The Role of Remote Sensing in Advancing Canada's Forest Management and Monitoring

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Natural Resources Canada / Ressources naturelles Canada
Canadian Forest Service / Service canadien des forêts

Canada


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Outline

- Forestry in Canada
- Canadian Forest Service
- Remote sensing + forestry
  - Large-area monitoring
  - Enhanced forest inventory

"Canada is big and has lots of forests"

Joanne White, 2014, personal communication.

https://thetruesize.com

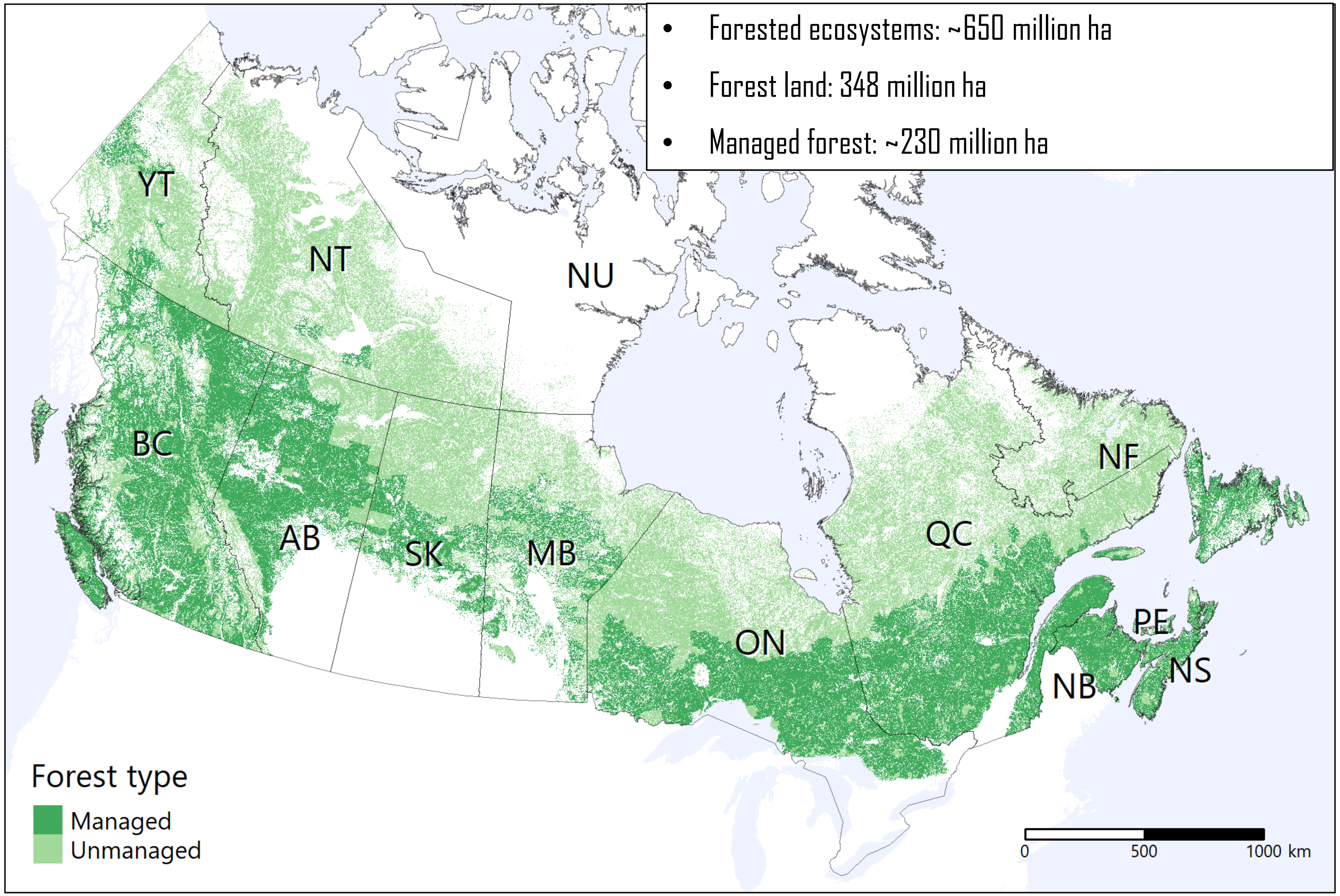
Canada's forests: Context

- Area of Canada = 998.4 million ha (31×PL)
  - 65% forested ecosystems (20×PL)
  - 40% treed (12×PL)
  - 20% managed (6×PL)
  - ~10% protected (~6% of forested ecosystems) (3×PL)
- 10% of global forests; 30% of global boreal
- 89% of Canada's forests are publicly owned

https://nfi.nfis.org/en/quickfacts

Canada's forests: Context

- Forested ecosystems: ~650 million ha
- Forest land: 348 million ha
- Managed forest: ~230 million ha



Forestry in Canada and Europe

Europe

- Ownership – mostly private
- Management – intensive (small FMUs)

Canada

- Ownership – 89% public
- Management – extensive (large FMUs)




Fassnacht, Fabian Ewald, Joanne C White, Michael A Wulder, and Erik Næsset. "Remote Sensing in Forestry: Current Challenges, Considerations and Directions." Forestry: An International Journal of Forest Research, May 10, 2023, cpad024. https://doi.org/10.1093/forestry/cpad024; https://thenarwhal.ca/; https://doi.org/10.1186/s13717-019-0181-9

Canadian Forest Service

- National science-based policy organization
- Established in 1899
- 6 research centres
- Strategic priorities:
    1. Advance environmental leadership
    2. Support forest sector competitiveness
    3. Optimize forest value

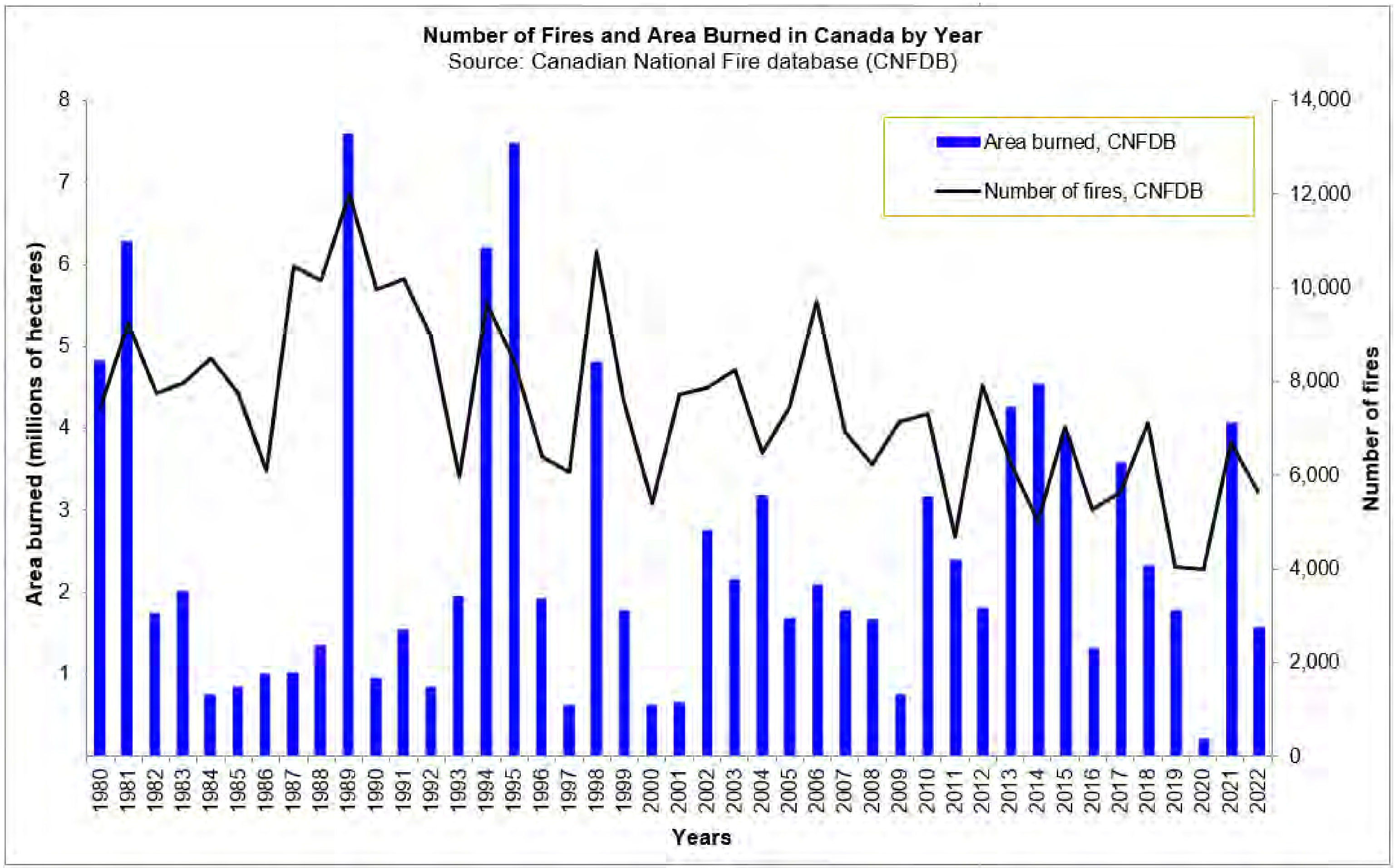
Information needs for forest monitoring

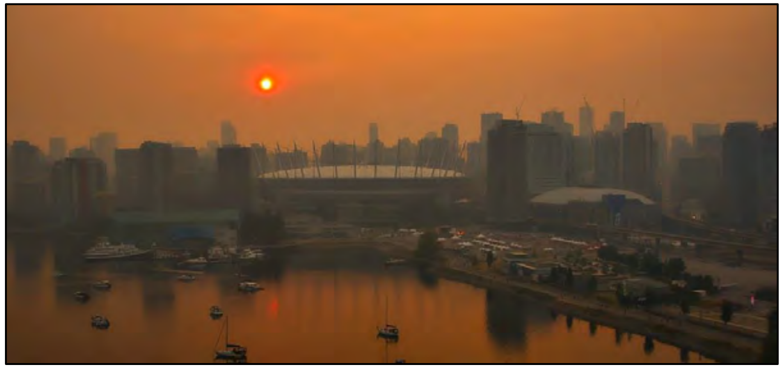
- GoC has national and international **reporting** commitments and obligations, national programs (NFI, Carbon Accounting)
- Need information that is **consistent**, **spatially explicit**, sufficiently **detailed** to capture anthropogenic impacts, and **national in scope**
- Longer baseline required to determine **trends**, define present, inform future

Current Challenges in Canadian Forestry

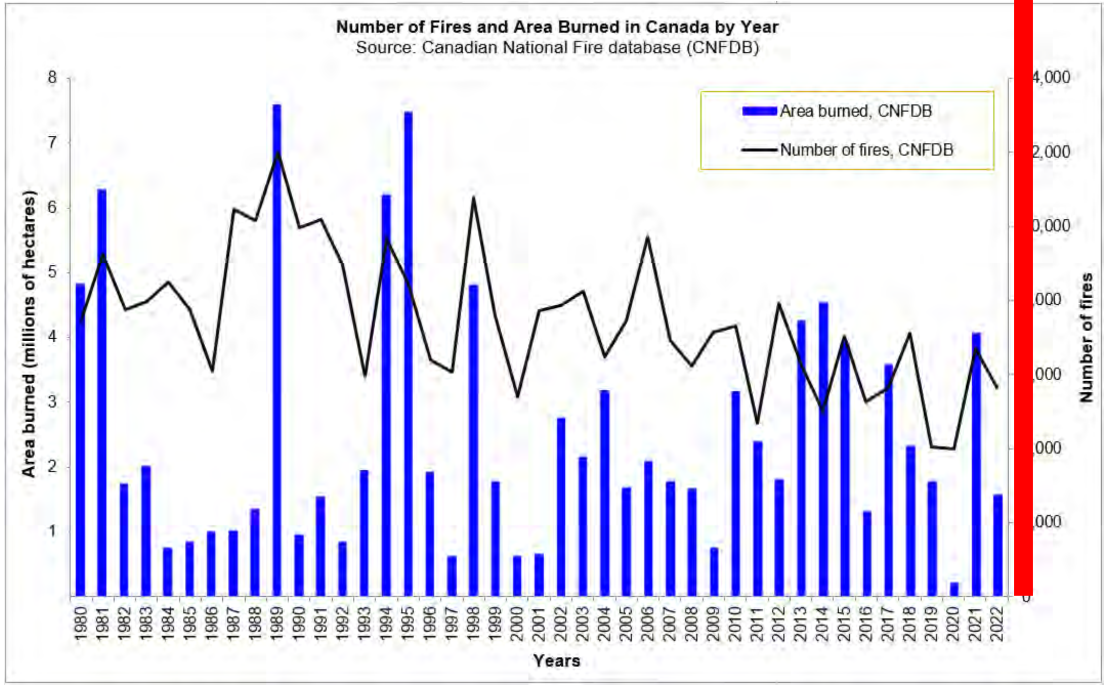
- **Climate Change**: Increased wildfire risk, changes in species distribution.
- **Forest Fires**: More frequent and severe.
- **Pest Infestations**: Significant damage from pests like mountain pine beetle.
- **Biodiversity Loss**: Impacts from management practices and environmental stress.
- **Sustainable Management**: Balancing logging with conservation
- **Economic Pressures**: Market fluctuations, trade disputes, affecting forestry economics.
- **Indigenous Rights**: Conflicts over land use and integration of traditional knowledge.
- **Technological Advances**: Adoption of remote sensing and GIS for improved forest management.

