**Boreal Ecosystem Recovery and Assessment (BERA)**

**COSIA Project Number:** LJ0220

**Research Provider**: University of Calgary

**Industry Champion:** ConocoPhillips Canada Resources Corp.

**Industry Collaborators:** Cenovus Energy Inc., Canadian Natural Resources Ltd., Alberta Pacific Forest Industries **Ltd.**

**Status:** Year 5 of 5

**PROJECT SUMMARY**

The boreal-forest regions of Alberta are under increasing pressure from human development related to natural-resource extraction. Roads, seismic lines, well sites, cut blocks, mines, pipelines, and other elements of human footprint exert cumulative environmental effects that can harm biodiversity, water quality, and the habitat of threatened species such as woodland caribou. In order to mitigate these effects, resource-extraction companies and provincial regulators are working to develop monitoring initiatives that track the amount of human footprint present in a given area and measure the rate at which previously disturbed areas are being restored.

The Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) Boreal Ecological Recovery and Assessment project (BERA <http://www.bera-project.org>) brings researchers, government, stakeholders, and industry together to mitigate the effects of non-permanent industrial activities, such as the construction of seismic lines, access roads, and well pads, on the boreal forest. The team, led by research experts from the University of Calgary, University of Alberta, Trent University, (Waterloo University added in 2019), and Natural Resources Canada, aims to develop cutting-edge technologies and techniques that can help to measure, monitor, and predict the recovery of vegetation and some animal uses after temporary human disturbance by industrial activity.

**The Technology**

The research program uses advanced geospatial technologies and modelling techniques to aid in the process of measuring, monitoring, and predicting vegetation recovery on non-permanent (i.e., to be reclaimed) human footprint features (i.e., seismic lines, roads, etc.).

The BERA project previously included three research areas: remote sensing, sensor networks and ecology. In 2019, a fourth research area was added: soils and ecohydrology.

**Objectives**

The research project addresses five specific research objectives:

1. Map human footprint features using advanced remote-sensing devices;
2. Assign descriptive attributes to human-footprint features that can be tracked through time in a monitoring program;
3. Develop low-cost ground-sensor networks that can track the physical condition and human or animal use of human-footprint features;
4. Develop statistical models that can predict the rate of vegetation recovery in human-footprint features across the boreal forest; and
5. Deliver a rapid verification protocol designed to assess the reclamation status areas disturbed by humans.

**Potential/Actual Environmental Benefits**

By discovering new ways to monitor and measure how humans impact the boreal forest and predict how vegetation can return to areas of temporary disturbance, the oil sands and forest industries can improve how they manage reclamation efforts across their areas of operation.

**Outcomes**

Innovative approaches to mapping the extent and condition of temporary footprint, monitoring vegetation recovery, and the efficacy of habitat restoration activities in the boreal forest are key to effective land reclamation.

Remote sensing technologies offer a credible and defensible way to map and monitor recovery of vegetation on disturbed sites. BERA’s research supports industry efforts to develop timely land-reclamation practices. Novel geosensor technology can aid in better understanding the use of recovering temporary disturbances, by both humans and boreal forest dwellers, which is an important factor determining future recovery success.

Arriving at a set of unambiguous scientifically defensible criteria determining vegetation recovery success and future success trajectories will aid in prioritizing areas for treatment as well as inform regulatory requirements for effective boreal forest reclamation.

**Progress and Achievement**

**Objective 1: Map human footprint features with advanced remote-sensing devices**

Gus Lopes Queiroz (M.Sc., 2019; now serving as a BERA Research Technician) continued the development of the Seismic Line Mapper (SLM), which is a software tool for measuring the path and extent of linear disturbances using least-cost-path analysis of canopy height models. An alpha version of the tool (SLMα) was previously developed within the BERA project.

Lopes Queiroz’s work addressed four main goals: (i) solve issues and limitations of the prototype version; (ii) apply an updated version of the SLM to generate line and footprint layers for the three BERA 2017 project areas: Kirby, LiDea I and LiDea II; (iii) conceptualize and implement line-attribution functionalities to the SLM so that the tool output would include attributes which relate to spatial properties, allowing for greater insight on seismic line conditions; and (iv) package the SLM tool as professional software for use by external stakeholders.

