KTTD Project: Updating forest road networks using LiDAR to classify road conditions and validating new road classes.

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Overview

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Project Overview

Objective:

- **Update** forest road networks and **assess road conditions** in Ontario's Boreal and Great Lakes—St. Lawrence (GLSL) Forest regions.

Method:

- **Identify** forest roads in densely forested areas. These roads were **categorized based on driveable width, edge vegetation, and surface and edge degradation**, using high-density **Single Photon LiDAR (SPL)** data.

Outcomes:

- Our project **enhances the precision of forest road networks** and provides forest managers a **valuable tool and accurate information** for the management of forested landscapes.

Forest Roads

Forest Roads:

- Critically important to the forest industry
- Silvicultural operations
- Forest harvesting
- Recreational activities
- Fire suppression
- Wildlife management

- Detrimental to biodiversity and conservation
- Allow access to protected areas
- Fragment the landscape
- Increasing species isolation
- Allow predation
- Increasing soil erosion

Information on the state and location of these roads is **essential for management, conservation, and ecological research**.

The Canadian Boreal Forest

Canadian Boreal Forest Roads:

- The Canadian Boreal Forest accounts for **28% (552Mha)** of the global boreal ecosystem (Brandt et al., 2013).
- **15% (84Mha)** of the Canadian Boreal Zone is located in the province of Ontario.
- Ontario has **~ 279,500 km** of forest roads classed as **active, decommissioned,** and **status unknown**:
  - *~ 23% are status unknown*
  - *~ 6% are ≥ 25 years old*

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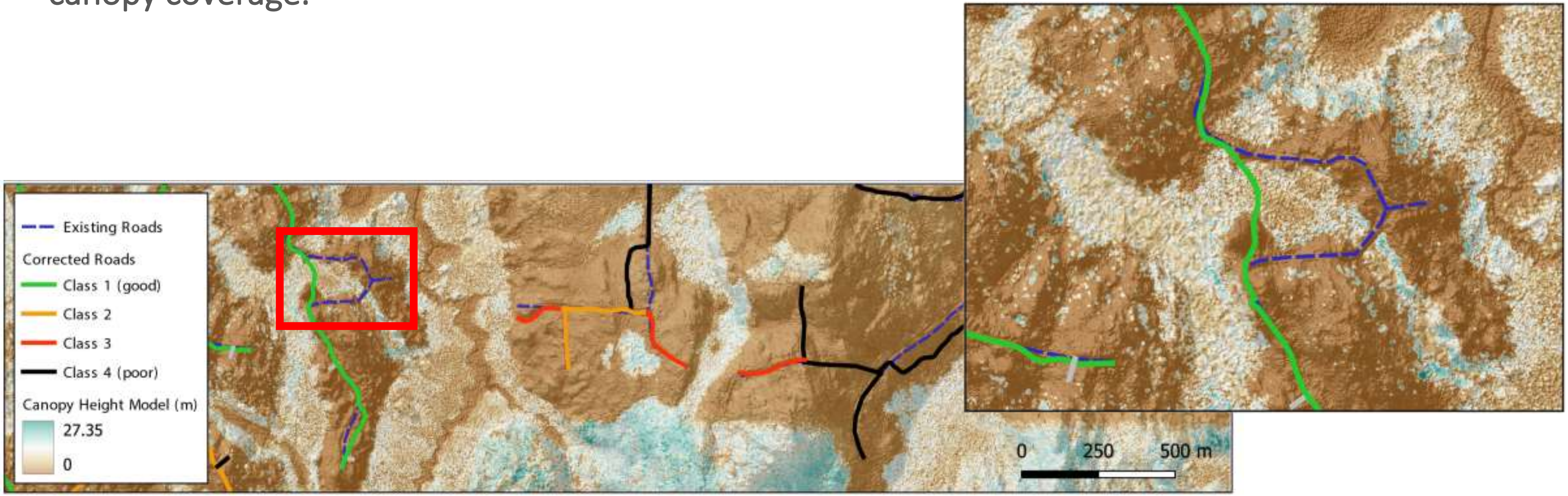
Conventional Road Extraction Methods

- Automated and semi-automated road extraction has been developed in **urban or peri-urban areas.**
- Road extraction in forested regions using air photos and optical passive imagery is limited by **canopy coverage.**