2023 forest fires

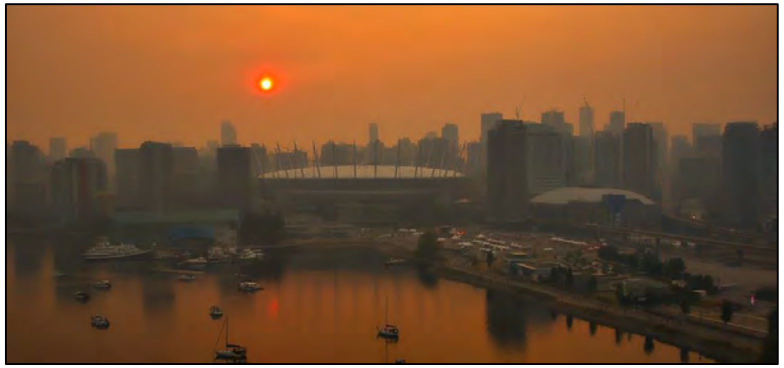




2023 forest fires



~18.5 million hectares (57% area of Poland)



Remote sensing?

Information needs

Key attributes for Canada's NFI, Carbon Accounting programs

Basic attributes:

- Land cover
- Crown closure
- Age
- Species
- Height
- Volume
- Biomass

Disturbance-related attributes:

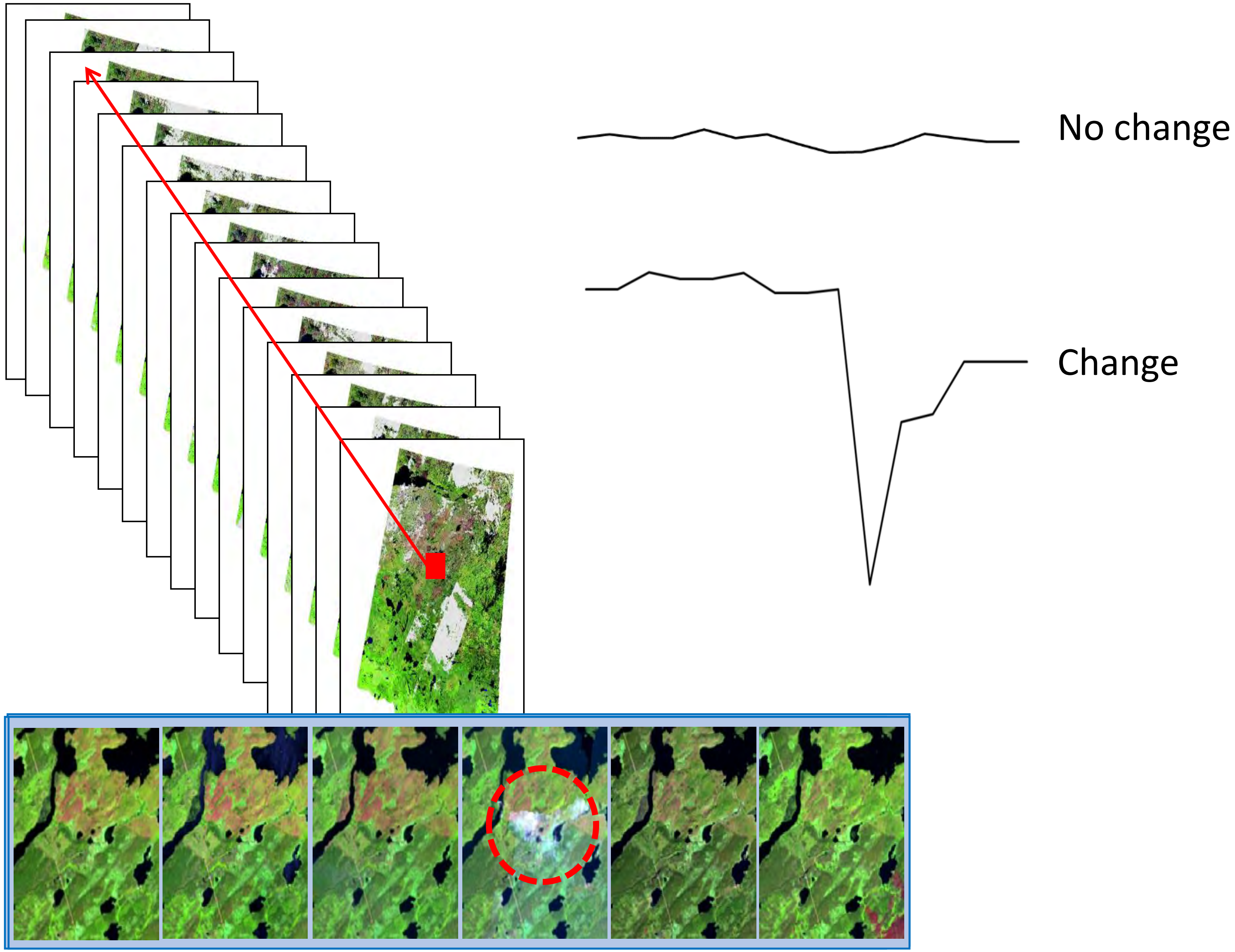
- Pre-disturbance land cover
- Post-disturbance land cover
- Disturbance agent
- Disturbance year
- Disturbance extent (area)
- Disturbance intensity
- Post-disturbance recovery

White, J.C., Wulder, M.A., Hobart, G.W., Luther, J.E., Hermosilla, T., Griffiths, P., Coops, N.C., Hall, R.J., Hostert, P., Dyk, A., Guindon. L. 2014. Pixel-based image compositing for large-area dense time series applications and science. Canadian Journal of Remote Sensing, 40(3): 192–212.

Data?

- National coverage
- Time series (monitoring)
- Sub-stand level of detail
- Free

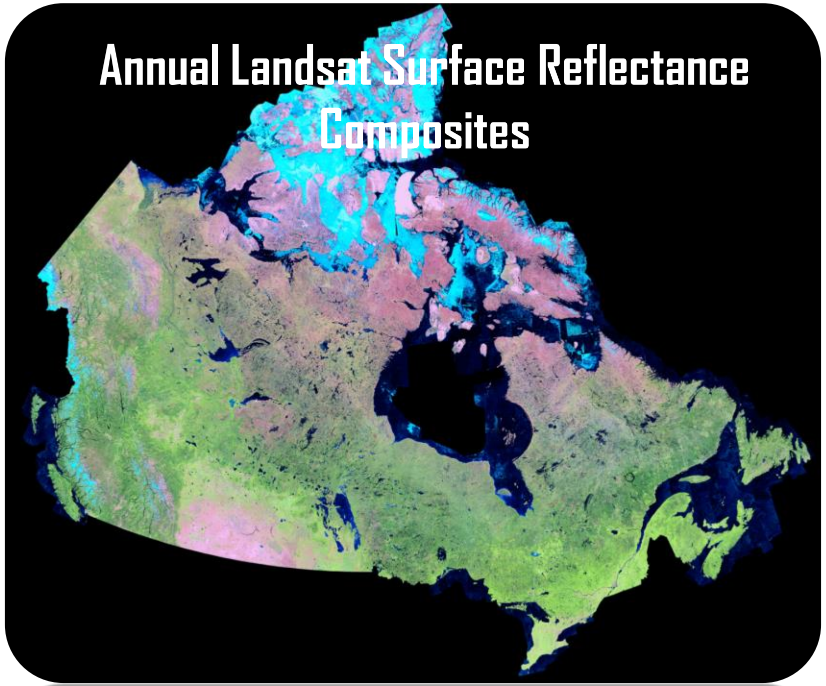
Landsat!

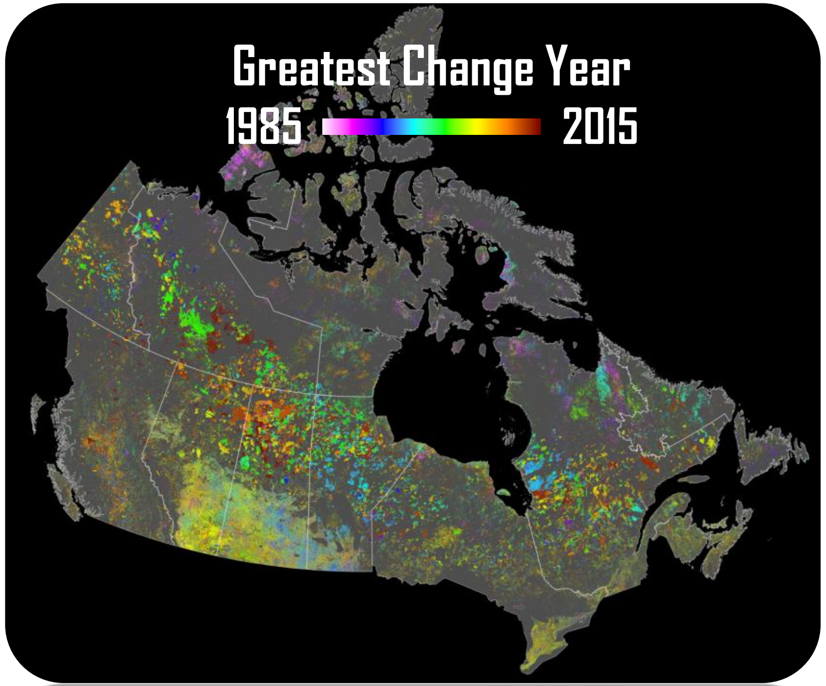


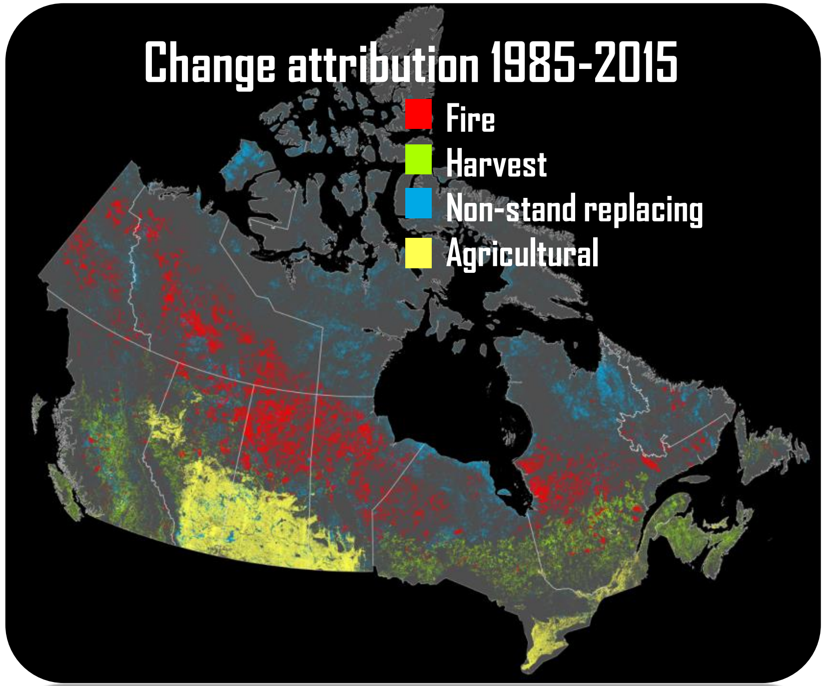
Hermosilla, Txomin, Michael A. MA Wulder, J.C. Joanne C. White, Nicholas C. NC Coops, and Geordie W. George W Hobart. "An Integrated Landsat Time Series Protocol for Change Detection and Generation of Annual Gap-Free Surface Reflectance Composites." Remote Sensing of Environment 158 (March 2015): 220–34. https://doi.org/10.1016/j.rse.2014.11.005.

