# ISSUES: DATA SET Arrested succession? Assessing plant community recovery on reclaimed oil and natural gas well pads in Alberta's boreal forests using multivariate analyses

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A picture containing grass, outdoor, sky, tree

Description automatically generated

This is a photo of a pump jack in an Alberta Boreal Forest. The well pads in this dataset have been reclaimed but the photo of the pump jack will help to convey the type of disturbance that we are studying the recovery of plant communities from after they have been decommissioned and received a reclamation certificate.

Crude oil pump jack in Alberta Boreal Forest. Pump jacks have been removed from well pads studied in this dataset. Pump jacks of this type created the original disturbance of plant communities. All areas sampled were decommissioned well pads that had undergone reclamation and received a certificate of reclamation.

**THE ECOLOGICAL QUESTION:**

Do plant communities on reclaimed well pads have similar composition to adjacent reference forests? (i.e., have they recovered?)

**ECOLOGICAL CONTENT:**

Succession, Disturbance ecology, Community ecology, Plant ecology, Forest ecology

**WHAT STUDENTS DO:**

Students will use a dataset (two .csv files) that compares plant community composition on reclaimed well pads and adjacent forested areas to develop hypotheses about how plant communities will recover from this disturbance and then investigate plant community recovery on the well pads using multivariate statistical analyses. An accompanying step-by-step primer is provided that will enable students to conduct a non-metric multi-dimensional scaling (NMS) ordination analysis using RStudio, which is an open-source statistical software environment. In addition to the ordination, students will also statistically test for differences in plant community composition among the well pad and reference forests using permutational multivariate analysis of variance (perMANOVA). They will then use indicator species analysis to identify which plant species are associated with the well pads compared with the reference forest study units. Finally, they can report summary statistics for the well pad and reference plant species of interest. There is a student worksheet that will be completed alongside the data analysis activity. For instructors that are not familiar with NMS – this is a multivariate ordination technique that doesn’t have any underlying assumptions about the data, and thus is very popularly used by ecologists who often have non-normal data. Points (which represent sampling sites – wellsites and reference sites) closer together in the ordination are more similar than those that are further apart. As the ordination just visualizes the separation among the sampling sites, perMANOVA, which is a multivariate equivalent of ANOVA that also does not require normality of the dataset to proceed, tests whether there are significant differences in grouping variables among study sites – in this case well pads vs adjacent reference.

**STUDENT-ACTIVE APPROACHES:**

Guided Inquiry, Cooperative Learning, Quantitative Learning

**SKILLS:**

* Develop hypotheses related to how plant communities may recover after disturbance – in this case an anthropogenic well pad disturbance.
* Application of existing ecological knowledge (e.g., disturbance ecology, community ecology, succession) to a plant community dataset that focuses on recovery after well pad disturbance.
* Recognize components of RStudio and use RStudio to run analyses and extract results from it.
* Use of RStudio statistical software for multivariate statistical analyses, including ordination to visualize data and perMANOVA to test for differences among a priori plant community groups.
* Interpretation of data to evaluate research hypotheses about plant community composition differences between well pads and reference forests.

**ASSESSABLE OUTCOMES:**

By the end of this activity, students should be able to:

* Write a high-quality ecological hypothesis to be tested by multivariate analysis.
* Explain what types of data are appropriate for multivariate analysis
* Briefly explain what an ordination shows the reader.
* Run a Non-metric multidimensional scaling (NMS) ordination in R that visualizes plant community composition patterns between well pads and adjacent reference forests.
* Apply permutational multivariate analysis of variance (perMANOVA) to distinguish between plant community groups on the well pad and in the adjacent forest reference sites.
* Use indicator species analysis to identify which species are contributing to separation among *a priori* groups (well pad vs forest).
* Describe and interpret the output of their multivariate statistical analyses, including their plant community ordination plot, perMANOVA, and indicator species analyses~~.~~

**SOURCE**:

* Data from: Lupardus R, McIntosh ACS, Janz A, Farr D. 2019. Succession after reclamation: Identifying and assessing ecological indicators of forest recovery on reclaimed oil and natural gas well pads. Ecological Indicators. 106, 105515. <https://doi.org/10.1016/j.ecolind.2019.105515>

