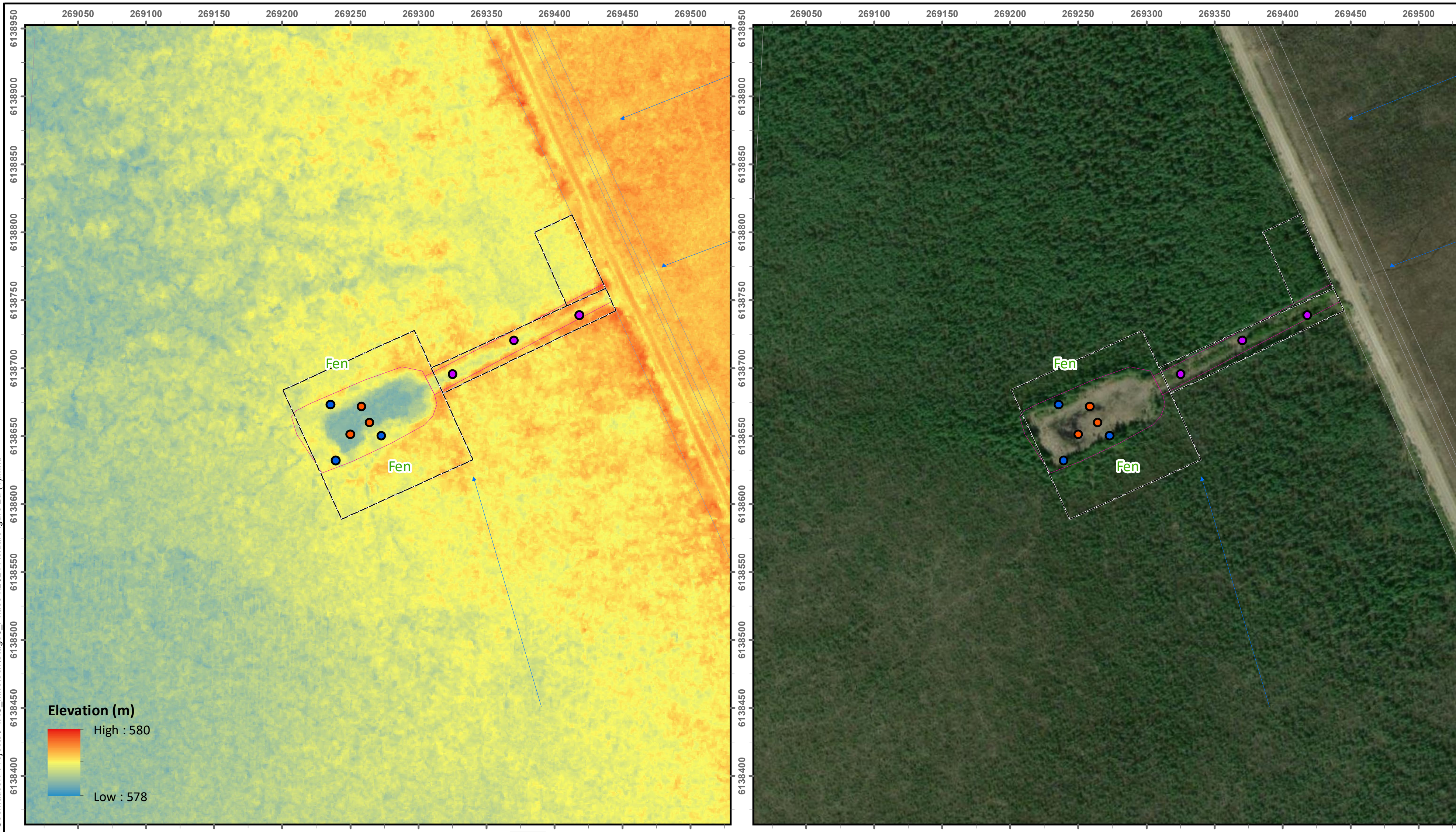


Access Road Sample Area
Pad Centre Sample Area
Pad Periphery Sample Area
Water Flow
Surveyed Site Boundary
Pad
Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N

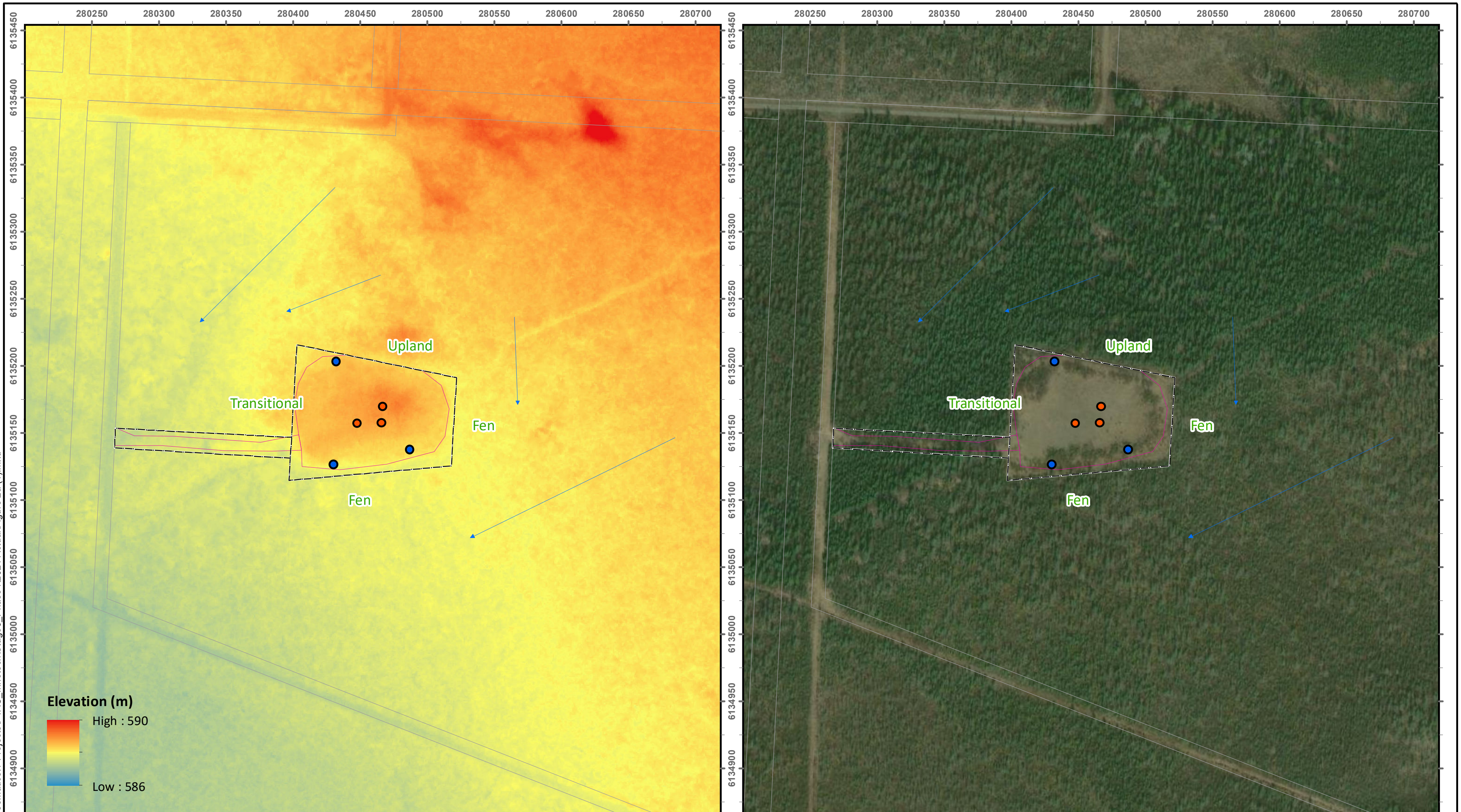
Date: Mar 17/22

N

100 / 12-24-073-05 W5 / 0
Digital Elevation Model and Aerial Imagery

MAP: **2e**

Note:



- Access Road Sample Area
- Pad Centre Sample Area
- Pad Periphery Sample Area
- Water Flow
- Surveyed Site Boundary
- Pad
- Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N

Date: Mar 17/22

N

100 / 13-07-073-03 W5 / 0
Digital Elevation Model and Aerial Imagery

MAP: **2f**

Note:

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- Access Road Sample Area
- Pad Centre Sample Area
- Pad Periphery Sample Area
- Water Flow
- Surveyed Site Boundary
- Pad
- Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N

Date: Mar 17/22

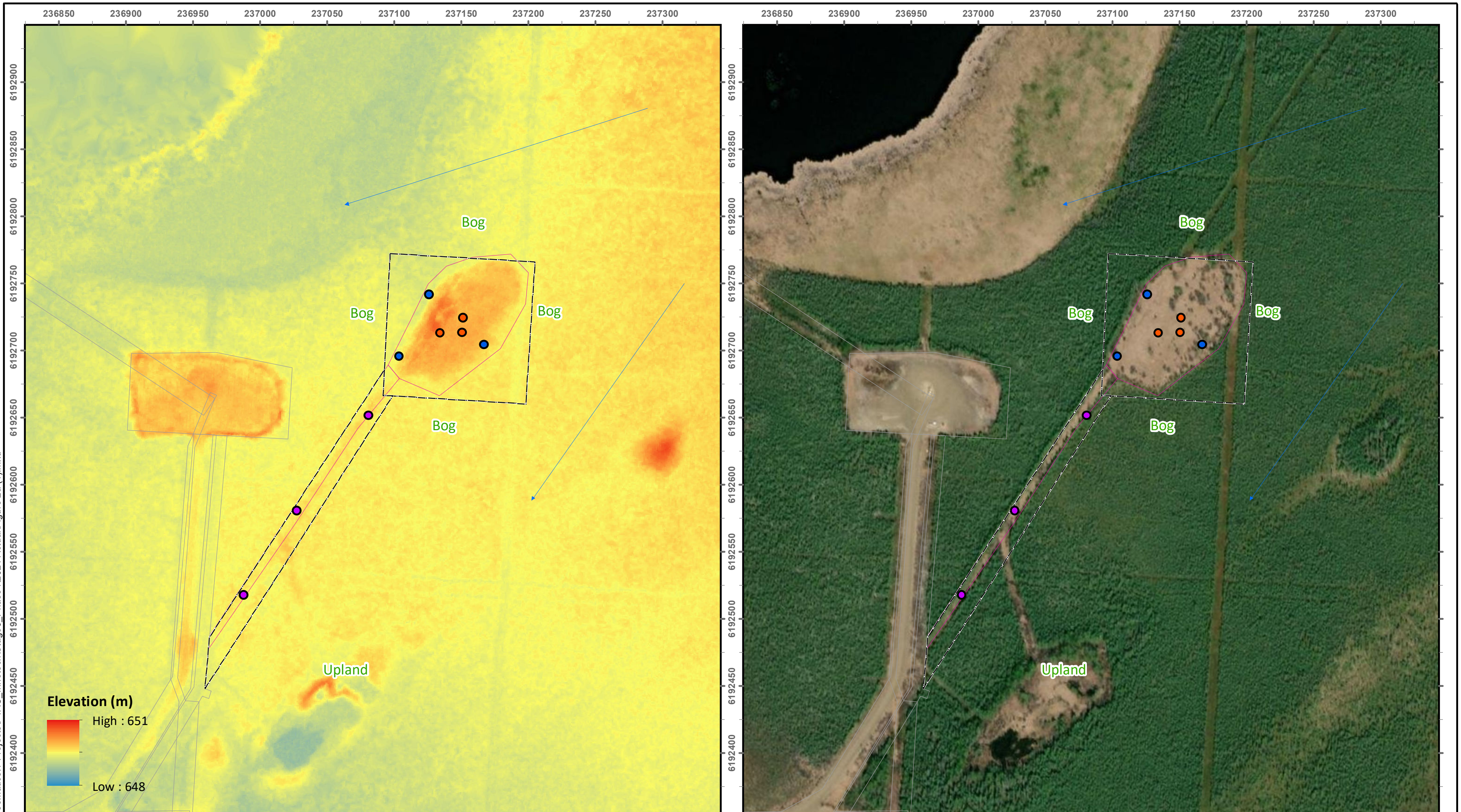
N

100 / 14-12-073-04 W5 / 0

Digital Elevation Model and Aerial Imagery

MAP: **2g**

Note:



Access Road Sample Area
Pad Centre Sample Area
Pad Periphery Sample Area
Water Flow
Surveyed Site Boundary
Pad
Disposition

0 12.525 50 75 100 125 m

NAD 1983 UTM Zone 12N
Date: Mar 17/22

N

100 / 16-32-078-08 W5 / 0
Digital Elevation Model and Aerial Imagery

MAP:
2h

Note:

APPENDIX E: FIGURES

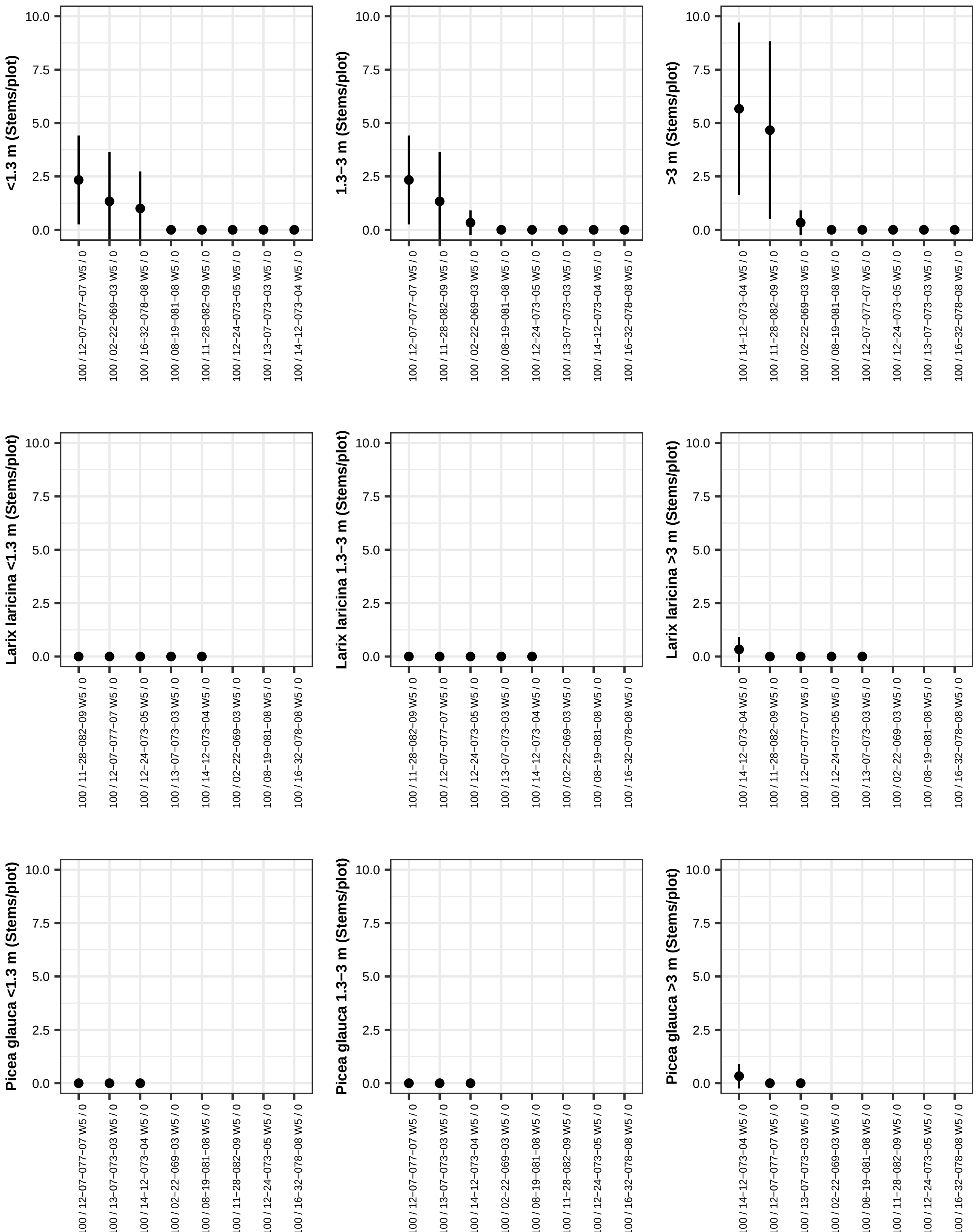
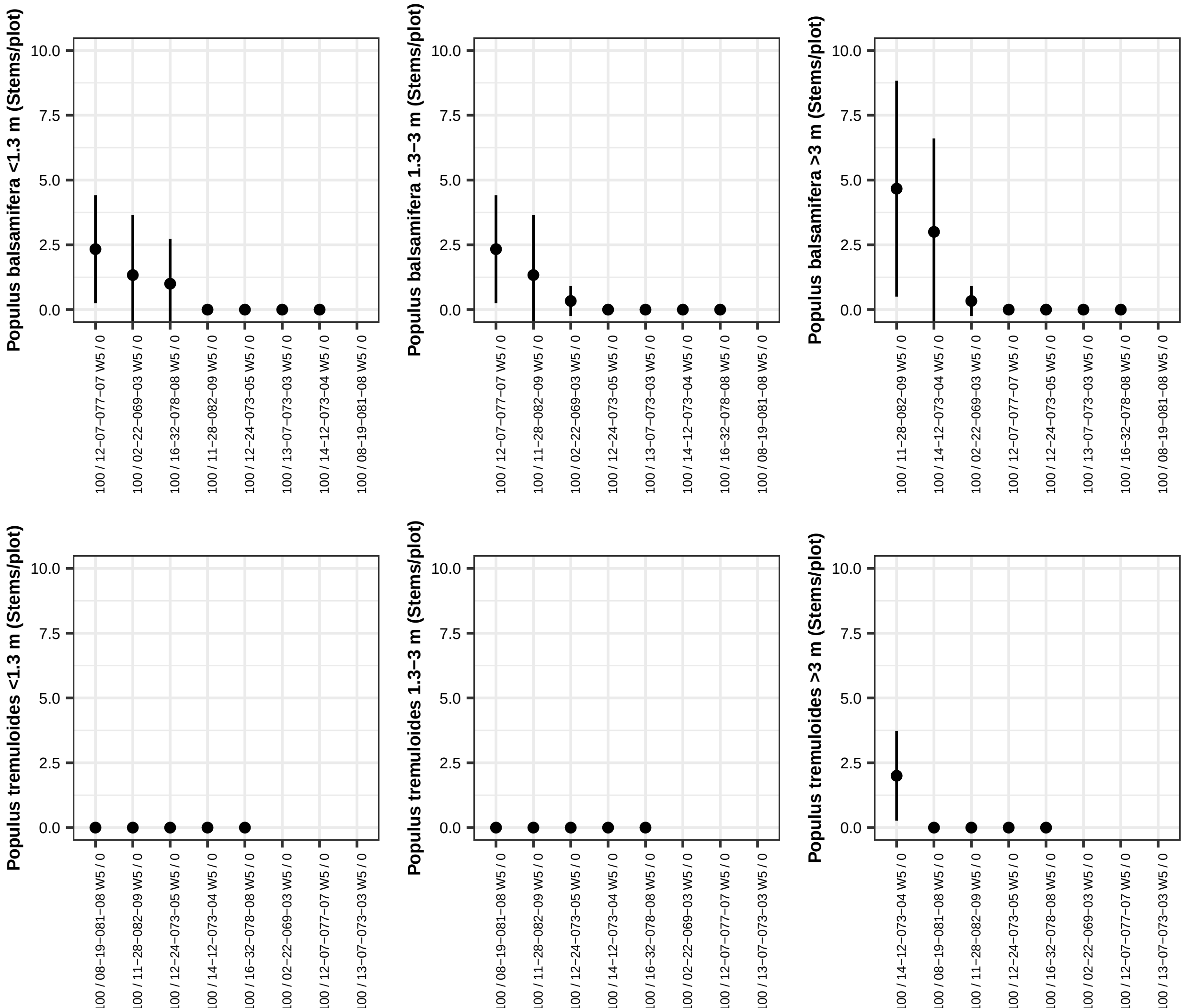


Figure 1a: Tree Stem Density in a 10 m² Plot by Species (including all species combined), Height Class, and Site. Error Bars Represent Standard Deviation of the Pad Centre Plots.



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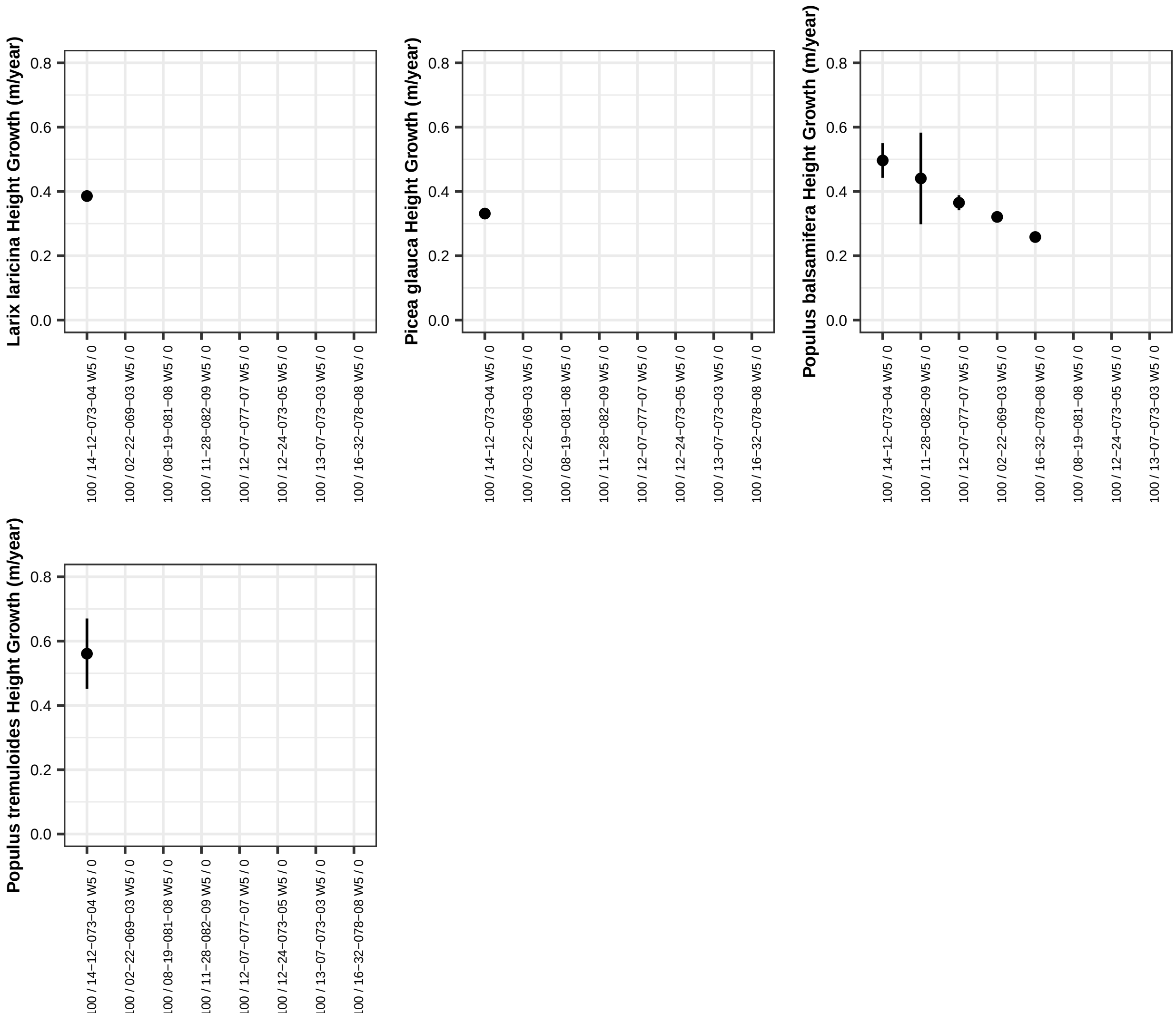


Figure 1b: Annual Tree Height Growth by Species and Site. Error Bars Represent Standard Deviation of the Pad Centre Plots.

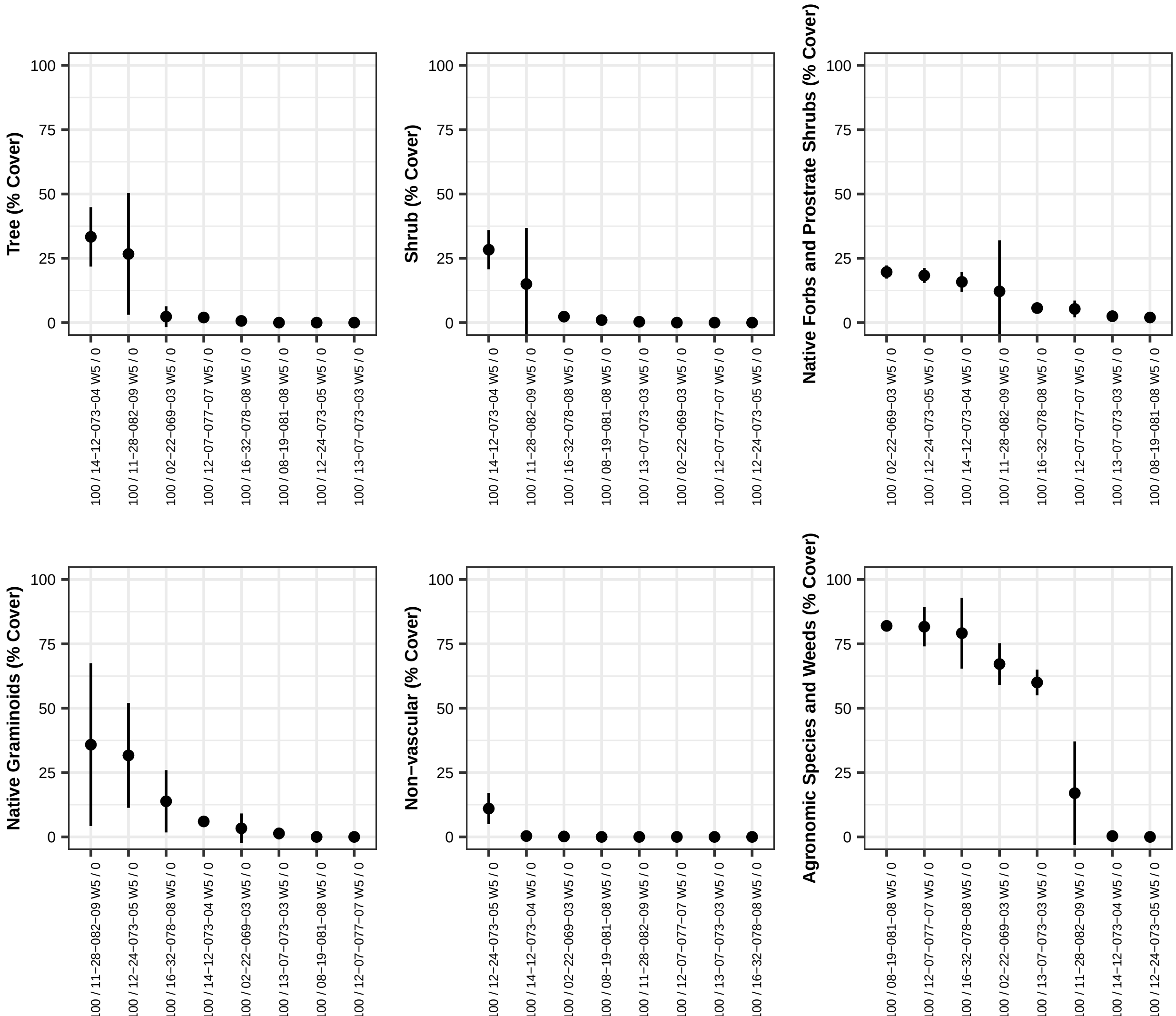


Figure 1c: Percent Canopy Cover by Vegetation Strata and Site. Error Bars Represent Standard Deviation of the Pad Centre Plots.