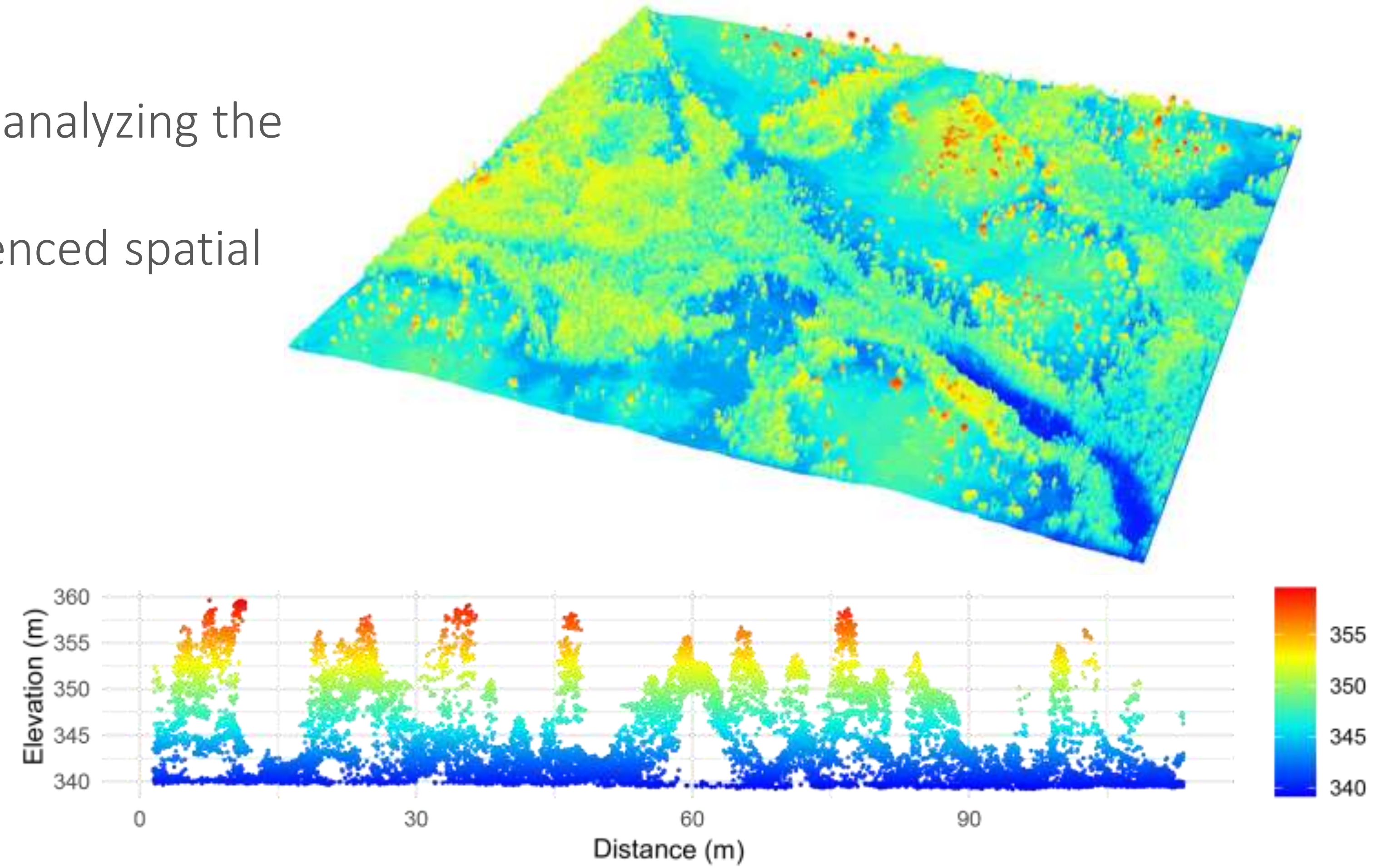


Canopy Height Model for a 3 km section of the Romeo Malette Forest, located in the province of Ontario, Canada.

Road Extraction using Airborne LiDAR Scanning (ALS)

LiDAR (Light Detection And Ranging):

- Illuminates a target with a laser and analyzing the reflected light to:
  - Generate precise and geo-referenced spatial information
  - Penetrate vegetation
  - Map surface features
    - *Including roads*



1km² LiDAR tile and cross section in the Romeo Malette Forest, Ontario, Canada.

Road Extraction using ALS-Derived Raster Surfaces

Digital Terrain Model (DTM)

- Topographic model of bare Earth elevation

Canopy Height Model (CHM)