While addressing these goals, Lopes Queiroz identified the need to fundamentally change the methods and workflow of the prototype version. The only required data input is a canopy height model map (raster) and a regional-scale digitized linear layer of seismic lines (~1:20,000). This new workflow is more streamlined and allows for much more precise and detailed outputs (footprint polygons and centrelines) at a fine scale (~1:500) including a series of spatial attributes. SLMα was redesigned to adopt a parallel processing method instead, allowing several central processing unit (CPU) cores to work simultaneously. This dramatically reduces the processing time on extensive application areas (i.e., from days to minutes). Finally, to achieve effective parallel processing and allow for multi-license support (i.e., both ArcMap and ArcGIS Pro) while aiming for effective user experience, SLMα was restructured as stand-alone scripts with its own graphical user interface (GUI), as opposed to ArcGIS script tools. SLMα is operational and ready to be shared as a beta release (SLMβ).

**Objective 2: Assign descriptive attributes to human-footprint features that can be tracked through time in a monitoring program**

Several BERA researchers from the University of Calgary and Natural Resources Canada (NRCAN) Canadian Forest Service Northern Forestry Center (CFS), are collaborating on the use of remote-sensing data sets and workflows to perform conifer seedling detection and stocking assessment in line with the Provincial Restoration and Establishment Framework for Legacy Seismic Lines. Greg McDermid (University of Calgary, BERA Principal Investigator) used manual image interpretation (i.e., softcopy interpretation) to document the effects of seedling size (height), species (evergreen versus deciduous), and phenology (leaf on versus leaf off) on seedling detectability. His preliminary findings suggest that good, unshaded imagery commissioned with a piloted aircraft (~5 cm/pixel ground resolution) enabled the detection of more than 80% of evergreen seedlings, with low rates (~2%) of false detection. Further preliminary work by Man Fai Wu (University of Calgary, M.Sc.) and Mustafiz Rahman (University of Calgary, Research Scientist) showed that these softcopy-interpretation results could be largely duplicated by automated workflows (object-based classifications performed on the same imagery), suggesting that large-area production should be possible. However, these techniques rely on a narrow phenological window (spring and fall) where surrounding vegetation was senesced. These workflows are not expected to perform well for small (< 70 cm) or deciduous seedlings.

Michael Fromm (Ludwig-Maximilian University, M.Sc.) assessed the effectiveness of machine-learning algorithms for automatic detection of coniferous seedlings from centimetric drone images of seismic lines. Upon successful completion of his thesis, demonstrating that convolutional neural networks (CNN) can be used as a feature extractor and object detector to classify seedlings, Fromm published his findings in 2019. The best model achieved a mean-average-precision (MAP) value of 0.81, which allowed the detection of eight out of ten seedlings with an error rate of 20%. Michael also found that by using a pretrained CNN, a high MAP (> 0.65) value could be accomplished with as few as 200 training annotations. A combination of leaf-on and leaf-off images produced the best result. Further tests on simulated flying altitude (pixel size) showed that algorithms trained at one resolution could not be applied effectively to imagery at another resolution, but that machine-learning approaches to seedling detection could perform well at a variety of resolutions given adequate training. Predictably, medium and large seedlings can be detected better (large-seedling MAP > 0.99; medium-seedling MAP > 0.85) than small seedlings (MAP > 0.7).

Annette Dietmaier (Ludwig-Maximilian University, M.Sc.) compared airborne laser scanning (LiDAR) and digital aerial photogrammetry for characterizing canopy opening in the boreal forest. Upon successful completion of her thesis, demonstrating that LiDAR data was still best equipped to characterize structural elements of forest canopies (canopy openings mapped with 87% overall accuracy), compared to photogrammetric models (~46 – 47% overall accuracy). Her findings were published in 2019.