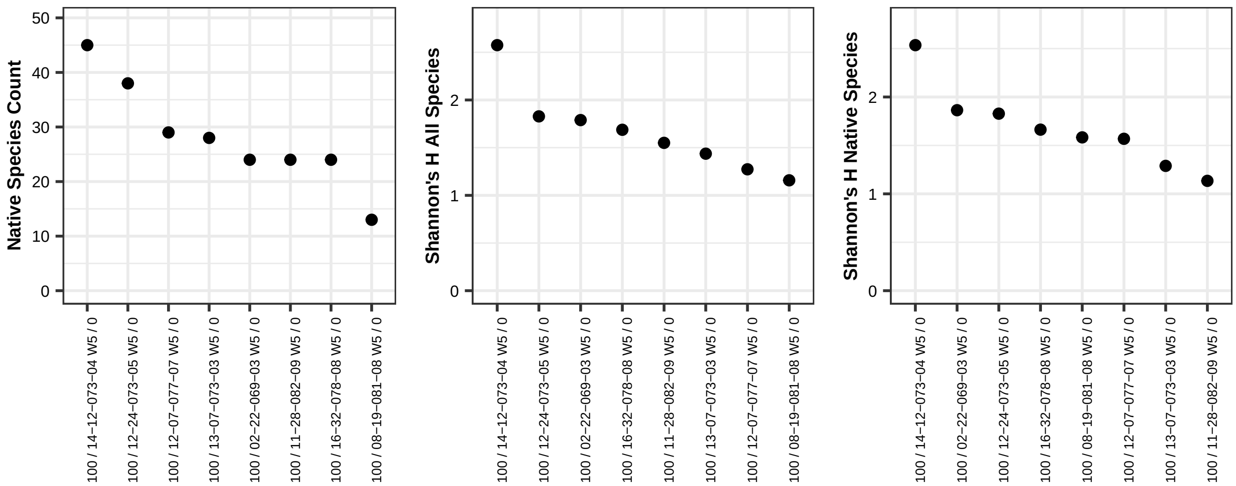


Figure 1d: Species Counts and Shannon Diversity Index by Site.

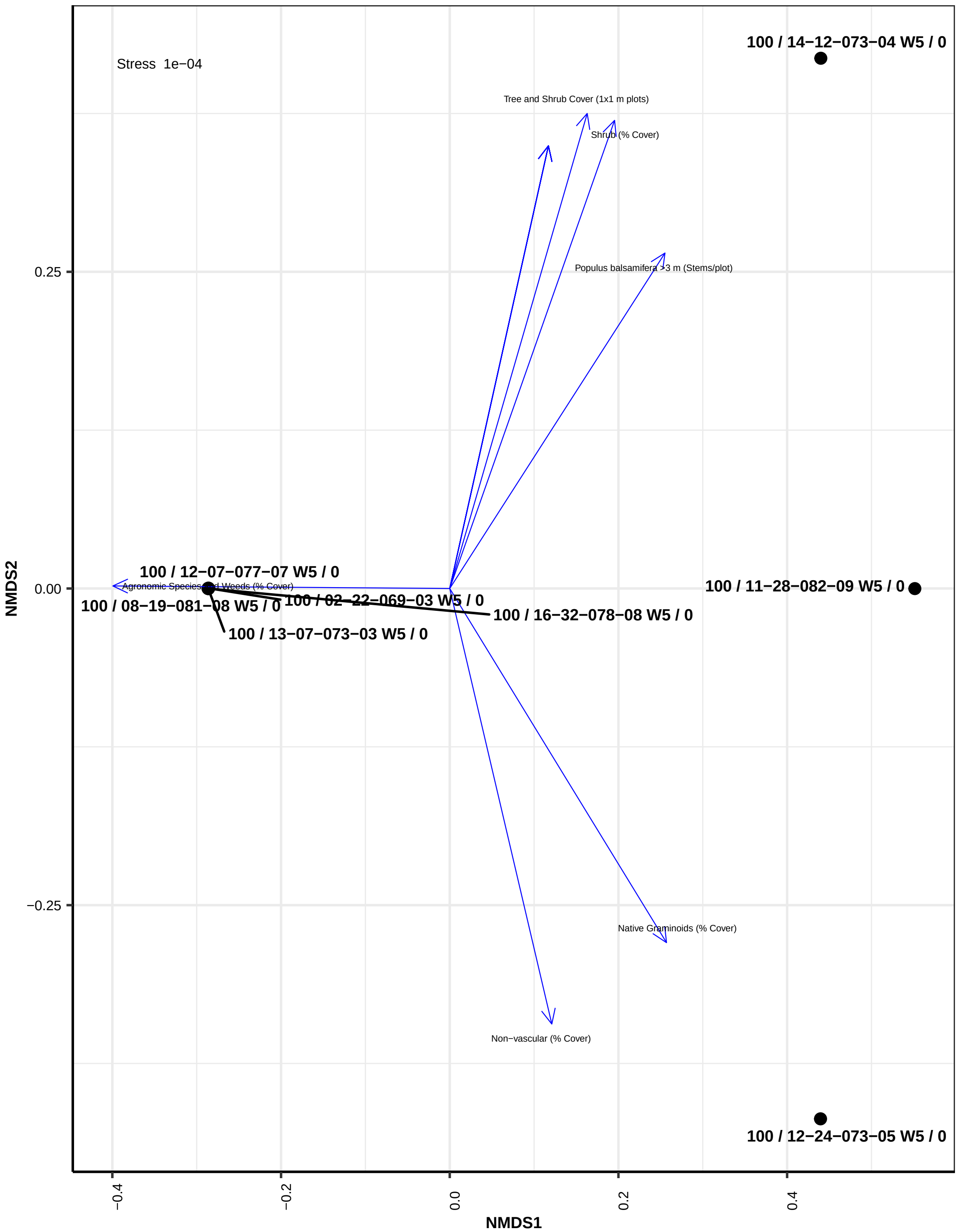


Figure 2: Non-metric Multidimensional Scaling of Vegetation Characteristics by Site. Measurements with a Coefficient of Determination Value (R^2) Greater than 0.6 are Shown as Vectors - the Measurement Increases in the Direction of the Vector.

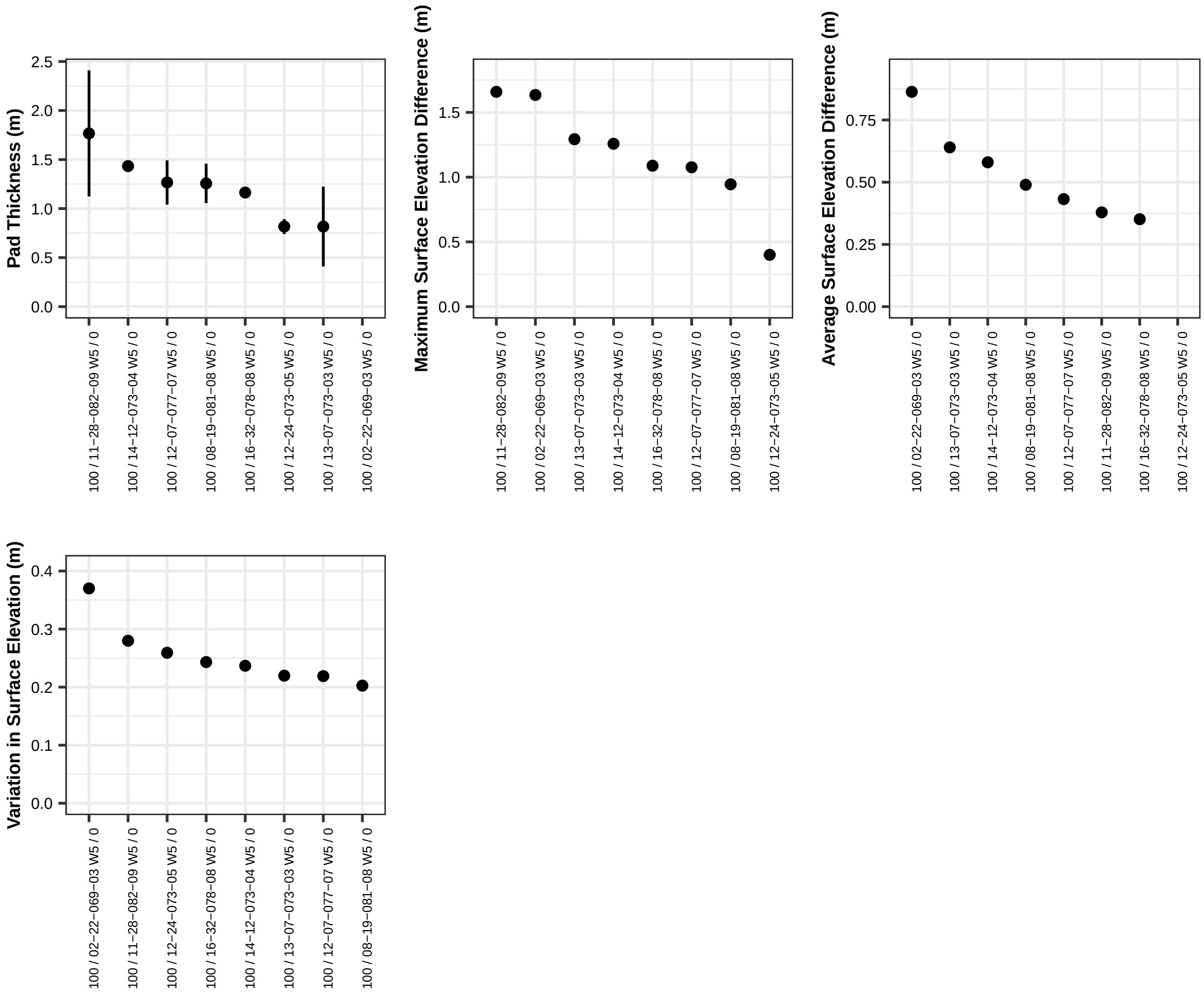


Figure 3a: Pad Centre Thickness and Elevation Characteristics. Error Bars Represent Standard Deviation of the Pad Centre Plots. Pad Thickness was not Characterized at 100/02−22−069−03 W5 / 0. Surface Elevation Difference is Between the Pad and Surrounding Peatland.

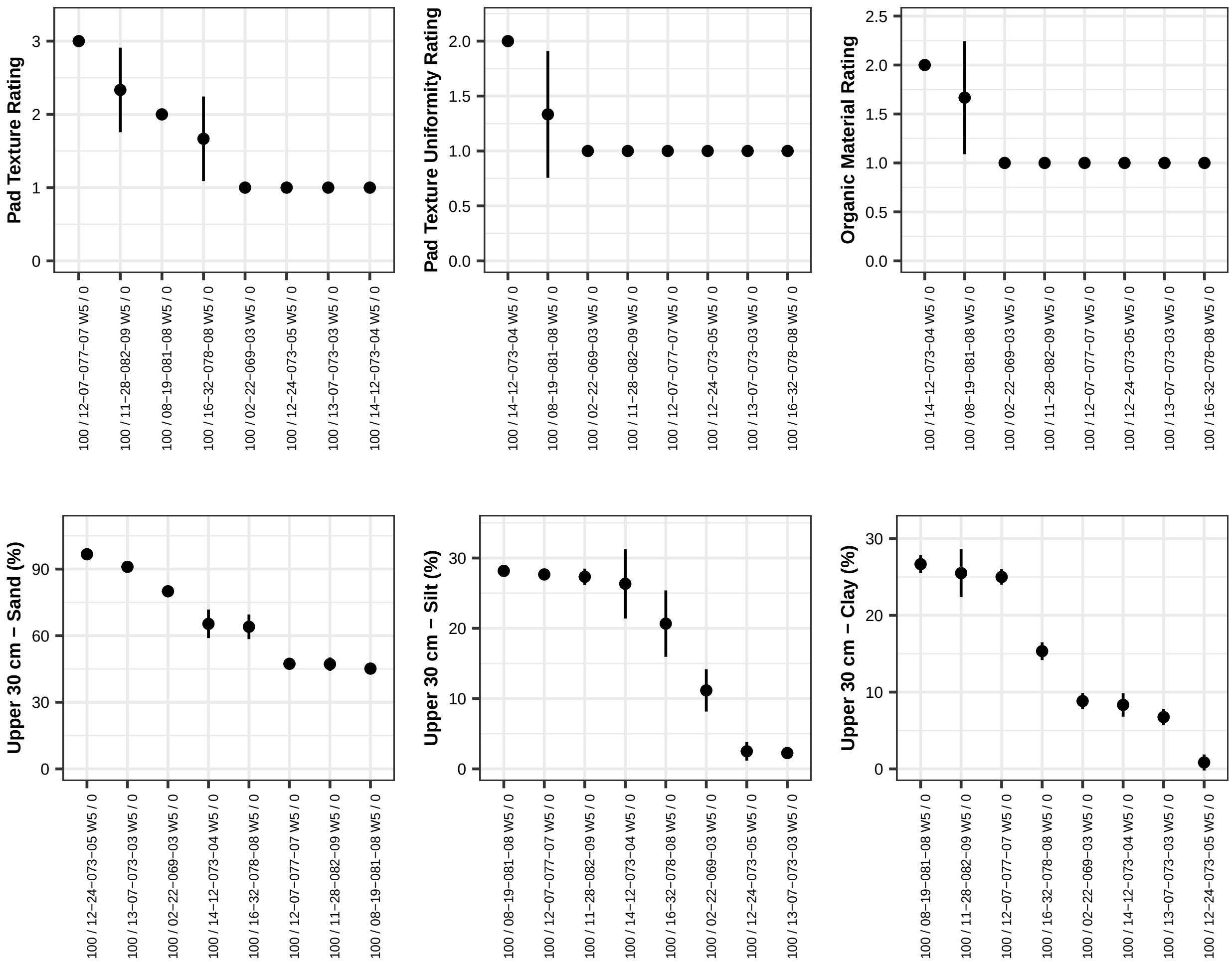


Figure 3b: Texture Characteristics, as Ratings, at Pad Centre for the Entire Pad Thickness and Upper 30 cm. Error Bars Represent Standard Deviation of the Pad Centre Plots. Soil Texture Rating (1=Coarse, 3 = Fine); Soil Texture Uniformity Rating (1=Uniform, 2=Variable); Organic Material Rating (1=Absent, 2=Present).

