Arrested succession? Quantifying plant community and functional recovery (or lack thereof) on reclaimed oil and natural gas well pads in Alberta's boreal forests

Anne CS McIntosh[1] **,** Randi C Lupardus [1,2], Arnold Janz[2], Dan Farr[2], Ermias T Azeria[3], Kierann Santala[4], Isabelle Aubin[4]

[1]University of Alberta, Science Dept – Augustana Campus, Camrose, Canada amcintos@ualberta.ca [2]Alberta Environment and Parks, Edmonton, Canada [3]Alberta Biodiversity Monitoring Institute, Edmonton, Canada [4]Great Lakes Forestry Centre, Sault Ste Marie, Canada

Introduction

- Alberta's forested regions have over 240,000 drilled well pads, including ~25% that have received a reclamation certificate
- Recovery of these reclaimed well pads is measured by evidence of a positive successional trajectory
- The long-term ecological recovery of soil properties, plant community composition, and plant traits on these recontoured and revegetated well pads remains unknown in boreal forests
- **The main objective of this study** was to determine if certified reclaimed well pads were recovering back to forested lands. Recovery is expected when soil and vegetation (both community and trait composition) properties are similar to those of undisturbed reference sites[1]

Methods

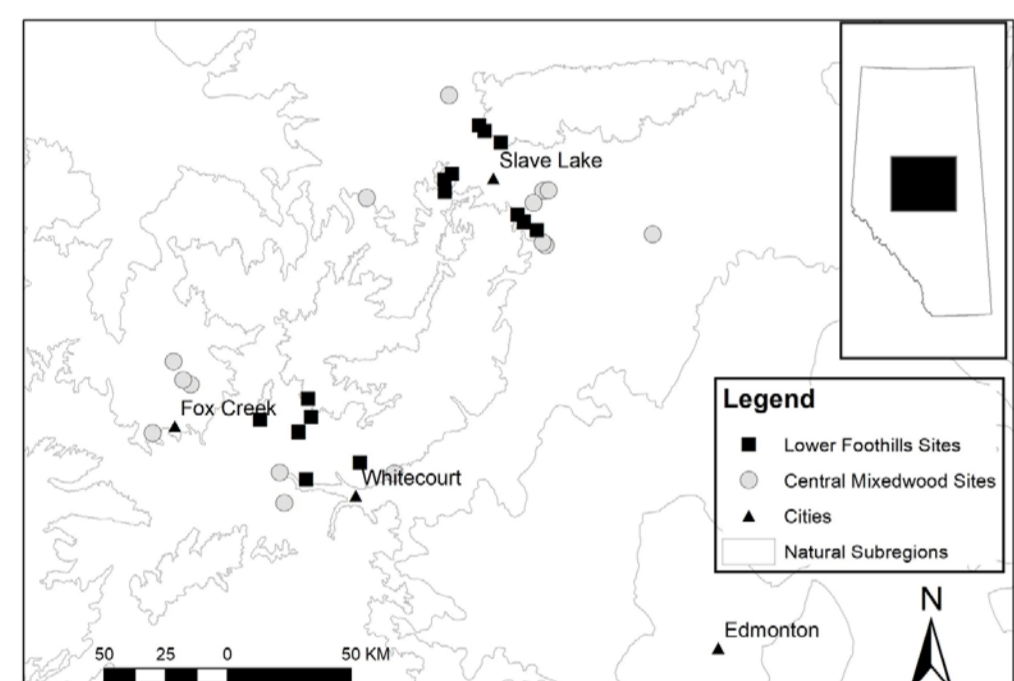Collected plant and soil data on northern boreal forest sites (n=30) in northern Alberta, Canada (Figs. 1-2).