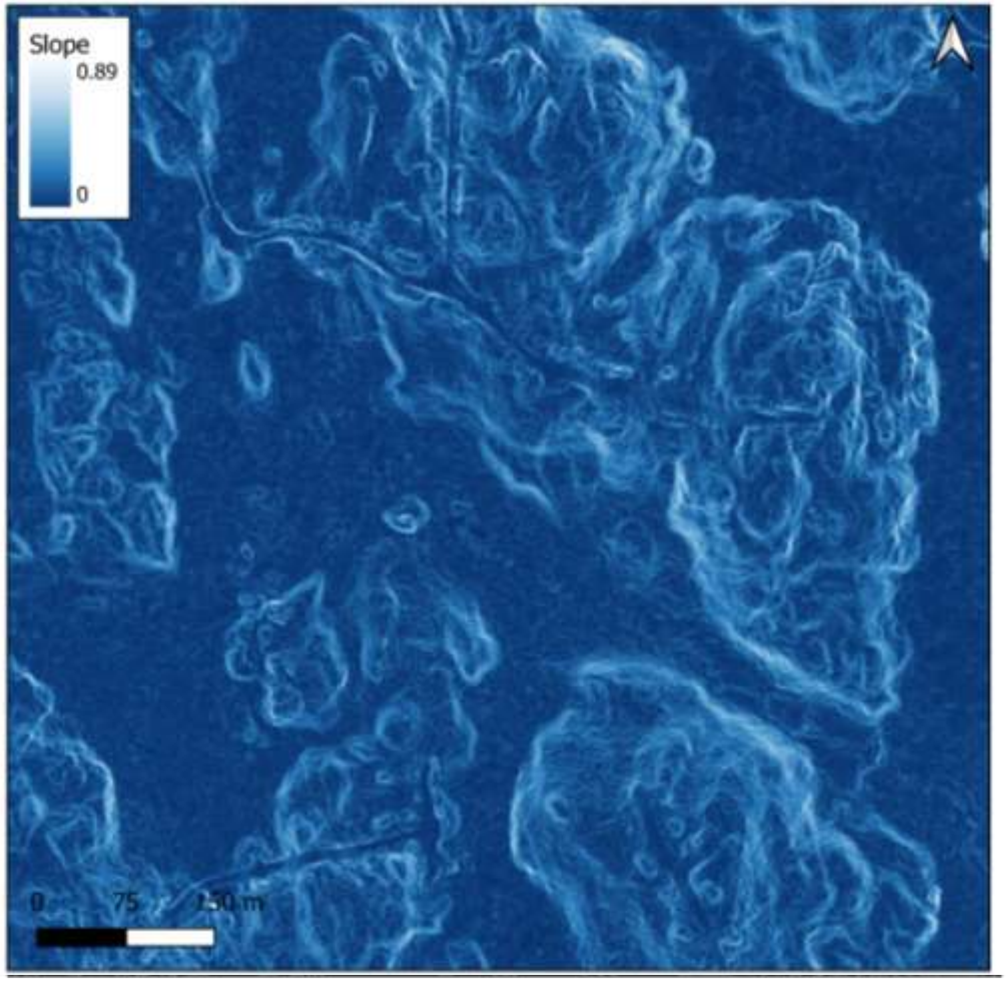
- Tree height as a continuous surface

Roughness

- Ratio between surface area and projected area

Slope

- Topographic map showing changes in elevation



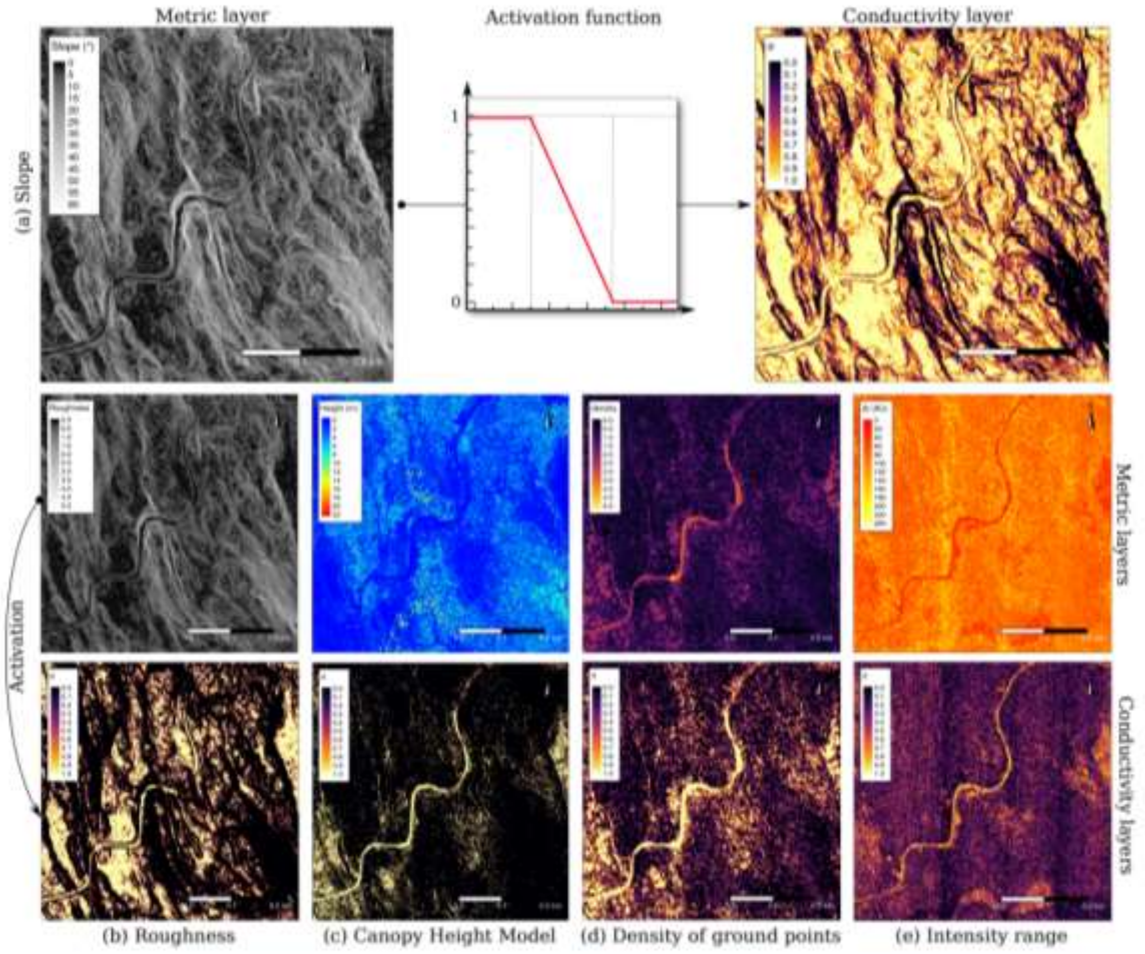
1km^2 raster surfaces (DTM, CHM, roughness, slope) in the Romeo Malette Forest.

The 'ALSroads' Method

- A **free** and **open R package** to **find roads from ALS data**, written by **Jean-Romain Roussel** , co-author of the lidR package.

- Uses **high-density lidar surfaces** and **point clouds** to find roads and **requires an existing road network.**

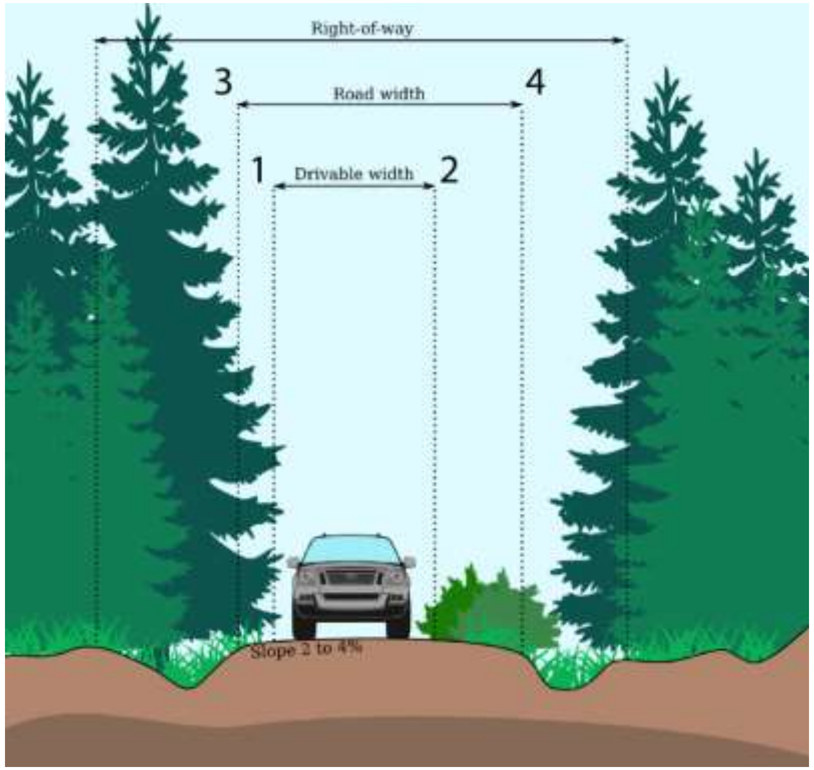
ALSroads Method: Finding the Road



ALSroads method workflow and example of derivation of the conductivity layers
(Source: Roussel et al., 2022)

- ALSroads **combines** attributes into a **single predictor** to detect a road.
- The **predictor** is based on the concept of **friction of distance**.
- The road is numerically “driven” by resolving a least cost path problem.