**ACKNOWLEDGEMENTS:**

The idea for publishing this dataset originated during a University of Alberta Augustana Faculty STEP research assistantship that funded undergraduate student Michelle Rude in Summer 2018. This dataset was also used to develop a project for students in the initial offering of AUBIO 315: Advanced Biological Analysis. Development of this dataset was continued by summer research assistantship funding to Chantal Ricard from the University of Alberta Augustana Campus in Summer 2019. We are grateful to the funding sources who funded collection of the well pad data: This ecological recovery monitoring project was initiated and funded by Alberta Environment and Sustainable Resource Development’s Land Monitoring Team (AESRD 2012-2015), the Alberta Environmental Monitoring Evaluation and Reporting Agency (AEMERA 2015-16), and Environmental Monitoring & Science Division, Alberta Environment and Parks (AEP 2016-21), including Environment and Parks grant funding to A. McIntosh. The ecological recovery monitoring project that collected these data has also been supported by the Alberta Biodiversity Monitoring Institute Application Centre and Alberta Innovates – Technology Futures (AITF – now Innotech Alberta). We also thank the field research assistants who collected this data including: Lee-Ann Bauman (Nelson), Victor Bachmann, Elise Martin, Andrew Underwood, Carissa Wasyliw, and Scott Wilson.

**OVERVIEW OF THE ECOLOGICAL BACKGROUND**

Ecological succession has been a long-standing area of focus in ecology (Connell and Slatyer 1977, Pickett et al. 1987). Boreal forest ecosystems have a somewhat predictable successional pathway, albeit with variation among individual stands. The general pathway of Canada’s boreal forest after stand-replacing disturbance (fire is the dominant natural stand-replacing disturbance agent and forest harvest is the dominant anthropogenic stand-replacing disturbance agent) is initial development of a shade-intolerant broadleaf forest (e.g., aspen and balsam poplar) that then transitions to conifers as the shorter-lived broadleaf forest species die off (see Bergeron et al. 2014). An alternative pathway occurs in shade-intolerant fire-adapted lodgepole pine forests that have serotinous cones and self-replace after fire. So, while there is variation in the relative abundance of the species, the species composition is deterministic after succession. Generally, we would expect the forest to return (eventually) to its original community structure after disturbance.

However, less studied are the ways in which anthropogenic disturbance agents, such as natural resource extraction, may alter the successional trajectories of ecosystems. For example, crude oil and natural gas well pads established for development of energy resources are estimated to have a footprint that covers over 500 000 ha of Alberta, Canada’s landscape. Reclamation of these sites is a critical step in alleviating impacts of this industrial human footprint, with reclamation criteria evolving over time (Powter et al. 2012). Approximately 130,000 well pads have been certified as reclaimed since 1963 in Alberta. However, given the significant additional disturbance to the soils that may result during oil and gas development and the subsequent reclamation practices, there is less certainty that these reclaimed sites will return to their original community structure – which is what we are exploring this in this dataset. Instead, there is a concern that resource development will have long-lasting legacy effects on soil, biological, and spatial characteristics of ecosystems and that their succession may be slowed or arrested.

Site preparation for oil and gas extraction is a high-intensity disturbance agent that removes the vegetation and surface soil on the well pad. After the well pad is decommissioned, subsequent reclamation, which includes requirements to meet criteria to receive certification (e.g., in Alberta - ESRD 2013), then attempts to restore vegetation and soil properties on the well pad (e.g., recontouring the ground that had been leveled so the heavy-duty equipment could be on it, sowing of non-native (historically) or native (newer criteria) seed to conserve top soil). The surface stripping of the forest floor often removes the native seedbank, thus resetting the successional pathway for the well pad. Therefore, the potential to shift (or even arrest) the well pad’s successional trajectory is high. Students in this research activity will use the accompanying datasets to investigate patterns in the understory plant communities (the percent cover of shrubs, herbs, grasses, clubmoss, fern, lichens, including non-native species) in clustered study units that include both certified reclaimed well pads and adjacent undisturbed forested reference sites. They will explore more specifically whether there is recovery of the plant communities in the reclaimed well pads compared with the adjacent undisturbed reference forest sites. These study units contained reclaimed well pads, ranging from 7-48 years post-certification. Other ecological variables measured included: age post-reclamation, the LFH depth (organic soil layer), soil bulk density, soil pH, organic soil carbon, soil nitrogen, the soil C:N ratio, number of live and dead trees, and live and dead basal area. Detailed sampling methods are described in McIntosh et al. (2019).

The dataset for this activity includes two .csv spreadsheets, one .csv file that includes the species composition data (percent cover by species) in the two ‘treatments’ (well pad and reference) and the second with grouping/categorical variables and environmental factors/properties that may be associated with the two different treatments that were collected for each sampling site. See the datasets section below for further information.

