Remote Sensing of Sub-Arctic Tree Species Information using Spectral Mixture Analysis and Multi-Temporal Satellite Imagery, Northwest Territories, Canada

Derek R. Peddle [1 *], **Jurjen van der Sluijs** [1], **Ronald J. Hall** [2,1], **Steve Schwarz** [3]

[1] Department of Geography and Alberta Terrestrial Imaging Centre (ATIC), University of Lethbridge, Lethbridge, AB., Canada

[2] Natural Resources Canada, Canadian Forest Service,Northern Forest Centre, Edmonton AB., Canada

[3] Government of the Northwest Territories, NWT Centre for Geomatics, Yellowknife NT., Canada.

*** Presenter: Dr. Derek R. Peddle: Project P.I.**
Professor - University of Lethbridge
Co-Director - ATIC
derek.peddle@uleth.ca

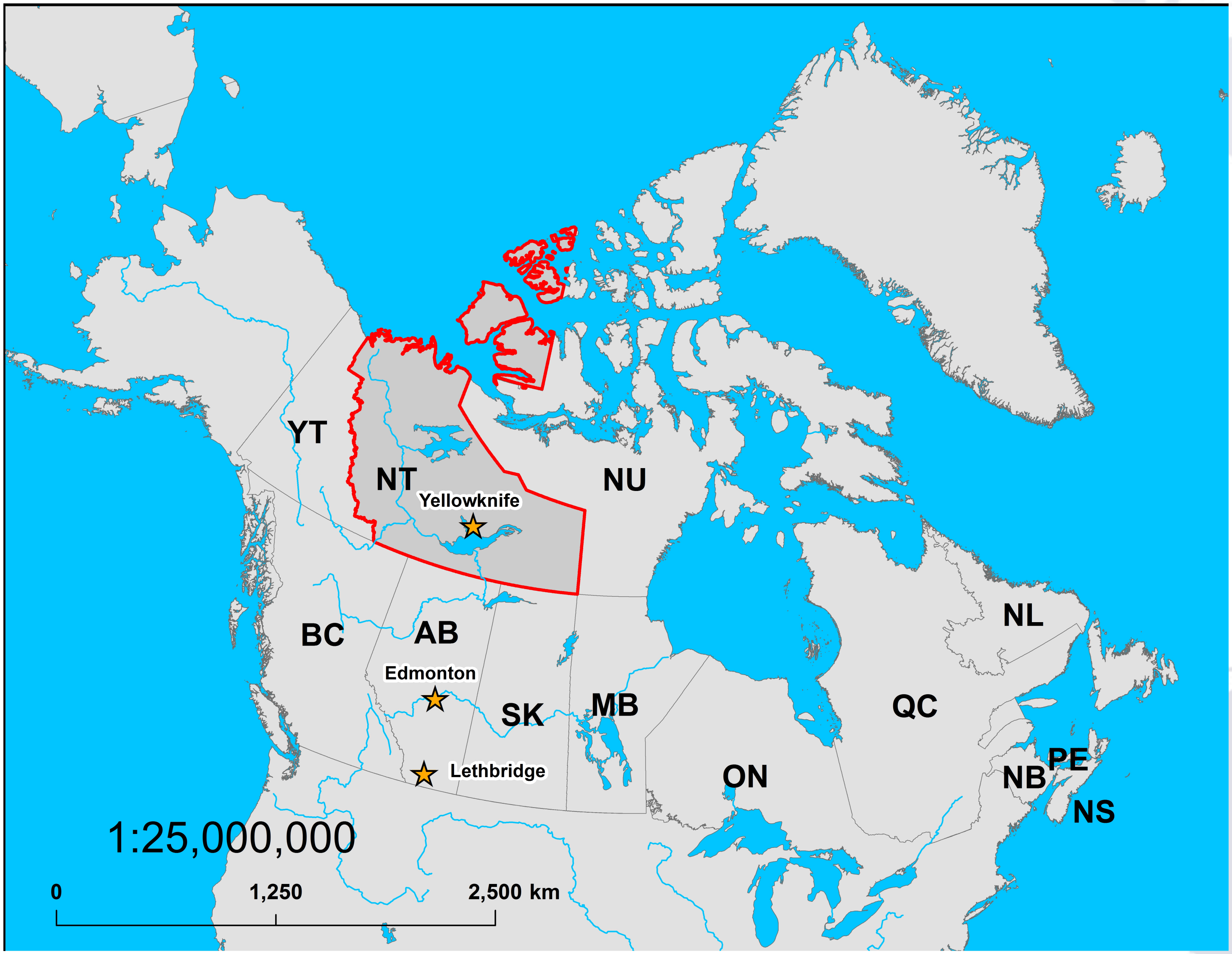
Partners

- **Collaboration**:
  - University of Lethbridge
  - Alberta Terrestrial Imaging Centre
  - Canadian Forest Service (Natural Resources Canada)
  - Government of Northwest Territories
    - Forest Management Branch
    - GNWT Centre for Geomatics
- **Financial Support**
  - TECTERRA (University Applied Research Funding Program)
  - In-kind contributions (Canadian Forest Service, GNWT)
  - Natural Sciences and Engineering Research Council (CREATE program) AMETHYST
  - University of Lethbridge

Outline

- Introduction
- Problem Statement and Rationale
- Methods
- Tree Species using *field spectra*
- Tree Species using *image spectra*
- Future work

Introduction



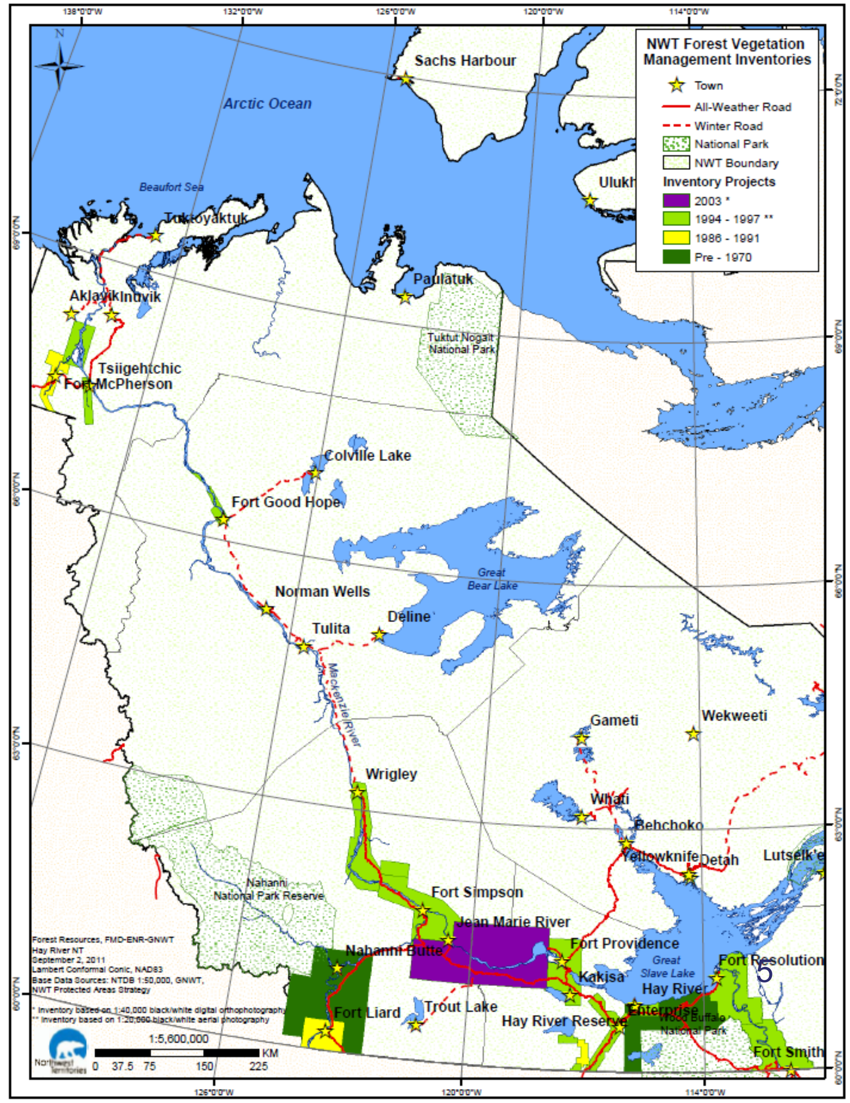
Introduction

- ***Northwest Territories – NWT Canada***
  - ± 33 million ha. forested land
  - < 10 % inventoried