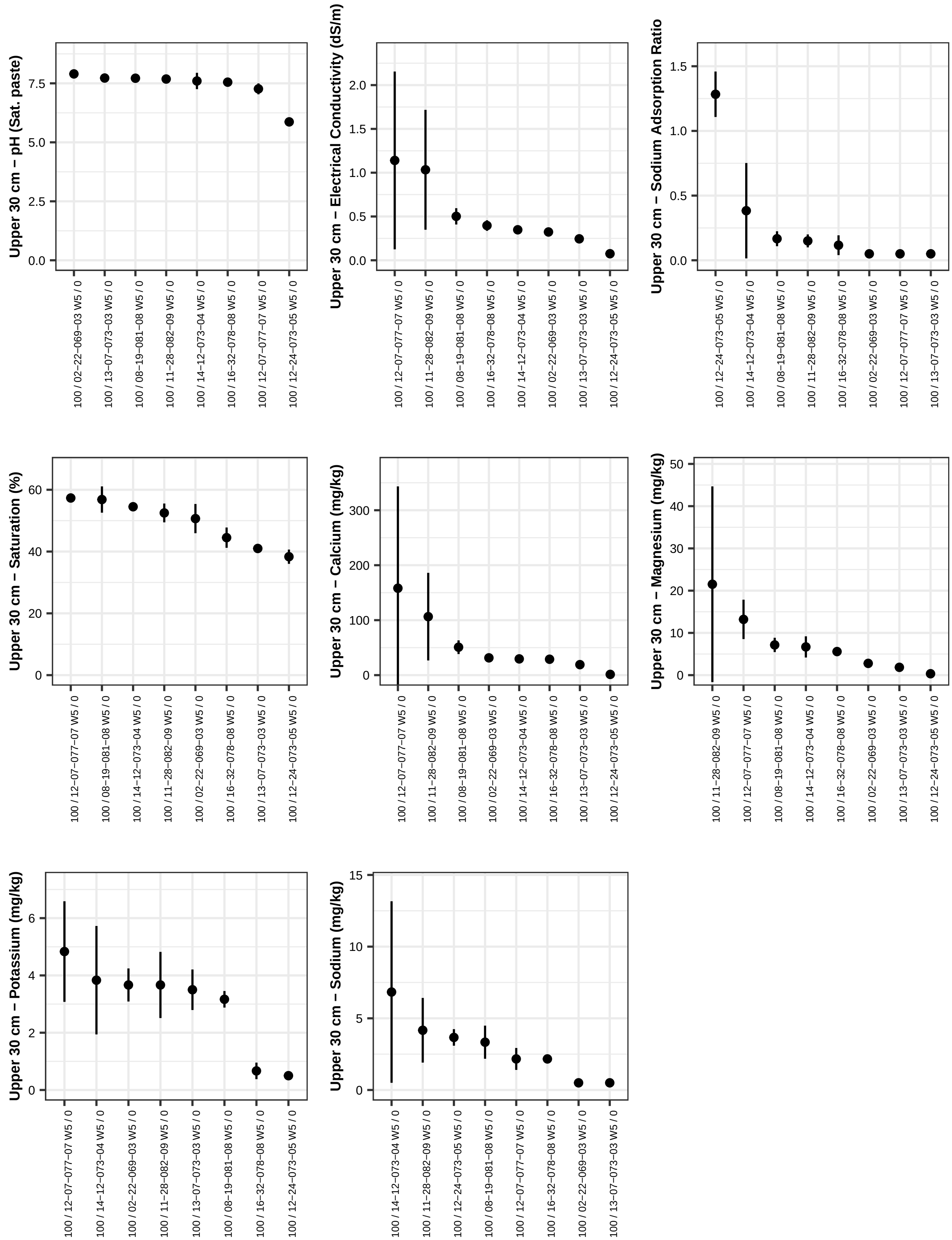


Figure 3c: Chemical Properties of the Upper 30 cm of Pad Material at Pad Centre. Error Bars Represent Standard Deviation of the Pad Centre Plots.

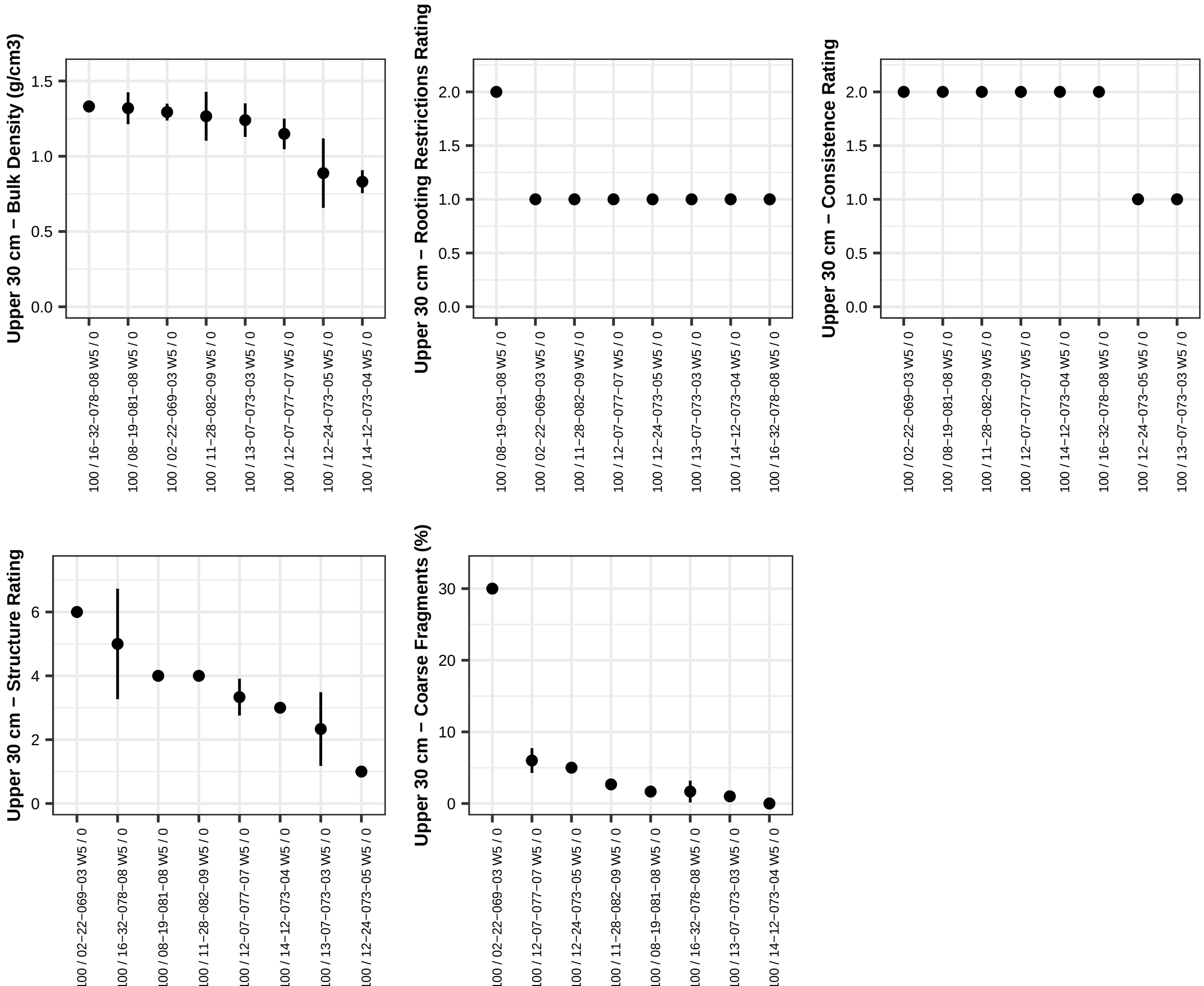


Figure 3d: Physical Properties of the Upper 30 cm of Pad Material at Pad Centre. Error Bars Represent Standard Deviation of the Pad Centre Plots. Rooting Restrictions Rating (1=None, 2=Slight); Consistence Rating (1=Loose, 2=Friable, 3=Firm); Structure Rating (1=Single Grain, 2=Medium Subangular Blocky, 3=Coarse Subangular Blocky, 4=Coarse Angular Blocky, 5=Platy, 6=Massive).

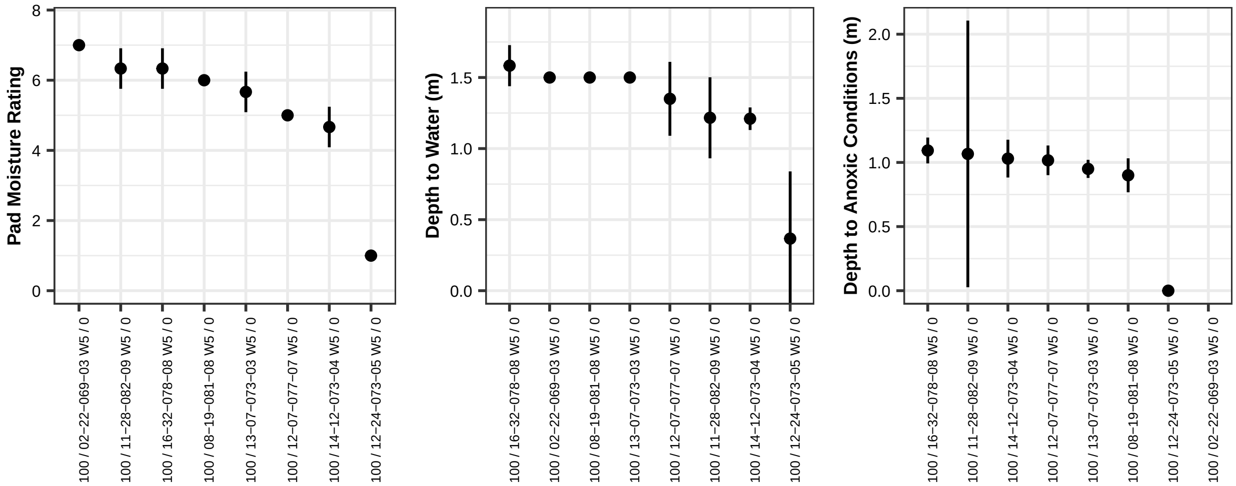


Figure 3e: Moisture Properties at Pad Centre. Error Bars Represent Standard Deviation of the Pad Centre Plots. Pad Moisture Rating (1=Saturated, 7=Dry).

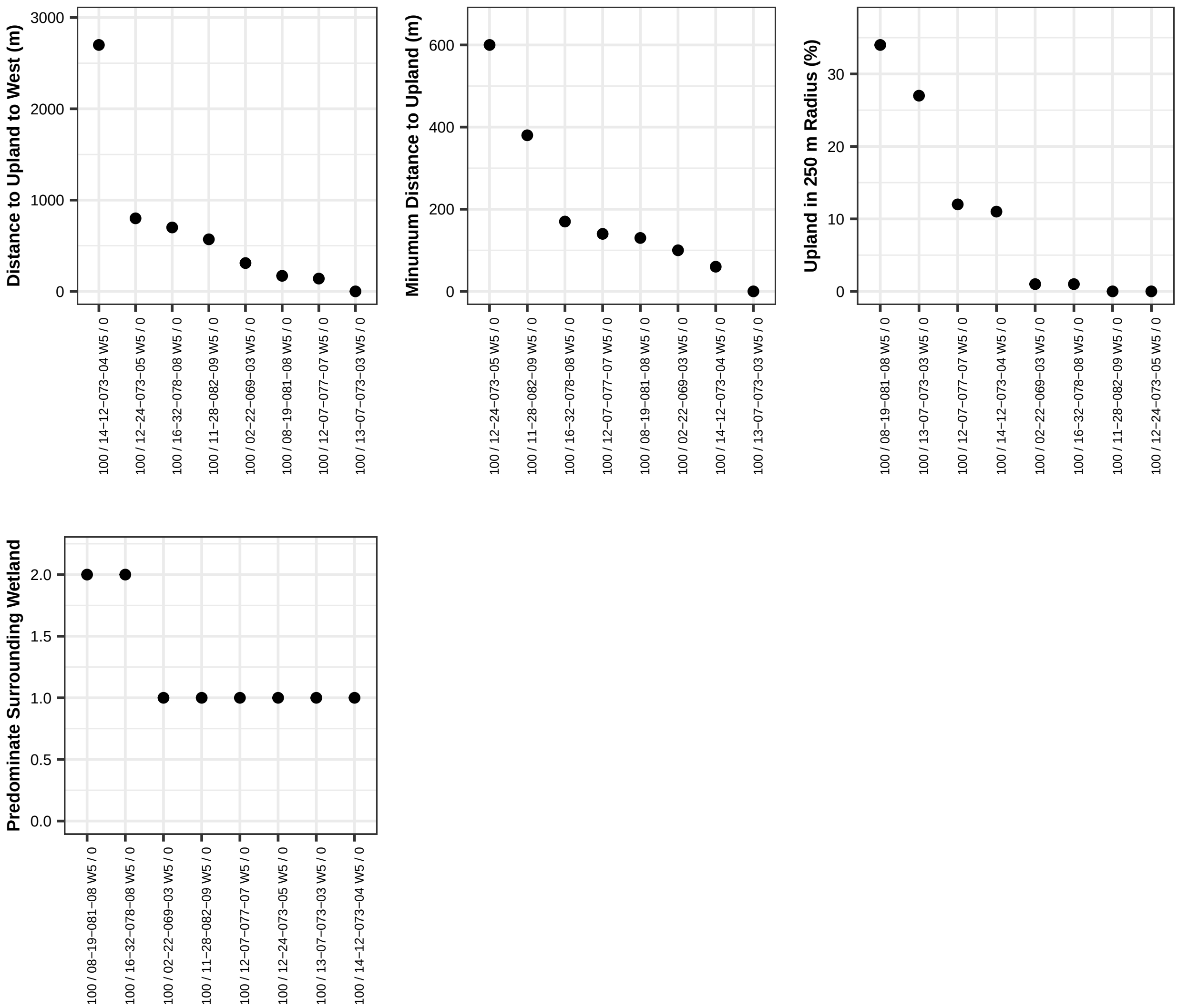


Figure 3f: Characteristics of the Surrounding Area. Wetland Type (1=Fen, 2=Bog).