**LITERATURE CITED:**

Bergeron, Y., H.Y.H. Chen, N.C. Kenkel, A.L. Leduc, and S.E. Macdonald. 2014. Boreal mixedwood stand dynamics: Ecological processes underlying multiple pathways. The Forestry Chronicle **90**:202-213.

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**DATA SETS**

For faculty:

* [IntrotoMultivariateAnalysisofWellPads.pptx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/IntrotoMultivariateAnalysisofWellPads.pptx): This MS Powerpoint© file contains some sample slides that should be used by the instructor to introduce multivariate analysis and this particular dataset prior to working with the datasets in the student assignment.
* [WellvsRef.R](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/WellvsRef.R): This is the .R script file for the faculty member to have as a resource to troubleshoot issues with students running the code. It includes all of the R code that will be used to conduct the statistical analysis by students and notes to guide the instructor.
* [StudentAssignmentWorksheetSolutions.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheetSolutions.docx): This is a set of sample solutions for the worksheet that the students will use in conjunction with the primer and dataset files in the lab. This is what you could use for grading the assignment and assessing the learning outcomes.
* [DemoAdvancedAssignment.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/DemoAdvancedAssignment.docx): This is the assignment that I use in my advanced biological analysis course for students to build on – this could be a next step activity for a semester-long project for students in the class using other datasets after they have done a demonstration of the analyses in this activity. I have extracted elements of this assignment to be the worksheet and activities for the current dataset submission.
* [Lupardus\_etal\_EcologicalIndicators.pdf](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Lupardus_etal_EcologicalIndicators.pdf): This is the publication that the data are taken from and provides more detailed information on the project and results. Note that it goes into additional types of analyses compared with what the students will do with the dataset.

For students:

* [Primarydataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Primarydataset.csv): This is the .csv file with the plant community data that will be imported into R. This is the same file as the instructor will use.
* [Seconddataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Seconddataset.csv): This is the .csv file with the additional environmental attribute data that were collected for each sample unit that will be imported into R. This is the same file as the instructor will use.
* [StudentAssignmentWorksheet.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheet.docx): This is a worksheet that the students will use in conjunction with the primer and dataset files in the lab.
* [WellvsRef\_RPrimer.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/WellvsRef_RPrimer.docx): This is the R primer for this dataset. Students will use it to walk through the steps and conduct the analyses of the demonstration well pad dataset.
* [WellvsRefMetadata.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/WellvsRefMetadata.docx): This is the metadata file that describes background information about the project and sampling and detailed entity-level metadata for both [primarydataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Primarydataset.csv) and [seconddataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Seconddataset.csv). It includes supplementary level of detail compared to the background information in [StudentAssignmentWorksheet.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheet.docx) and instructor may opt to include this.

We give permission for this dataset to be posted and distributed on the TIEE website. This ecological recovery monitoring project and collection of these data in particular were initiated and funded by Alberta Environment and Sustainable Resource Development’s Land Monitoring Team (AESRD 2012-2015), the Alberta Environmental Monitoring Evaluation and Reporting Agency (AEMERA 2015-16), and most recently Environmental Monitoring & Science Division, Alberta Environment and Parks (AEP 2016-20), including Environment and Parks grant funding to A. McIntosh.

**STUDENT INSTRUCTIONS**

This is the [StudentAssignmentWorksheet.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheet.docx) document that is provided above. It includes specific instructions about what students should do plus background information so that they can understand the data without reading the paper that these data are from. It should be used in conjunction with the [WellvsRef\_RPrimer.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/WellvsRef_RPrimer.docx), [WellvsRefMetadata.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/WellvsRefMetadata.docx), and the two .csv files ([Primarydataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Primarydataset.csv) and [Seconddataset.csv](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/Seconddataset.csv)). It will also be essential that students have been provided with the background materials that are in the [.pptx file](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/IntrotoMultivariateAnalysisofWellPads.pptx).