- **Multisource Vegetation Inventory**
  - NWT Forest Vegetation Inventory
  - Satellite Vegetation Inventory

- **Initiatives**:
  - NWT Biomass Energy Strategy
  - Boreal Caribou Action Plan

- **Reporting**:
  - NWT State of Environment
  - Annual State of Canada's Forests / Carbon Accounting



Wulder et al. (2008a); Gov. of NWT (2010a,b, 2011a,b); Natural Resources Canada (2012)

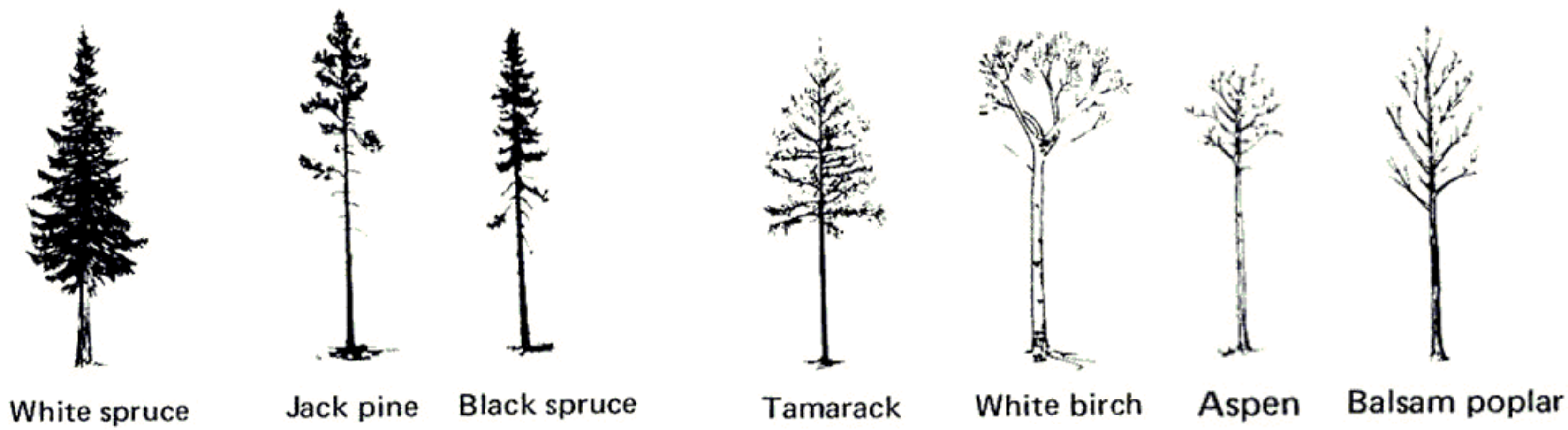
Importance of Species Composition

Resource Management

- Forest inventories
- Wildlife habitat
- Forest fire dynamics
- Biophysical parameters

Environmental Change

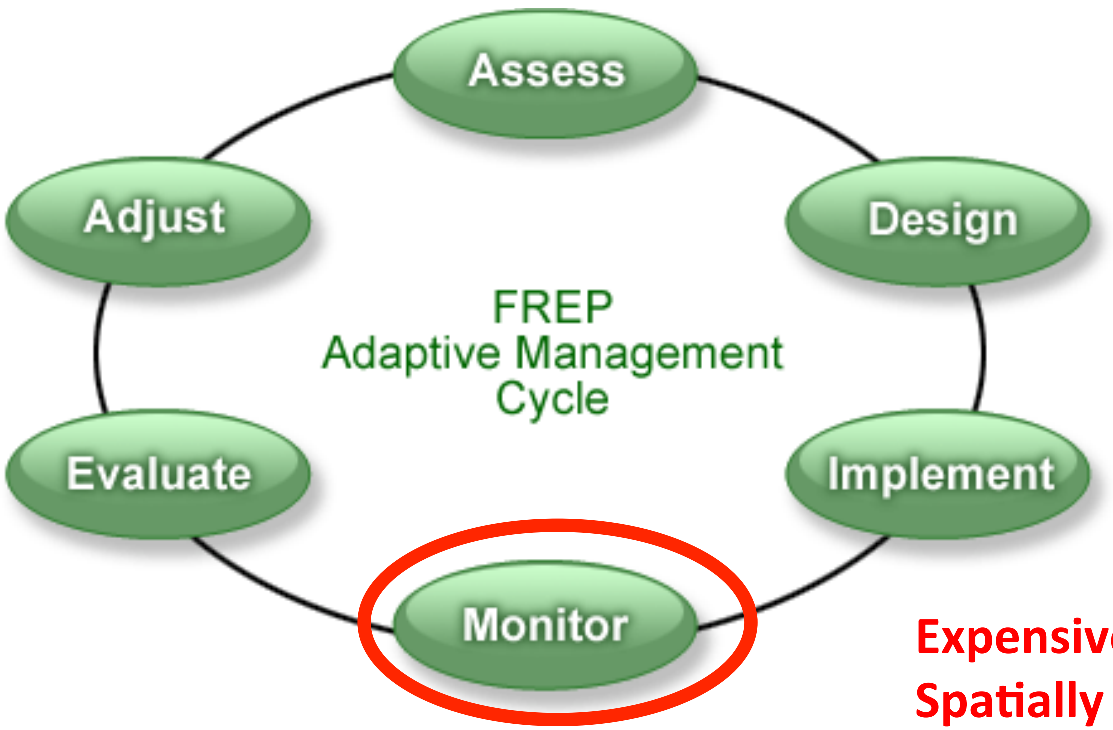
- Disturbances / regeneration
- Permafrost melting
- Forest dieback
- Shifts in suitable climate



Franklin (2001); Boudewyn et al. (2007); Tang et al., (2010); Barr et al. (2002); Amos-Binks et al. (2010)

Adaptive Management for Natural Resources

- Systematic approach to learn from the outcomes of management actions to improve future management