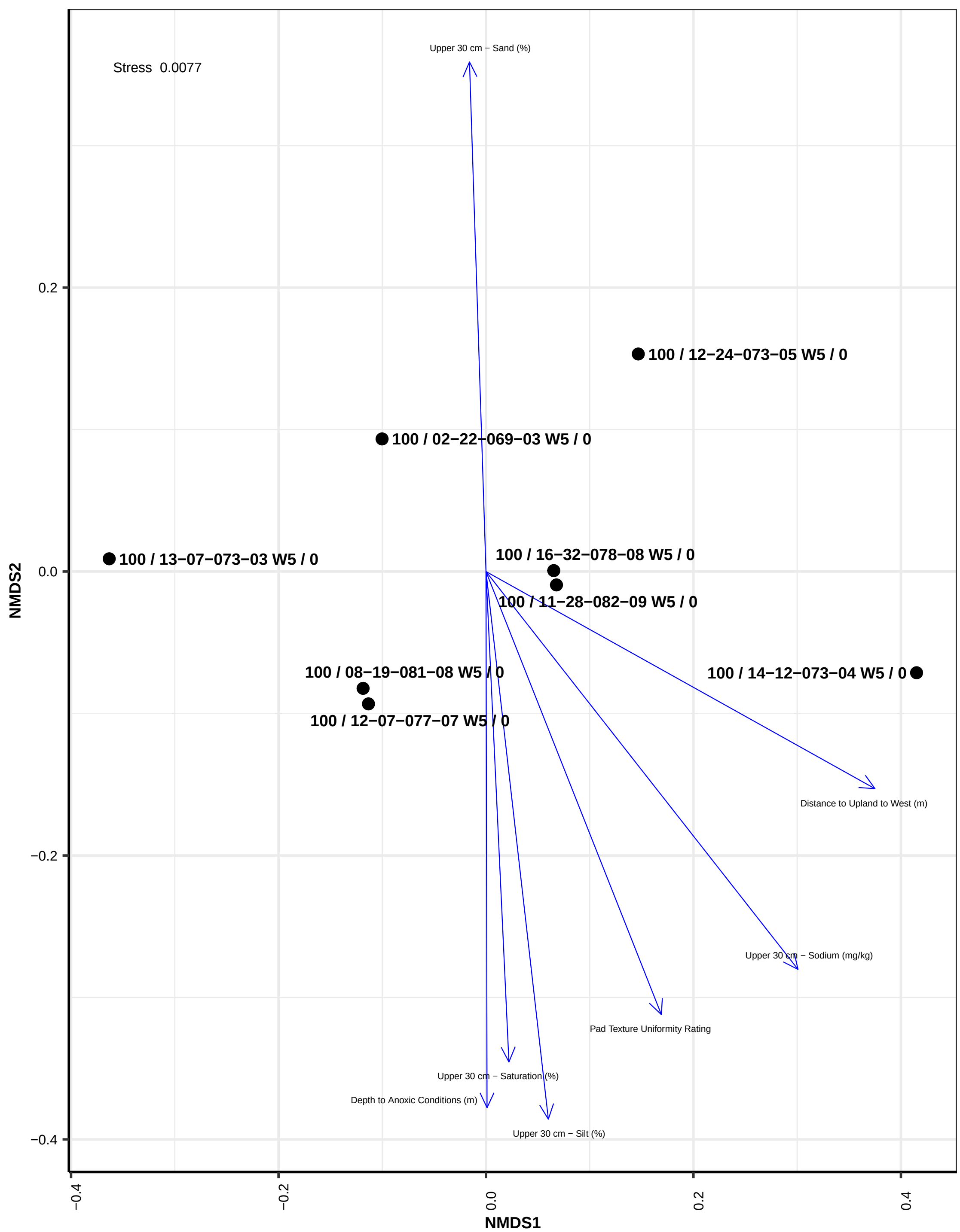


Figure 4: Non−metric Multidimensional Scaling of Pad Characteristics by Site. Measurements with a Coefficient of Determination Value (R2) Greater than 0.6 are Shown as Vectors − the Measurement Increases in the Direction of the Vector.

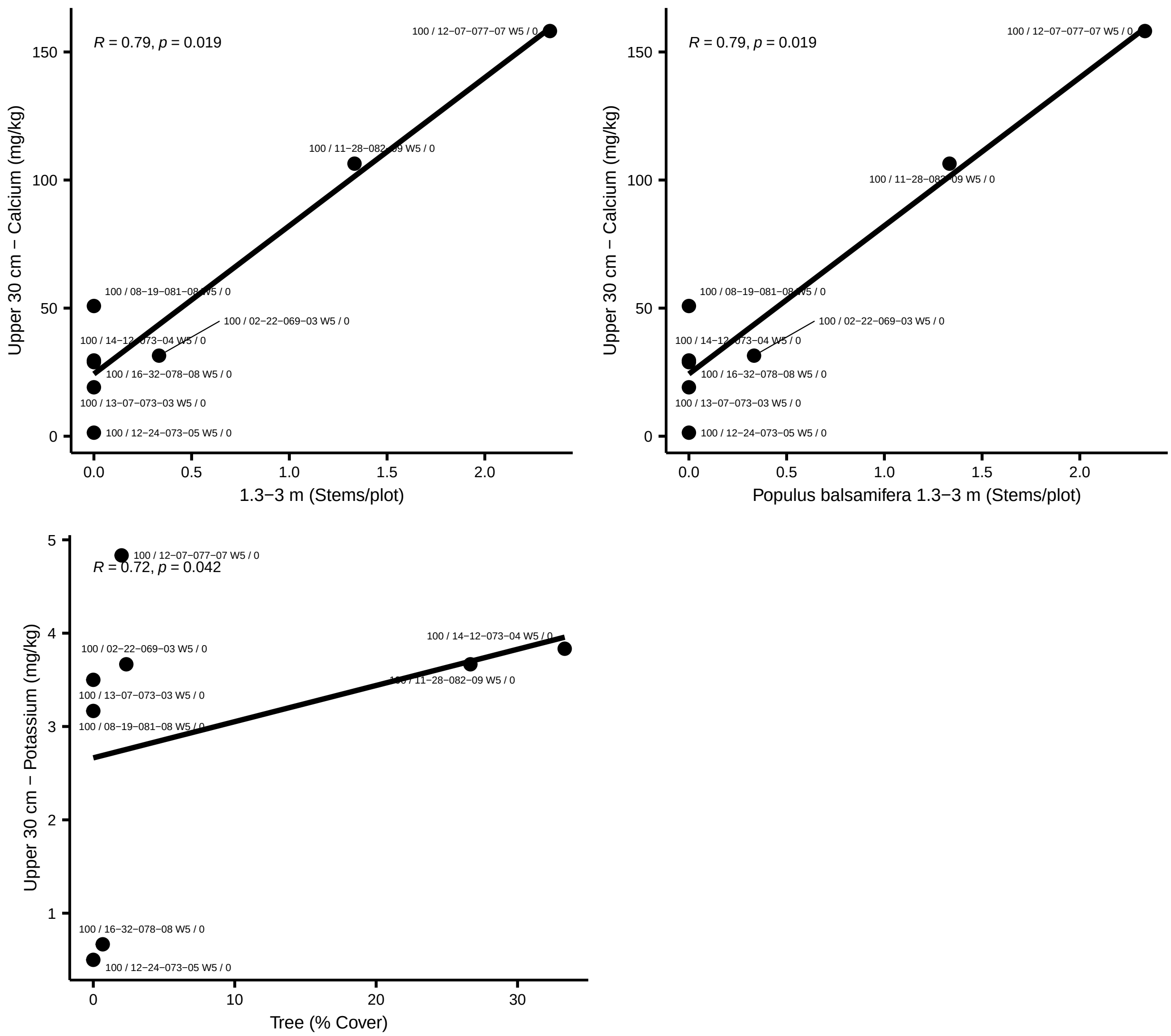


Figure 5a: Spearman Rank Correlation between Pad Chemical Characteristics of the Upper 30 cm of Pad Material and Vegetation.

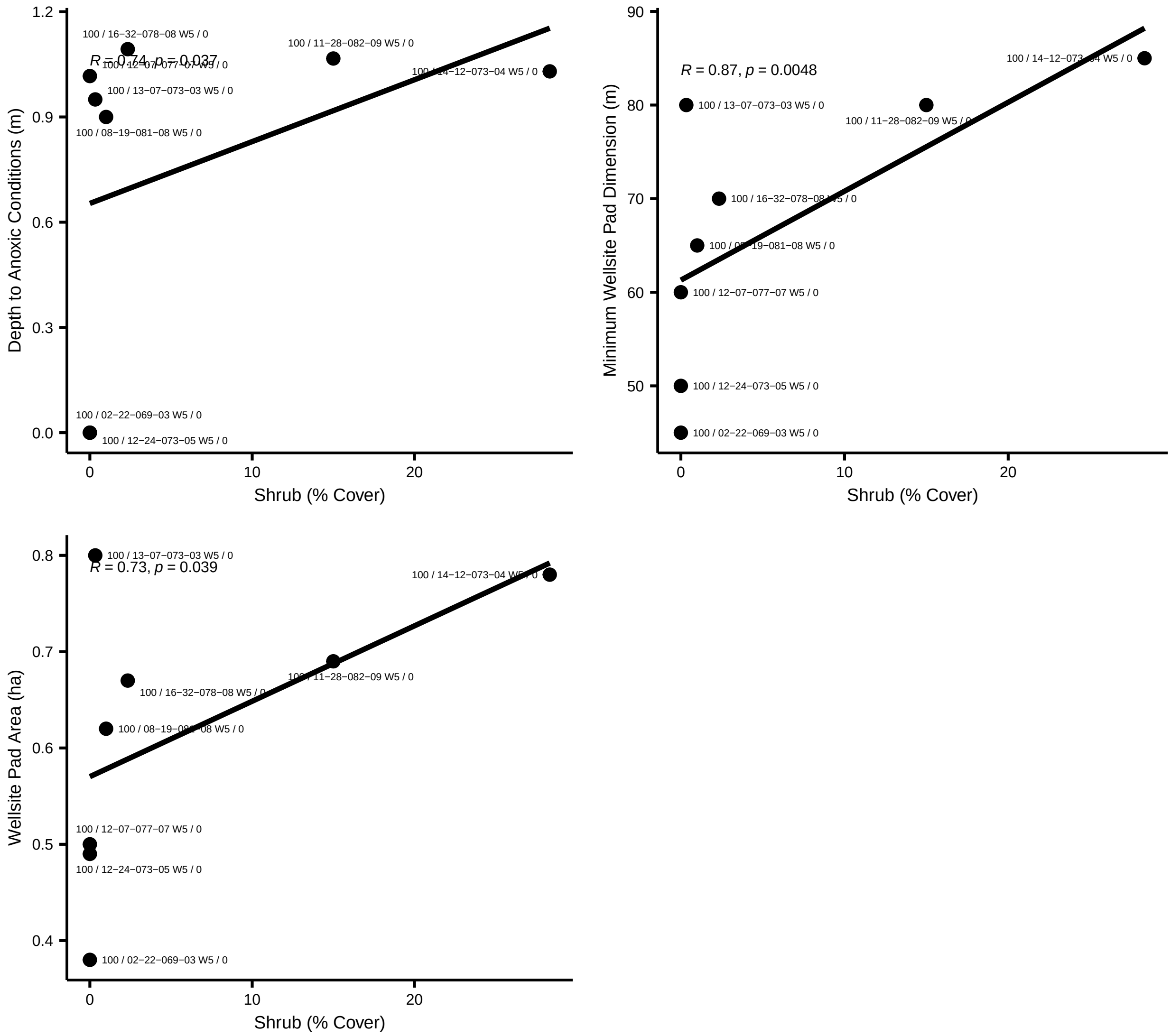


Figure 5b: Spearman Rank Correlation between Pad Moisture and Size Characteristics and Vegetation.

