Land Cover Change at Canadian Post-Closure Mine Sites: Remote Sensing Applications in Support of Sustainable Resource Development

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Background

The mining industry continues to play an important role in the Canadian economy and supports massive amounts of local employment in rural communities and Northern Canada.[1] Meanwhile, however, a key sustainability challenge that mining operations must face is that of mine closure and legacy, where the disturbed land must be rehabilitated to standards set by regulatory bodies. Incorporating sustainability throughout the planning and operating stages of a mine's life becomes worthless if adequate reclamation is not achieved post-closure and legacies are left to harm both the environment and human health. Further, a mine company's record of successful land-stewardship can play a significant role in its ability to gain access to land for extractive purposes.[2] Thus, history of successful site reclamation can act as a qualifier for land access for future projects and operations. To this end, prior research suggests that the monitoring of long-term changes in vegetation and overall land cover using remotely sensed data may present a viable, low-cost indicator of reclamation success.[3] While there is a significant amount of literature focused on individual reclamation and revegetation cases globally, there is a lack of literature assessing the use of low-cost remote sensing techniques for long-term monitoring in a Canadian context, as well as recent trends in reclamation efforts and their observed effectiveness spatially across Canada.

Objectives

The objective of this study was to advance the understanding of mine site reclamation behavior in Canada and quantify the relevant sustainable practices. The following research questions were addressed:

1. How much information regarding mine site reclamation behavior (e.g. the speed, extent, and ecosystem complexity of mine site recovery across Canada) can be inferred using remote sensing techniques?
2. How has landscape recovery behaved at target reclaimed mine sites in the recent past?

Methodology

Site Selection: Five study areas at mining operations across four provinces in Canada were chosen as the representative revegetated sites. The selected sites were the Pine Point mine in the Northwest Territories, the Athabasca oil sand's Gateway Hill and Wapisiw Lookout in Alberta, Stanrock Mine in Ontario, and the Highland Valley Copper mine in British Columbia (Figure 1). All sites are previous Tailings Management Areas (TMAs) apart from Gateway Hill, which was an overburden stockpile.

Data Collection: Near-anniversary satellite imagery from Landsat 5 and Landsat 8 TM was obtained for each study site, from the respective site-closure year to 2021.

Analysis: To quantify the temporal land cover change at the selected sites, the Normalized Difference Vegetation Index (NDVI), land classification, post-classification change detection, and a Regrowth Index (RI) were used.

Image download → Preprocessing (clip/stack layers)

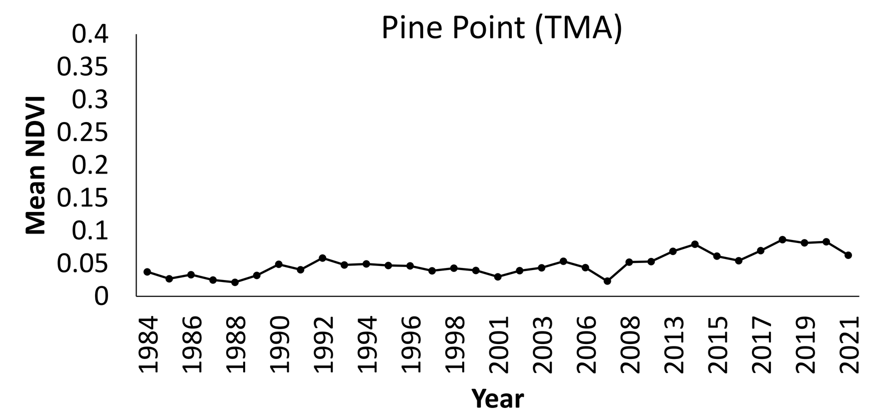
Preprocessing (clip/stack layers) → Extract and calculate NDVI → $NDVI = \frac{NIR - Red}{NIR + Red}$ → NDVI Trend