NTEMS

National Terrestrial Ecosystem Monitoring System

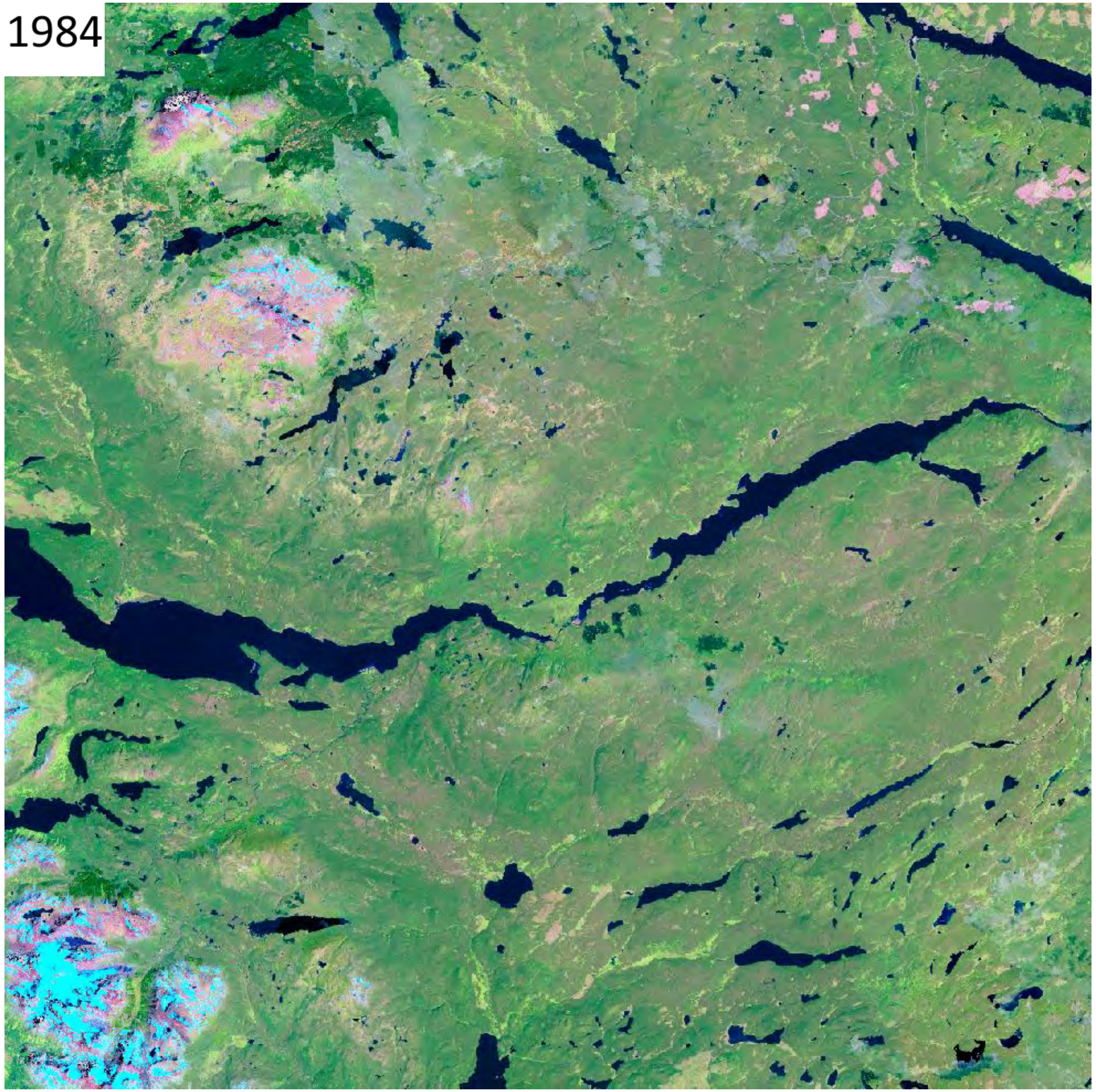


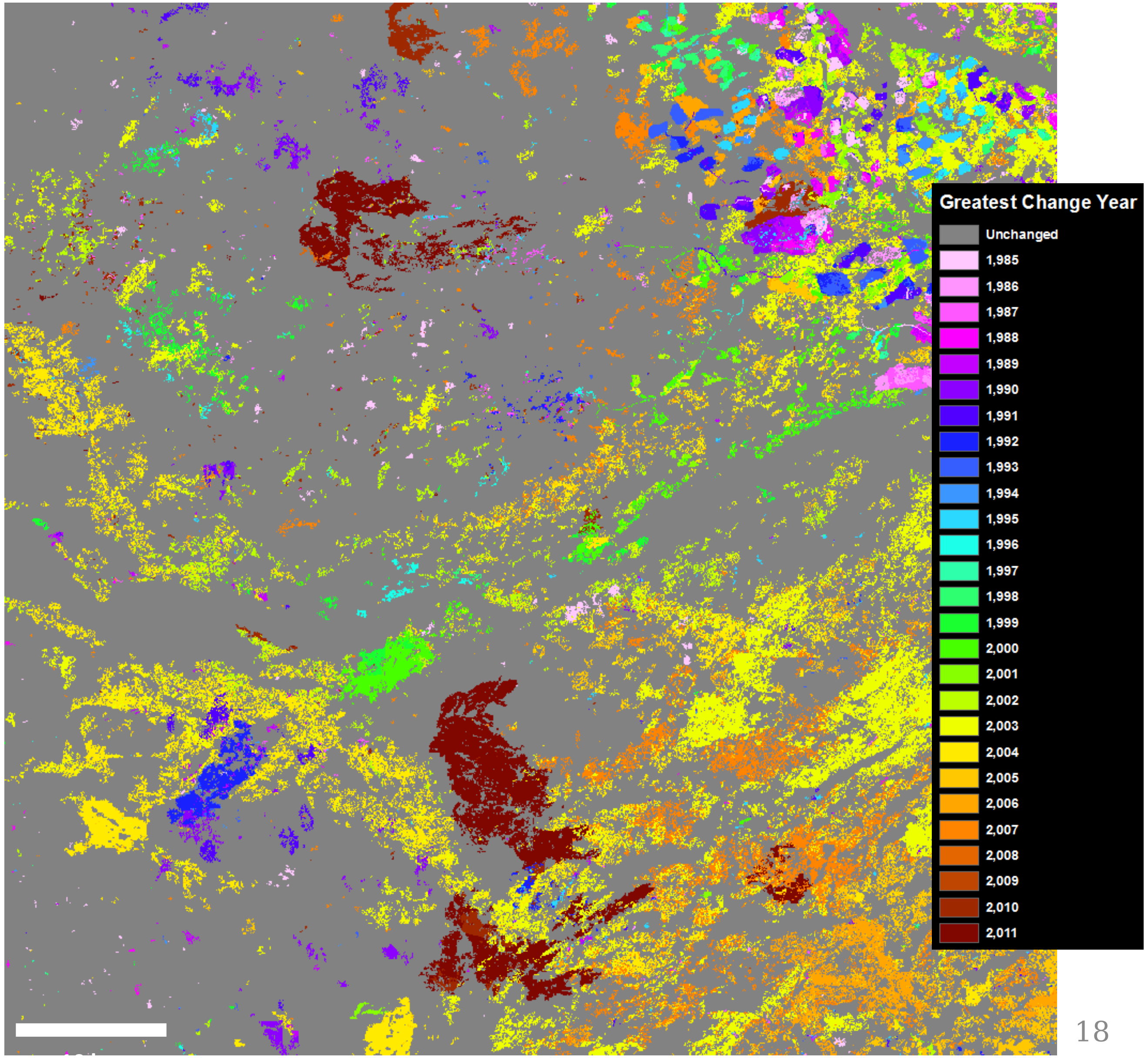




Hermosilla, T., Wulder, M. A., White, J. C., Coops, N. C., Hobart, G. W., & Campbell, L. B. (2016). Mass data processing of time series Landsat imagery: pixels to data products for forest monitoring. International Journal of Digital Earth, 9(11), 1035-1054.