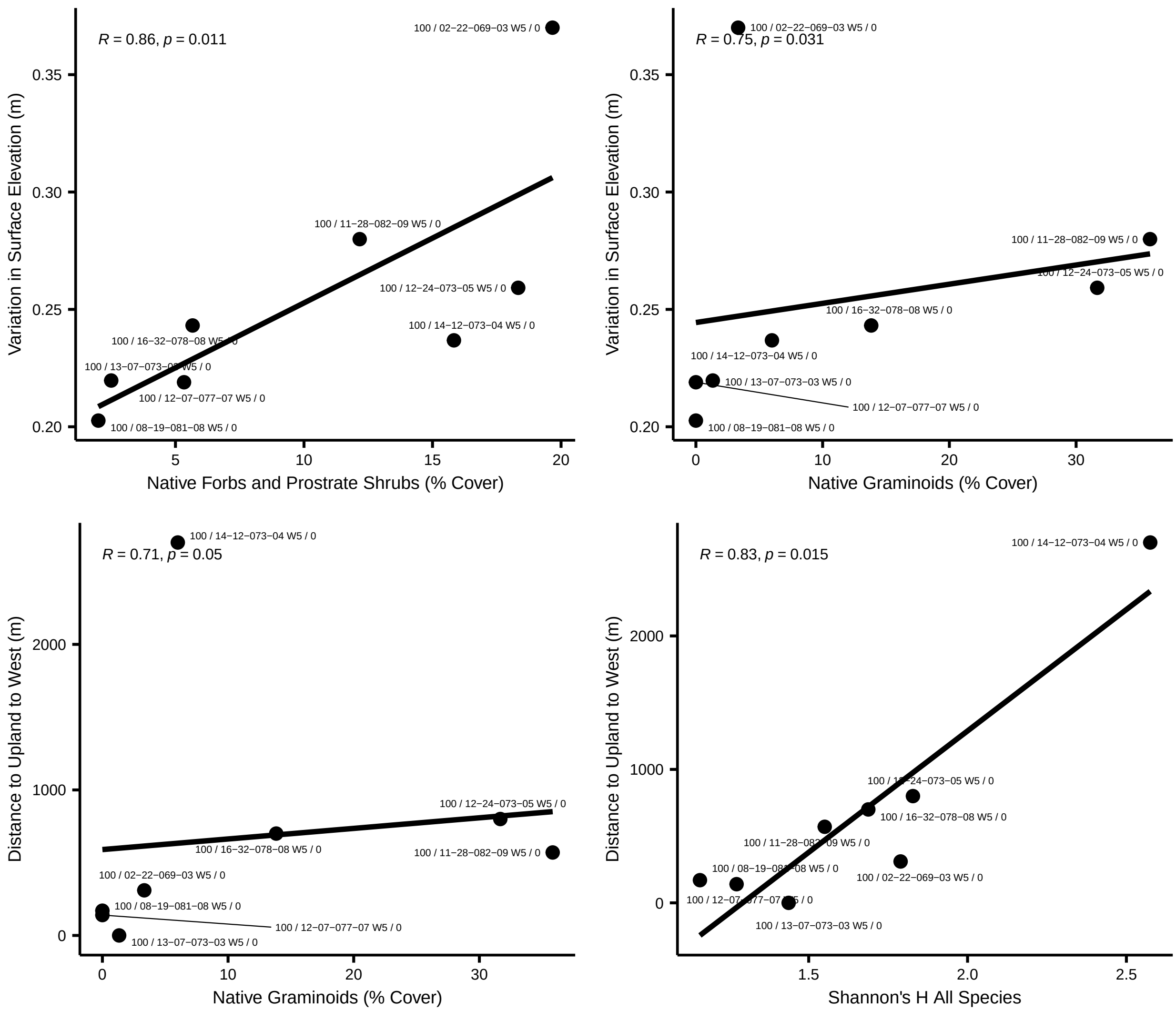


Figure 5c: Spearman Rank Correlation between Pad Elevation Characteristics and Proximity to Upland and Vegetation.

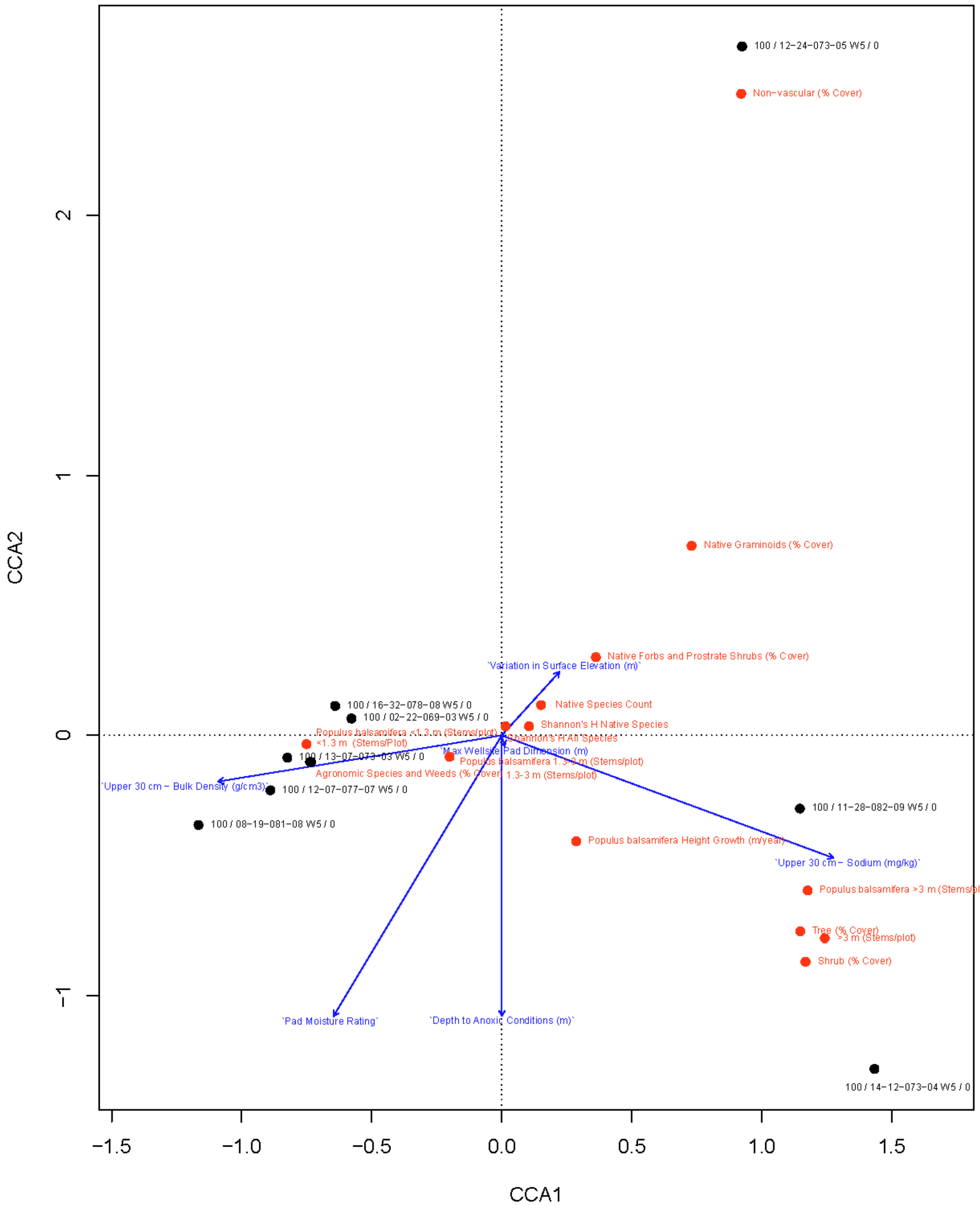


Figure 6: Canonical Correlation Analysis of Pad and Vegetation Characteristics. Positive Correlations between Variables are Indicated by Proximity to One Another or in the Direction of the Vector.

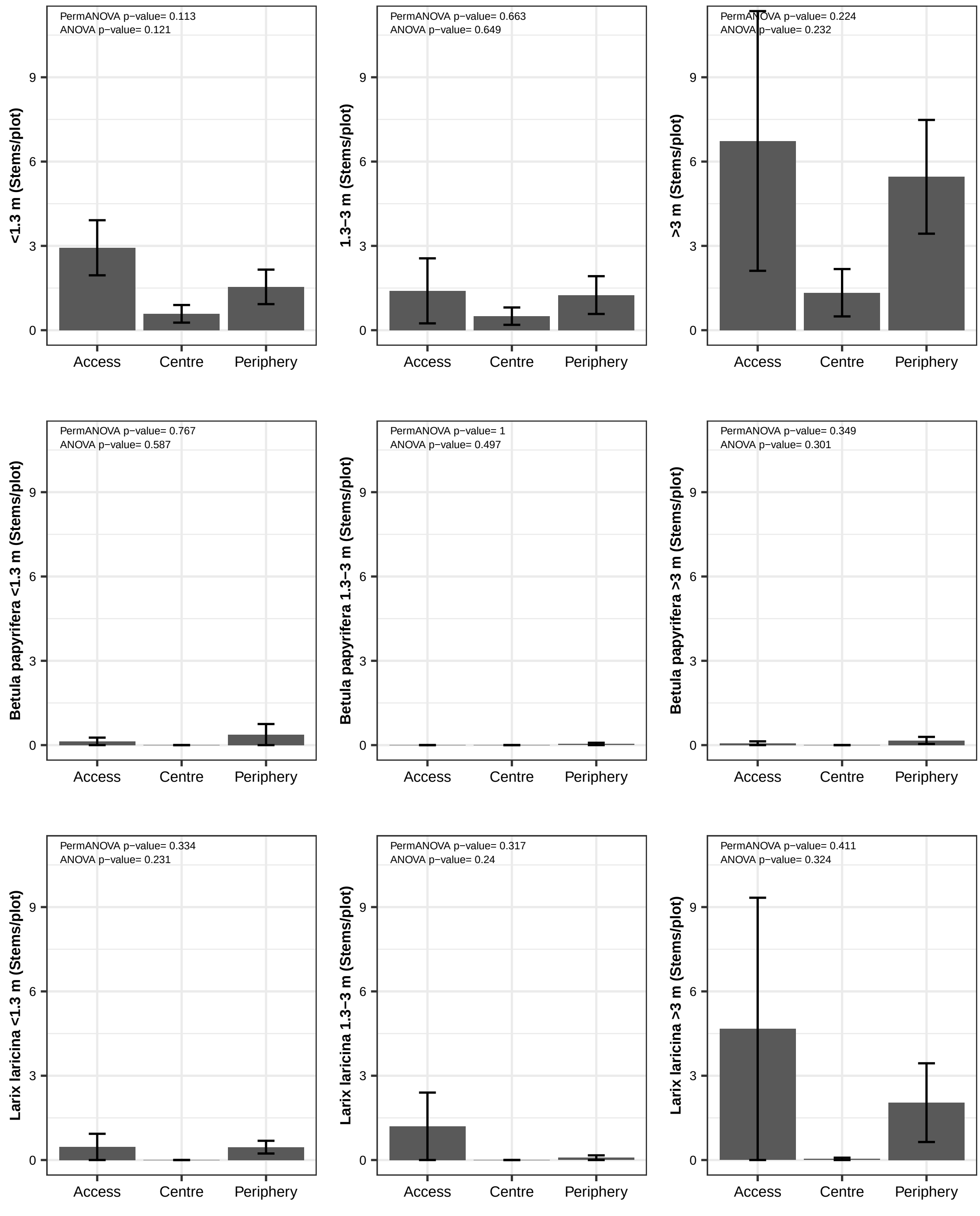
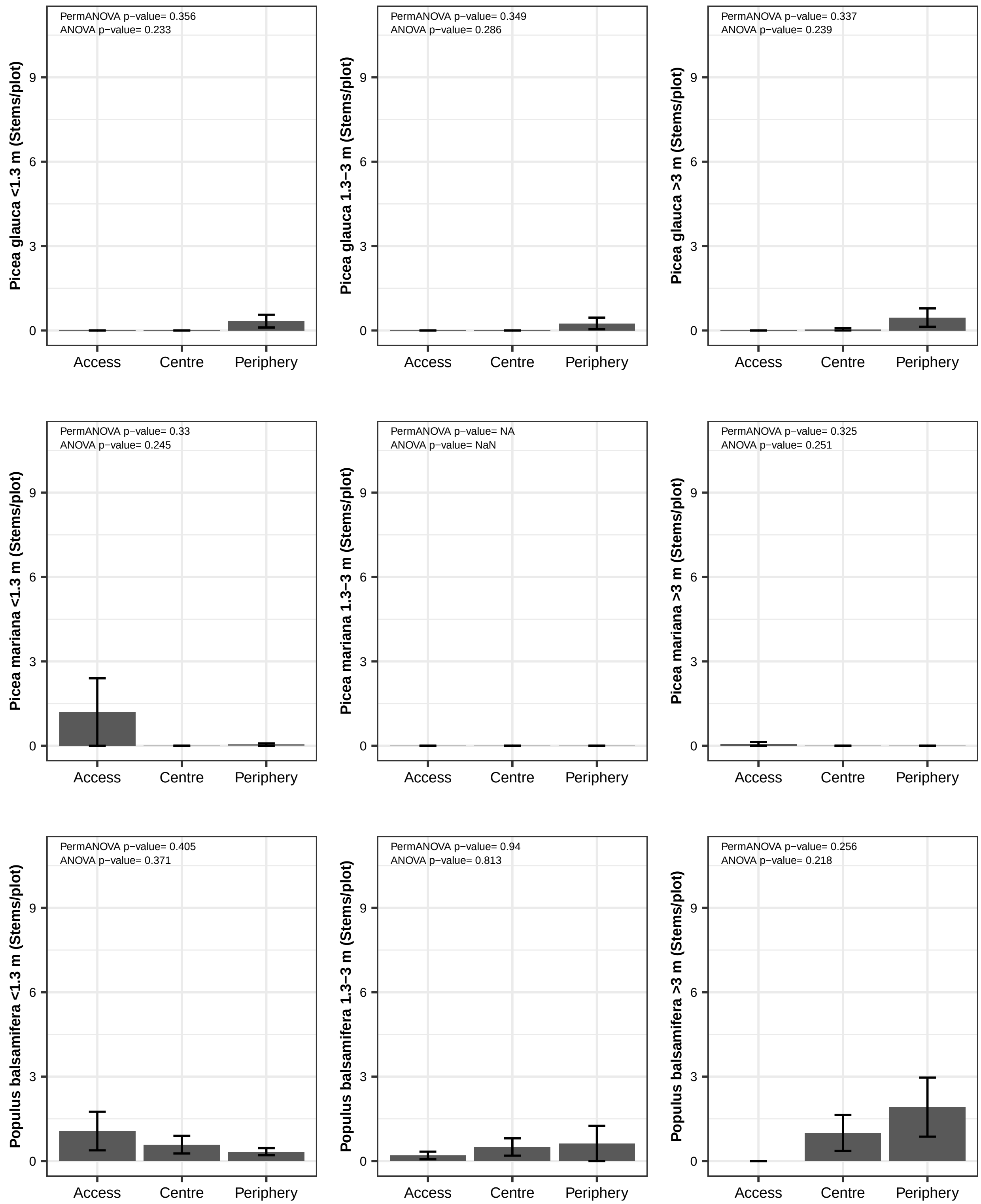


Figure 7a: Comparison of Tree Stem Density by Height Class in a 10 m^2 Plot Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error.