Understory vegetation is an important component of the boreal forest, providing wildlife habitat, influencing nutrient cycling, forest succession, and fire regimes. However, it often is excluded from forest structure assessment due to the lack of its direct economic significance. As a result, limited research has been conducted on this forest layer. Silvia Losada (University of Calgary, M.Sc.) has taken on the task of advancing the mapping and characterizing of understory vegetation with remote sensing. Using high-density airborne LiDAR and field measurements, Losada was able to collect data across a large spatial extent. Preliminary results show strong correlations between LiDAR and field data. However, some systematic biases were identified. Losada is continuing her analysis to understand the nature of that bias.

Gustavo Lopes Queiroz (University of Calgary, M.Sc.) successfully defended his thesis in the summer 2019. During his thesis research, he developed novel methods to mapping and estimating the volume of coarse woody debris (CWD) both on boreal seismic lines and the surrounding forest. His research tested the effectiveness of a geographical object-based image analysis (GEOBIA) workflow with random forest classification for mapping CWD logs and snags in a 4,300-hectare study area in northeastern Alberta, Canada. The models successfully mapped (up to 93.4% completeness and 94.5% correctness) and estimated volume of CWD (0.623 R², 0.224 RMSE), with good accuracies. Machine learning proved a valuable tool for detecting CWD on orthophotos. Given a large training sample created by a human interpreter, the artificial intelligence was able to achieve high accuracies with relatively little efforts from the user. CWD estimations in the surrounding forest are more challenging than on disturbances, but good results are achievable through sophisticated statistical modelling.

Kiran Basran (University of Calgary, MGIS) worked on extending an existing depth-to-water mapping , originally developed by Rahman et al. (2017). Kiran applied the technique to a large and complex Kirby study site and developed a new strategy for communicating confidence in water-depth estimates over varying conditions. The study concluded that remote sensing can map depth to groundwater table in the low-lying areas with acceptable accuracy (±30 cm) under the following assumptions: (i) surface water is abundant and visible from the aerial platforms; (ii) surface water is tightly linked with ground water; and (iii) the terrain is flat or gently sloping. (Rahman, M. M., McDermid, G. J., Strack, M., & Lovitt, J. (2017). A new method to map groundwater table in peatlands using unmanned aerial vehicles. Remote Sensing, 9(10), 1057.)

Marko Dejanovic (Ludwig-Maximilian University, Bachelor Honours Student) built on Basran’s work by attempting to apply the depth-to-water mapping technique across time using repeated remote-sensing flights. He demonstrated that the technique can serve as a near-real-time monitoring tool, given the same mapping assumptions.

Cassondra Stevenson (University of Alberta, B.Sc.) used a high-precision altimeter to investigate microtopographic variation on seismic lines compared to adjacent undisturbed forests. After successful completion of her Bachelor’s thesis, where she demonstrated that microtopographic complexity on seismic lines was simplified by 20% compared to adjacent stands, she published her findings in 2019. There was no significant change between recently burned and unburned sites, nor between ecosites. Stevenson found that not only were seismic lines simplified, but they were also depressed in elevation by an average of 8 cm compared to adjacent forests due presumably to the mechanical creation of the seismic line. Some minor variation between ecosites was observed, but not with recent wildfires.

In an effort to understand the factors limiting tree recruitment on seismic lines, Caroline Franklin (University of Alberta, Post-Doctoral Fellow) examined the variation in several abiotic conditions – light intensity, air temperature, and relative humidity – within and adjacent to seismic lines. Her findings demonstrated that edge effects on the microclimate of seismic lines were most pronounced in wider lines and along north forest edges (south-facing exposure) and east forest edges (west-facing exposure). Light intensity on north edges of wide and narrow seismic lines was 2.8 times and 1.7 times, respectively, higher than light intensity on south edges (north-facing exposure). Edge effects on light intensity extended up to 5 m into the forests adjacent to wide lines but were restricted to the forest edge for narrow lines. Changes in air temperature and relative humidity extended up to 10 m into the forest edge varying by time of day. The afternoon temperature for north and west (east-facing) edges of wide seismic lines was significantly higher, and relative humidity lower, than in the seismic line centrelines and the interior forest. Meanwhile, evening temperatures were significantly higher at north and east edges and evening relative humidity significantly lower at east edges compared to the interior forest. Wide seismic centrelines were characterized by ≥ 1°C increases in evening temperatures and 2.9% (east-west orientation) and 14% (north-south orientation) lower evening relative humidity than that of narrow seismic centrelines. Tree regeneration was highest where light intensity was highest (the centrelines of wide north-south seismic lines) and a 10-fold increase in light intensity resulted in 5.8 times more regenerating trees.