Fig. 1. Study locations units (N=30) in Alberta's Central Mixedwood and Lower Foothills Natural Subregions; wellsites ranged from 7-48 years post-reclamation.
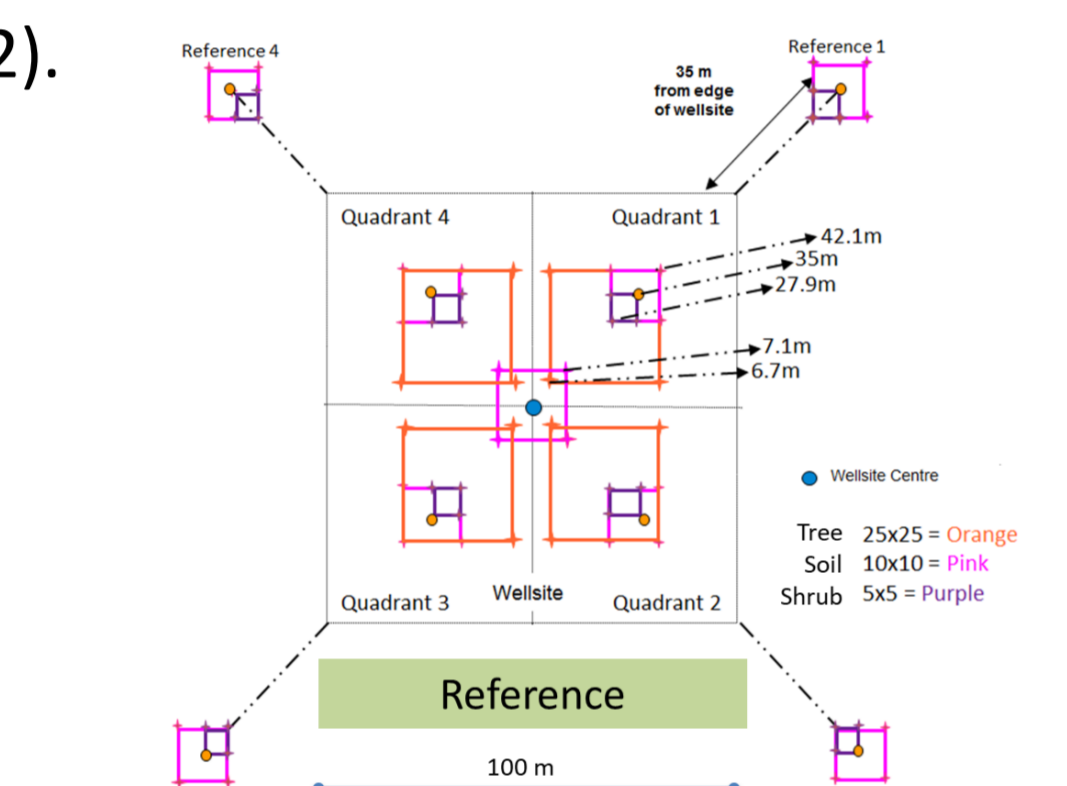
Fig. 2. Sampling design for reclaimed & adjacent reference sites (forest) at each location unit. [2]Detailed sampling design info.
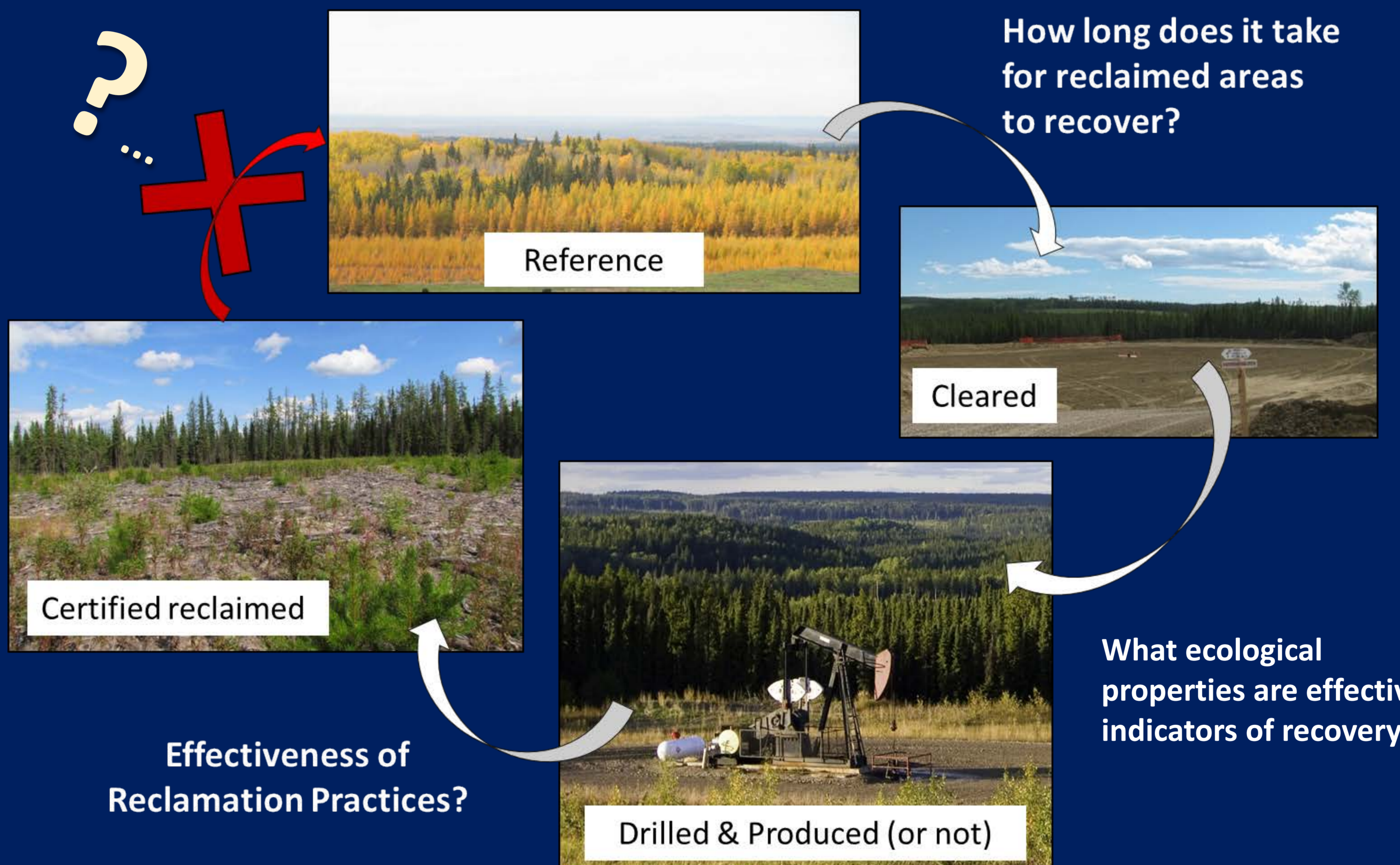
Statistical Analyses[3,4] :