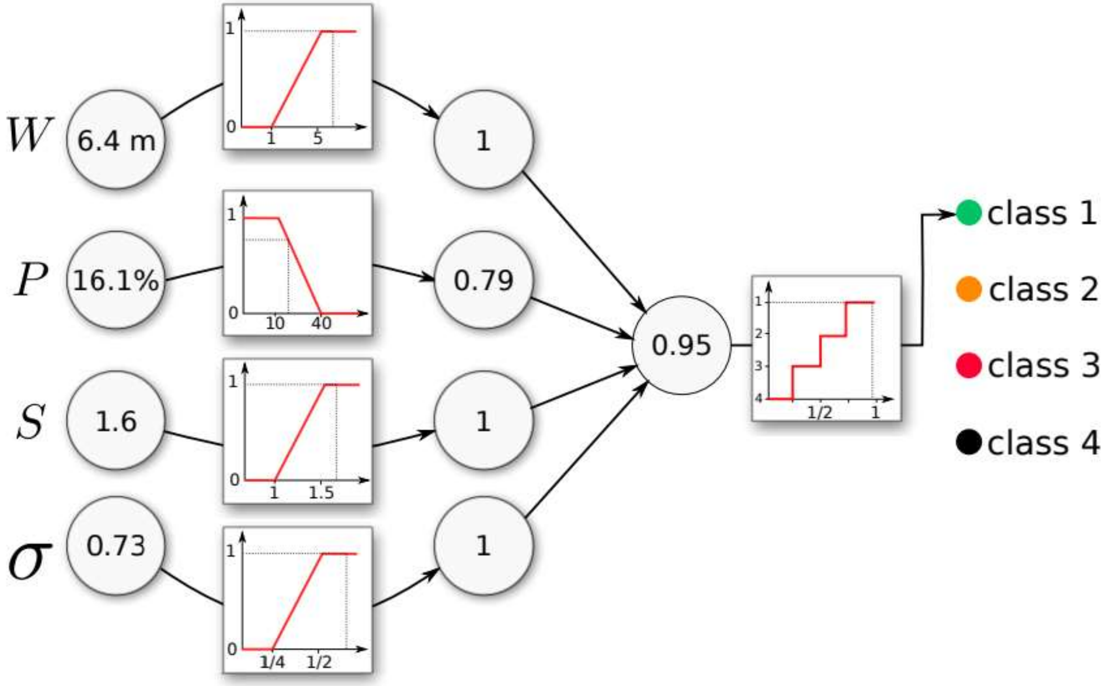
ALSroads Method: Measuring the Road



- Road shoulders are detected based on abrupt variations of the slope.
- Road edges are detected using the DTM complexity.
- The percentage of points between 0.5 and 5 m above the ground dictates the drivable width of the road.

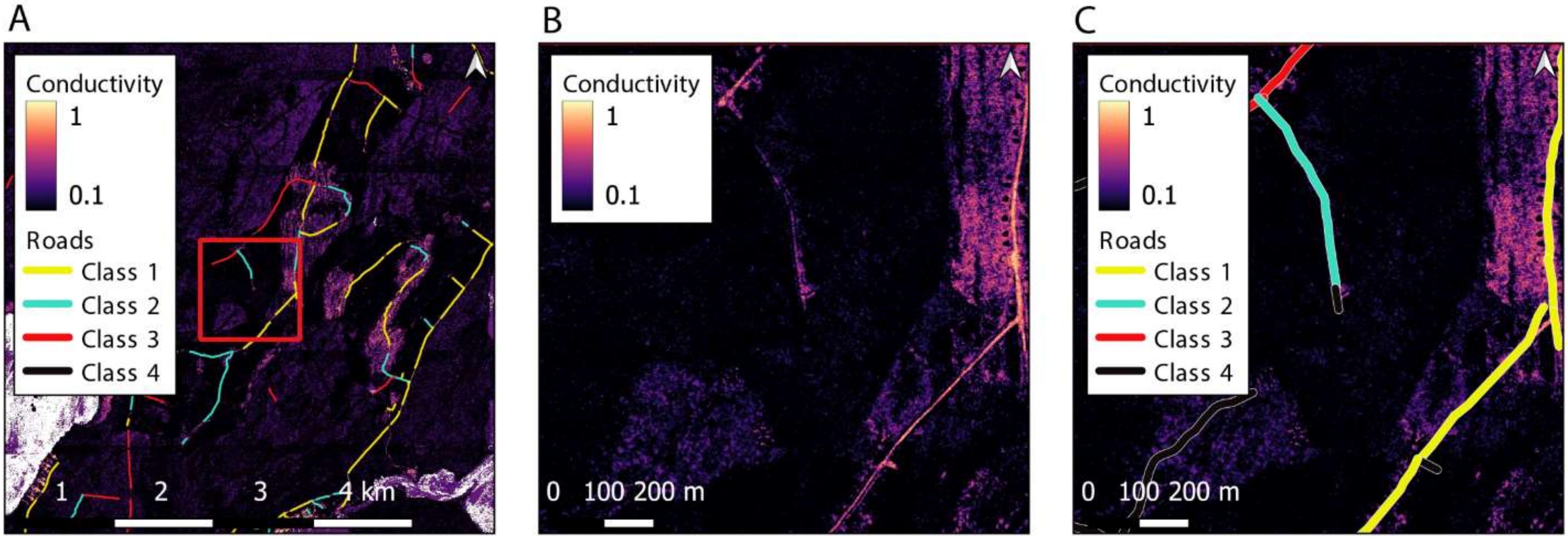
ALSroads Method: Estimation of Road State

- w = Drivable width
- P = Percentage of points
    - *Between 0.5 and 5 m above the road.*
- S = Average number of shoulders detected
    - *Detected to derive road width based on variations of the slope.*
- σ = Conductivity per linear meter
    - *Combination of conductivity layers*



Four metrics (W, P, S, σ) are used to estimate the class of the road (Source: Roussel et al., 2022).

Method Application: Network Update Example



(A) Conductivity map of a 5 km x 5 km surface in the Romeo Malette Forest (RMF), (B) Conductivity map of a 1 km x 1 km SPL tile. (C) Example application of road extraction in the RMF using the MNRF road data.