Expensive
Spatially limited
Limited re-visit times

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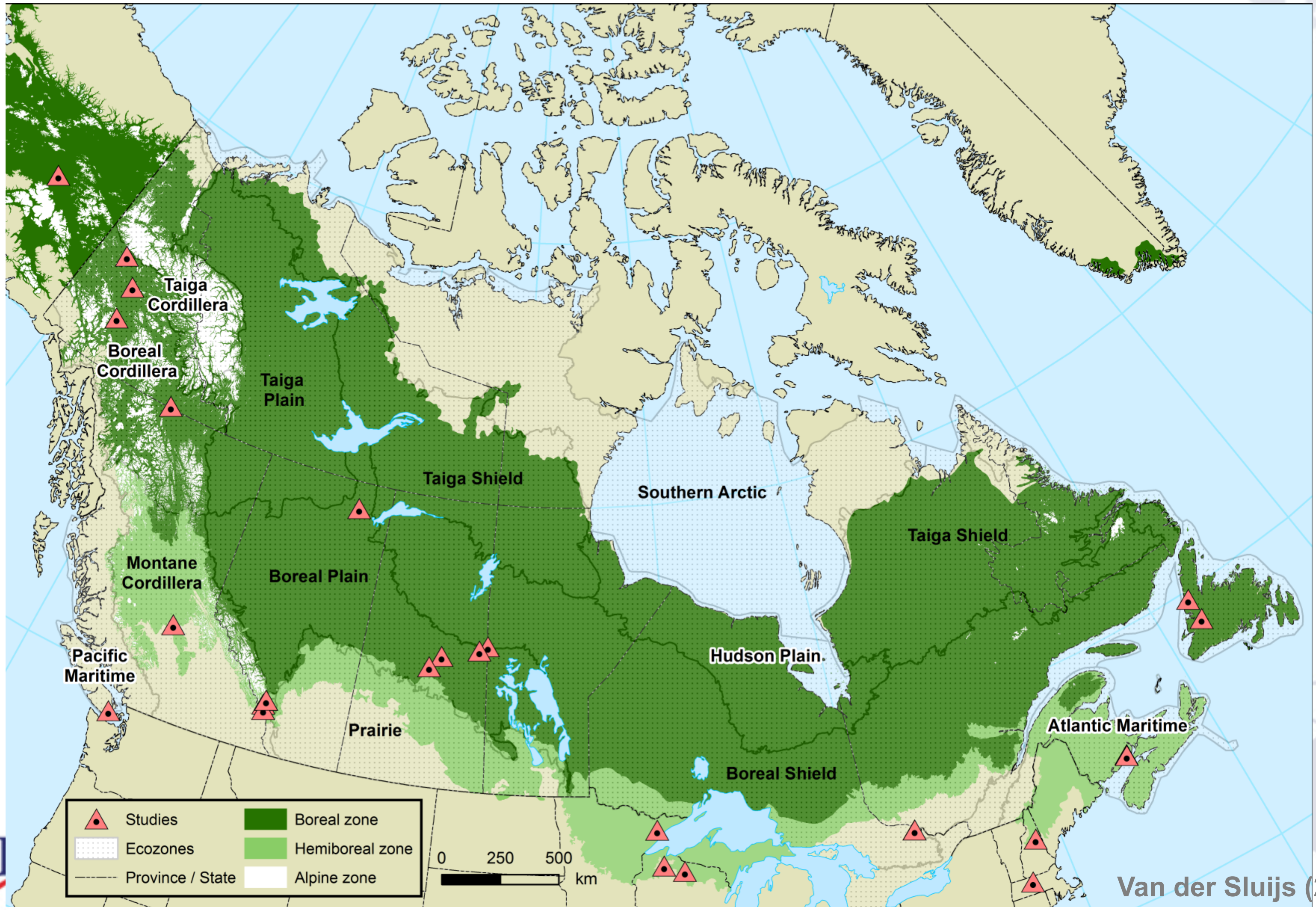
Kohm and Franklin (1997), Franklin (2001), Michalak et al. (2002), Hall (2003), Falkowski et al. (2009)

Primary Forest Inventory Approaches

- Aerial photo-interpretation / ground inventory
- Manual delineation of polygons

Hall (2003); Lillesand and Kiefer (1987); Leckie and Gillis (1995); Falkowski et al. (2009)

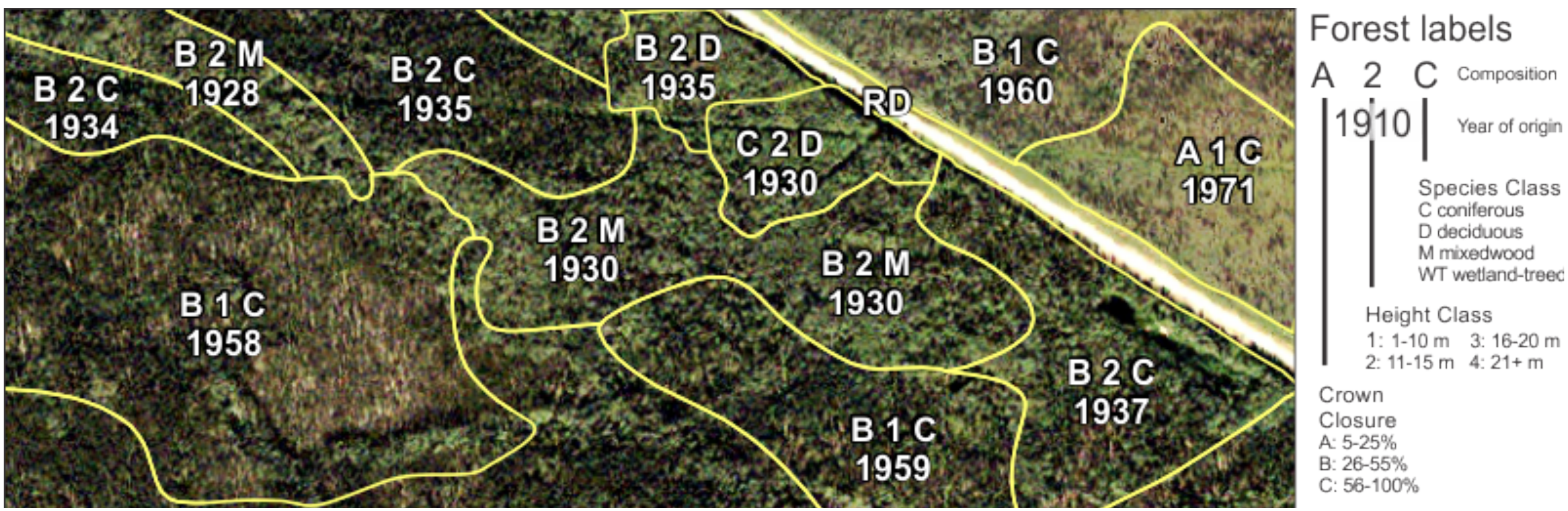
Introduction



Shapefiles from Brandt (2009) and Ecological Stratification Working Group (1995)

Introduction

- **Multisource Vegetation Inventory**
  - NWT Forest Vegetation Inventory
  - Satellite Vegetation Inventory



- **Study objective:**

Can species composition be derived through remote sensing?

Problem Statement and Rationale

1. **<u>Needed</u>**: an effective approach to characterize tree species composition over large, remote forests in the Northwest Territories

2. Potential of *Spectral Mixture Analysis (SMA)* to map tree species in the Taiga Plains Ecozone is unknown
   - Use leading species as target output

3. Investigate extent leading species can be determined from multi-temporal Landsat TM imagery using Multiple Endmember Spectral Mixture Analysis (MESMA).

Spectral Mixture Analysis (SMA)

A forest pixel is a mixture of trees, background, and shadow.

Pixel areas:

Forest density gradient and mixture fractions.