Kim Kleinke (University of Waterloo, M.Sc.) and Scott Davidson (University of Waterloo, Post-Doctoral Fellow) investigated the impact of seismic lines on physical and chemical soil properties. Field soil samples, measurements of bulk density and soil moisture, and plant data were collected on seismic lines in Kirby and a new area in the Cenovus Energy Inc. lease called Clyde. The sample area included seismic lines restored in varying years, unrestored lines, as well as natural areas. Kleinke further set up a block treatment study design on three seismic lines to test different restoration techniques with the intention of returning next year (in June and October 2020) for sampling. Laboratory analysis of collected plant and peat samples for total carbon, nitrogen, and phosphorus, and stable carbon and nitrogen isotopes were started as well as peat bulk density, volumetric water content, and organic matter content. Preliminary results to date suggest that that removal of vegetation and compacting of soil following seismic line disturbance significantly modifies soil physical and chemical properties including greater bulk density, higher moisture content, greater organic matter loss and changes in nutrient availability. Preliminary results further suggest that total nitrogen in the peat may be higher on seismic lines and changes in stable nitrogen isotopes indicate altered processes. Total phosphorus does not seem to change on seismic lines. Different plant species are responding to these changes in different ways, with conifers responding the most poorly. Potential competitive advantages of species such as Labrador tea may help explain the lack of desired conifer recovery.

Percy Korsah (University of Waterloo, PhD) continued his research, investigating the impact of seismic lines on peatland vegetation communities and carbon exchange. His long-term goal is to develop a tool to map vegetation communities across a boreal peatland impacted by seismic lines using unmanned aerial vehicle (UAV) imagery and use this to upscale local measurements of carbon flux. Korsah completed his second field season in Peace River measuring carbon dioxide (CO2) and methane (CH4)fluxes on seismic lines in peatlands and adjacent undisturbed areas. Preliminary data analysis was started on microbial community function and physical conditions (water table, soil moisture and soil temperature) at each study site. He further collaborated on conducting a laboratory incubation study of peat soil respiration—investigating the effect of soil moisture and temperature from samples on and off the line. Results from this work are anticipated after his final field season in 2020.

**Objective 3: Develop low-cost ground-sensor networks that can track the physical condition and human or animal use of human-footprint features**

To date, most research on acoustic animals has used relatively coarse measures of abundance to evaluate the success of recovery and restoration. Researchers have shown that such approaches do not have the resolution to accurately represent how animals react to energy sector disturbances. As such, a variety of new techniques using sound triangulation by means of autonomous recording units (ARUs) have been developed. They allow researchers to precisely locate where animals are spending their time and exactly what elements influence whether an animal will or will not use an energy sector footprint.

In particular, limited information exists on how songbirds respond to the regeneration of wellsites following reclamation. Scott Wilson (University of Alberta, M.Sc.) used acoustic localization to determine the assemblage of songbirds on 12 reclaimed wellsites, each covering about 1 ha in size and ranging from 7 to 49 years since reclamation. Wilson also evaluated the similarity of this assemblage to 12 control mature forest sites (greater than 80 years old). Songbird community composition became more similar to mature forest as canopy cover increased on reclaimed wellsites. This suggests that wellsite reclamation practices are allowing for initial suitable vegetation recovery. However, more research on the effectiveness of different strategies at promoting regeneration of wellsites and subsequent impact on songbird communities is required. Ongoing work by Richard Hedley (University of Alberta, Post-Doctoral Fellow) is showing that sound truncation can be used instead of sound triangulation to assess (quite affordably) how birds react to disturbances.