ALSroads Method: New Road Classes

Class 1:
- Wide
- Not Impacted by edge vegetation
- Well-shaped edges and surface

Class 2:
- Narrower
- Minimal impact of edge vegetation
- Not as well defined edges and surface

ALSroads Method: New Road Classes

Class 3:

- Very narrow
- High impact of edge vegetation
- Surface and edges show clear alteration

Class 4:

- Impassable by standard vehicles
- High impact of edge vegetation
- Surface and edges are not recognizable

Method Application in Ontario

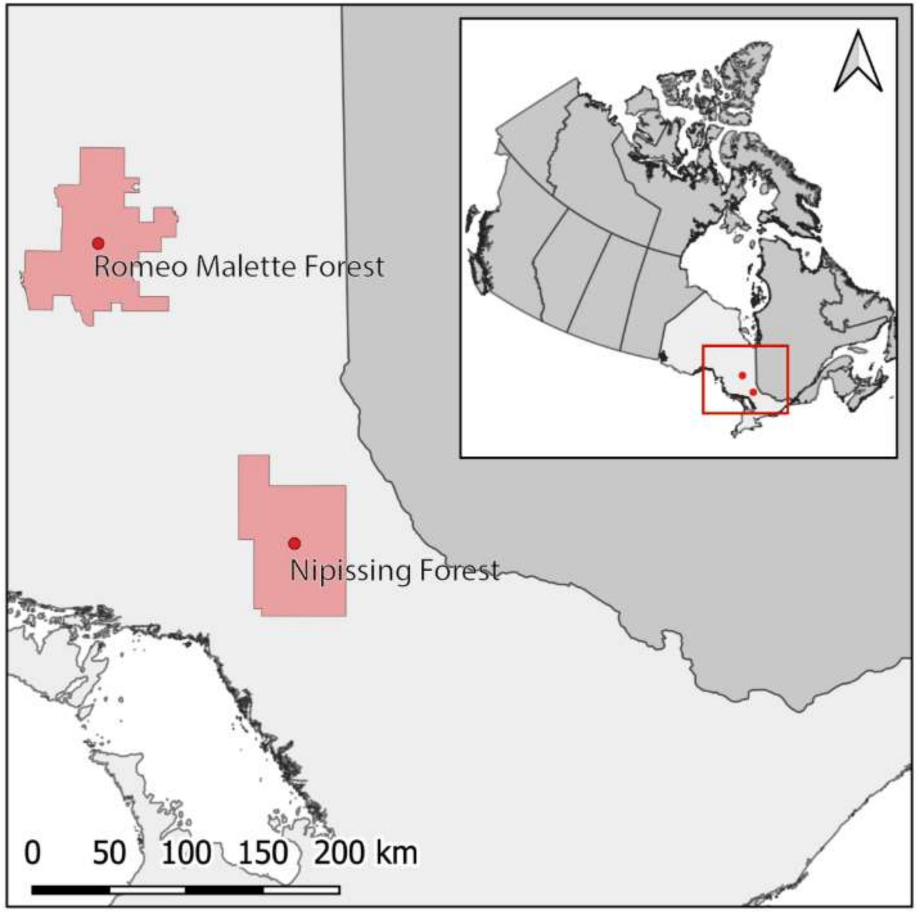
We applied the **road extraction** method in **two study sites in Ontario**, I will overview this application by:

1. **Summarizing the study areas and input data,**
2. **Evaluating the new road network,**
3. **Measuring the distance** between new roads and ministry roads,
4. **Assessing differences in road widths** (total and drivable) between road classes.

Method Application: Study Areas

We apply the road extraction method using ALS for two study sites:

- Romeo Malette Forest (689,700 ha):
  - *> road density*
  - *< Slope*
  - *Highly managed*
- Nipissing Forest (582,455 ha):
  - *< road density*
  - *> Slope*
  - *Older, established forest*



The two study areas Romeo Malette Forest (RMF) and Nipissing Forest (Block 2J) (NPS) located in Northern Ontario, Canada.

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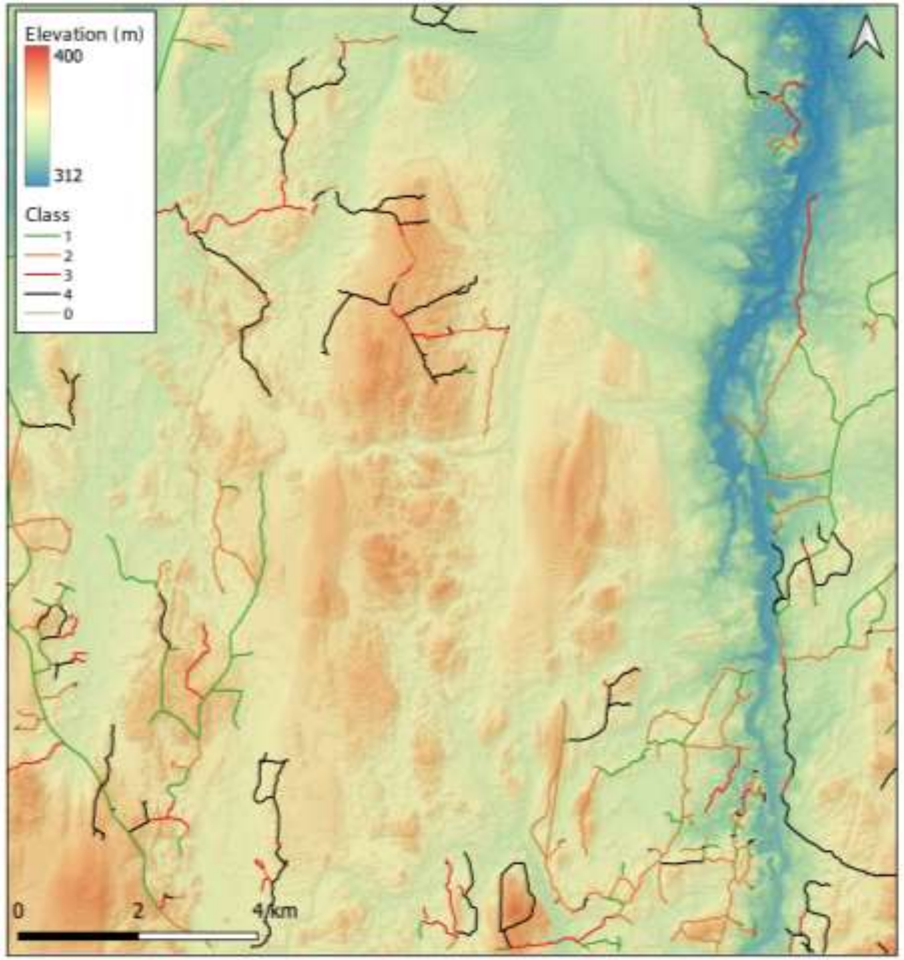
Method Application: Input Data

