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Mapping undesired Vegetation on Oil and Gas Reclamation Sites using a multi-sensor Approach

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Under the Environmental Protection and Enhancement Act (EPEA), operators are responsible for reclaiming lands disturbed by oil and gas activities to an equivalent capability, while the Alberta Energy Regulator (AER) oversees and enforces compliance with these requirements (AER, 2021). A critical component of successful reclamation is the detection and management of undesired vegetation—including species such as Canada thistle (Cirsium arvense), sow thistle (Sonchus oleraceus), tansy (Tanacetum vulgare), cicer milkvetch (Astragalus cicer), and non-native grass species (e.g., Kentucky bluegrass [Poa pratensis], smooth brome [Bromus inermis], and crested wheatgrass [Agropyron cristatum]) in northern Alberta. To support detection of these species, field work was conducted at reclamation sites near Lac La Biche, Sandy Lake, Fox Creek, Whitecourt, and Drayton Valley, Alberta, to collect ground reference data for validating remote sensing assessments (Figure 1).

Large-area planning for natural resource development requires spatially explicit data on land-use and land-cover composition that capture both permanent industrial infrastructures and transient land disturbances associated with oil and gas activities (e.g., access roads, well pads, and pipeline corridors). As documented by Chowdhury et al. (2017, 2021), reclamation assessments and compliance monitoring of these anthropogenic changes are critical to sustainable management practices. Given that many of Alberta's reclamation sites are remote and often difficult to access—making field-based assessments time consuming and costly—there is a compelling need for satellite-based monitoring using Earth Observation (EO) data.

Our study integrates Sentinel-2, Landsat, and SuperDove multispectral imagery within the Google Earth Engine (Gorelick et al., 2017) to provide a transparent, repeatable, and efficient monitoring approach. Publicly available Sentinel-2 imagery was employed using the Spectral Angle Mapper (SAM) algorithm during peak flowering periods to detect undesired vegetation. Time-series analyses of Landsat imagery (1984–2024) using the LandTrendr algorithm (Kennedy et al., 2018) captured the reclamation lifecycle—from initial construction through to revegetation—by highlighting pre- and post-disturbance conditions (Figure 2). Additionally, SuperDove imagery (2019–2024) was used to compute a time-integrated cumulative NDVI for phenological assessments, further enhancing vegetation detection via a SAM-based approach inspired by Moon et al. (2021). Inclusion of land cover classification (Chowdhury, 2021) and monthly leaf area index (Fernandes and Sun, 2024) derived from Sentinel-2 data further refined our detection capabilities.

Utilization of hyperspectral drone imagery at five selected sites validated satellite-based detection thresholds. This ground-reference data included full vegetation identification using 0.5 m × 0.5 m quadrats randomized within nine plots (each 10 m²) per site, as well as an assessment of dominant species, trees, and shrubs across the entire plot area. Data from these 40 ground-reference sites yielded a field-verified overall accuracy of 78% (Figure 3), primarily focusing on the flowering phenology of Canada thistle mixed with non-native grass species. Notably, only

Canada thistle flowers displayed a distinct spectral signature and were more abundant than other undesired vegetation—such as tansy, cicer milkvetch, and sow thistle. Furthermore, Canada thistle often co-occurred with these species, highlighting its pervasive presence in the study areas. In several instances, however, goldenrod (Solidago canadensis) or cattails (Typha latifolia) were misclassified as Canada thistle, likely due to the similar spectral characteristics of their fluffy white seed heads. Notably, Sentinel-2 proved effective in mapping larger patches of Canada thistle intermixed with grass, while SuperDove imagery excelled at detecting smaller patches (Figure 4).

These findings underscore the value of a multi-sensor remote sensing approach for monitoring undesirable species at reclaimed sites, including those that are remote or inaccessible. While current policy frameworks may limit the formal use of remote sensing for site-level certification, the approach presented here could inform future policy directions. By facilitating evidence-based decision-making, this methodology supports AER audits and certification processes and ultimately contributes to more efficient management of reclamation efforts across Alberta.