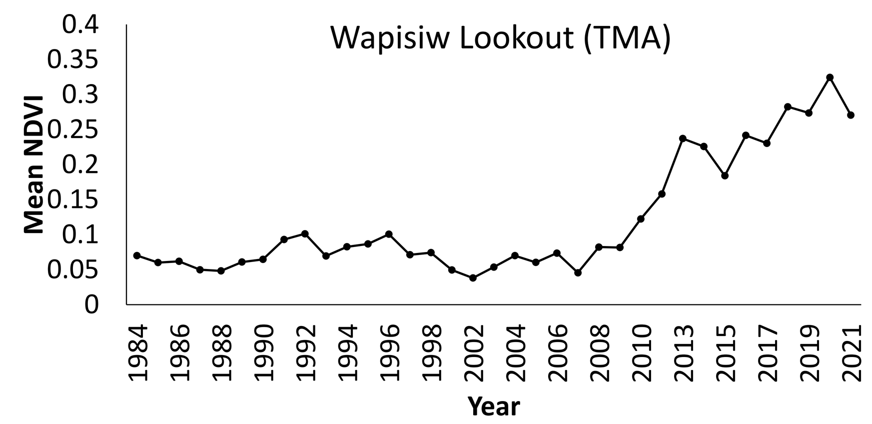
Preprocessing (clip/stack layers) → Unsupervised Classification → Post-classification Change Detection

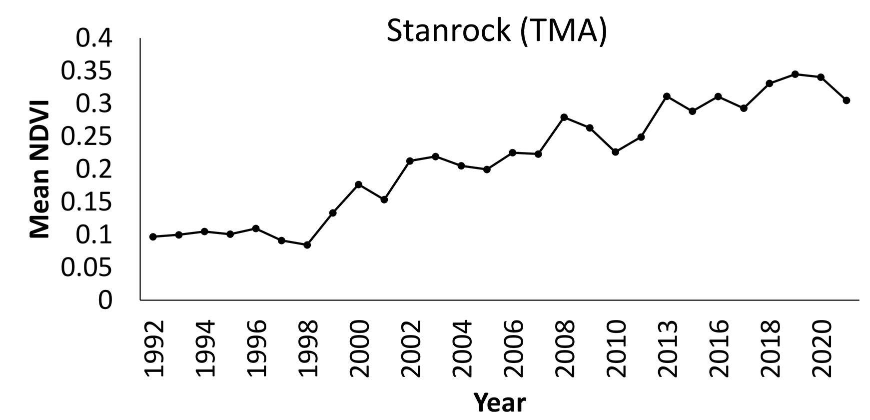
Preprocessing (clip/stack layers) → Reference Sites (Undisturbed) → Calculate Regrowth Index (RI) → $RI = NDVI_{Study\ Site} - NDVI_{Reference\ Site}$