- **Indicator species analysis**
- **Non-metric multidimensional scaling (NMDS) Ordination**
- Multivariate joint generalized estimating equations (JGEEs)
- Standardized Principal Component Analysis (PCA)
- Permutational multivariate analysis of variance (PERMANOVA)
- Generalised least square models (GLS) and time lag analysis
- **Community weighted mean redundancy analysis (CWM-RDA)**
- Fourth-corner analysis

bold methods presented on poster, remaining results can be found in linked publications

Results and Implications (see Figs. on right)

- Some sites are on an arrested plant community composition recovery trajectory (Fig. 3): 2 resembled vegetation community structure of reference sites; 18 were treeless grasslands (two >35 years post disturbance); remaining 10 on a positive trajectory towards recovery
- Reclaimed sites contained legacy noxious and introduced species (Fig. 4)
- Trait composition in reclaimed wellsite showed directed yet slow successional trajectory, with variation in the trajectory of traits towards reference level (Fig. 5)
- Significant environmental property effects on plant community and trait composition along succession gradient (Figs. 3-5)
- Enduring biophysical legacies from wellsite operation and reclamation may delay plant community and functional trait recovery
- Impacts can be long-lasting and may remain for decades or more post reclamation, potentially flat lining the recovery trajectory
- Permanent losses and gains in each ecological indicator can affect the long-term availability of resources, biodiversity, ecosystem services and processes on these reclaimed well pads

---

Well pad impacts may remain for decades or more after reclamation, with potential for arrested succession of plant communities, likely because of enduring legacies (e.g., non-native species, ⬆ soil pH & bulk density). However, there is slow directional recovery for plant functional traits.

How long does it take for reclaimed areas to recover?

Reference

Cleared

Certified reclaimed

Effectiveness of Reclamation Practices?

Drilled & Produced (or not)

What ecological properties are effective indicators of recovery?

Click here to access complete research publications

Results (Figs. 3-5)