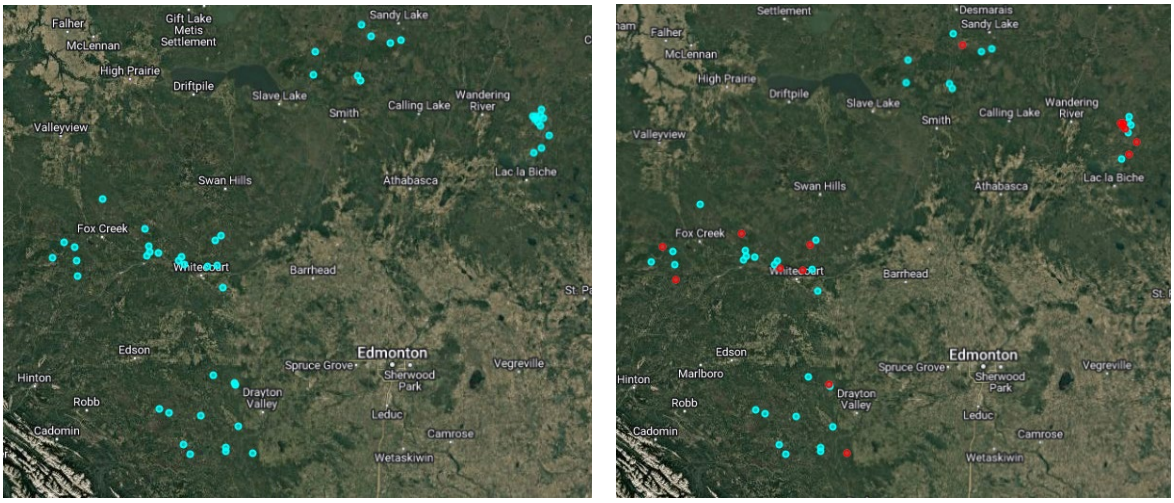


Figure 1. Left image shows reclamation site locations where ground reference data were collected (cyan), and right image shows sites where undesired vegetation was detected (red) using Sentinel 2 multispectral imagery.

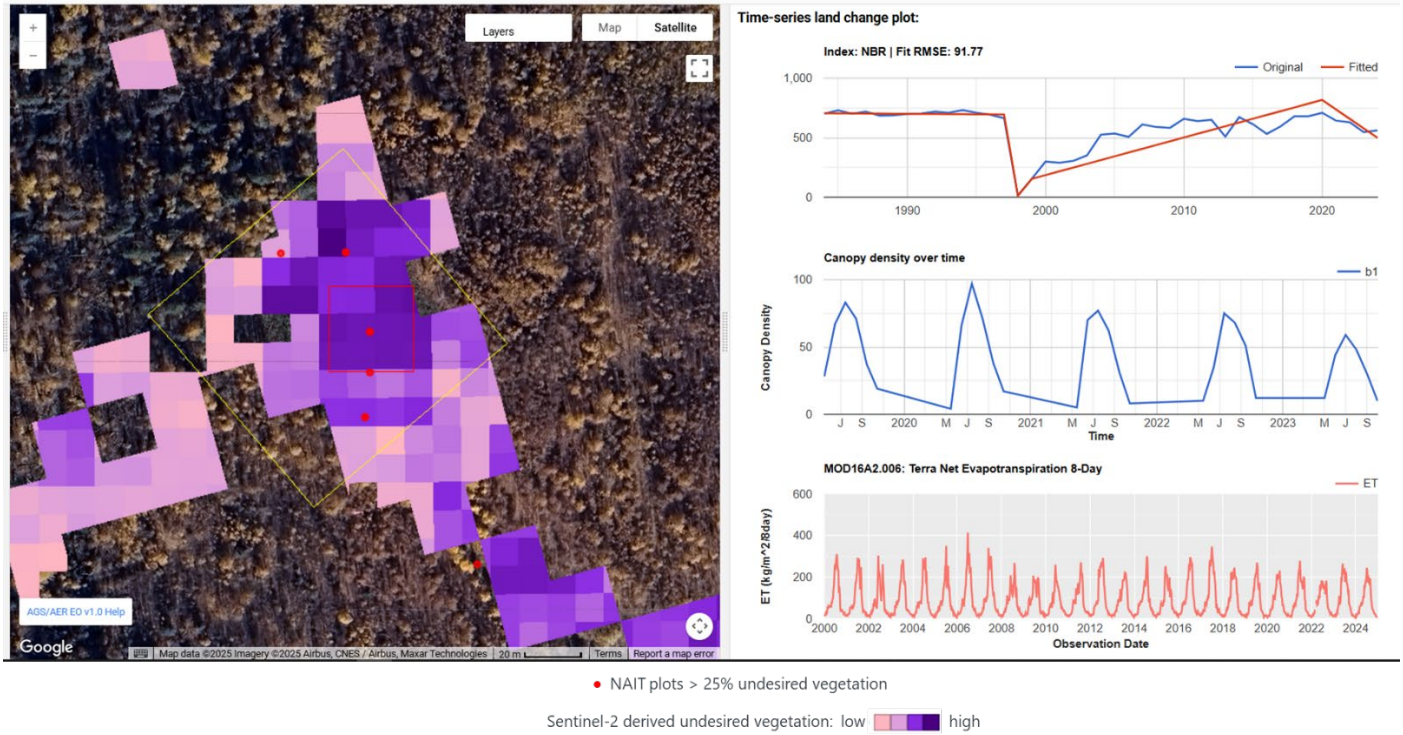


Figure 2. Sentinel 2 derived undesired vegetation probability map (pink to dark purple indicates low to high probability). Time series charts show the 1998 disturbance and the post 2000 recovery from the Landsat NBR vegetation trend (1984–2024), declining canopy density, and annual evapotranspiration variation. The red point indicates vegetation plots with more than 25 percent undesired vegetation