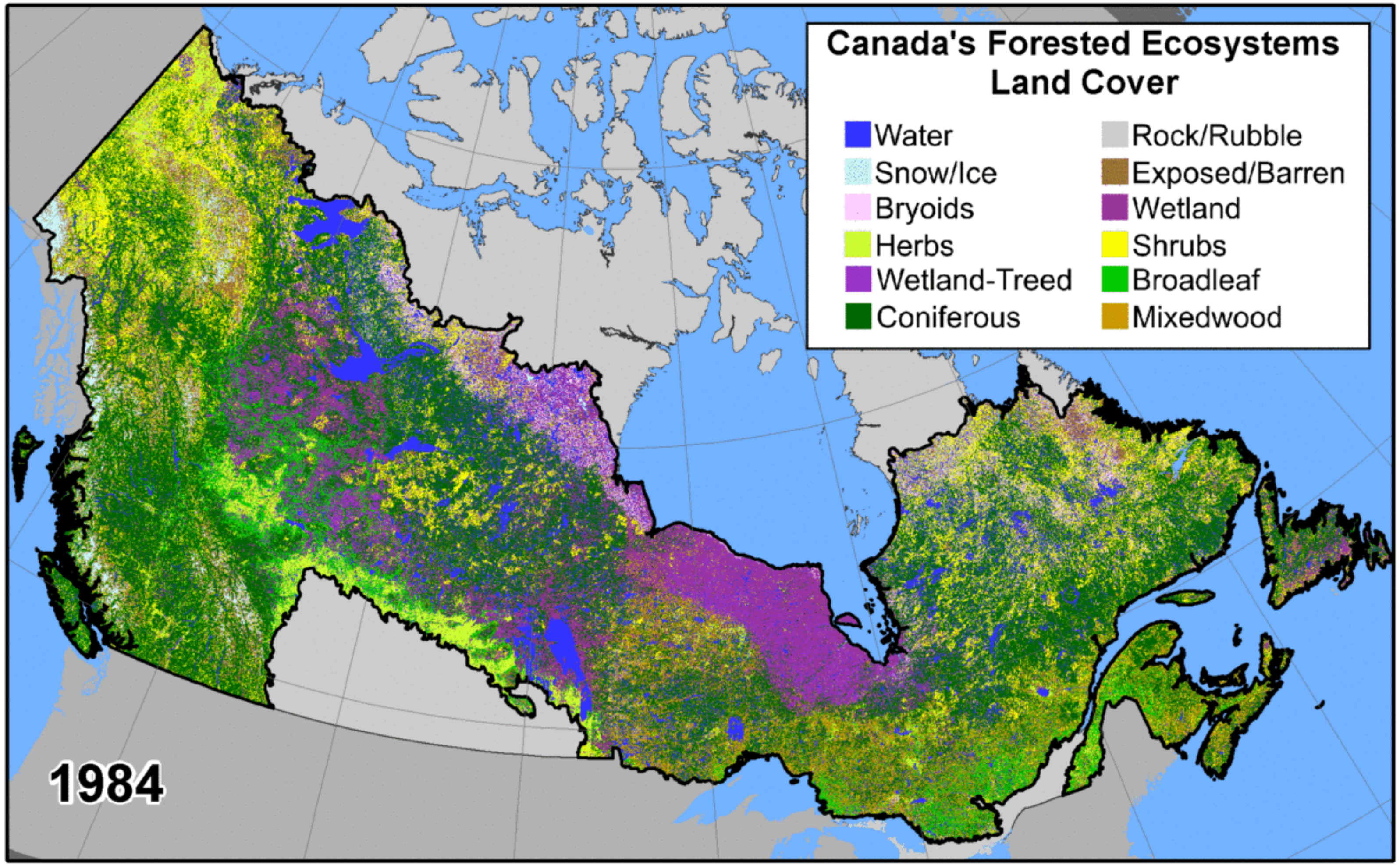
British Columbia: Tetachuck Lake





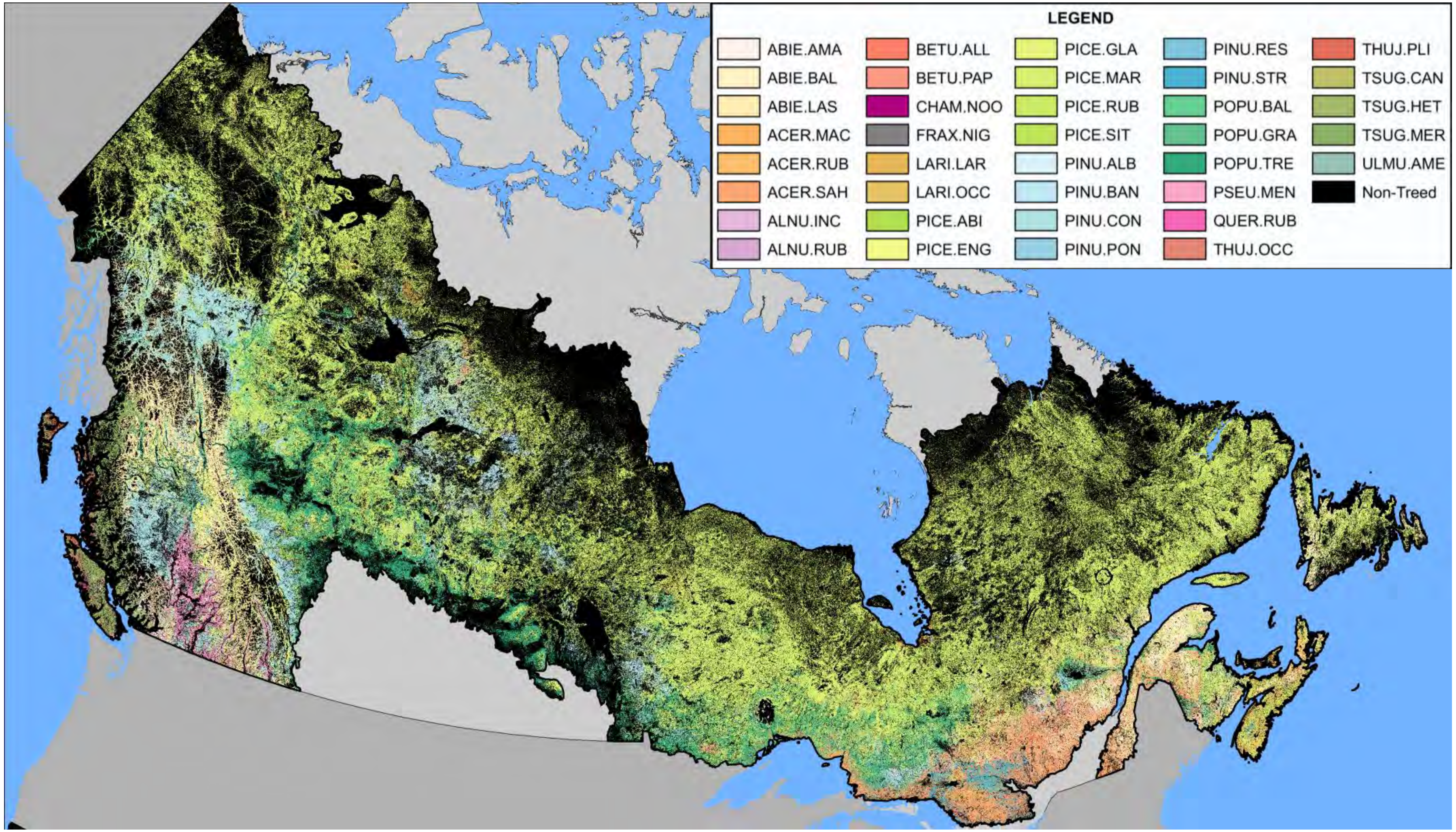
NTEMS

National Terrestrial Ecosystem Monitoring System

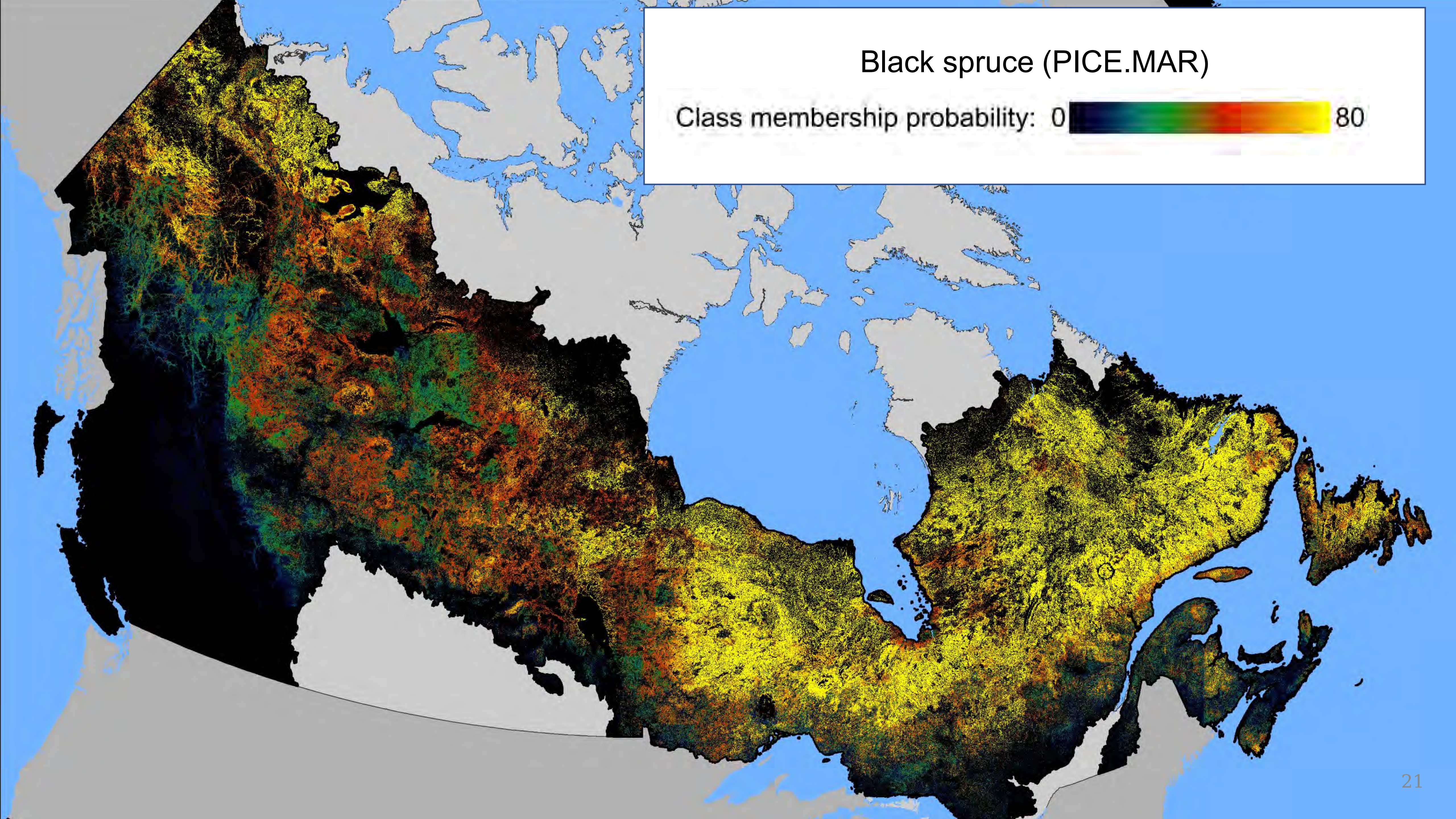


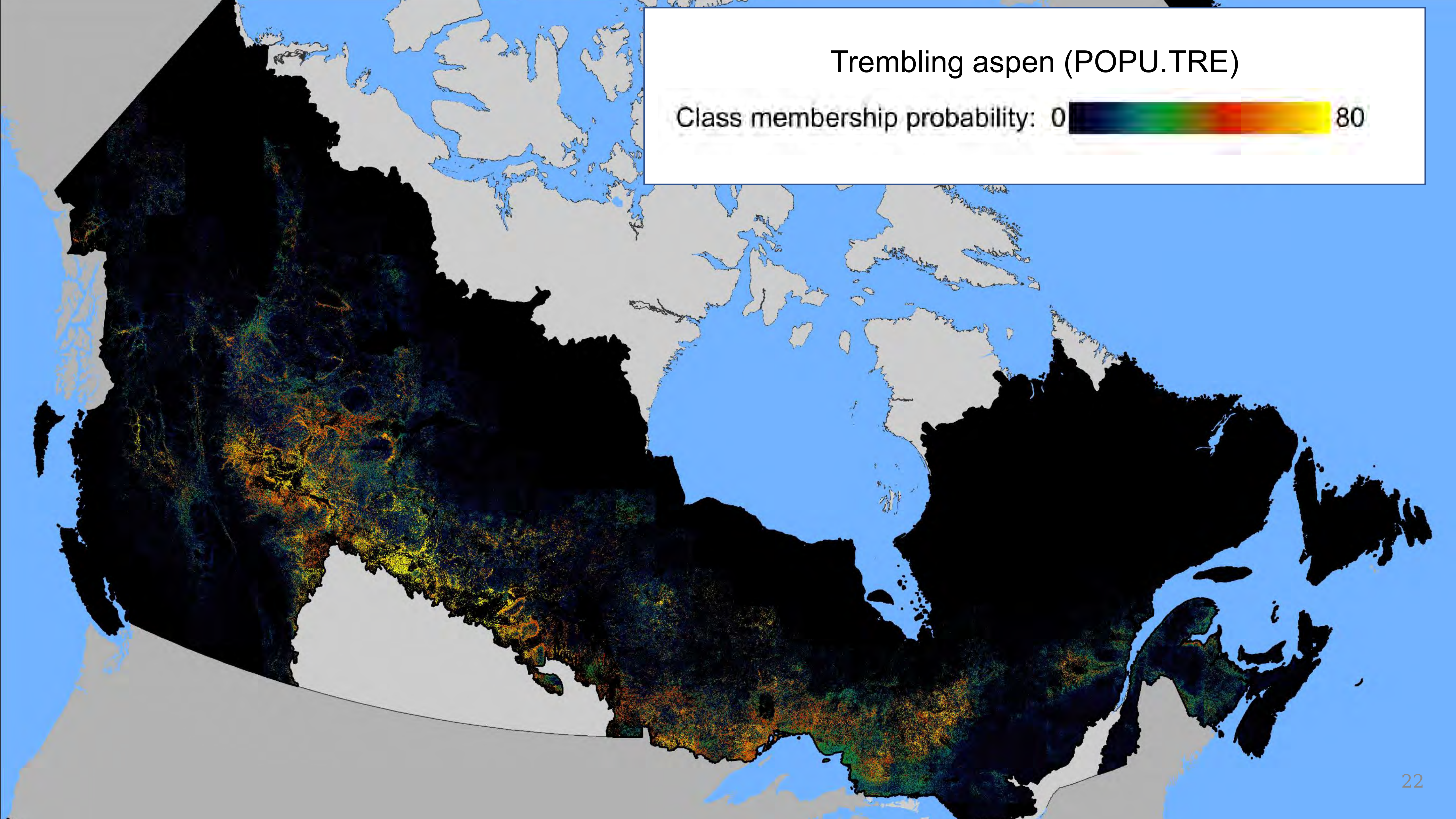
Hermosilla, T., Wulder, M.A., White, J.C., Coops, N.C., Hobart, G.W., (2018). Disturbance-informed annual land cover classification maps of Canada's forested ecosystems for a 29-year Landsat time series. Canadian Journal of Remote Sensing. Vol. 44, No. 1, pp. 67-87