Fig. 3. Indicator Species Analysis. [a]Introduced species, [b]noxious species, R[2] = correlation between species & group (reclaimed or reference), only species with R[2] ≥ 0.7 and p ≤ 0.001 reported.
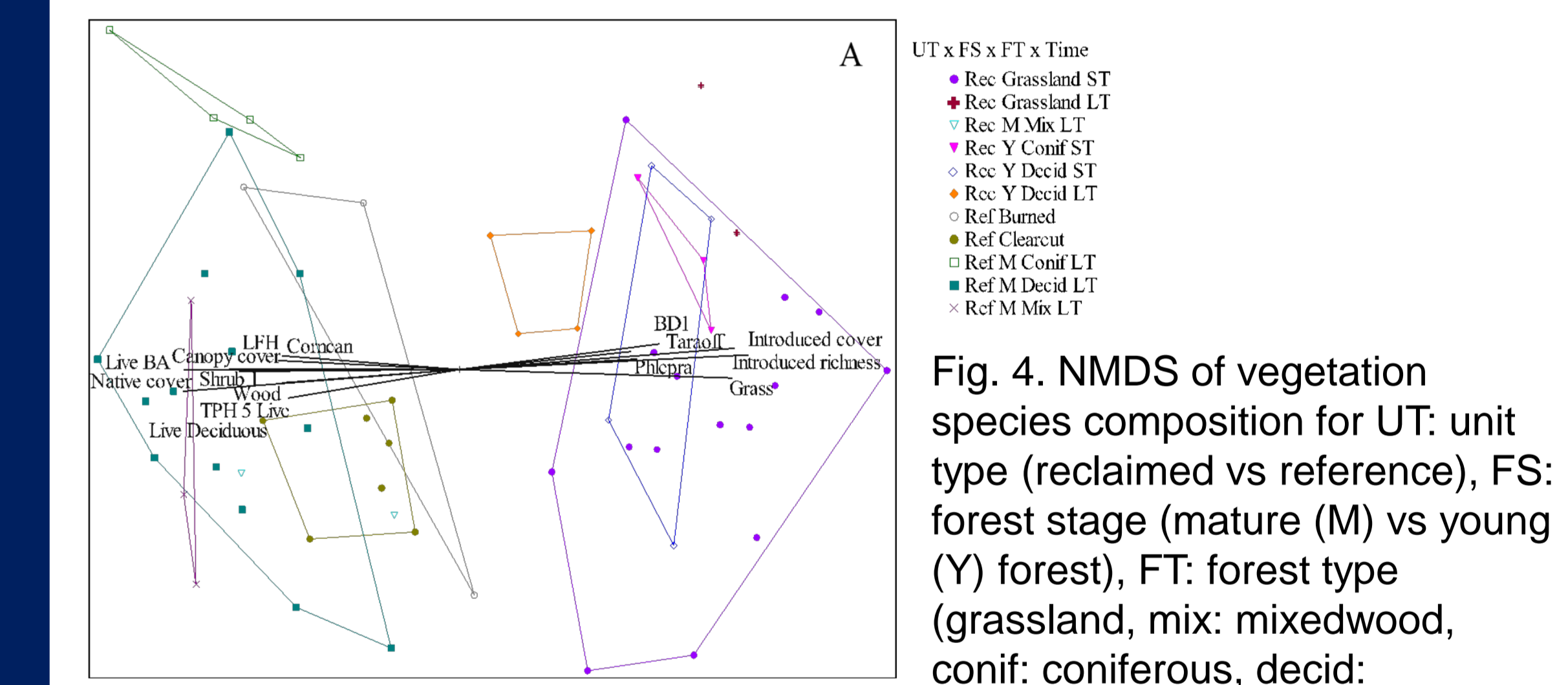