	Predicted Desired	Predicted Undesired	Total
Truth Desired	197	14	211
Truth Undesired	41	43	84
Total	238	57	295

Overall accuracy	(197 + 43) / 295	0.8136 (81.36 %)
Kappa	—	0.4933
Producer's accuracy (Desired)	197 / 211	0.9336 (93.36 %)
Producer's accuracy (Undesired)	43 / 84	0.5119 (51.19 %)
User's accuracy (Desired)	197 / 238	0.8286 (82.86 %)
User's accuracy (Undesired)	43 / 57	0.7544 (75.44 %)

Figure 3. Accuracy assessment comparing predicted versus observed desired and undesired vegetation across reclamation sites.

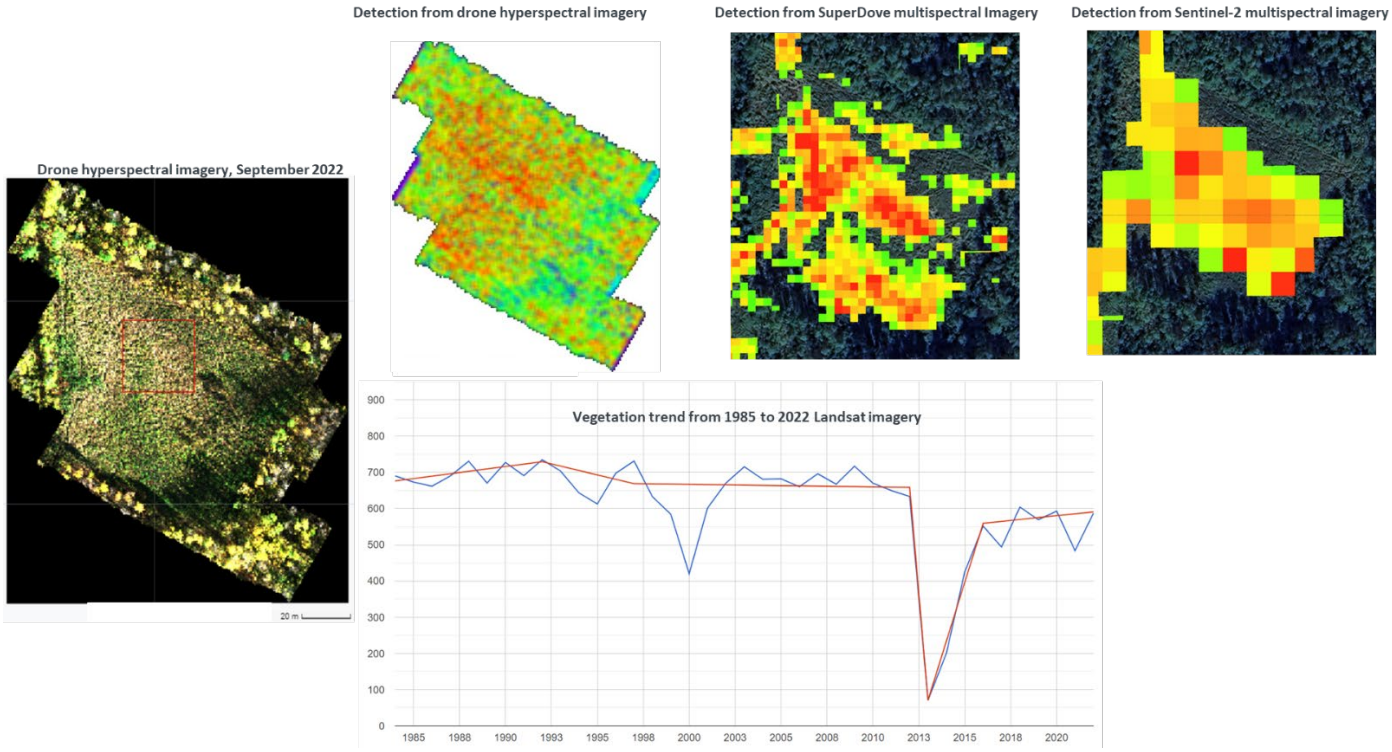


Figure 4. Comparison of undesired vegetation detection results from 50 cm resolution hyperspectral drone imagery, 3 m resolution SuperDove multispectral imagery, and 10 m

resolution Sentinel 2 multispectral imagery. Landsat vegetation trend (1984–2022) for the area in the red box in the drone image shows a 2014 disturbance and vegetation recovery beginning in 2015.

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