[NASA COVER Project]

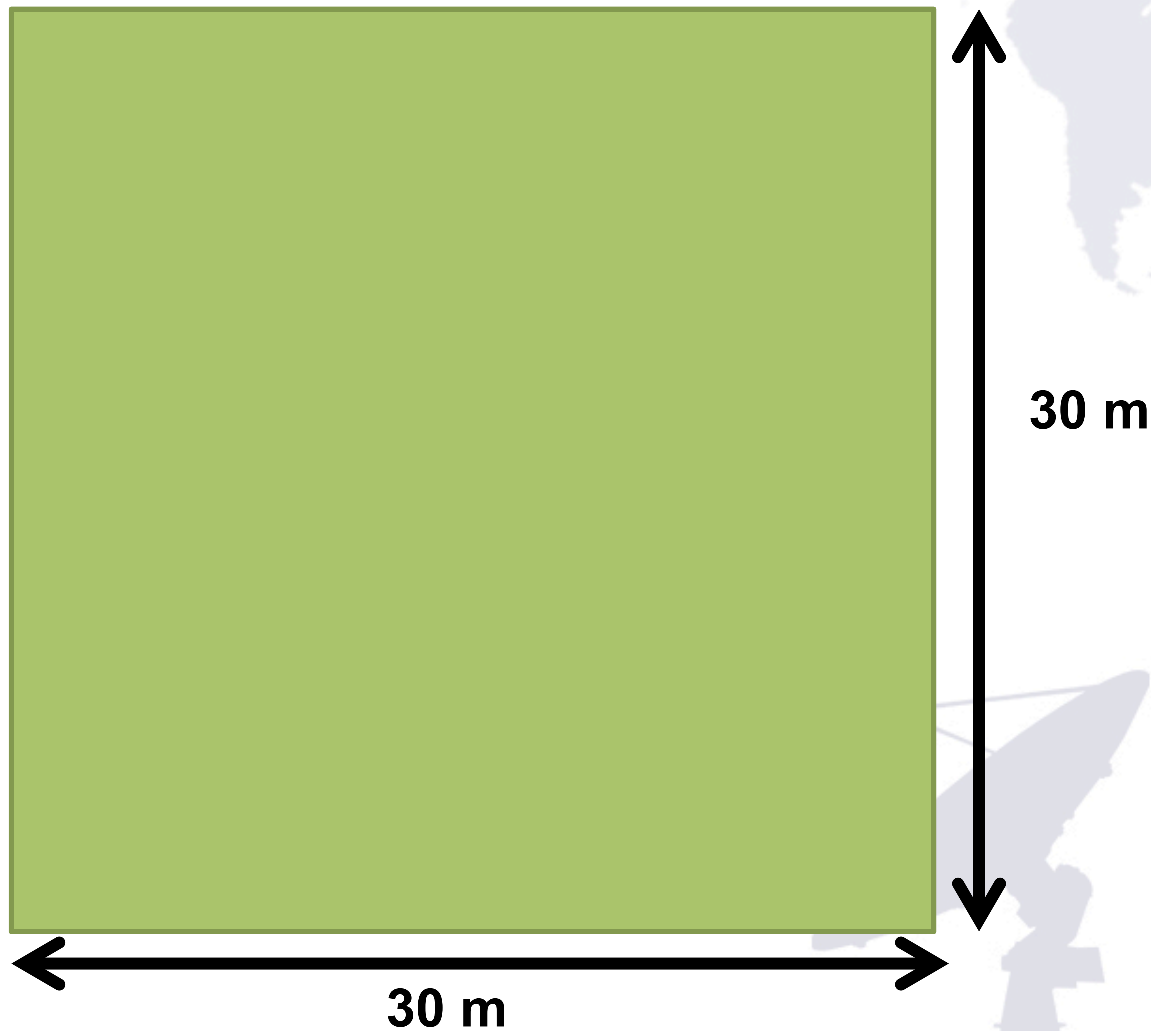
Tree Density: **Low** **Medium** **High**

Methods

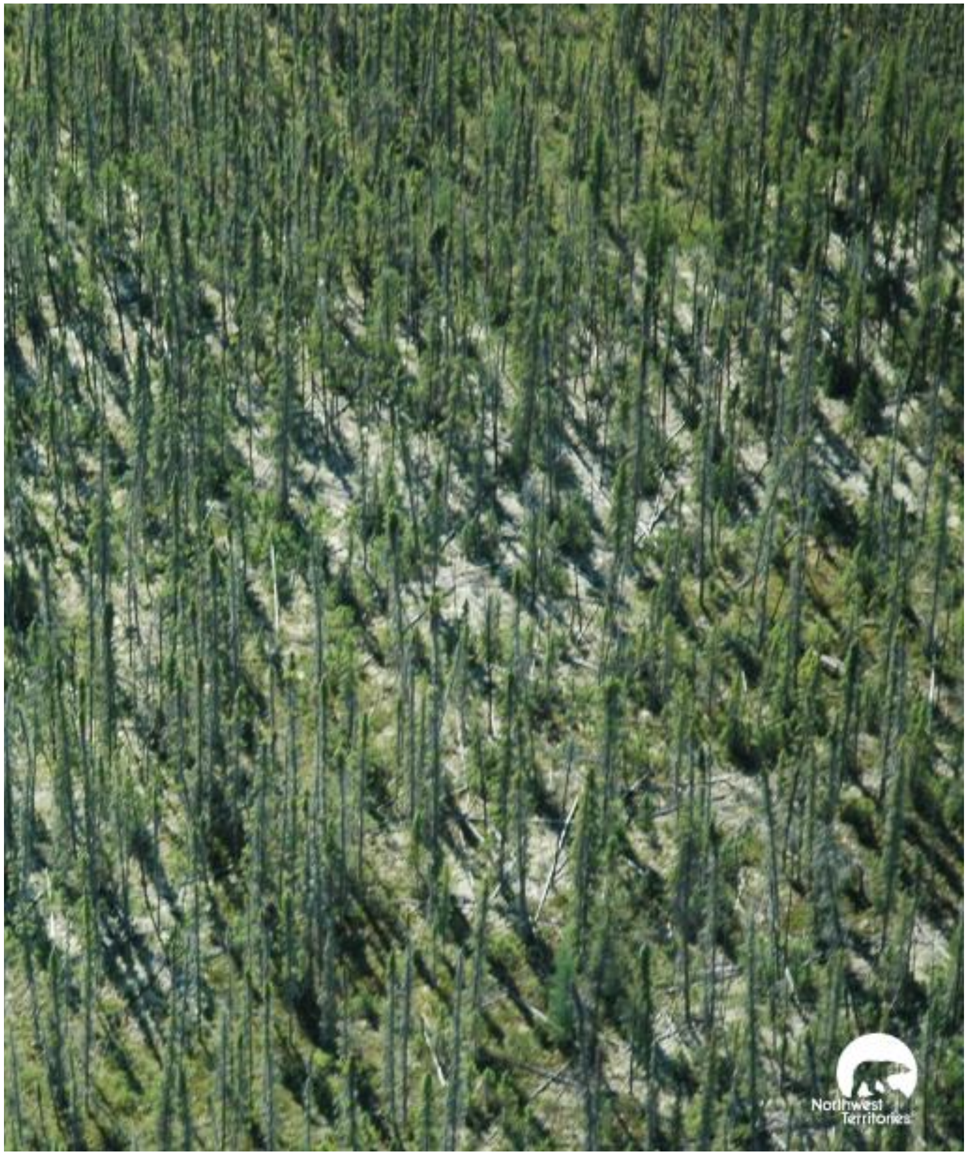
Remote sensing imagery:

One value averaged over pixel area (per wavelength band).

