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:
    - 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

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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