Regarding bird responses to seismic lines, Jocelyn Gregoire (University of Alberta, M.Sc.) is in the process of investigating the behavioural response of the Canada warbler during the different stages of recovery of linear features using sound triangulation techniques. Her objectives are to; (i) determine how Canada warblers use space around seismic lines; and (ii) to identify how vegetation regeneration influences this response. Deploying 46 grids of GPS time-synchronized SM3 song meters across seismic lines at different stages of regeneration, Gregoire achieved precise locations of singing events with minimal human disturbance. Vegetation surveys were conducted along the disturbance and in the adjacent forest to assess regeneration. Preliminary insights gained so far suggest that Canada warblers live across seismic lines when the vegetation reaches a critical stage. They also suggest that they are also more likely to be near recovered seismic lines relative to lines with less vegetation cover.

Research on using autonomous recording units to investigate bird responses to industrial noise is also being pursued by Natalie Sanchez (University of Alberta, PhD). Sanchez is testing whether songbirds avoid noisy areas— taking into account the human disturbance in addition to the noise source. For this work, she is estimating the occupancy of four songbirds breeding in Northern Alberta: Lincoln’s sparrow, white-throated sparrow, Tennessee warbler, and yellow-rumped warbler. Her focus is on abundance responses to industrial noise sites in very different habitats from those previously studied. Preliminary insights suggest that the Lincoln's sparrow (a habitat generalist generally tolerant of physical disturbance) shows some response to noise with evidence suggesting they may adapt their songs slightly to be heard in such environments. However, more analysis is required before conclusions can be drawn.

Lionel Leston (University of Alberta, Post-Doctoral Fellow) has started to investigate the response of forest birds to cumulative effects at multiple spatial scale using data from Big Grids. Recent studies suggest that models of bird abundance are improved by including fine-scale vegetation structural data (e.g., crown height, canopy cover, shrub density). However, fine-scale vegetation data collected from field surveys are time consuming and labour intensive to obtain, even over small extents. In addition, the improvement in model-fit achieved by including fine-scale data may be insufficient relative to the expended effort. Leston is modelling how well abundance of boreal bird species are predicted by different kinds of spatial data, from coarse-scale remotely sensed layers and forest-resource inventory shapefiles, to fine-scale LIDAR point cloud data. It is anticipated that the spatial scale will influence the effect size for most disturbance stressors.

Over the course of the year, Steve Liang and his team (University of Calgary) have continued the development of a new generation of the end-to-end low-cost and low-power IoT (Internet of Things: a network of Internet connected objects able to collect and exchange data) sensing system for environmental monitoring including; (i) upgrades to the cloud-based managed services (i.e., Amazon Web Services (AWS) IoT Core) for provisioning sensors and field gateways, that has no single-point-of-failure and is scalable to a very large number of IoT devices; ii) changes to the field LoRA gateway from a lab prototype to a commercial system that is designed to be deployed in the field; (iii) changes to the environmental sensing nodes from a lab prototype PCB-board to a commercial sensor that is designed to be deployed in the field; (iv) development on a new frond-end IoT portal for field data management, visualization, and analysis over the Web; and (v) tests and deployments of the new system for data collection. The team further led and worked with international experts to update the Open Geospatial Consortium (OGC) SensorThings API v1.0 to v1.1., which is fundamental IoT technical architecture for the developments in this research. The advancement of the SensorThings standard has a significant impact for scientists constructing IoT systems for environmental sensing around the world. The team also led and worked with United Nations’ ITU-T to define an international standard for IoT data management and processing based on the OGC SensorThings API. This United Nations’ standard will have a global impact on how nations around the world construct and share IoT sensing data.