**Notes to Faculty**

Depending on their career path, as biology students move forward into their careers or graduate studies, they may require a higher-level understanding in statistical analyses for carrying out more rigorous scientific studies. They also need to learn to use statistical software packages. R is free and open source and more and more there is a shift to it being the dominant software that students are using. Therefore, this dataset module is intended to introduce undergraduate students to multivariate analyses using this forest ecology study as an exemplar to build their analytical toolbox. Using R to conduct their analyses will give them the opportunity to become more comfortable with using a code-driven software package in place of traditional point and click software. I have previously taught students how to conduct multivariate analyses using PC-ORD but given that this is not software they will have readily available for them after they graduate, I have shifted to put an emphasis on doing these analyses in R. Students should be able to use the primer that we have provided to walk them through the steps of multivariate analysis in R using the sample dataset – they do not have to have any prior exposure to R. The instructor can then incorporate other study datasets for students to potentially analyze for a longer course activity. For example, I have a project where students are provided with a dataset that they then have to analyze (my assignment included as an attachment). If you are interested in any of these datasets you are welcome to reach out to us for further information. If you wanted to expand on the student assignment, another option would be to have a follow-up activity where you could have students write a discussion section of a scientific report that interprets the results. Alternatively, after the data analysis is complete, students can refer to the associated manuscript (Lupardus et al. 2019) and be asked more detailed questions based on the findings of this paper – e.g., why are some of the sites arrested in their successional trajectory? If you want to go even further, you could explore plant functional traits (as analyzed in Azeria et al. 2020) but this would definitely require much more significant time input. Alternatively, if you want to combine this activity with measuring of alpha and beta community diversity measures you could have students calculate species richness, Shannon diversity, and Simpson’s dominance within each wellpad and adjacent reference site, and then calculate species turnover between each wellpad and the adjacent reference forest. Students could start by doing this activity to get familiar with the dataset and then delve into the multivariate statistics. Students could then explore whether the findings are different or similar when looking at the diversity statistics compared with the multivariate ordination results. This would be a way to compare both univariate and multivariate responses variables for the study dataset and get students thinking about both species and communities and how they may potentially interact.

Be prepared for students to be intimidated at first as they walk through this project. In teaching introductory statistics and the advanced biological analysis course where I have introduced this project (albeit with PC-ORD in previous offerings) students were definitely anxious and overwhelmed at first. These are the kinds of activities though where some initial struggle will be met with improved understanding after they have completed the project. We have provided a MS Powerpoint© file to provide some additional background materials to help set the stage for this activity. This also includes a brief introduction to R so that they have a bit of background on the statistical environment they are working in. Doing an introduction with the Powerpoint slides to set the stage and provide context will be essential to student success. In addition, you may want to encourage your students to use a Windows based operating system, as some reviewers expressed concerns with using R and RStudio on a Mac computer. The activities in this dataset have only been tested using Windows.

It is also helpful to explain to students the premises behind multivariate analysis – i.e., that rather than just looking at one plant species at a time – it is of interest to examine collectively the responses of all the plant species together. In terms of the details of ordination – students do not have to understand the details of how the program does the analysis. The goal is that they can get an ordination plot that they can look at and interpret. You can highlight to the students that an ordination plot is just trying to simplify the patterns in the data and visualize patterns in the plant communities among sites. Essentially, we want to code each study unit based on whether it is a well pad or a forest reference and see if we find any separation between them (suggesting they have different plant community compositions). If we don’t see separation between the well pads and reference sites and instead find a lot of overlap between them then that suggests that they have similar plant community compositions. In the ordination plot, study units that are closer together have a more similar plant community composition than do study units that are further apart. We have intentionally focused on selecting non-metric multidimensional scaling (NMS) as the type of ordination to do, because plant community data are inherently not normal, and NMS lacks any requirements related to the normality of the data unlike some of the other ordination types (e.g., Principal component analysis). If you want more detailed information about ordination and the other types of analyses in this paper, I recommend you refer to McCune and Grace (2002). For more information on the use of ordination in R see Oksanen (2016). Additional resources have been included in the [.pptx file](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/IntrotoMultivariateAnalysisofWellPads.pptx).

Oil and gas exploration has led to well pads being a ubiquitous anthropogenic disturbance agent in large regions of North America, including Alberta. Site preparation for oil and gas extraction is a high intensity disturbance agent that removes the vegetation and often the surface soil on the well pad. After the well pad is decommissioned, subsequent reclamation, which includes requirements to meet criteria to receive certification (e.g., in Alberta - ESRD 2013), then attempts to restore vegetation and soil properties on the well pad. However, the surface stripping often removes the native seedbank, thus resetting the successional pathway for the well pad, and therefore the potential to shift (or even arrest) the well pads successional trajectory is high.