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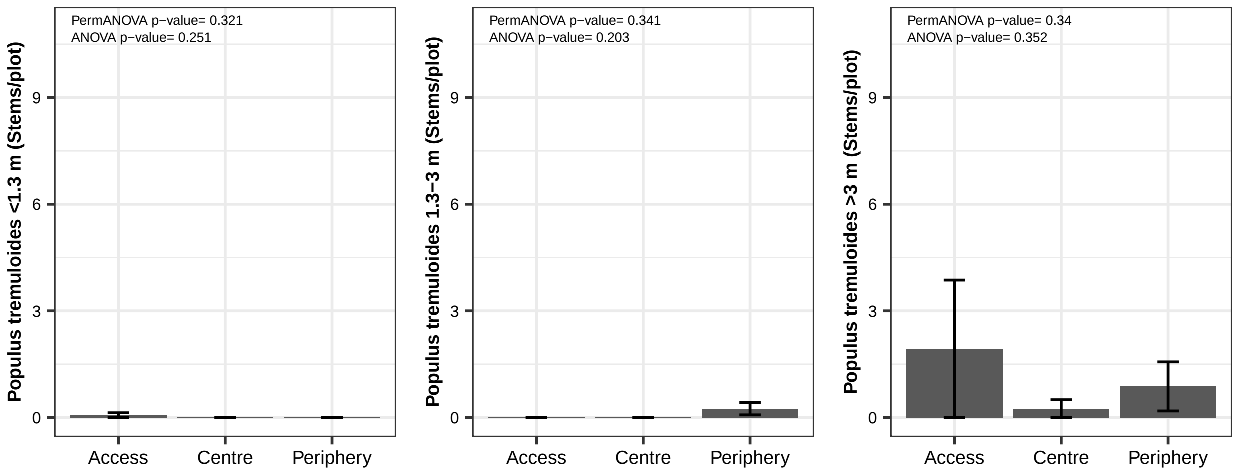

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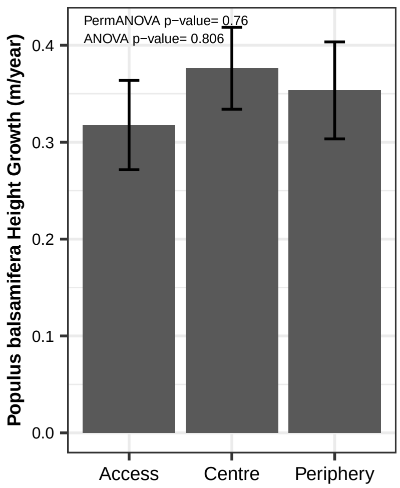

Figure 7b: Comparison of Annual Tree Height Growth Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error.

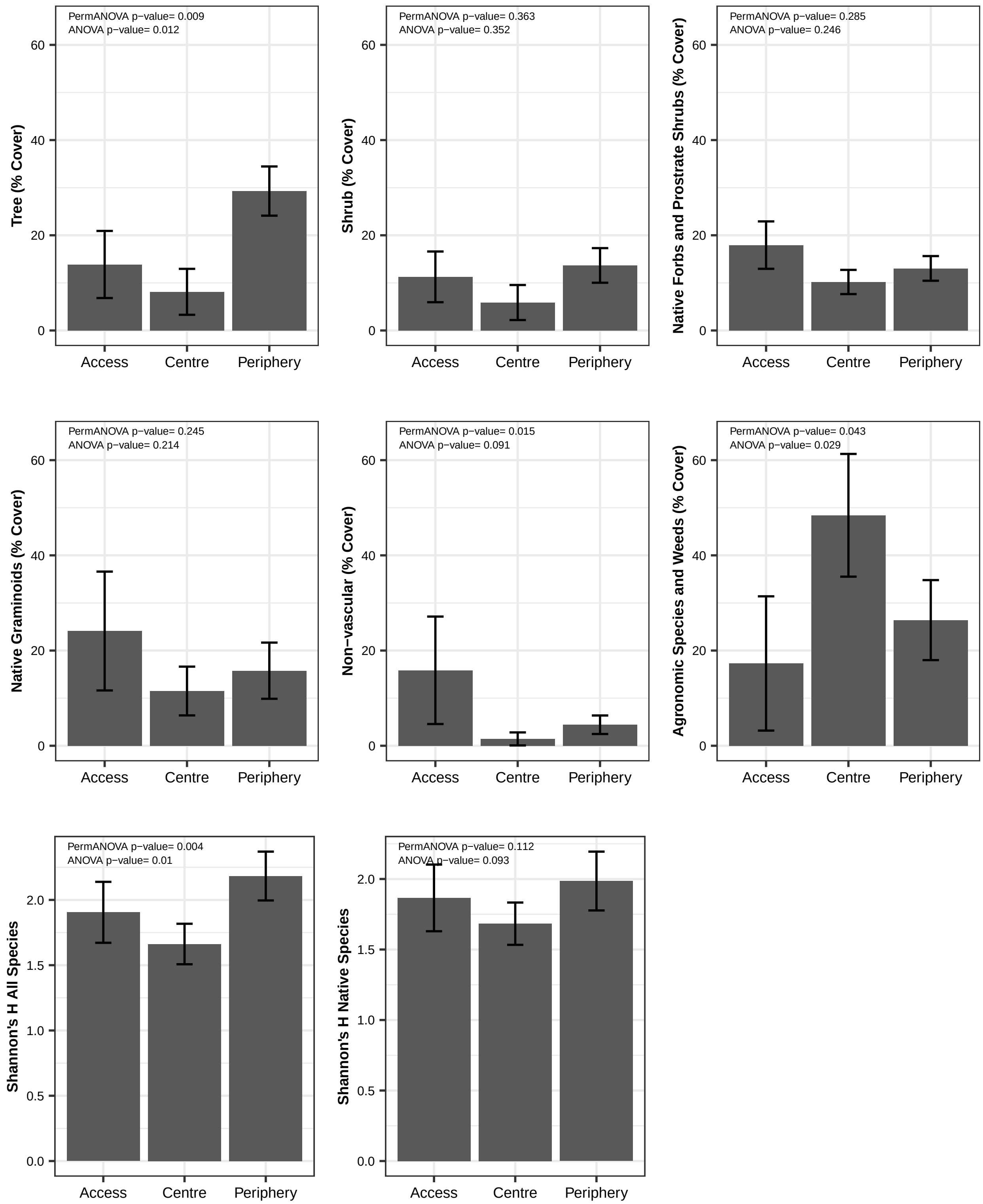

Figure 7c: Comparison of Percent Canopy Cover by Vegetation Strata and Species Diversity Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error.

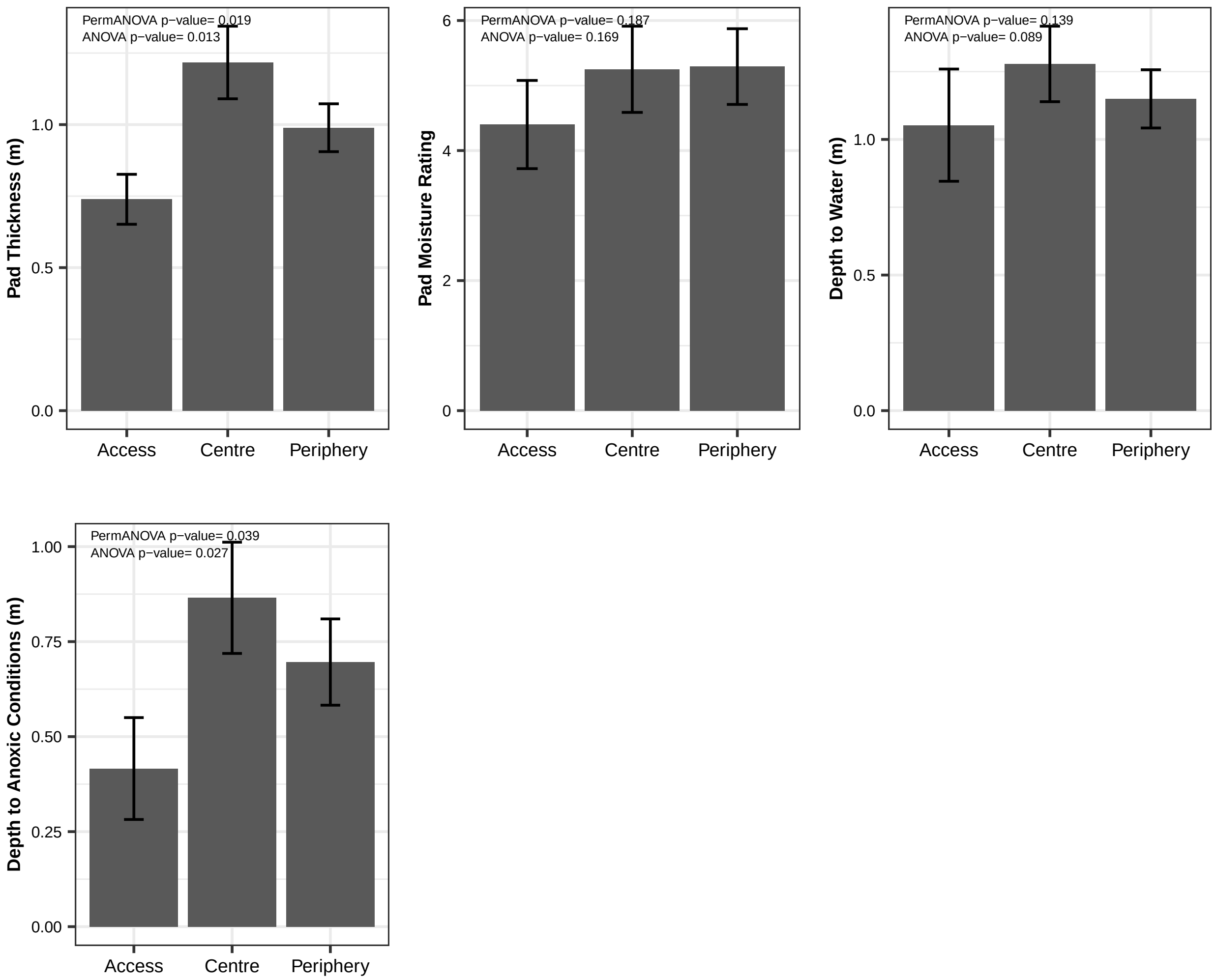

Figure 8a: Comparison of Pad Thickness and Moisture Characteristics Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error. Pad Moisture
Rating (1=Saturated, 7=Dry).

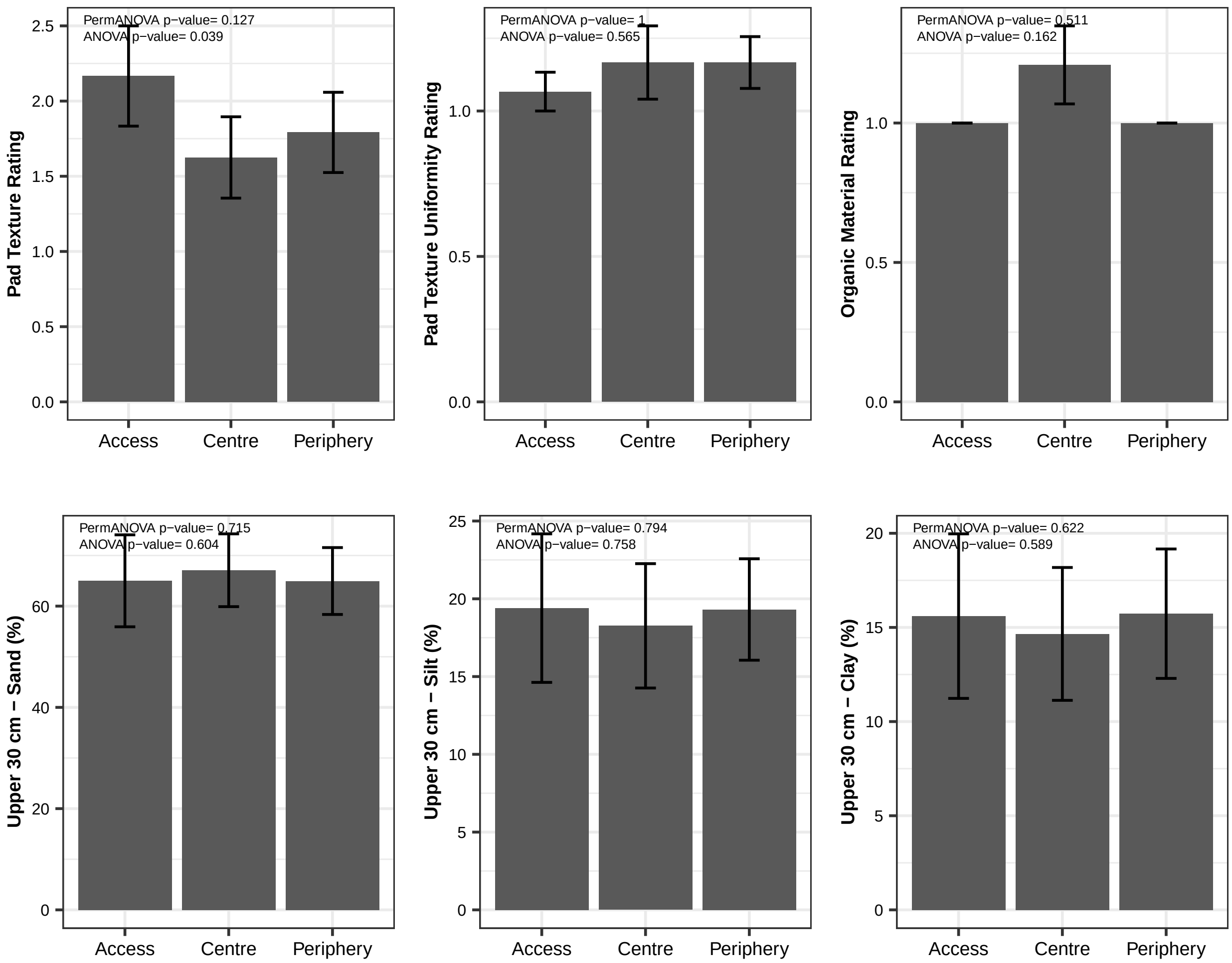

Figure 8b: Comparison of Texture Characteristics Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error. Soil Texture Rating (1=Coarse, 3 =Fine); Soil Texture Uniformity Rating (1=Uniform, 2=Variable); Organic Material Rating (1=Absent, 2=Present).