Fig. 4. NMDS of vegetation species composition for UT: unit type (reclaimed vs reference), FS: forest stage (mature (M) vs young (Y) forest), FT: forest type (grassland, mix: mixedwood, conif: coniferous, decid: deciduous, burned, clearcut), and time since disturbance (ST= 7-34 yrs, LT 35 to 49 yrs). Sites nearest each other in ordination space have similar floristic assemblages. A) vectors indicate environmental, vegetation, soil, and diversity variables which had an R[2] ≥ 0.4. Vector direction and length reflect the strength of correlation with the first two axes. Variables described in Supplemental Table 1[3].
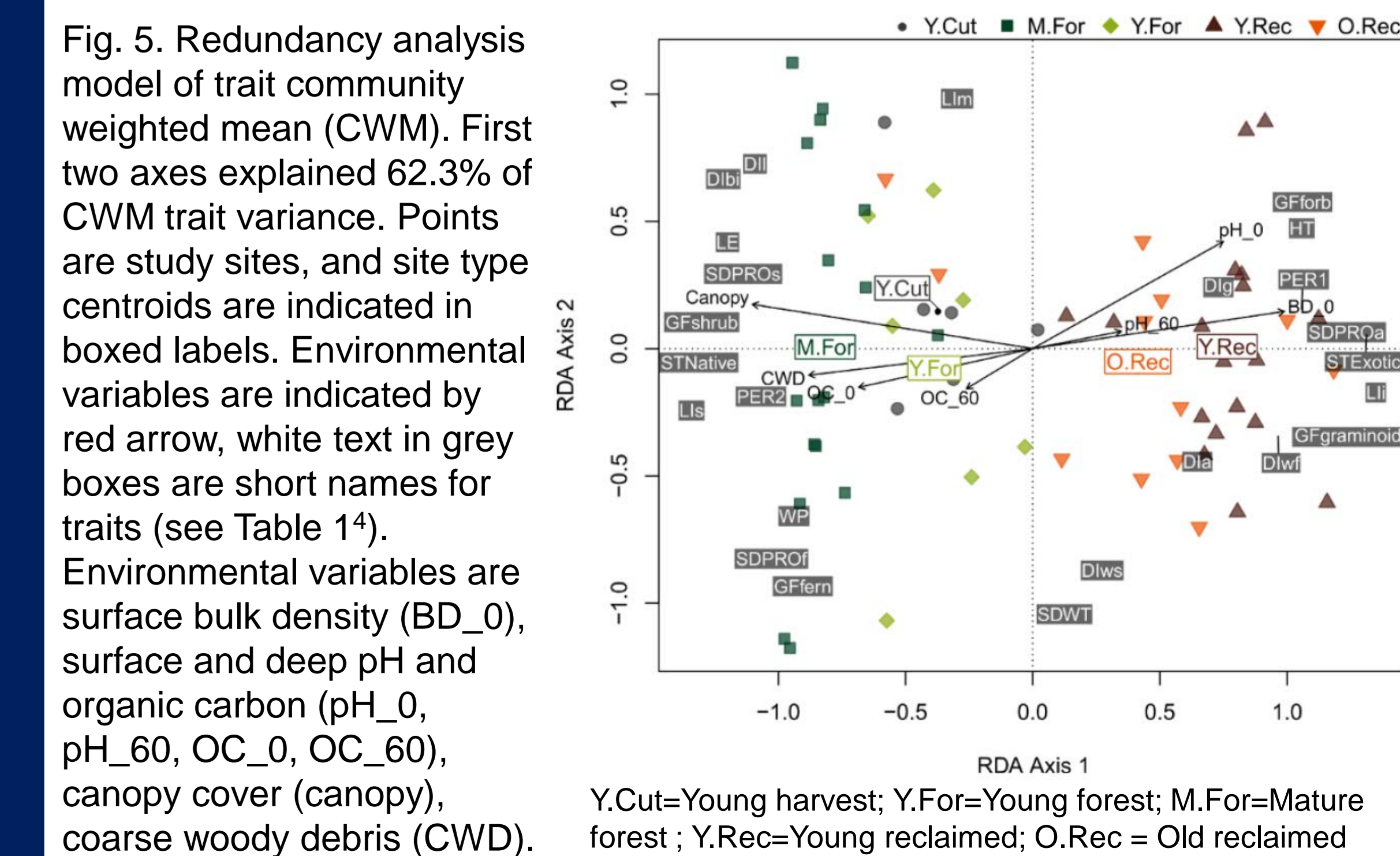

Fig. 5. Redundancy analysis model of trait community weighted mean (CWM). First two axes explained 62.3% of CWM trait variance. Points are study sites, and site type centroids are indicated in boxed labels. Environmental variables are indicated by red arrow, white text in grey boxes for traits (see Table 1[4]). Environmental variables are surface bulk density (BD_0), surface and deep pH and organic carbon (pH_0, pH_60, OC_0, OC_60), canopy cover (canopy), coarse woody debris (CWD).

Y.Cut=Young harvest; Y.For=Young forest; M.For=Mature forest ; Y.Rec=Young reclaimed; O.Rec = Old reclaimed

References: [1]Ruiz-Jaen M, Aide TM. 2005. Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. Forest Ecology and Management [2]McIntosh ACS, Drozdowski B, Degenhardt D, Powter CG, Small CC, Begg J, Farr D, Janz A, Lupardus RC, Ryerson D, Schieck J. 2019. Monitoring ecological recovery of reclaimed wellsites: protocols for quantifying recovery on forested lands. [3]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. [4]Azeria ET, Santala K, McIntosh ACS, Aubin I. 2020. Plant traits as indicators of recovery of reclaimed wellsites in forested areas: slow but directional succession trajectory. Forest Ecology and Management.