Landsat TM pixel:
30 m x 30 m



Forestry SMA



Spectral Mixture Analysis (SMA)

Basic SMA Equation (forestry)

Pixel = mixture of tree canopy (C), background (B), shadow (S).

$$\rho_{T(\lambda)} = \%\mathbf{C}\rho_{c(\lambda)} + \%\mathbf{B}\rho_{b(\lambda)} + \%\mathbf{S}\rho_{s(\lambda)} + \varepsilon$$

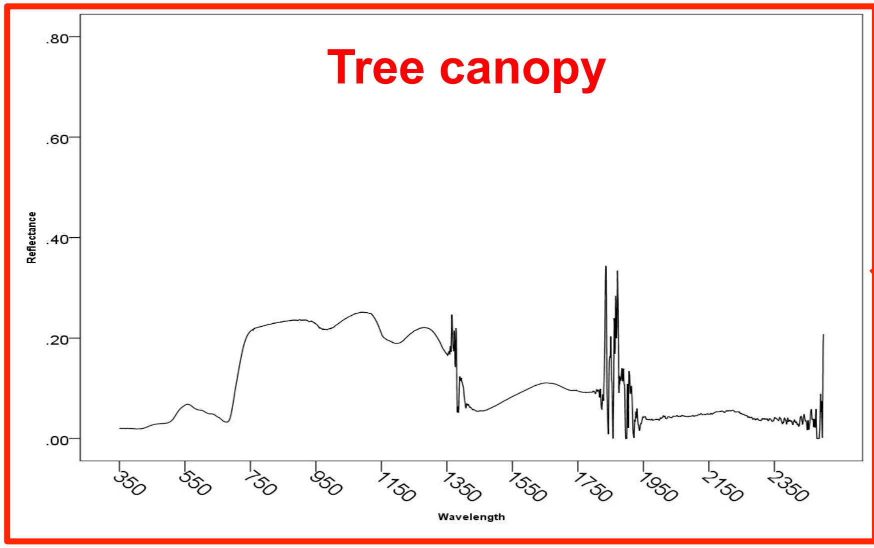
System of equations: 1 per band $_{(\lambda)}$

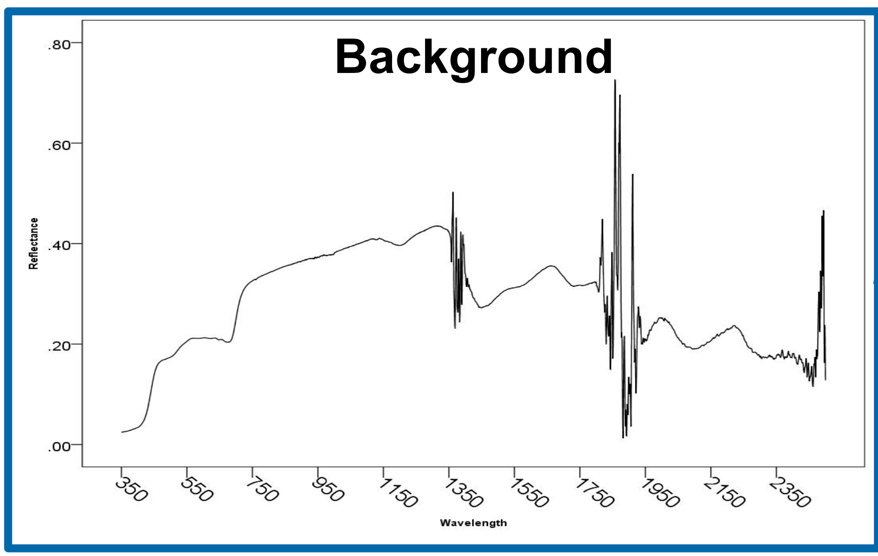
Input: “endmember” spectra $\rho_{c(\lambda)}, \rho_{b(\lambda)}, \rho_{s(\lambda)}$

Output: Sub-pixel scale Fractions of

Canopy (%C), Background (%B), Shadow (%S)