**Objective 4: Develop statistical models that can predict the rate of vegetation recovery in human-footprint features across the boreal forest**

Lack of recovery is common in unproductive forests, such as treed peatlands, due to conditions that limit tree growth such as simplification of microtopography (loss of microsites). The persistence of these features affects biodiversity, including threatened woodland caribou. Although natural regeneration occurs in some places, it is not an effective strategy in treed peatlands, the primary habitat of woodland caribou. This has led to active restoration.. However, the current approach to restoration does not consider wildfires that destroy planted trees, yet also initiate early seral conditions that favour natural regeneration. Angelo Filicetti (University of Alberta, PhD) compared tree regeneration on seismic lines and adjacent forests controls for burnt (75 sites) and unburnt (68 sites) treed peatlands in northeast Alberta. Tree regeneration varied from; 28,500 stems/ha in burnt lines; 11,440 stems/ha in unburnt lines; 18,210 stems/ha in burnt forest; and 9,520 stems/ha in unburnt forest. Wildfires promoted natural regeneration in bogs and poor mesic sites, but not in fens where regeneration was negatively related to open water and positively related to cover of bryophyte and woody debris. Finally, tree regeneration was related to microtopography on seismic lines for burnt lines, but not unburnt lines.

Filicetti also examined the natural and planted recovery of trees in the LiDea restoration site in the Cold Lake Air Weapons Range. He found that, when compared to untreated lines, silvicultural treatments of mounding increased tree density of natural regeneration despite averaging only 3.8 years since treatment (versus 22 years since disturbance for untreated). Specifically, treated lines averaged 12,290 regenerating tree stems/ha. This is 1.6-times more than untreated lines (7,680 stems/ha) and 1.5-times more than the adjacent undisturbed forest (8,240 stems/ha). Treated seismic lines consistently have more regenerating trees across all ecosites. Although, the higher amounts of stems observed on treated poor fens were not significantly different to untreated or adjacent undisturbed reference stands.

**Objective 5: Deliver a rapid verification protocol designed to assess the reclamation status areas disturbed by humans**

Guillermo Castilla (Canadian Forest Service, BERA Principal Investigator) and his team continued working on automated estimations of conifer seedling heights from high-resolution drone images at 0.35 cm, 0.7 cm, and 2.5 cm ground resolutions. The team returned to the field in May 2019 for additional measurements to explain some outliers in their height estimates from the drone photogrammetry. The preliminary analysis results for these drone images indicate that the minimal height error that can be achieved under ideal conditions is approximately 30 cm; meaning that small conifer seedlings (~< 60 cm) cannot currently be reliably measured with high-resolution drone photogrammetry. Final analysis results are expected in spring 2020.

**Lessons Learned**

**Remote Sensing**

* Remote sensing is an effective and authoritative source of information for canopy structure and coarse woody debris (CWD). Under the correct conditions, remote sensing data can also provide an authoritative source of information for forest understory structure, depth to water, and conifer seedling detection/measurement. Specific lessons include:
  + While digital aerial photogrammetry is a less expensive alternative to map canopy structure, it is unable to compete with the accuracy of LiDAR. This is particularly evident with small structural features such as canopy openings up to 20 m2, where the photogrammetric technique performs poorly. For now, it is recommended that operational use of digital aerial photogrammetry in forests be limited to mapping large canopy features.
  + Remote sensing can and should be used to study CWD on seismic lines, given that open canopy conditions allow for very accurate and extensive estimations of CWD. The inputs necessary to achieve good accuracies on seismic lines are accessible—an RGBN orthophoto and a training set. Machine learning proved a valuable tool to detect CWD on orthophotos. Given a large training sample created by a human interpreter, the artificial intelligence was able to achieve high accuracies with relatively little efforts from the user. CWD estimations in the surrounding forest are more challenging than on disturbances due to canopy interference, but are achievable through sophisticated modelling. Field measurements become instrumental to achieve good estimates where CWD is invisible from orthographic view.
  + High-density LiDAR point clouds show strong correlations with understory structure information collected in the field, suggesting promising future insights. This work is still ongoing, and the source of systematic LiDAR overestimations will need to be understood before any recommendations can be made.
  + Depth to groundwater table can be mapped across space and time in low lying areas with acceptable accuracy (± 30 cm). However only when the following assumptions are met; (i) surface water is abundant and visible from the aerial platforms; (ii) surface water is tightly linked with ground water; and (iii) the terrain is flat or gently sloping. This is a substantial development for ground-water monitoring.
  + For remote conifer seedling detection, preliminary findings suggest it is unlikely that survival surveys (two to five year after treatment) will be feasible from piloted aircraft, given current camera technologies. However, establishment surveys (done eight to ten years after treatment) are expected to become feasible given the larger size of seedlings at that age. The preliminary results for automated seedling detection workflows applied on 5 cm/pixel ortho-imagery, which constitutes an image resolution that can be feasibly obtained over larger tracts of land using piloted aircraft, suggest good performance on larger conifer seedlings (> 70 cm). However, these results rely on a short phenological window (spring and fall). Further testing is still ongoing.
  + The use of artificial intelligence for conifer-seedling detection on centimetric drone imagery indicates reliable results for seedlings with crown diameters greater than 60 cm. More research will be undertaken in this area, but in the future it should be feasible to use convolutional neural networks for automated establishment surveys on sites more than five years after treatment/regeneration, where seedlings are sufficiently large for reliable detection.
  + Preliminary analysis on automated height estimation of conifer seedlings suggest that this can be performed with high-resolution (finer than 2.5 cm/pixel resolution) drone imagery with a minimal error of 30 cm, suggesting that seedlings smaller than 60 cm cannot be estimated reliably. More research is needed to assess the accuracy of estimating seedling height at piloted aircraft imagery at resolutions 5 cm/pixel and coarser.