The study area was located in both the Central Mixedwood (conifer & deciduous; n=15) and Lower Foothills (n=15) Natural Subregions of Alberta (The Natural Regions Committee, 2006). These forested areas are dominated by mosaics of aspen (*Populus tremuloides*), white spruce (*Picea glauca*), and coniferous/deciduous mixedwood (aspen and white spruce) forest on uplands, with extensive areas of lodgepole pine (*Pinus contorta*) and jack pine (*Pinus banksiana*) on coarse soils. This dataset investigates patterns in the understory plant communities (the percent cover of shrubs, herbs, grasses, clubmoss, fern, and lichens, including identifying non-native species) as a function of measuring vegetation recovery in clustered study units that include both certified reclaimed well pads and adjacent undisturbed forested reference sites. These study units contained reclaimed well pads, ranging from 7-48 years post-certification. Other ecological variables measured include: age post-reclamation, the LFH depth (organic soil layer), soil bulk density, soil pH, organic soil carbon, soil nitrogen, the soil C:N ratio, number of live and dead trees, and live and dead basal area. Detailed sampling methods are described in McIntosh et al. (2019). Historic practices were focused on a model of ‘green is good’ and there was a lot of use of exotic/non-native species whereby topsoil conservation was highlighted as important. More recent reclamation criteria require the use of native species mixes. So, there are interesting patterns that can be observed over time post certification for reclaimed well pads.

For background, it will be useful to show students a video of one of the field sites from the sampling: <https://vimeo.com/140343926>.

**LITERATURE CITED:**

Azeria, E.T., K. Santala, A.C.S. McIntosh, and I. Aubin. 2020. Plant traits as indicators of recovery of reclaimed wellsites in forested areas: slow but directional succession trajectory. Forest Ecology and Management **468**: 118180. [This is a manuscript also based on the same dataset as Lupardus et al. 2019. However, it includes additional analysis of plant traits – so it could be something that more advanced students might be interested in exploring, but all of the data on plant traits are not part of this study dataset]

Lupardus, R., A.C.S. McIntosh, A. Janz, and D. Farr. 2019. Succession after reclamation: Identifying and assessing ecological indicators of forest recovery on reclaimed oil and natural gas well pads. Ecological Indicators **106**:105515. <https://doi.org/10.1016/j.ecolind.2019.105515>

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**Comments on introducing this activity to your students**

We envision this being an activity that could be conducted independently by students, getting them engaged in their own learning. However, it is important that the instructor first set the stage by presenting the [IntrotoMultivariateAnalysisofWellPads.pptx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/IntrotoMultivariateAnalysisofWellPads.pptx) file. This will give students the necessary background/context to prepare them to complete the worksheet assignment.

**How to use this activity in a class**

Students will then primarily work on their own (or in a small team – but when it comes to working with software you would want to keep the group small, perhaps two students working together). Given that these would be senior undergraduate students – they should be capable of working their way through this dataset analysis and completing the assignment as a lab activity. This will empower them to develop their quantitative multivariate analytical skills. Students will struggle at first – you can encourage them to try going through the steps of the R primer more than once to get a better feel for how the program works. This will be especially important if they are going to use this as a starting point for working with their own dataset to conduct analyses for a follow-up project/assignment (such as the one I have provided in [DemoAdvancedAssignment.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/DemoAdvancedAssignment.docx) above). There will be the most value from this assignment if, rather than it being a ‘one off’, it is scaffolded within a semester long project where students take ownership of a dataset that they select to analyze. This will maximize the potential for student-active teaching. While this activity could be done in a single lab session, it is also amenable to being separated out into multiple lab/seminar/lecture slots. In this context, the instructor just needs to make sure that the students are saving their .R script file. Then, the next time they start to work on the activity, they just need to re-run the initial part of their code and continue from where they left off.

**Assessment of student learning outcomes**

We have provided the [StudentAssignmentWorksheet.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheet.docx) and that is a way in which the instructor can evaluate whether the student was able to effectively run through the analyses. We have also provided a [StudentAssignmentWorksheetSolutions.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/StudentAssignmentWorksheetSolutions.docx) file for the instructor to use. If you compare what students submit to this – this will give you an idea on whether they are achieving the assessable outcomes that are listed within that assignment (and above). We recognize that this worksheet assignment could be a launching point for students to use another dataset to conduct analyses at the individual student group level for a semester long project (see [DemoAdvancedAssignment.docx](https://tiee.esa.org/vol/v18/issues/data_sets/mcintosh/resources/DemoAdvancedAssignment.docx) that is provided with this dataset for ideas on how that could be achieved). You are welcome to reach out to Dr. McIntosh for other sample datasets that my students have worked with that are available for use. Given time limits we did not include a question related to the vectors – you may consider adding in a question to the assignment related to vectors.

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