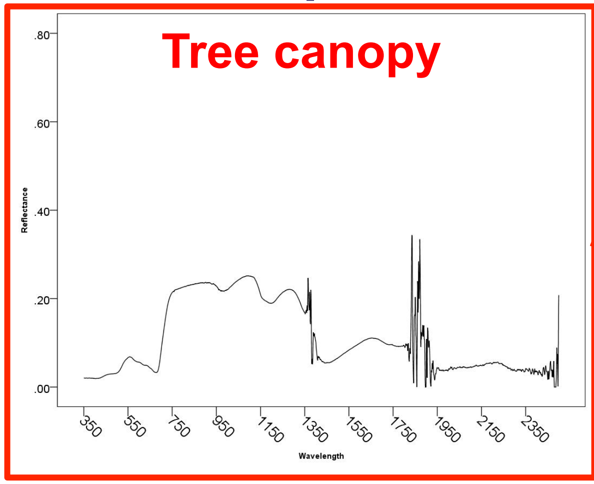
Forestry SMA

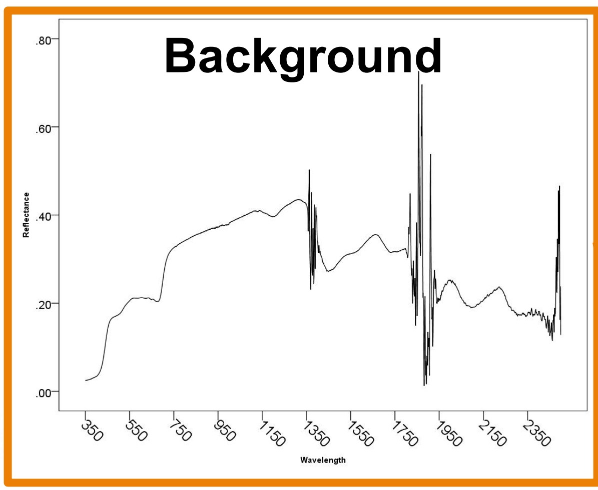


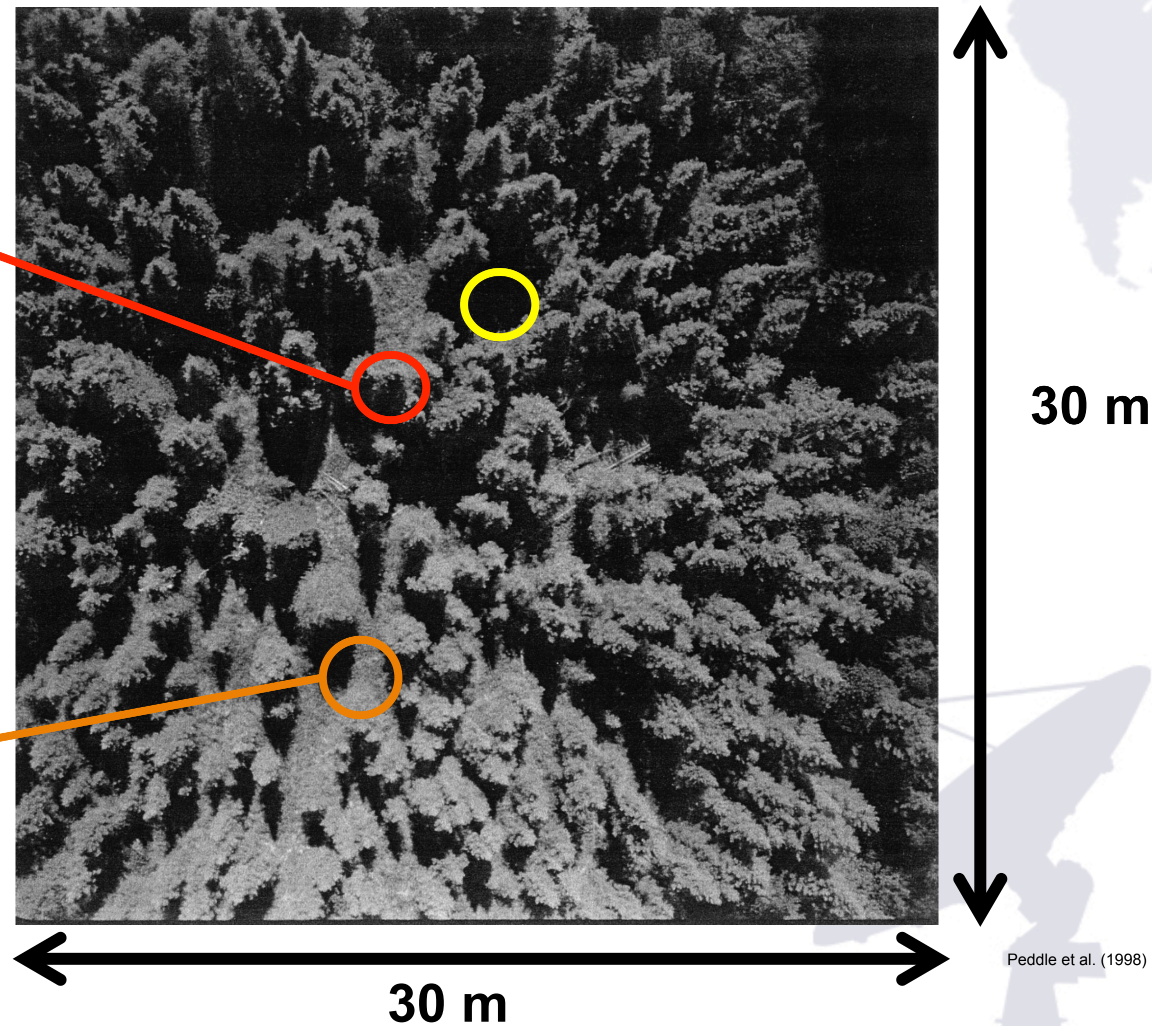


Methods

- Spectral Mixture Analysis







Peddle et al. (1998)

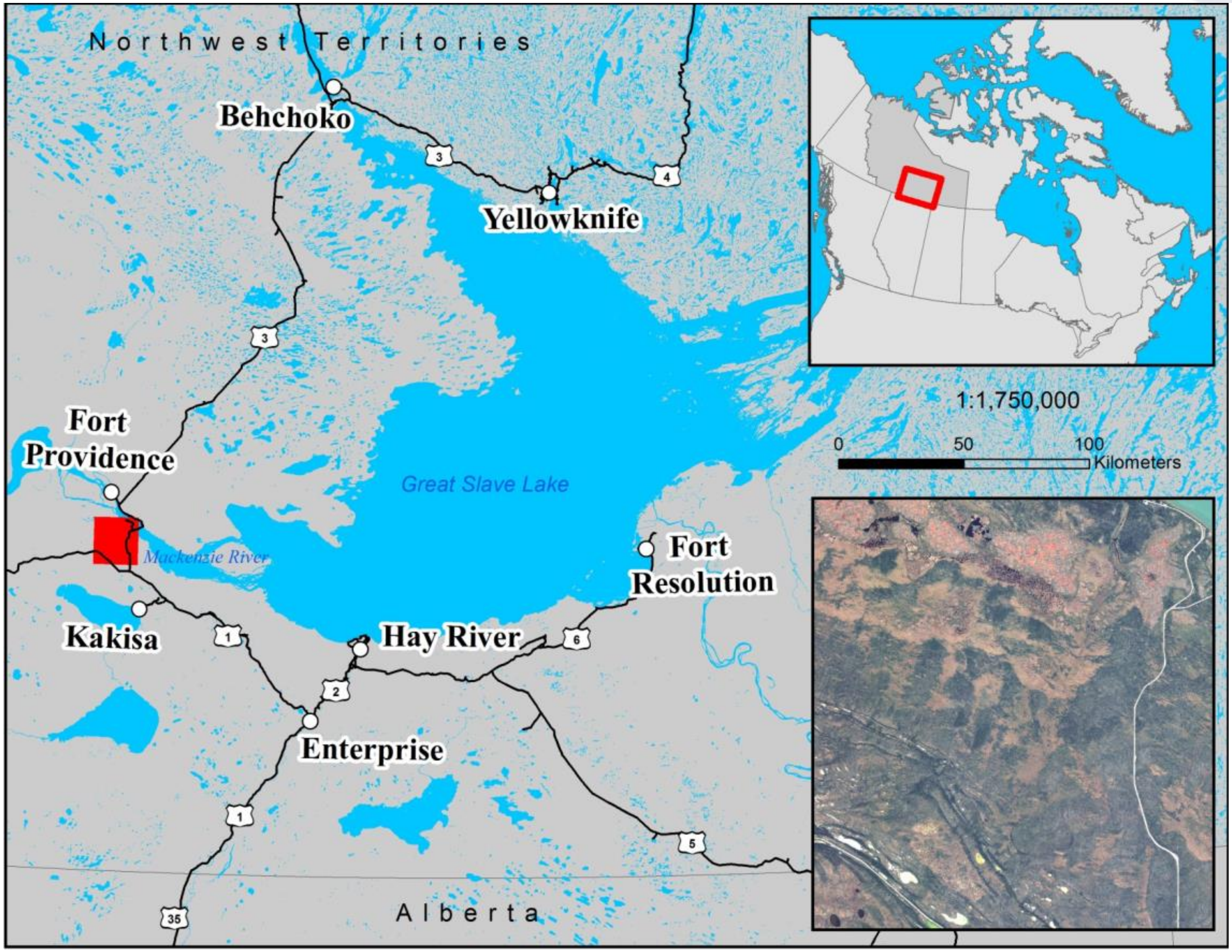
Methods: Multiple Endmember SMA (MESMA)

- Model each individual mixed pixel as a combination of known pure components (endmembers; EM)

Model #	1st EM (canopy)	2nd EM (background)	3rd EM (Shadow)	Error (RMSE)
1	Aspen 1	Feather Moss 1		0.20
2	Aspen 2	Feather Moss 2		0.15
3	White spruce 2	Feather moss 1		0.10
4	Jack pine 3	Reindeer Lichen 2		0.05
.. 980	**Black spruce 5**	**Sphagnum Moss 3**		**0.01**

Roberts et al. (1998), Dennison and Roberts (2003), Youngentob et al. (2011), Somers and Asner (2012)

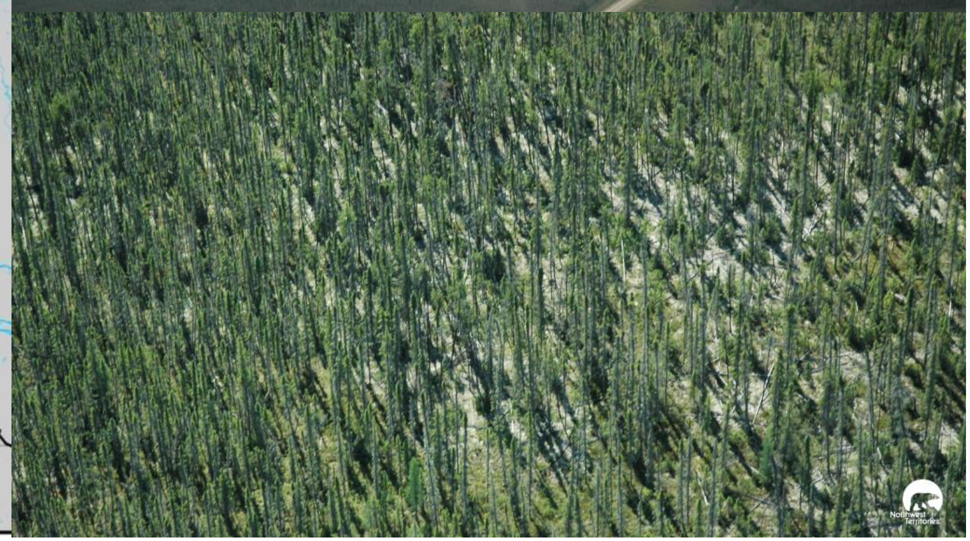
Study area



Northwest Territories
Behchoko
Yellowknife
Fort Providence
Mackenzie River
Great Slave Lake
Fort Resolution
Kakisa
Hay River
Enterprise
Alberta
1:1,750,000
0
50
100
Kilometers