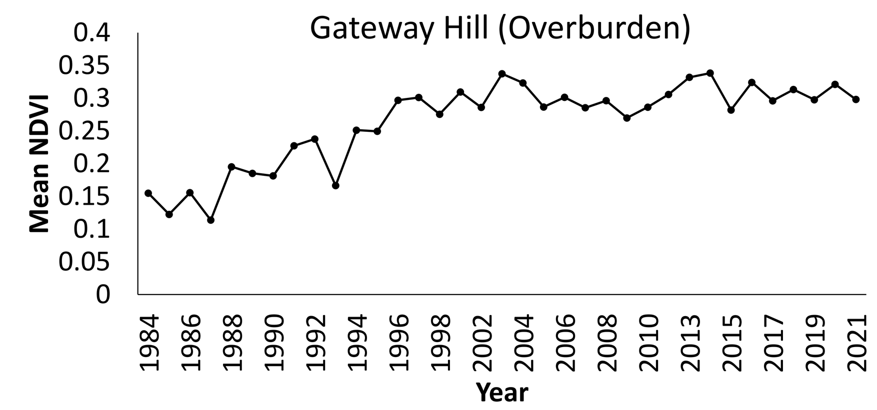
Results

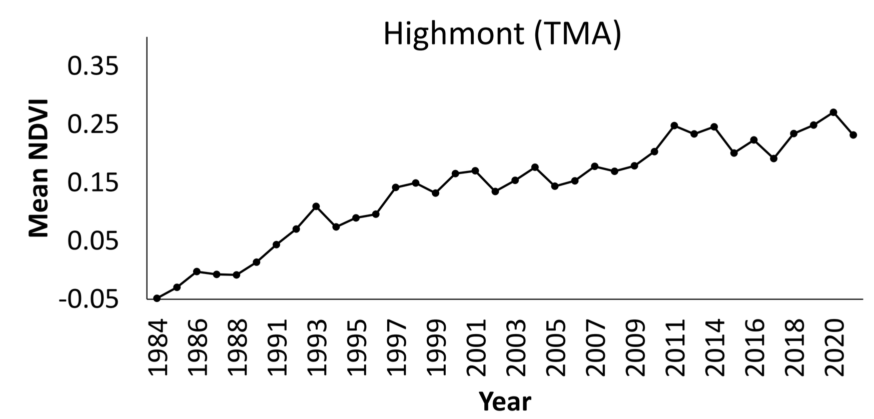
Trends in NDVI



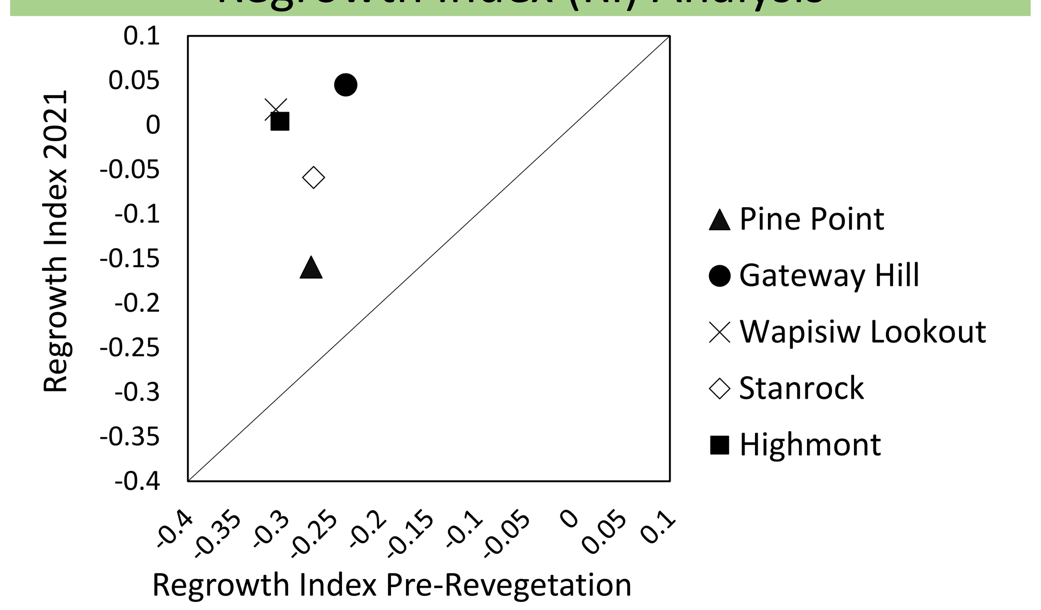








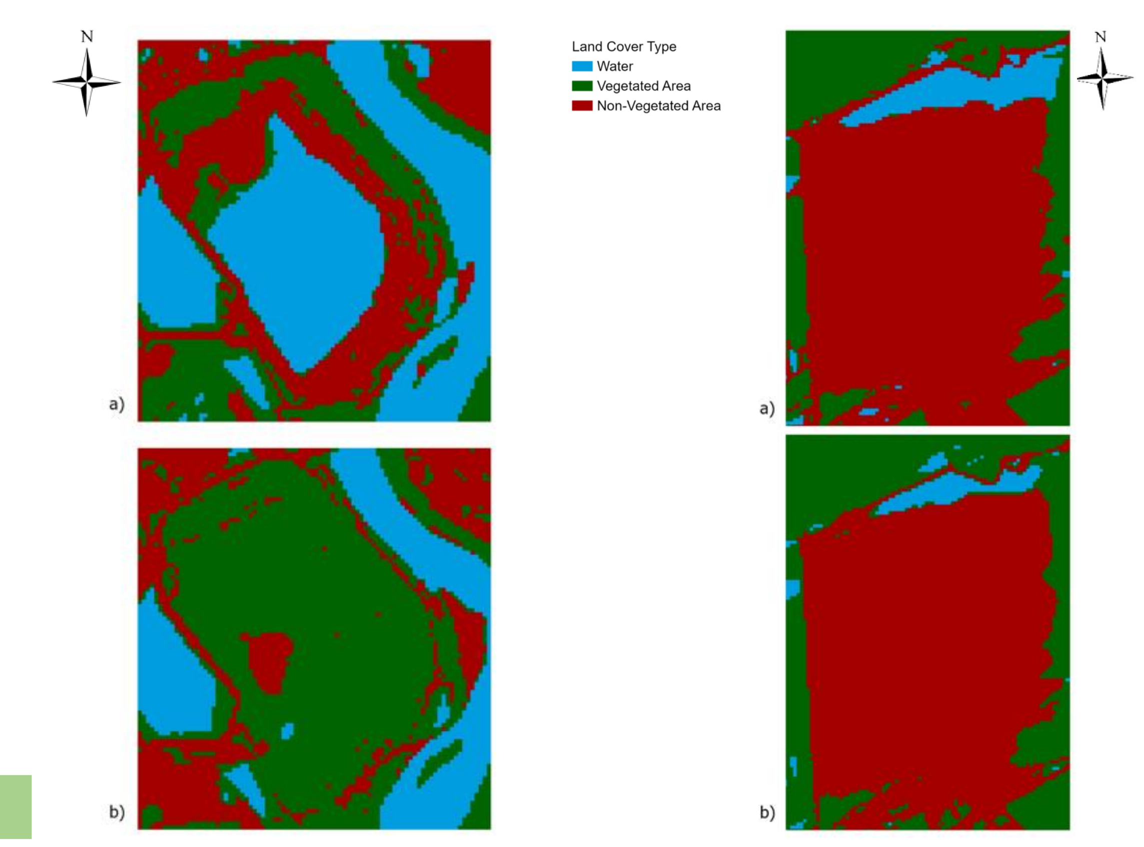
Regrowth Index (RI) Analysis



Land Cover Classification & Change Detection

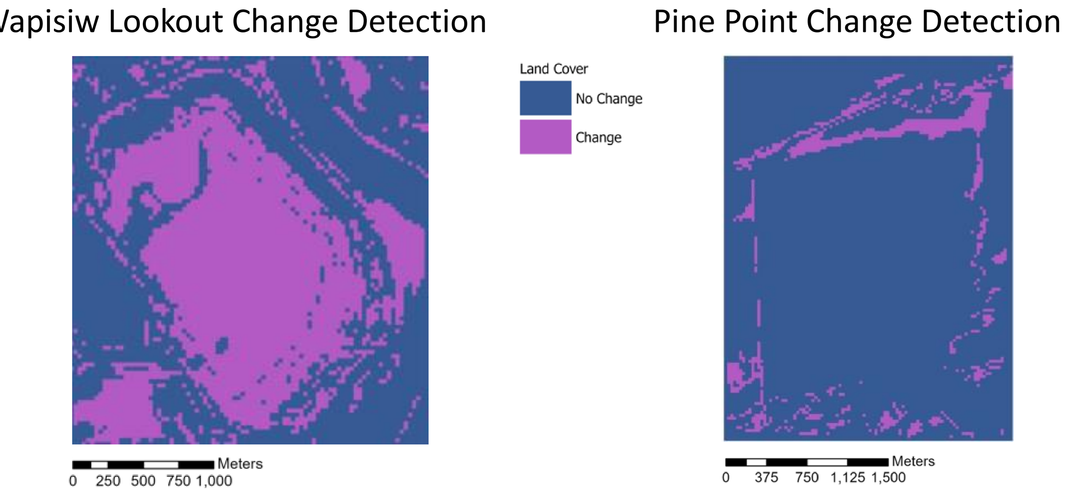
Wapisiw Lookout: a) 1997, b) 2021

Pine Point: a) 1989, b) 2021



Wapisiw Lookout Change Detection

Pine Point Change Detection



Discussion

- The Gateway Hill, Wapisiw Lookout, Stanrock, and Highmont study sites all displayed a significant increasing trend in NDVI post-closure, indicating an improvement in the health and abundance of vegetation at each site. This result was consistent with the land cover classification and change detection results, which showed significant conversion to vegetated area (Example: Wapisiw Lookout land cover classification and change detection). This large increase in NDVI and the associated land cover change was attributable to these sites all undergoing active reclamation and revegetation practices, including the technical remediation of contaminants, addition of topsoil and mineral mix, application of biosolids, and reseeding with various tailored plant species.