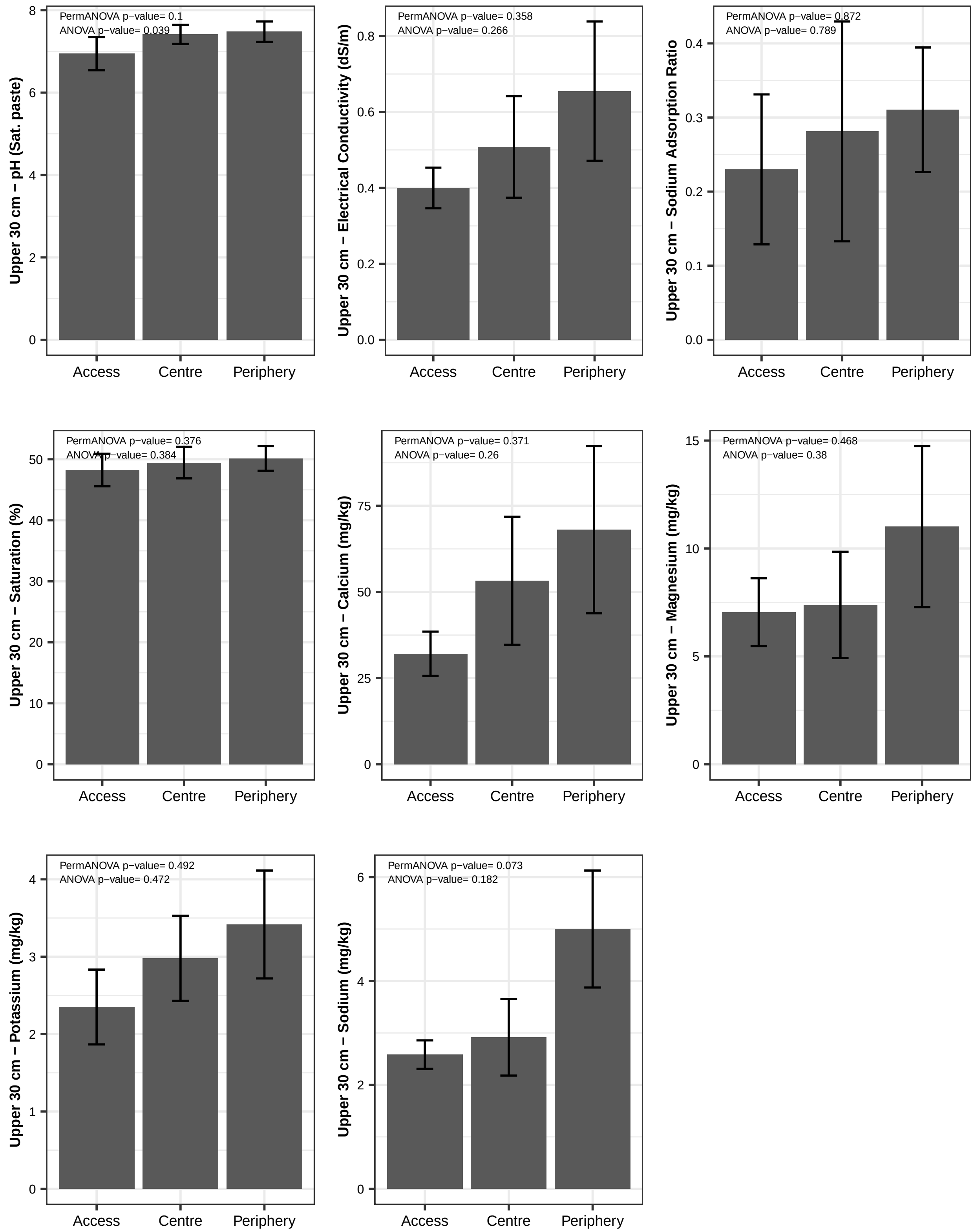

Figure 8c: Comparison of Chemical Properties of the Upper 30 cm of Pad Material Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error.

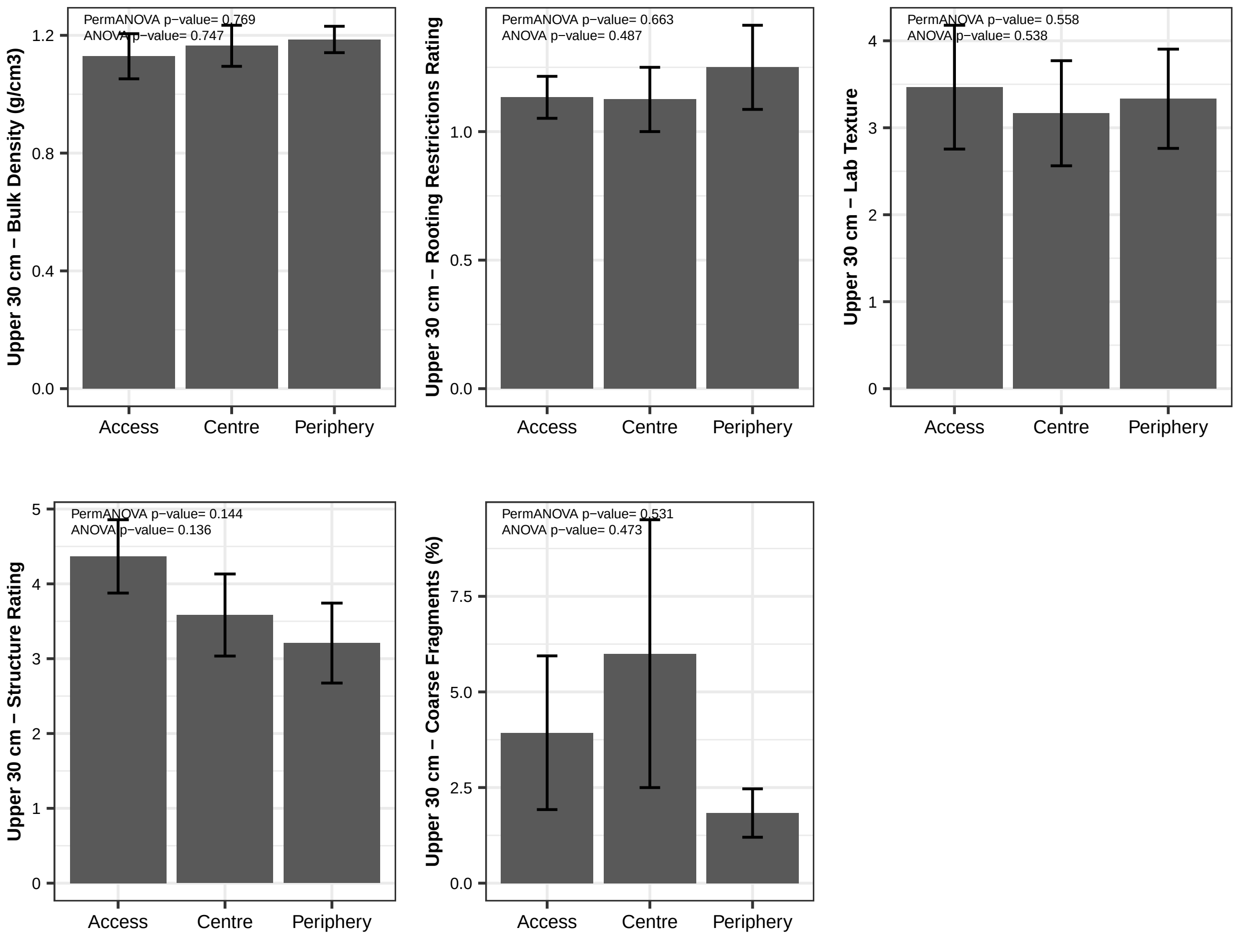

Figure 8d: Comparison of Physical Properties of the Upper 30 cm of Pad Material Between Padded Access Road, Wellsite Pad Centre and Wellsite Pad Periphery. Error Bars Represent Standard Error. Rooting Restrictions Rating (1=None, 2=Slight); Consistence Rating (1=Loose, 2=Friable, 3=Firm); Structure Rating (1=Single Grain, 2=Medium Subangular Blocky, 3=Coarse Subangular Blocky, 4=Coarse Angular Blocky, 5=Platy, 6=Massive).

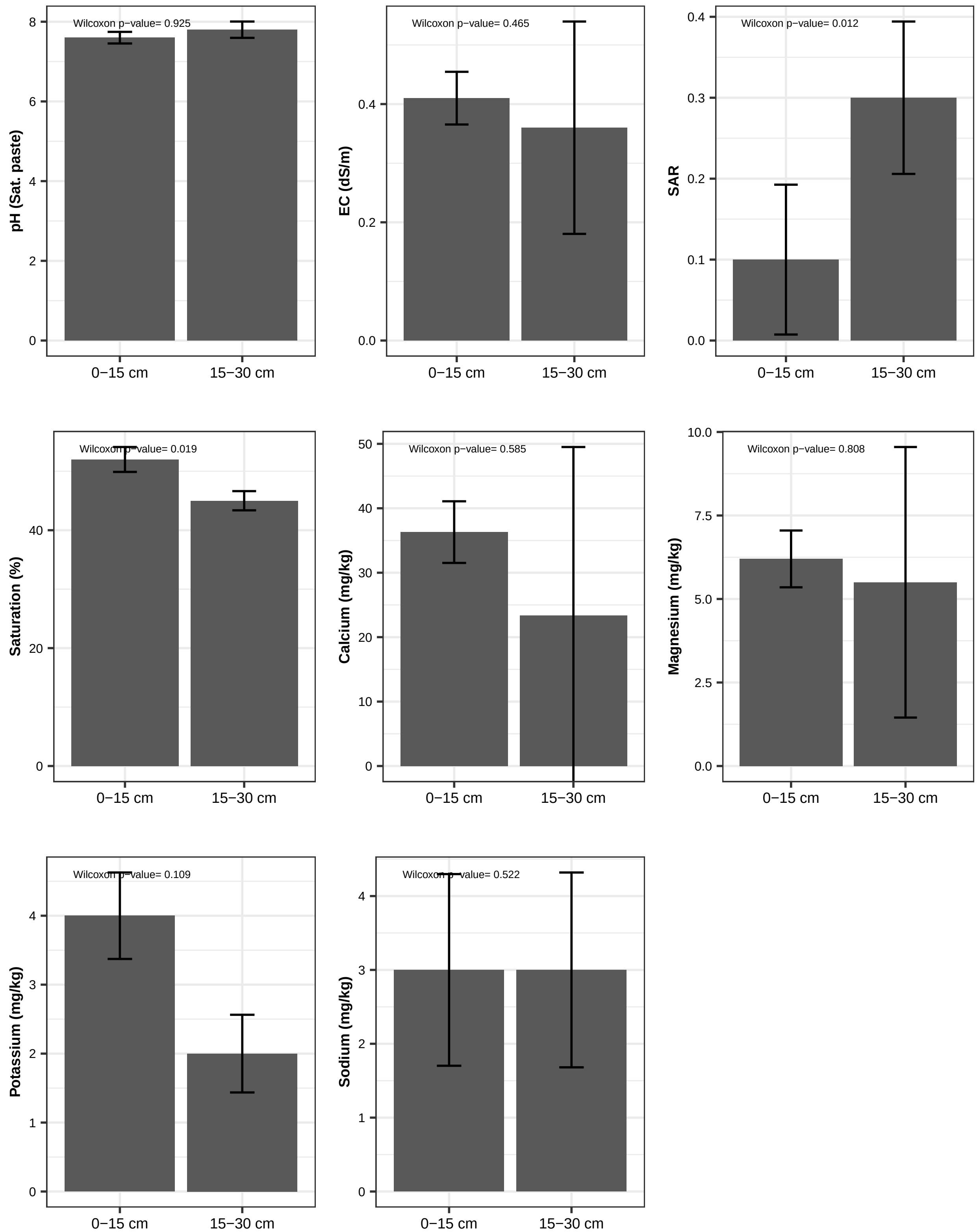

Figure 9a: Comparison of Chemical Properties of Pad Material Between Sample Depths. Medians are Presented and Error Bars Represent Standard Error.

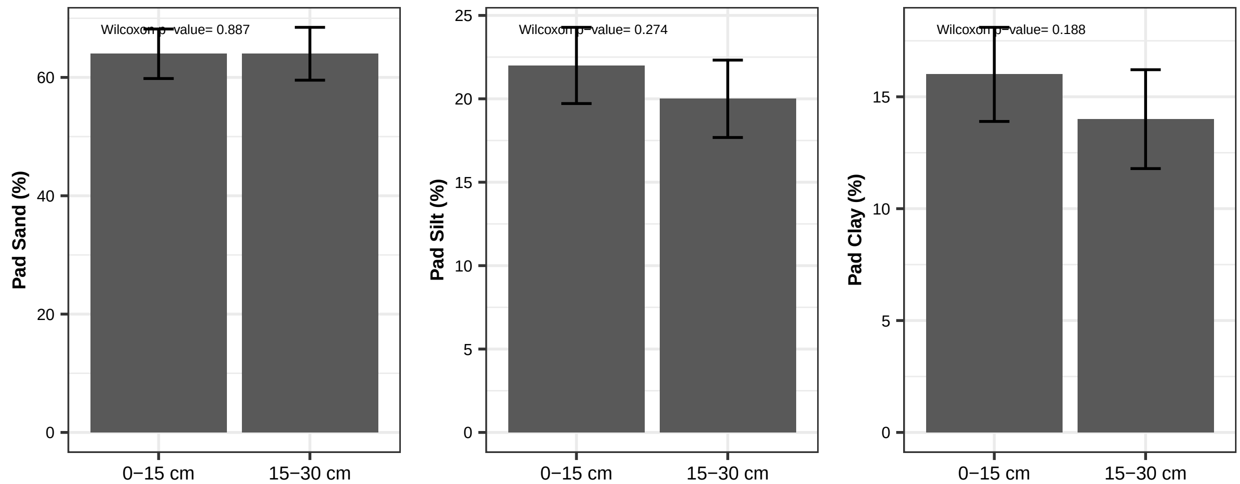

Figure 9b: Comparison of Physical Properties of Pad Material Between Sample Depths. Medians are Presented and Error Bars Represent Standard Error.