NTEMS
National Terrestrial Ecosystem Monitoring System

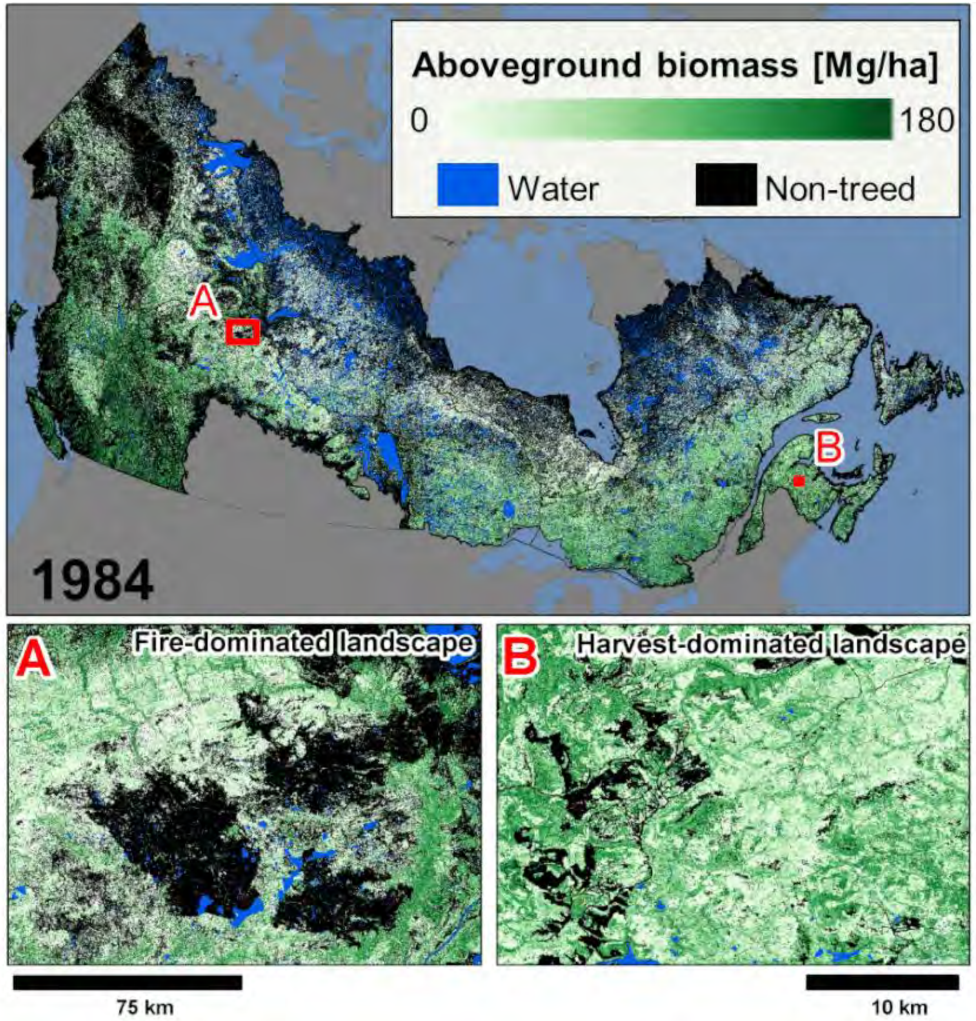


Maltman, J.C., Hermosilla, T., Wulder, M.A., Coops, N.C., White, J.C., 2023. Estimating and mapping forest age across Canada's forested ecosystems. Remote Sensing of Environment 290, 113529.


Black spruce (PICE.MAR)
Class membership probability: 0
80

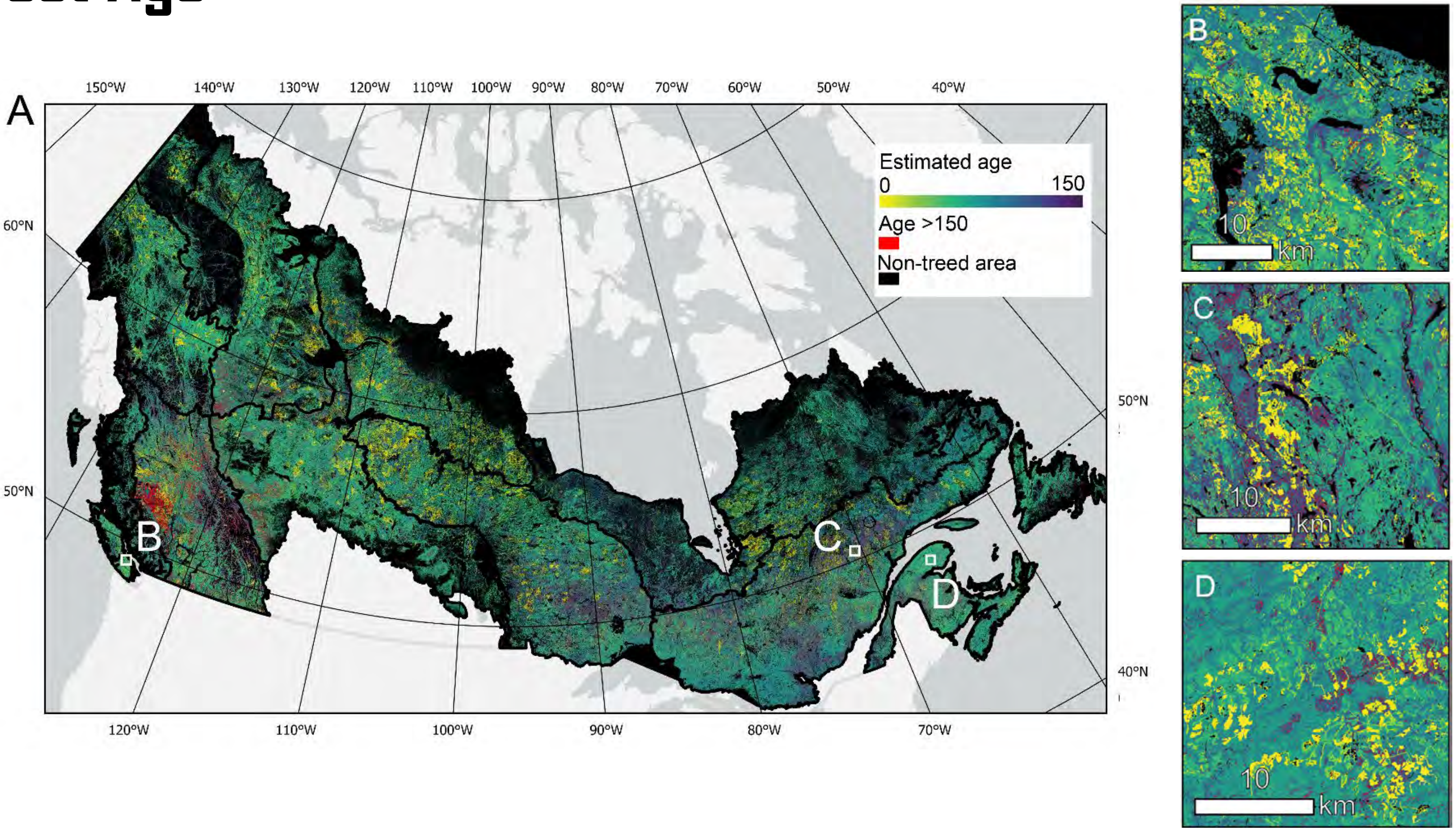

Trembling aspen (POPU.TRE)
Class membership probability: 0
80

NTEMS – Stand attributes



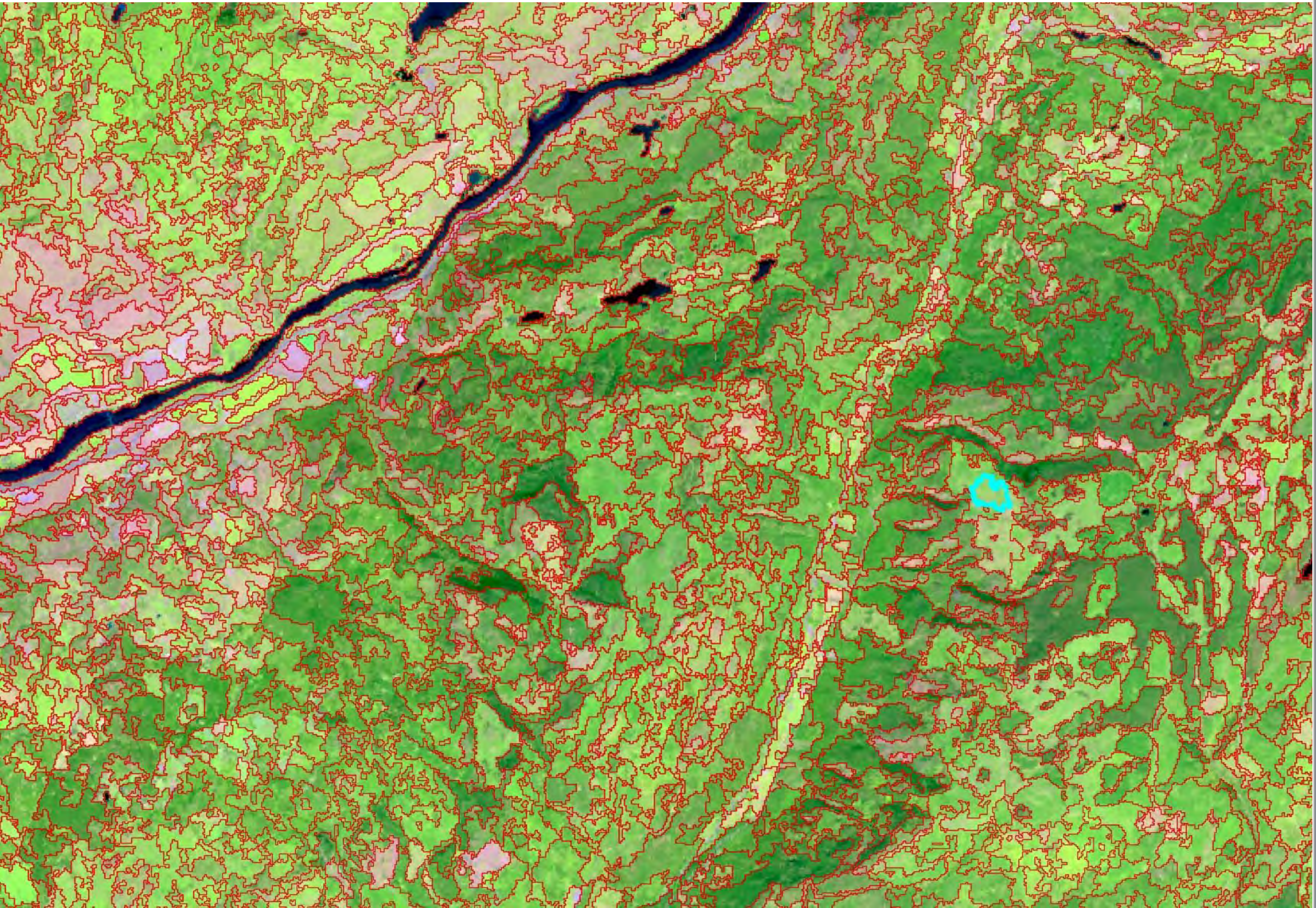
Matasci, Giona, Txomin Hermosilla, Michael A. Wulder, Joanne C. White, Nicholas C. Coops, Geordie W. Hobart, Douglas K. Bolton, Piotr Tompalski, and Christopher W. Bater. "Three Decades of Forest Structural Dynamics over Canada's Forested Ecosystems Using Landsat Time-Series and Lidar Plots." Remote Sensing of Environment 216, no. May (October 2018): 697–714. https://doi.org/10.1016/j.rse.2018.07.024.

Forest Age



Maltman, J.C., Hermosilla, T., Wulder, M.A., Coops, N.C., White, J.C., 2023. Estimating and mapping forest age across Canada's forested ecosystems. Remote Sensing of Environment 290, 113529.