**Soils and Ecohydrology**

* Simplification of microtopographic complexity and the creation of depressions along seismic lines can persist decades after initial disturbance, with some differences between peatland ecosites. This underscores the need for ecosite-specific restoration of topographic complexity. The importance of microtopography for tree regeneration on seismic lines remains an important question for reforestation of these disturbances and thus long-term recovery of habitat for species dependent on undisturbed peatlands.
* A better understanding of the microclimatic variables affecting tree growth and establishment on seismic lines can help guide restoration efforts. Preliminary findings for poor-mesic conifer forest ecosites suggest that seismic-line width and orientation affect abiotic factors within the linear disturbance, and up to 10 m into the adjacent forest—with patterns in tree regeneration mostly relating to local patterns of light associated with orientation and width of these linear disturbances. This suggests light availability on lines is an important limiting factor for regeneration.
* Preliminary work suggests that the removal of vegetation and the compaction of soil following seismic line disturbance appears to significantly impact soil physical and chemical properties including greater bulk density, higher moisture content, greater organic matter loss and changes in nutrient availability. Future work will investigate links between changes in soil properties and vegetation recovery.
* Total nitrogen in the peat may be higher on seismic lines, and changes in stable nitrogen isotopes indicate altered processes. Preliminary findings also show that total phosphorus does not seem to change on seismic lines. Different plant species are responding to these changes in different ways with conifers responding the most poorly. Potential competitive advantages of species such as Labrador tea may help explain the lack of desired conifer recovery.
* Preliminary insights deem pristine peatlands still to be the best-case scenario in terms of carbon exchange. Carbon loss from soil and changes to rates of carbon exchange can likely be reduced by minimizing soil disturbance (e.g., reducing compaction through use of lighter machinery or cutting lines by hand).

**Sensor Networks**

* Low-cost, long-range, low-power IoT networks, such as LoRAWAN, have matured significantly in the past year. Since the first year of the project researchers have pioneered the development of environmental sensing with LoRAWAN. At that time there were no suitable commercial products available for purchasing and testing. However, in 2019 researchers found commercial solutions are much more widely available and mature.
* A serverless solution for IoT devices, such as AWS IoT Core, is more mature. This solution enables the research team to upgrade their architectural design and is also more scalable and reliable.
* Autonomous recording units (ARUs) can be used to determine wildlife singing locations, based on time of arrival differences of songs to an array of microphones by means of sound triangulation. This allows for precise location of where animals are spending their time and exactly what elements influence whether an animal will or will not use an energy sector footprint.
* Latest insights suggest that “sound truncation” can be used instead of “sound triangulation” to affordably assess how birds react to disturbances .