Conventional road data:

- Ministry of Natural Resources and Forestry (MNRF),
    - *Year built/closed, maintenance level, speed, surface type, number of lanes.*
- Reported during **road construction and via aerial imagery.**

ALS Data:

- Romeo Malette Forest (RMF)
    - *June and July 2018*
- Nipissing Forest (NPS)
    - *June 2019*



Reference map of example Romeo Malette Forest roads.

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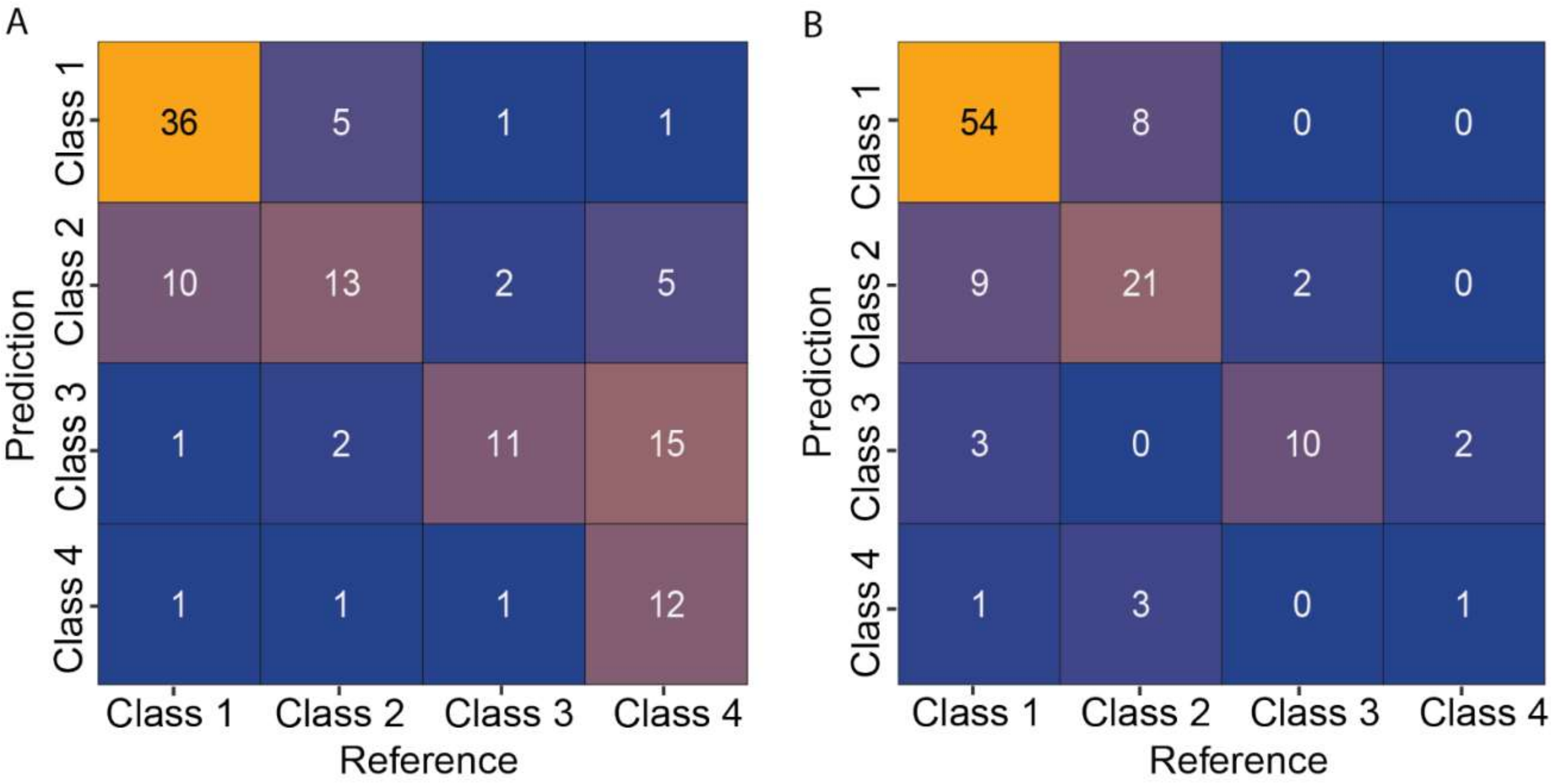
Method Application: Network Update

Road Classification - Class prediction accuracy:

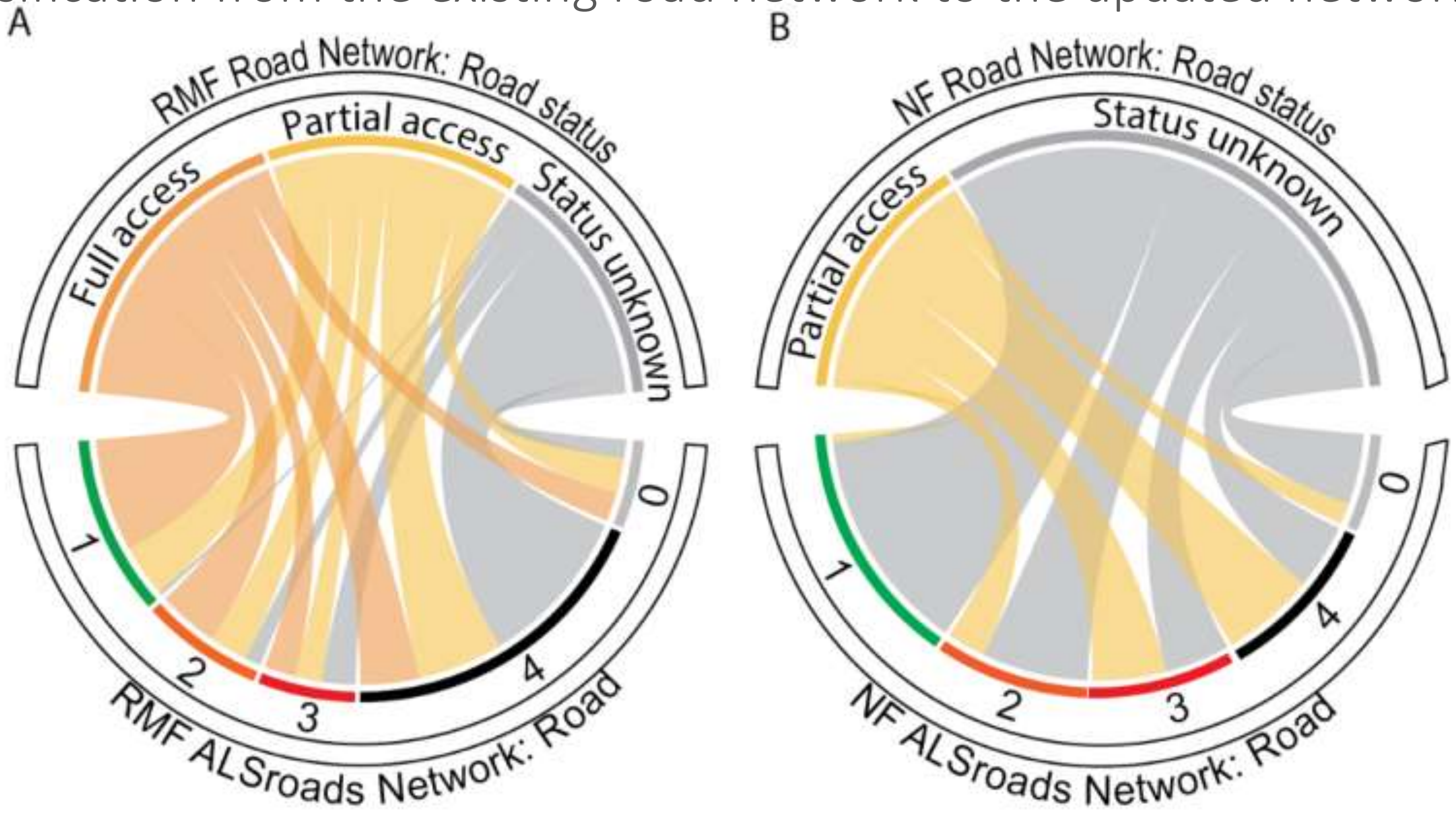


Confusion matrix of the actual road classes vs predicted road classes for (A) the Romeo Malette Forest (RMF) and (B) the Nipissing Forest (NF).

Method Application: Network Update

Road Classification - Updated road network:

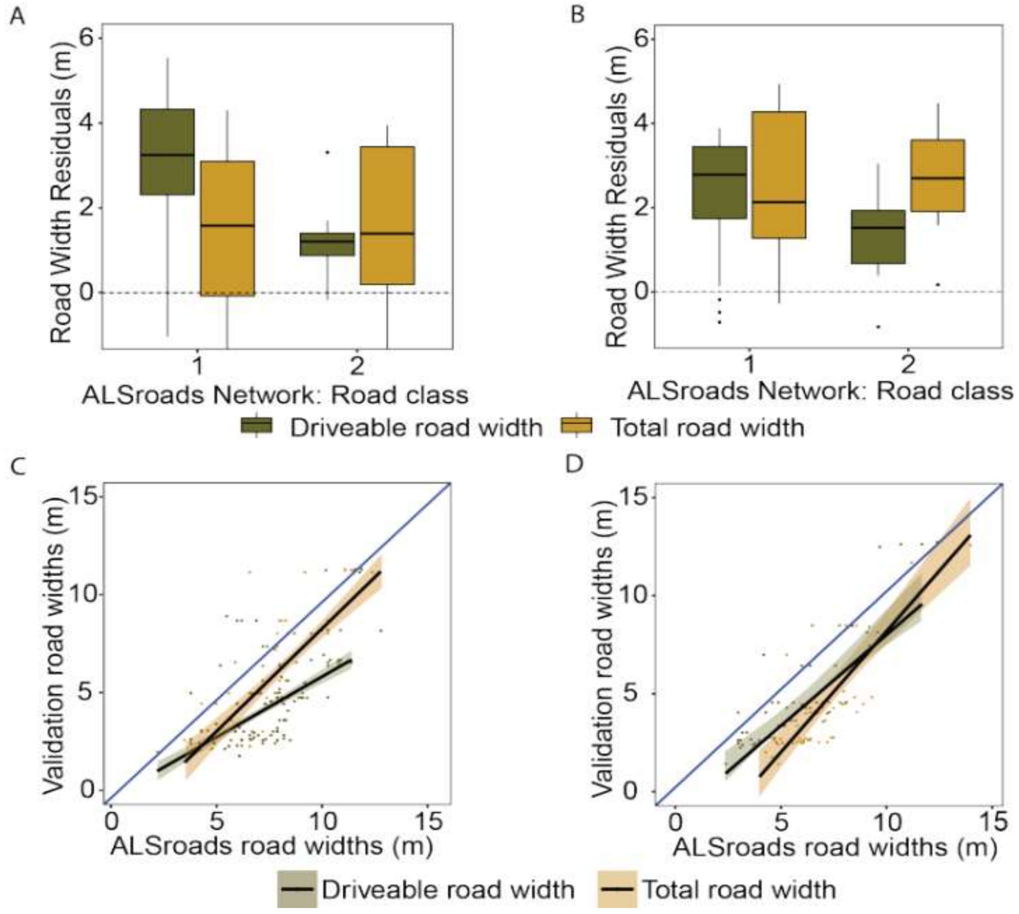
Change in road classification from the existing road network to the updated network.



Chord diagram of pre-existing road network classes and ALSroads classes for the (A) Romeo Malette Forest (RMF) and the (B) Nipissing Forest (NF).