Study area

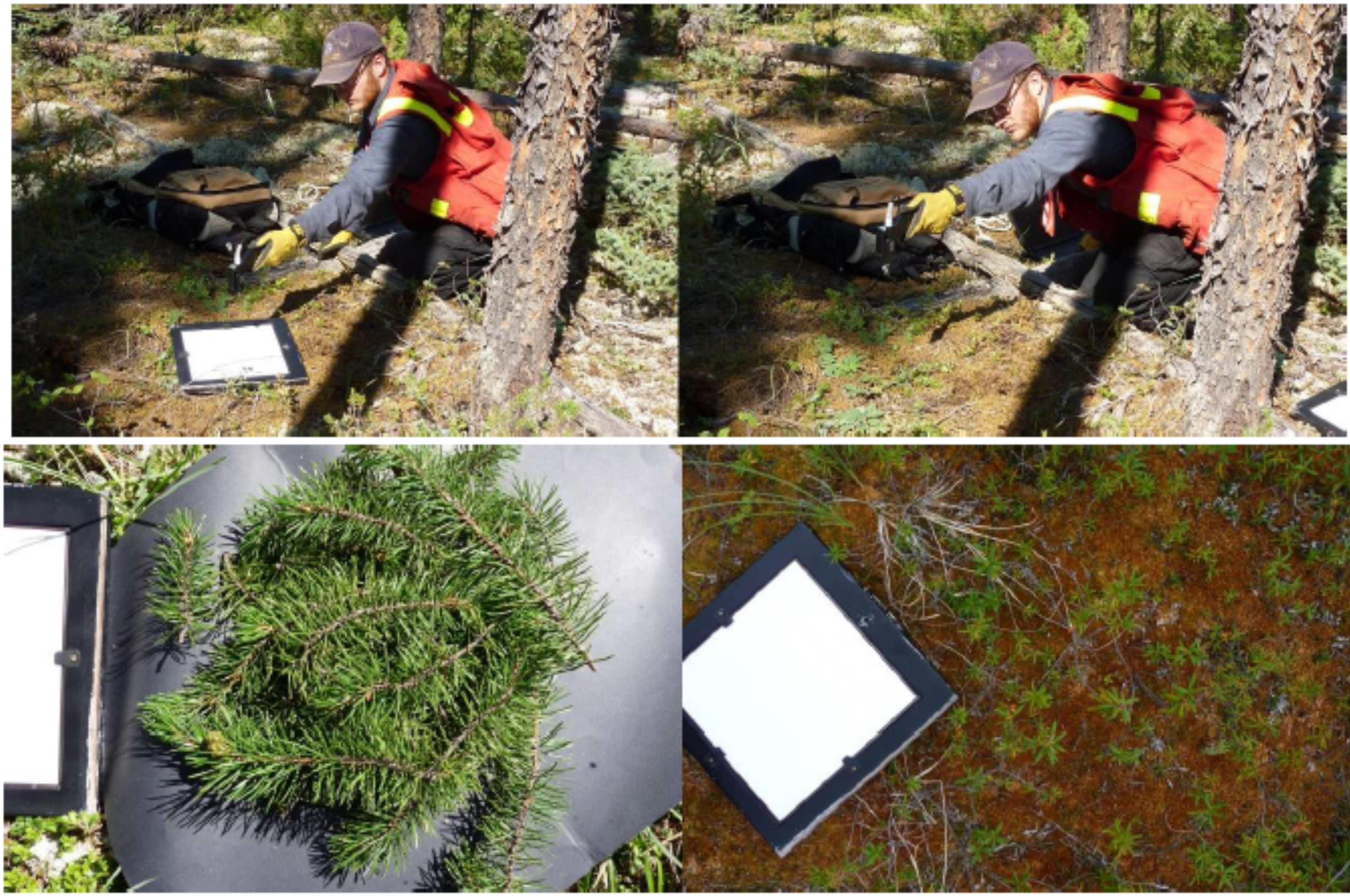

Northwest Territories
Behchoko
Yellowknife
Fort Providence
Great Slave Lake
Mackenzie River
Fort Resolution
Kakisa
Hay River
Enterprise
Alberta
3
4
1
2
6
5
35



Methods: Data

- 48 ground inventory plots (20 m x 20 m)
  - Jack pine, black spruce, white spruce, and mixedwood (white spruce-aspen) stands
- Landsat TM imagery
- Field spectra of sunlit canopy and background

Data



Data

Landsat Thematic Mapper

Data at 7 wavelength bands;
185 km x 185 km scenes;
Every 16 days;
30 m x 30 m pixel size

Spectral Unmixing

- Viper Tools software with ENVI to run MESMA
  (Roberts et al., 2007)

- Provides raster image of sub-pixel fractions of endmembers and a per-pixel classification of best model

- Minimum and maximum EM fractions constrained to -0.01 and 1.01, and a RMSE criterion of 0.025

Alberta Terrestrial Imaging Centre
University of Lethbridge

Classification using Field Spectra

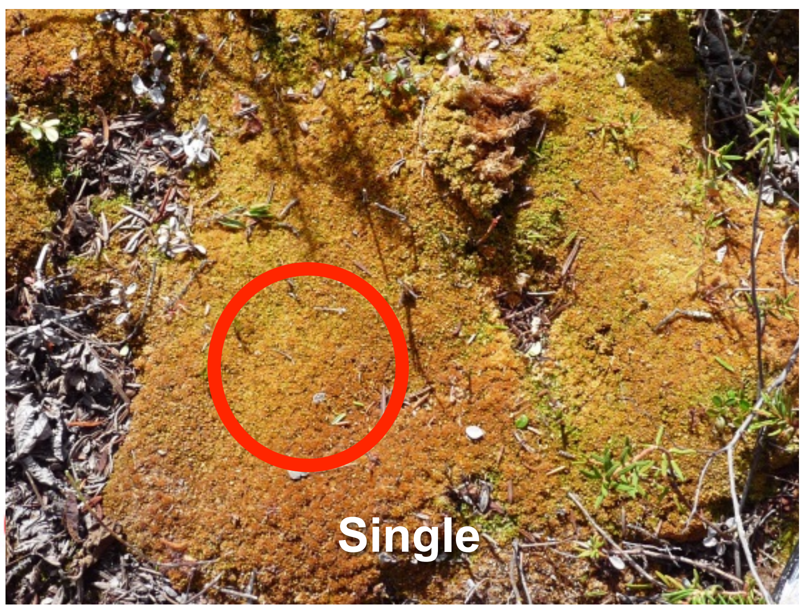
University of Lethbridge

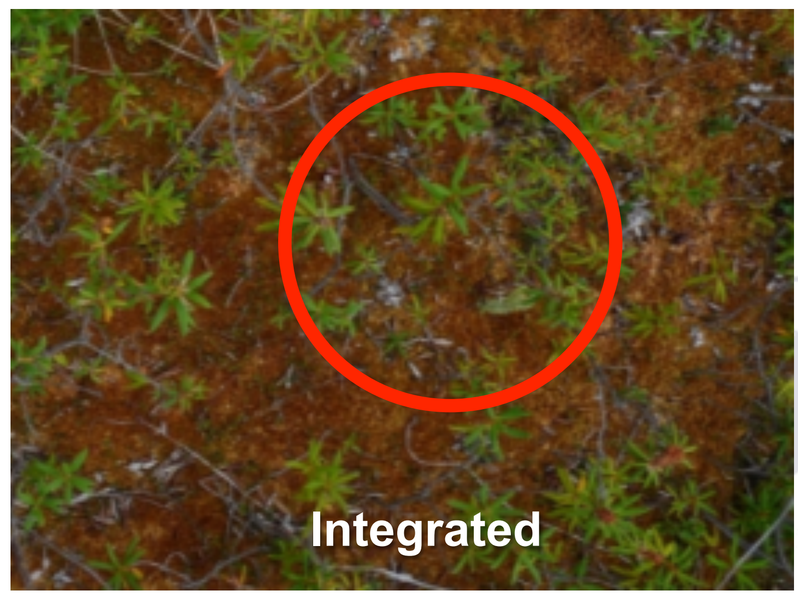
Classification using field spectra

- **Leading species / Species composition:**
  - Can be described in various ways:
    - e.g. by basal area, crown area, stem density
  - Relative abundance estimations may not be the same between indicators
  - Which indicator is Landsat TM most sensitive to?