Application: Satellite-Based Forest Inventor



Field	Value
STRUCTURE.CANOPY_HEIGHT.MAX	26.98
STRUCTURE.CANOPY_HEIGHT.AVG	8.08
STRUCTURE.CANOPY_HEIGHT.SD	4.58
STRUCTURE.CANOPY_HEIGHT.MEDIAN	7.5
STRUCTURE.CANOPY_COVER.MIN	7.44
STRUCTURE.CANOPY_COVER.MAX	93.59
STRUCTURE.CANOPY_COVER.AVG	49.4
STRUCTURE.CANOPY_COVER.SD	22.42
STRUCTURE.CANOPY_COVER.MEDIAN	53.5
STRUCTURE.LOREYS_HEIGHT.MIN	5.55
STRUCTURE.LOREYS_HEIGHT.MAX	26.19
STRUCTURE.LOREYS_HEIGHT.AVG	9.34
STRUCTURE.LOREYS_HEIGHT.SD	3.98
STRUCTURE.LOREYS_HEIGHT.MEDIAN	8.95
STRUCTURE.BASAL_AREA.MIN	3.93
STRUCTURE.BASAL_AREA.MAX	33.18
STRUCTURE.BASAL_AREA.AVG	10.21
STRUCTURE.BASAL_AREA.SD	6.42
STRUCTURE.BASAL_AREA.MEDIAN	9.6
STRUCTURE.BASAL_AREA.TOTAL	69.85
STRUCTURE.AGB.MIN	11.29
STRUCTURE.AGB.MAX	169.25
STRUCTURE.AGB.AVG	36.79
STRUCTURE.AGB.SD	31.51
STRUCTURE.AGB.MEDIAN	31.27
STRUCTURE.AGB.TOTAL	251.64
STRUCTURE.VOLUME.MIN	14
STRUCTURE.VOLUME.MAX	372.7
STRUCTURE.VOLUME.AVG	59.72
STRUCTURE.VOLUME.SD	66.75
STRUCTURE.VOLUME.MEDIAN	44.3
STRUCTURE.VOLUME.TOTAL	408.46
SPECIES.NUMBER	2
SPECIES.1	PICE.ENG
SPECIES.1.PERC	69.74
SPECIES.2	PINU.CON
SPECIES.2.PERC	30.26
SPECIES.3	
SPECIES.3.PERC	0
SPECIES.4	
SPECIES.4.PERC	0
SPECIES.5	
SPECIES.5.PERC	0
SPECIES.CONIFEROUS.PERC	100

NTEMS - summary

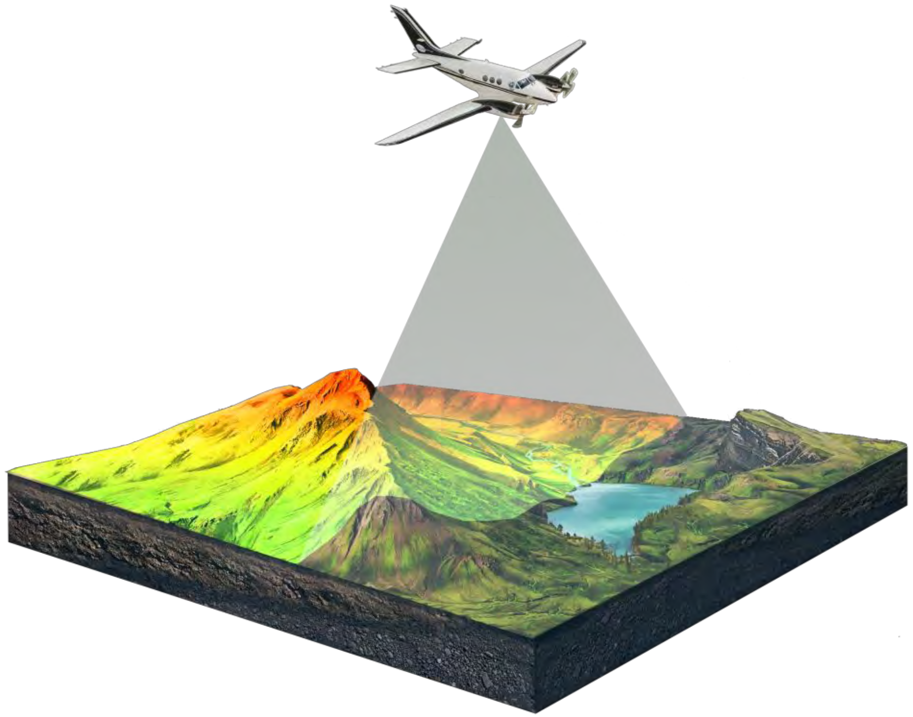
Basic attributes:

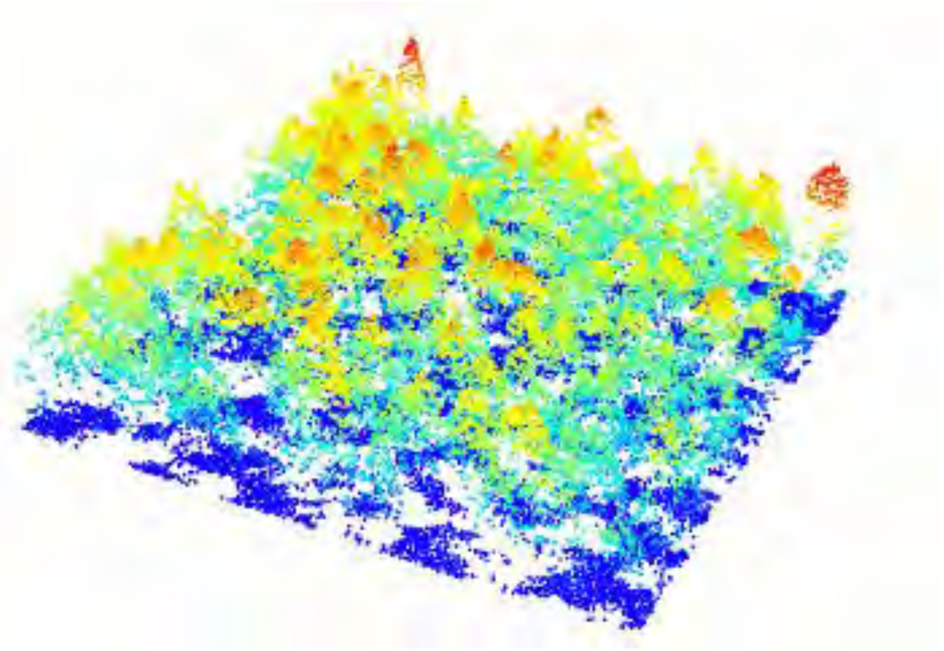
- Land cover
- Crown closure
- Age
- Species
- Height
- Volume
- Biomass

Disturbance-related attributes:

- Pre-disturbance land cover
- Post-disturbance land cover
- Disturbance agent
- Disturbance year
- Disturbance extent (area)
- Disturbance intensity
- Post-disturbance recovery