Method Application: Road Width

Road Classification - Road width accuracy:



Road width validation data for the Romeo Malette Forest (RMF) (A and C) and the Nipissing Forest (NF) (B and D). Plots A and B present the difference between validation road width data and the updated road network result. Plots C and D are scatterplots of extracted road widths and validation roads widths.

Consistent overestimation trend in both **'Class 1' and 'Class 2' roads.**

Project field work emphasized the necessity for method tuning, while affirming the **overall robustness** of the method.

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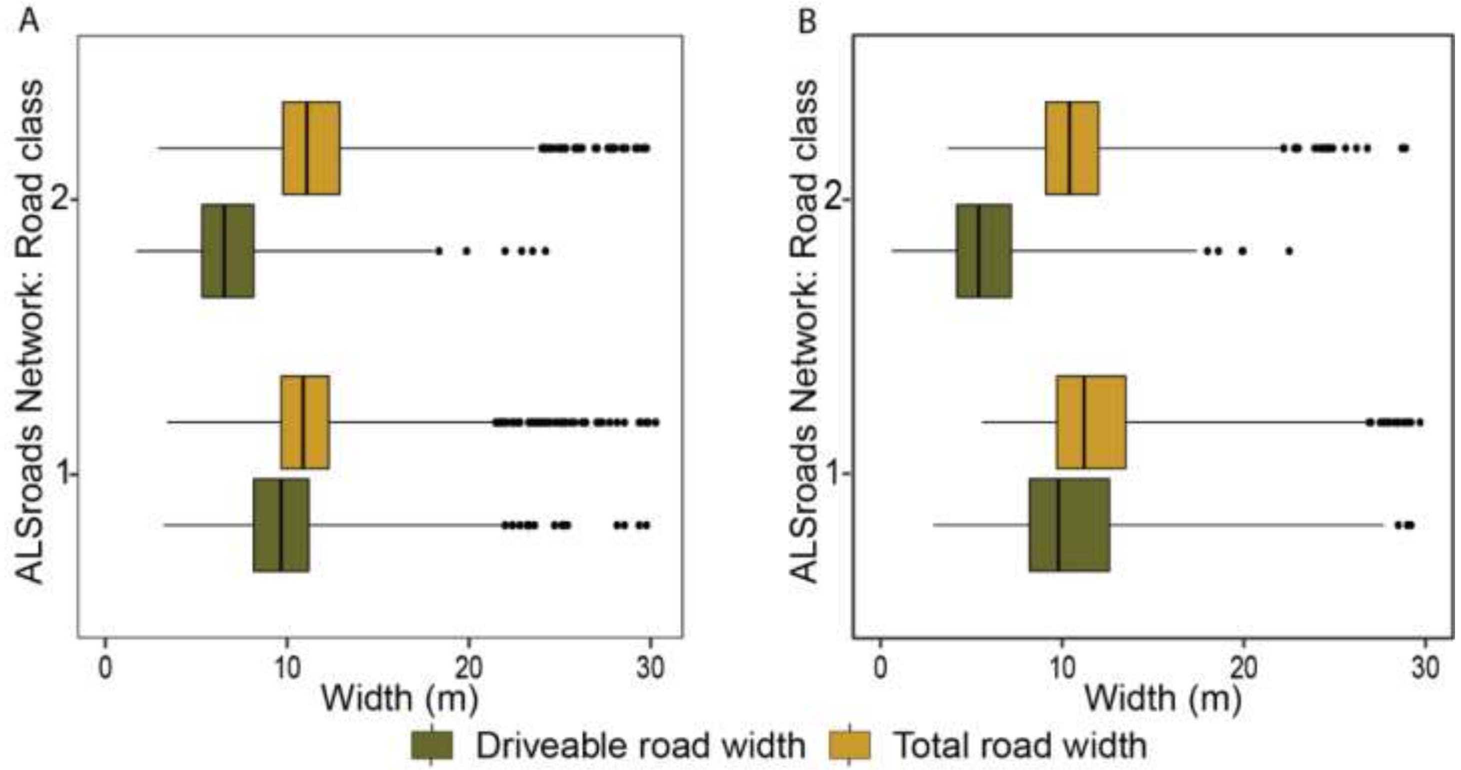
Method Application: Road Width

Road Classification - Comparison between driveable and total road width:



Box plots showing the width of 'Class 1' and 'Class 2' roads for (A) the Romeo Malette Forest (RMF) and (B) the Nipissing Forest (NF).

Differentiates between the available **"canopy gap" and the width** of roads.

'Class 1' roads generally have greater mean driveable and total road widths compared to 'Class 2' roads.

Method Application: Summary

Results:

- Accuracy of Road Classification: Results indicate high accuracy in determining road class, position, and geometry.
- Accuracy of Road Position: The method provides good road positional accuracy for 'Class 1' and 'Class 2' roads, with a mean difference of 0.4 m.
- Accuracy of Road Width: The method distinguishes between total and drivable width.
- Supporting Forest Management: This project's outcomes enable the update of forest roads in Ontario, providing valuable data for forest management.

Limitations:

- Regional Specificity: The method relies on existing road networks.
- LiDAR Density Requirements: The method requires ALS coverage with a density of at least 5-10 points/m2.

ALSroads R Package

The road extraction method (Roussel et al., 2022) is a fully documented open-source software. ALSroads is available as an R package (R Core Team, 2021).

Access:

https://github.com/Jean-Romain/ALSroads

User Guide:

User Guide: The ALSroads Package (ilythiamorley.github.io)

Publications and Appearances:

Conference:

Symposium on Systems Analysis in Forest Resource 2022, Este Park, Colorado

Publications:

Vectorial and topologically valid segmentation of forestry road networks from ALS data

https://www.sciencedirect.com/science/article/pii/S1569843223000894

Correction, update, and enhancement of vectorial forestry road maps using ALS data, a pathfinder and seven metrics

https://www.sciencedirect.com/science/article/pii/S1569843222002084\

Updating Forest Road Networks using Single Photon LiDAR in Boreal Forest Environments

https://academic.oup.com/forestry/advancearticle/doi/10.1093/forestry/cpad021/7146573

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