**Ecology**

* Forest birds are responding positively to increasing tree and shrub cover growing on well pads and seismic lines in aspen forest. This suggest that practices being implemented to facilitate more rapid growth of trees and shrubs by active restoration are likely to be an effective strategy for recovering these habitats for forest bird species. Which reclamation practices facilitate the fastest recovery from a bird’s perspective requires more research. As well, most research on recovery of oil sands footprints using birds as indicators has taken placed in upland forests dominated by aspen. Work is needed in wetlands and other conifer dominated uplands to confirm the generality of the patterns observed to date.
* Preliminary findings for the response of Canada warbler to seismic lines suggests that this species lives across seismic lines when the vegetation reaches a critical stage. They are also more likely to be near recovered seismic lines than lines with less vegetation cover.
* Wildfires promoted natural regeneration in bogs and poor mesic sites, but not in fens.
* Mechanical site preparation (mounding and ripping) on seismic lines increased tree density on these treated lines when compared to untreated lines—despite averaging 3.8 years since treatment versus 22 years since disturbance for untreated sites.

Presentations and Publications

**Published Theses**

Basran, K. K. 2019. [Mapping Depth to Water (DTW) in Alberta’s Boreal Region Using Remote Sensing Techniques.](http://beraproject.org/wp-content/uploads/2019/06/MGIS_Project_KiranBasran_MAY2019.pdf)  MGIS thesis, University of Calgary.

Dietmaier, A. 2019. [Comparison of airborne laser scanning and digital aerial photogrammetry for characterizing canopy openings in the boreal forest in Alberta, Canada.](file:///C:\Users\mcdermid\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\OQ875X7J\beraproject.org\wp-content\uploads\2018\12\Masterarbeit_Dietmaier_20181130.pdf) M.Sc. thesis, Ludwig Maximilian University (LMU) of Munich.

Lopes Queiroz, G. 2019. [Remote Sensing Boreal Coarse Woody Debris](file:///C:\Julia\PDF\Projects_Abbynet&CRD\Projects\CRD_GeoSpToolsVegRecovery\Documents\COSIA\report_2020\beraproject.org\wp-content\uploads\2020\01\ucalgary_2019_lopes-queiroz_gustavo-5.pdf). M.Sc. thesis. University of Calgary, Calgary, AB.

**Journal Publications**

Filicetti, A.T., Cody, M., and Nielsen, S.E. 2019. Caribou Conservation: Restoring Trees on Seismic Lines in Alberta, Canada. Forests 10(2), 185.DOI: 10.3390/f10020185

Fromm, M., Schubert, M., Castilla, G., Linke, J. and McDermid, G., 2019. Automated Detection of Conifer Seedlings in Drone Imagery Using Convolutional Neural Networks. Remote Sensing, 11(21), p.2585. DOI: 10.3390/rs11212585.

Dietmaier, A., McDermid, G. J., Rahman, M. M., Linke, J., & Ludwig, R. 2019. Comparison of LiDAR and digital aerial photogrammetry for characterizing canopy openings in the Boreal Forest of Northern Alberta. Remote Sensing, 11(16), 1919. DOI: 10.3390/rs11161919.

Lopes Queiroz, G., McDermid, G. J., Castilla, G., Linke, J., & Rahman, M. M. 2019. Mapping Coarse Woody Debris with Random Forest Classification of Centimetric Aerial Imagery. Forests, 10(6), 471. DOI:10.3390/f10060471

Stevenson, C.J., Filicetti, A.T., and Nielsen, S.E. 2019. High Precision Altimeter Demonstrates Simplification and Depression of Microtopography on Seismic Lines in Treed Peatlands. Forests 10(4), 295. DOI:10.3390/f10040295

Wilson, S. J, and E. M. Bayne. 2019. Songbird community response to regeneration of reclaimed wellsites in the boreal forest of Alberta. Journal of Ecoacoustics 3: # I4B2LF DOI: 10.22261/JEA.I4B2LF

**Reports & Other Publications**

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**Research Team and Collaborators**

Institution: University of Calgary

Principal Investigator: Dr. Greg McDermid

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| --- | --- | --- | --- | --- |
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