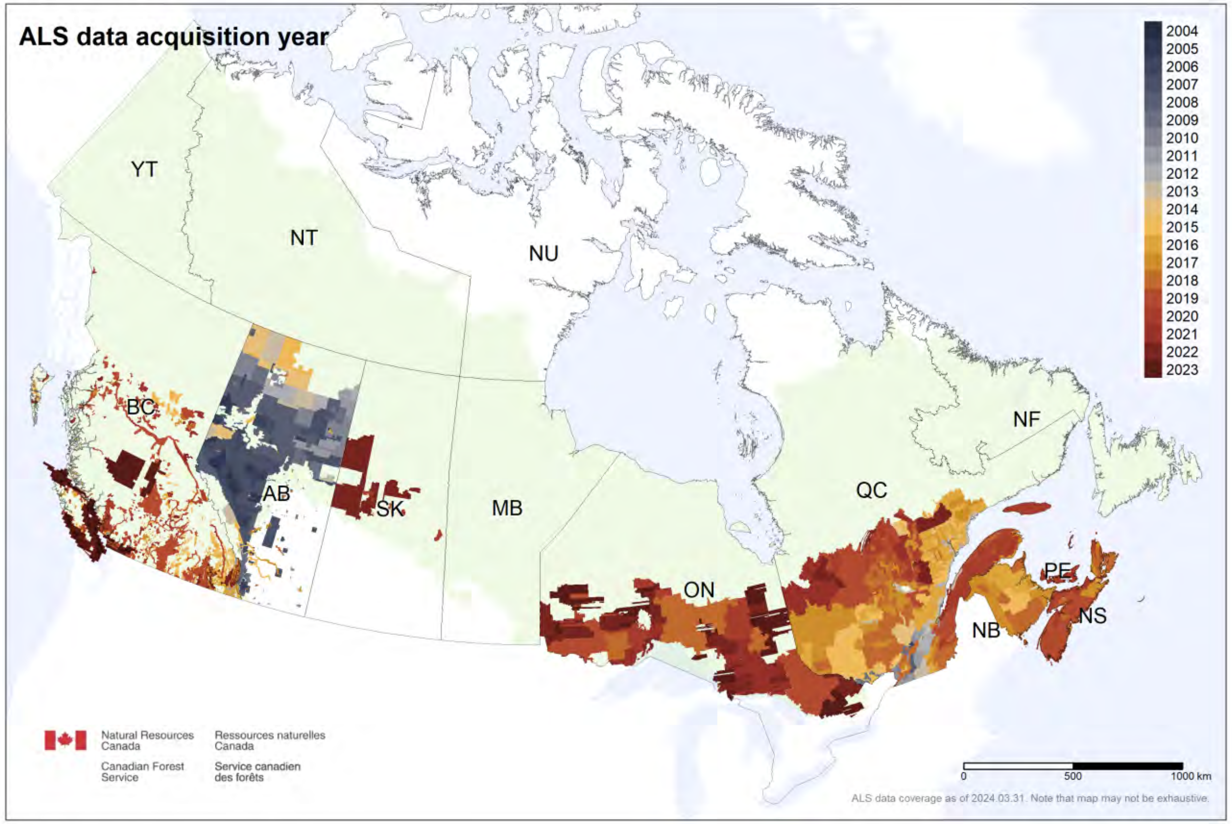
Airborne laser scanning

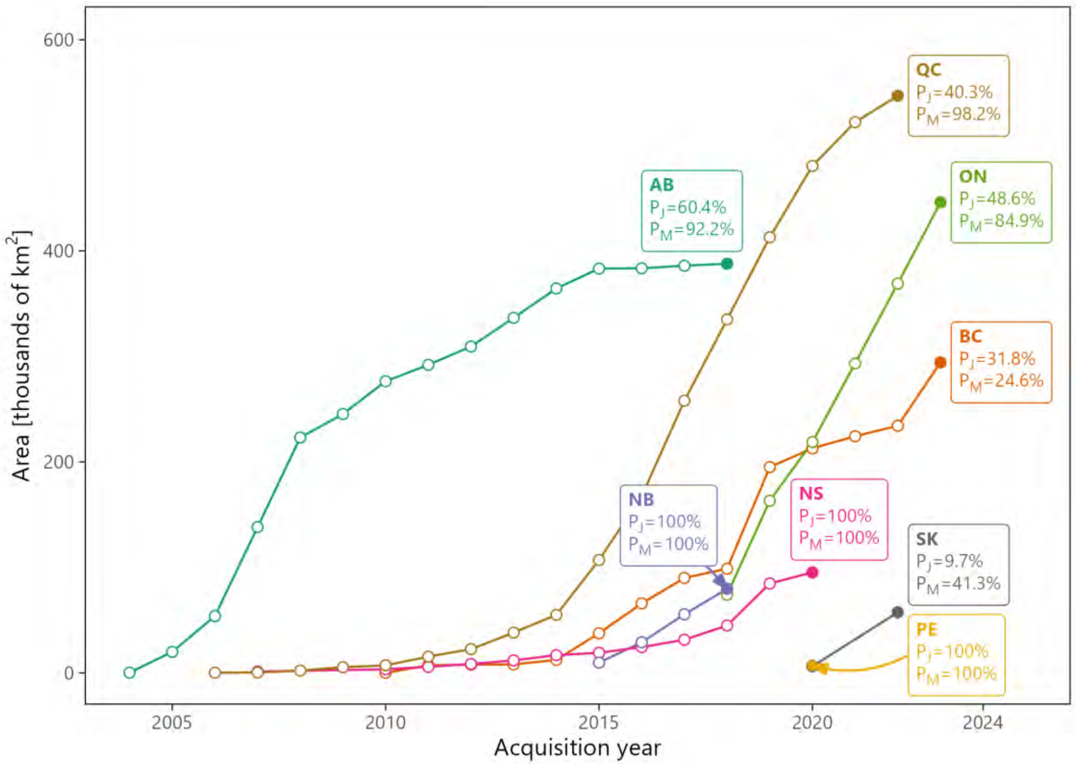




https://natural-resources.canada.ca/; https://github.com/r-lidar/lidR

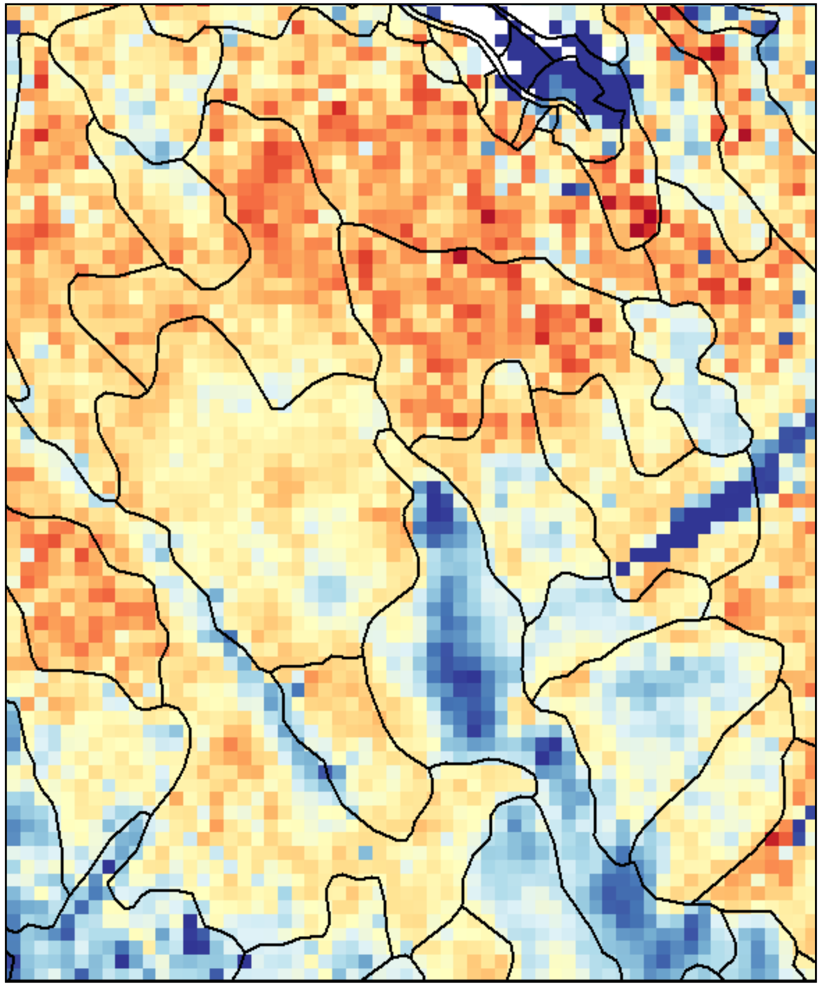
ALS in Canada



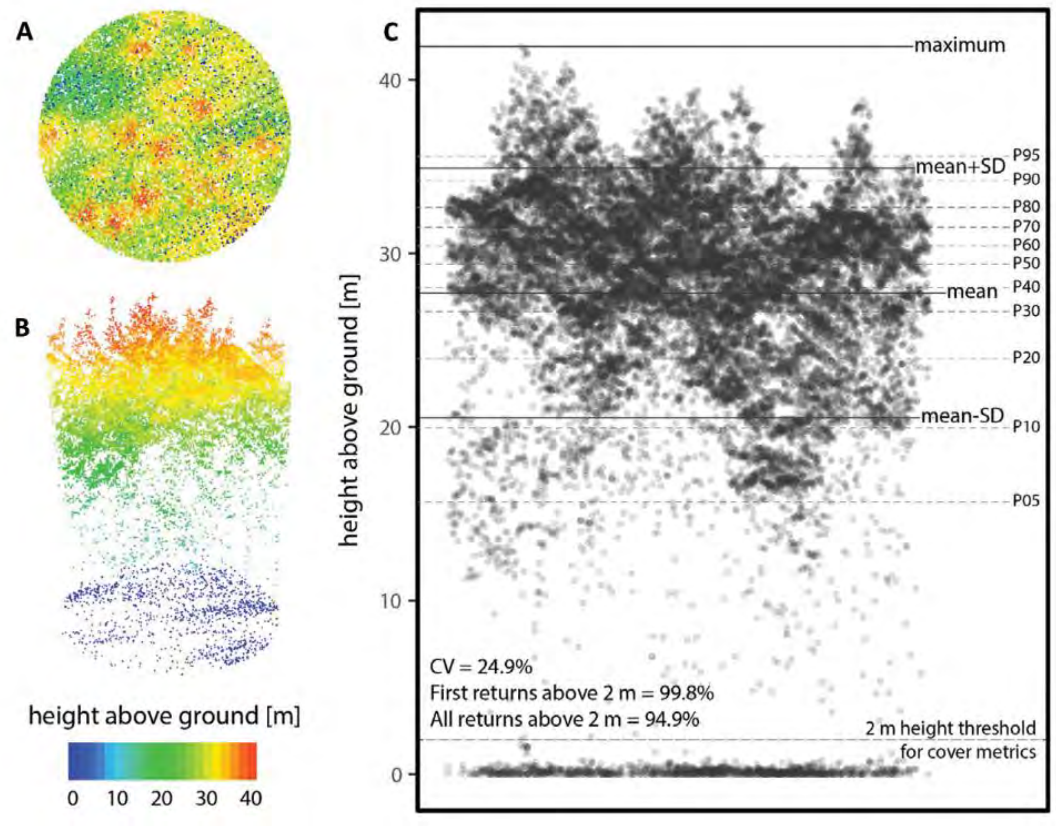


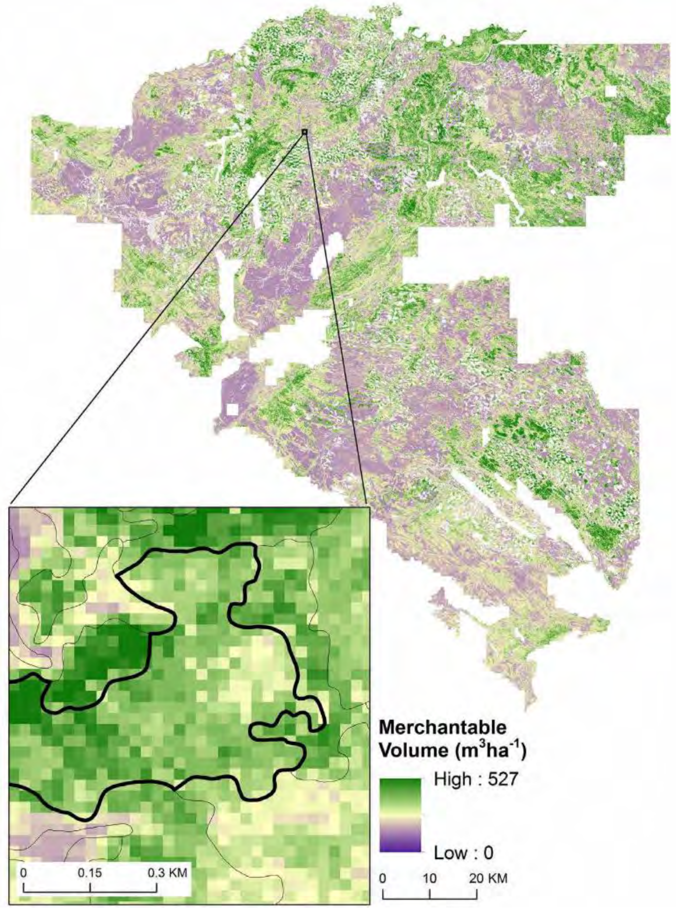
EFI

- Stand attributes at pixel- or tree-level
- Height, basal area, volume, biomass + many more
- Accurate, detailed, wall-to-wall
- "Enhanced forest inventory" - EFI



EFI

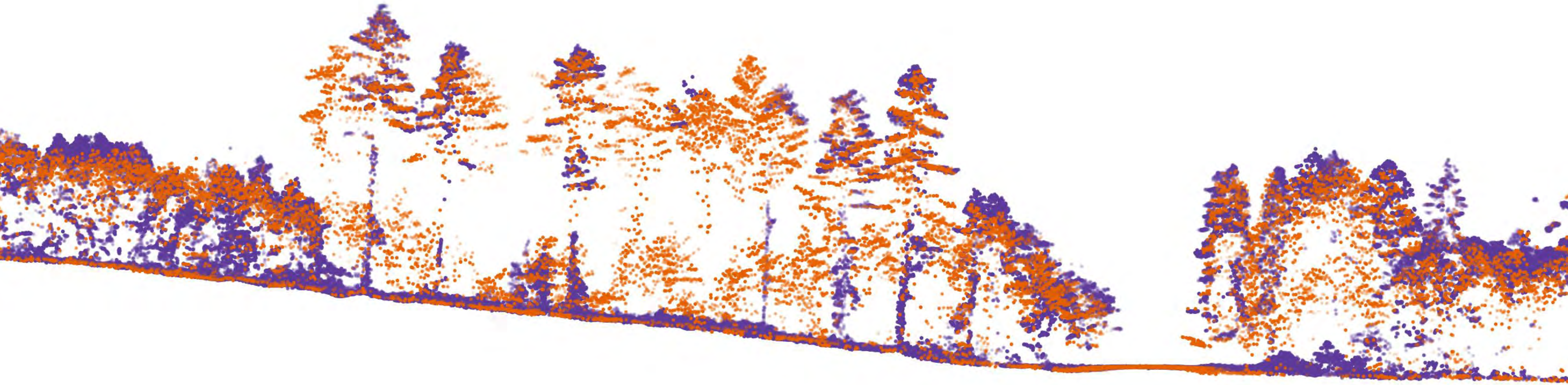




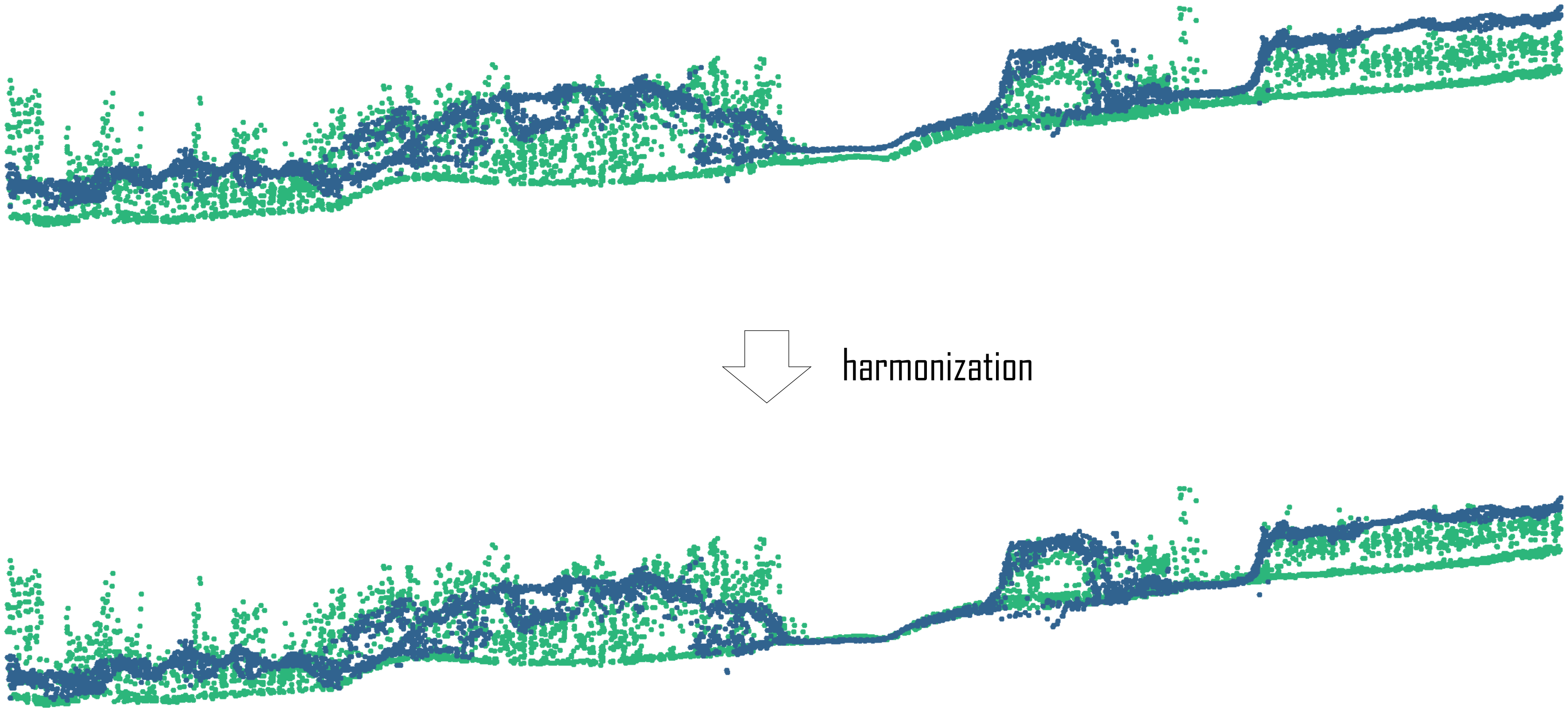
White, J. C., Tompalski, P., Vastaranta, M., Wulder, M. A., Saarinen, S., Stepper, C., & Coops, N. C. (2017). A model development and application guide for generating an enhanced forest inventory using airborne laser scanning data and an area-based approach. CWFC Information Report FI-X-018, Canadian Forest Service, Pacific Forestry Centre: Victoria, BC, Canada. 38 pp. https://doi.org/10.5558/tfc2013-132

EFI – status

- Some jurisdictions (e.g. NB, QC) – operational and primary
- Other – on the path to operational
- Some (e.g. NF) - research
- Different standards, modeling approaches, attributes, formats
- In-house (e.g. QC) / outsourced (e.g. PEI)