Field inputs…

- **Can improved classification accuracies be realized through a better characterization of the understory?**
  - ***Single****: the dominant understory species*
  - ***Integrated****: a mixture of dominant species (cover fractions unknown)*
  - ***Weighted****: the diversity of all species (cover fractions known)*





Classification using field spectra

Source of endmember spectra	Endmember model	Overall accuracy (%)	Kappa
	Tree spectra + Individual Spectra	48	0.23
Field	Tree spectra + Integrated spectra	29	0.00
	Tree spectra + Weighted average	56	0.35

Crown closure	Accuracy
5 – 25 %	90 %
26 – 45 %	37 %
> 46 %	63 %

Variable	ρ-value
Stem density	0.13
Stand height	0.06
Crown closure	0.62

Results

- Landsat TM most sensitive to dominant / co-dominant description of leading species

- Weighted spectral library was preferred
  (i.e. need to know ground cover estimates)

Discussion

- Lower accuracies from field spectra likely due to:
  - Calibration issues (field spectra vs imagery)
  - Differences in scale (branch vs. stand)
  - Difficult to collect in the field

Classification using Image Spectra

Methods – Spectral Libraries

Tree image endmembers

- Ten most pure plots identified in ground reference data + 4 additional aspen stands using a panchromatic QuickBird

Understory image endmembers

- Endmember extraction algorithms (e.g. PPI) tested
- Iterative "*fishnet*" approach was better:
- Homogenous (non-treed) areas (fens, shrubs, grasses)

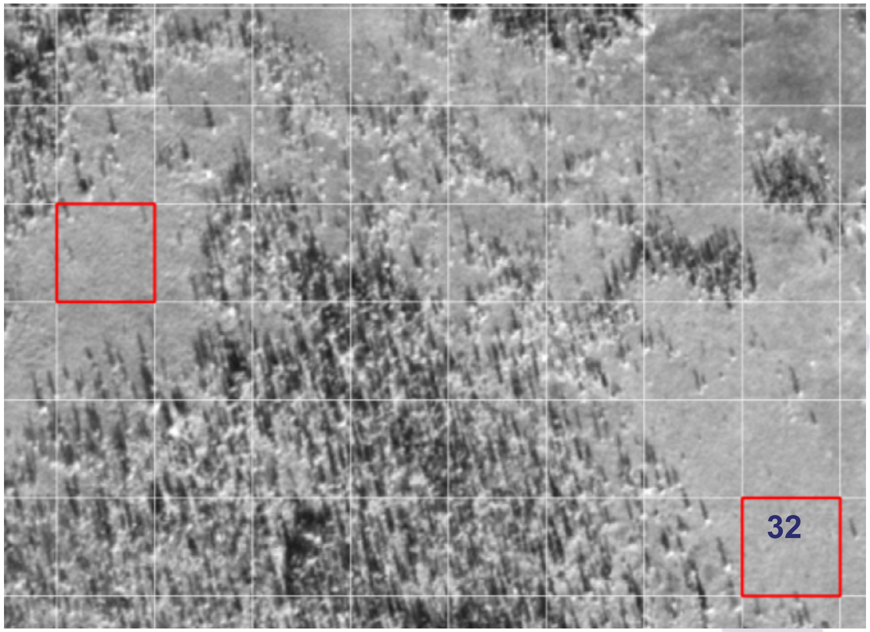


Image endmember spectra

- Understory: Variability in composition/distribution of understory vegetation can be challenging
- Canopy: Varying open patches in the forest canopy means that sunlit canopy image spectra not 100% pure

- Are impure spectra acceptable for classification purposes?

- Benefits of multi-temporal imagery?

Classifications using image spectra

1. Does image-derived spectra offer improvements over field-based endmember spectra?

2. Is the performance of image-derived spectra dependent on how the sunlit and background components are selected?

3. Does multi-temporal imagery provide improved results ?
   -i.e. represent different stages of vegetative phenology for leading species

Classifications using image spectra

- Selection of image endmembers:
  - **Sunlit Canopy**
    - By purest species composition
    - By purest sunlit canopy “signal”
  - **Background endmember**
    - By purest background signal outside forest (nearby, but may not be fully representative of understory species)
    - By purest background signal inside forest (at lowest crown closures; representative of understory species)

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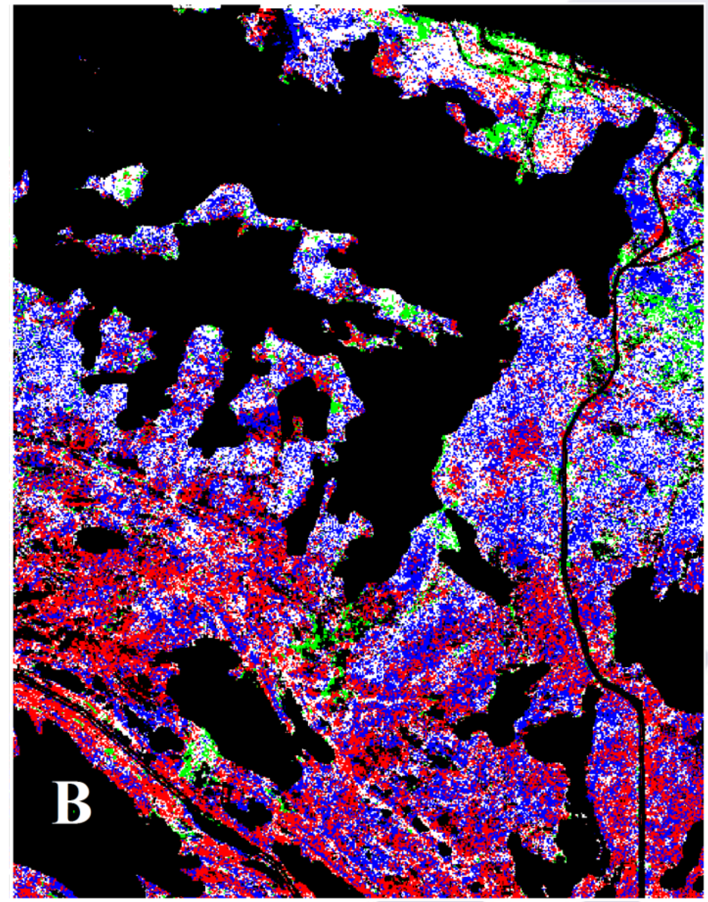
Results

Single-date (July) : multi-temporal imagery

Jack pine: 54 % : **77 %**

White spruce: 50 % : **83 %**

Black spruce: 44 % : **78 %**



Non-forest EOSD
Jack pine
White spruce
Black spruce
Aspen

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Conclusions / Next steps…

- Results suggests that classification of Landsat TM using MESMA at the leading species level is feasible using image endmember spectral inputs

- Spectral impurity in image endmembers is tolerated for mapping leading species in study area

- Multi-temporal imagery of is definite benefit

- Applications in Fort Liard / Fort Simpson forest settings

- Compare MESMA to other classification procedures

Funding and Support

TECTERRA

University of Lethbridge

FIAT LUX

NSERC
CRSNG

AMETHYST

Northwest Territories

Natural Resources Canada
Ressources naturelles Canada

Canada

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Questions

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