- In contrast, the Pine Point TMA which never underwent any successful revegetation efforts, displayed only a slight increase in NDVI post-closure. The change in NDVI was attributable to the passive revegetation of sparse grasses and shrubs at the perimeter of the site, consistent with the results of the image classification and change detection. More rapid natural land cover conversion to vegetation at the Pine Point site was likely prevented by the poor soil texture and quality of the TMA, and high levels of heavy metals.
- In the pre-revegetation year, the RI was negative (around -0.23 ~ -0.3) across the study sites, indicating the mine sites had high levels of disturbance relative to the undisturbed reference sites.
- In 2021, the RI at all actively revegetated study sites was near or above zero and was significantly higher than the passively revegetated Pine Point site, which was still quite negative despite some improvement.
- All five study sites experienced an increase in RI (above the unity line), indicating that revegetation had really occurred at the sites and that the detected NDVI improvement resulted from land cover conversion to vegetation rather than the impact of regional factors or phenological variation.

Conclusion

- The results of this study suggest that active reclamation involving revegetation significantly outperformed passive reclamation for the restoration of land cover and vegetation and is a necessary practice in restoring healthy vegetation to post-closure mine sites, especially when the site use resulted in contamination.
- Remote sensing techniques and Landsat satellite imagery are suitable and effective for the monitoring of more broad-scale changes associated with the recovery of landscapes and vegetation at post-closure mine sites in Canada.
- The Regrowth Index (RI) can provide value to monitoring projects through both its ability to reduce noise in long-term vegetation trends and its potential for benchmarking against other successful projects.
- This study would improve regulatory and industry ability to quantify and monitor the progress and success of post-closure mine site revegetation and landscape recovery, a necessary step to evidence-based sustainable resource management in Canada.

References

1. Holcombe, S., & Kemp, D. (2020). From pay-out to participation: Indigenous mining employment as local development? Sustainable Development, 28(5), 1122–1135. https://doi.org/10.1002/sd.2063C. Grant et al., 2016
2. Grant, C., Loch, R., McCaffrey, N., Anstee, S., & Doley, D. (2016). Mine Rehabilitation: Leading Practice Sustainable Development Program for the Mining Industry.
3. McKenna, P. B., Lechner, A. M., Phinn, S., & Erskine, P. D. (2020). Remote Sensing of Mine Site Rehabilitation for Ecological Outcomes: A Global Systematic Review. Remote Sensing, 12(21), 3535. https://doi.org/10.3390/rs12213535