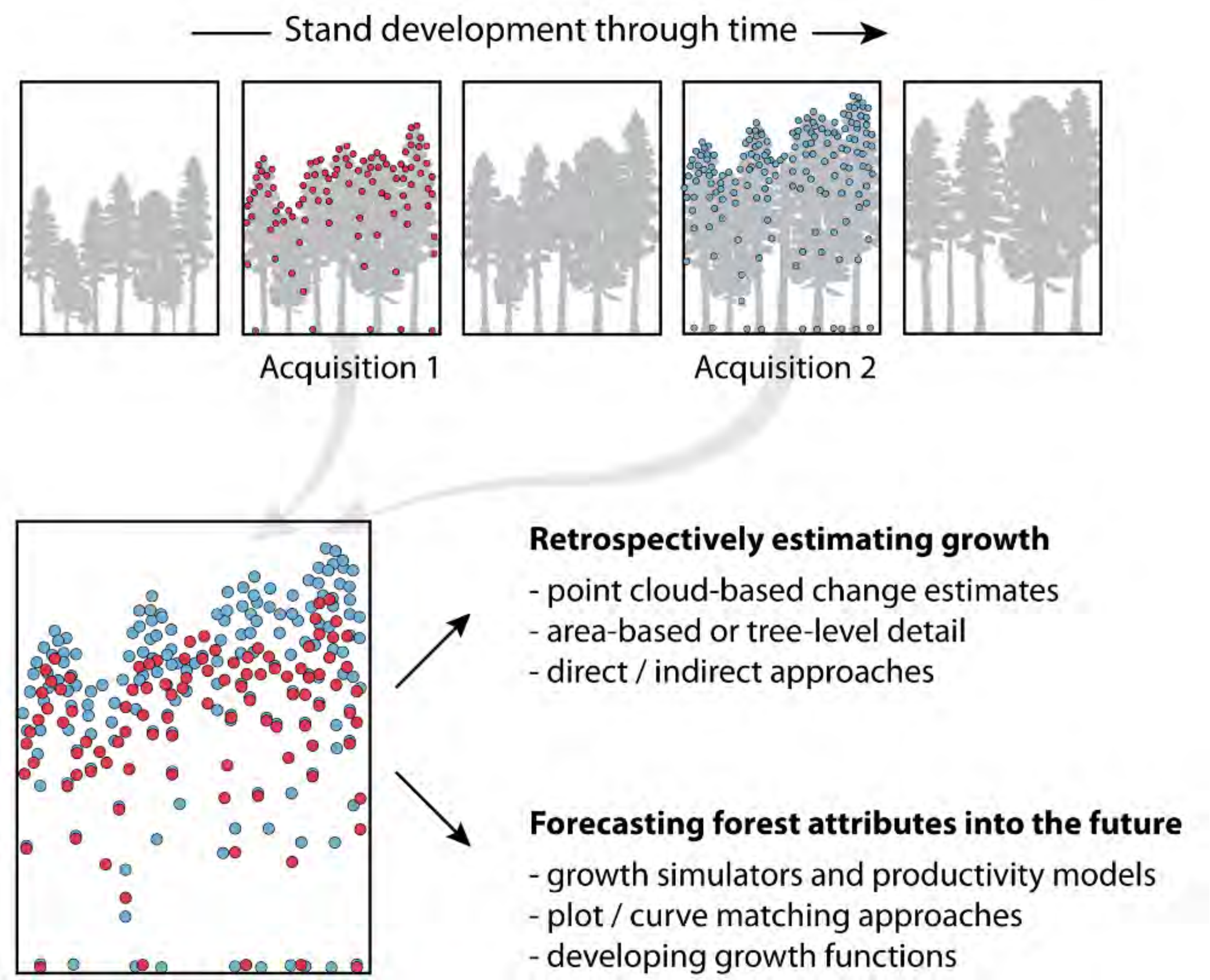


Data harmonization



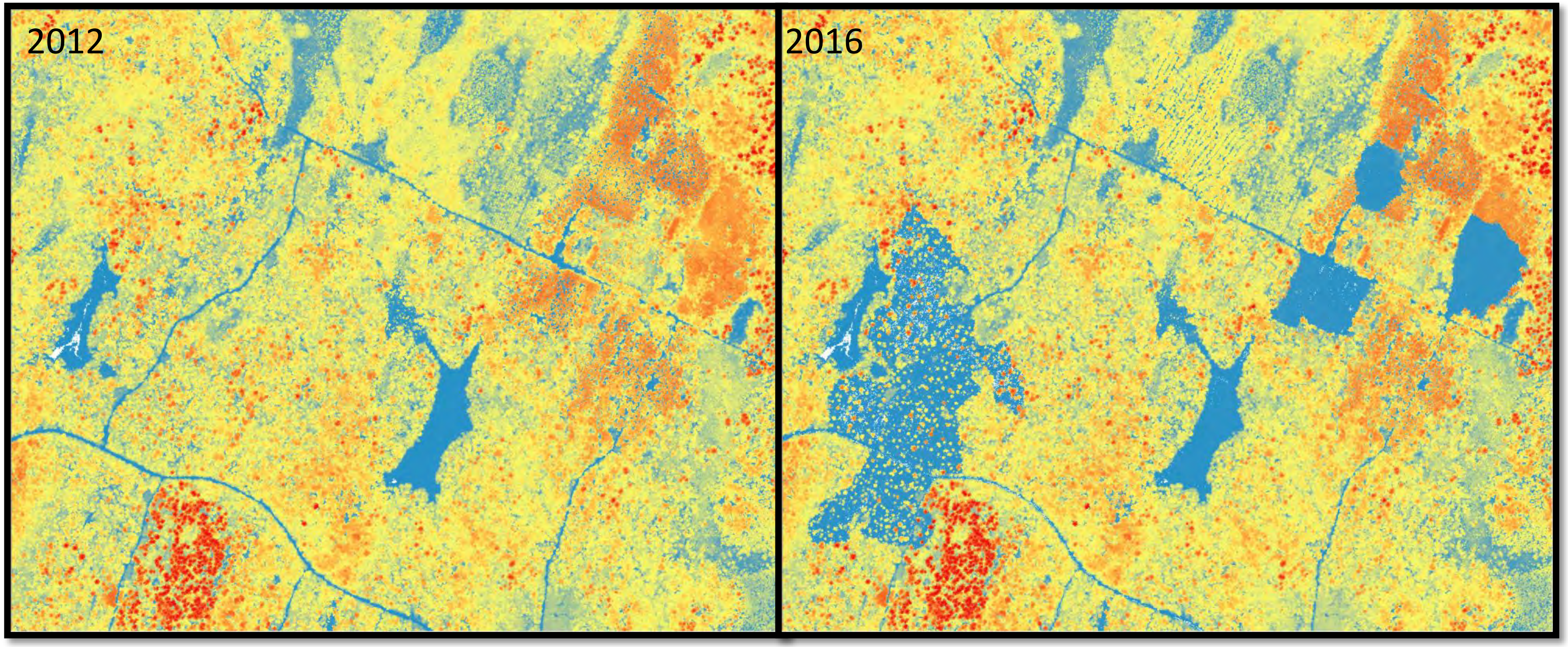
Riofrío, José, Joanne C. White, Piotr Tompalski, Nicholas C. Coops, and Michael A. Wulder. "Harmonizing Multi-Temporal Airborne Laser Scanning Point Clouds to Derive Periodic Annual Height Increments in Temperate Mixedwood Forests." Canadian Journal of Forest Research 19 (September 6, 2022): 1–19. https://doi.org/10.1139/cjfr-2022-0055.

Multi-temporal ALS

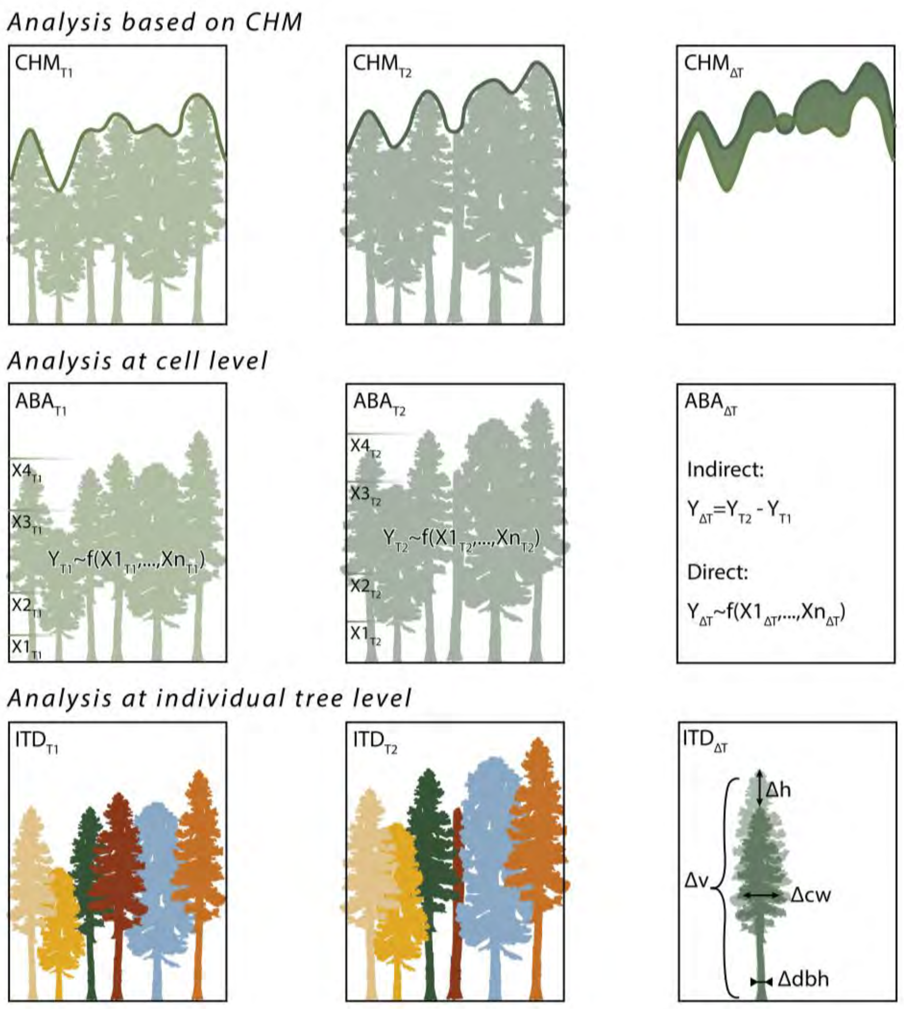


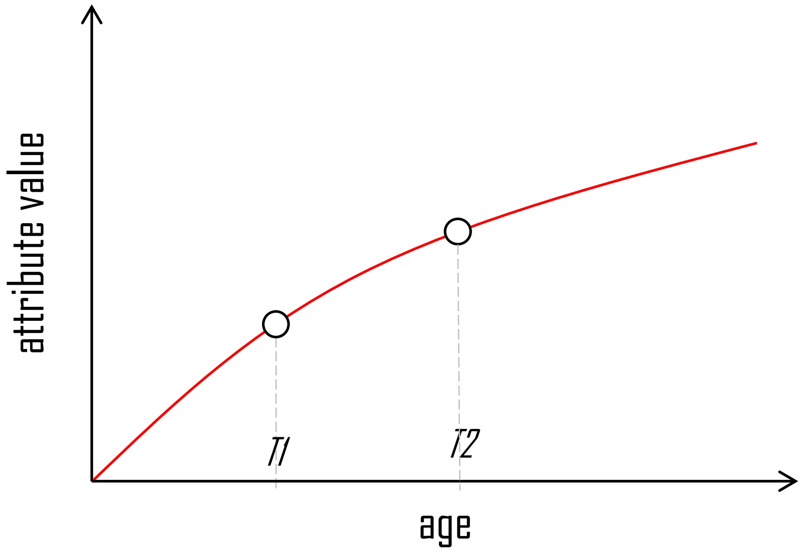
Tompalski, Piotr, Nicholas C. Coops, Joanne C. White, Tristan R.H. Goodbody, Chris R. Hennigar, Michael A. Wulder, Jarosław Socha, and Murray E. Woods. "Estimating Changes in Forest Attributes and Enhancing Growth Projections: A Review of Existing Approaches and Future Directions Using Airborne 3D Point Cloud Data." Current Forestry Reports, February 19, 2021. https://doi.org/10.1007/s40725-021-00135-w.

Multi-temporal ALS



Multi-temporal ALS





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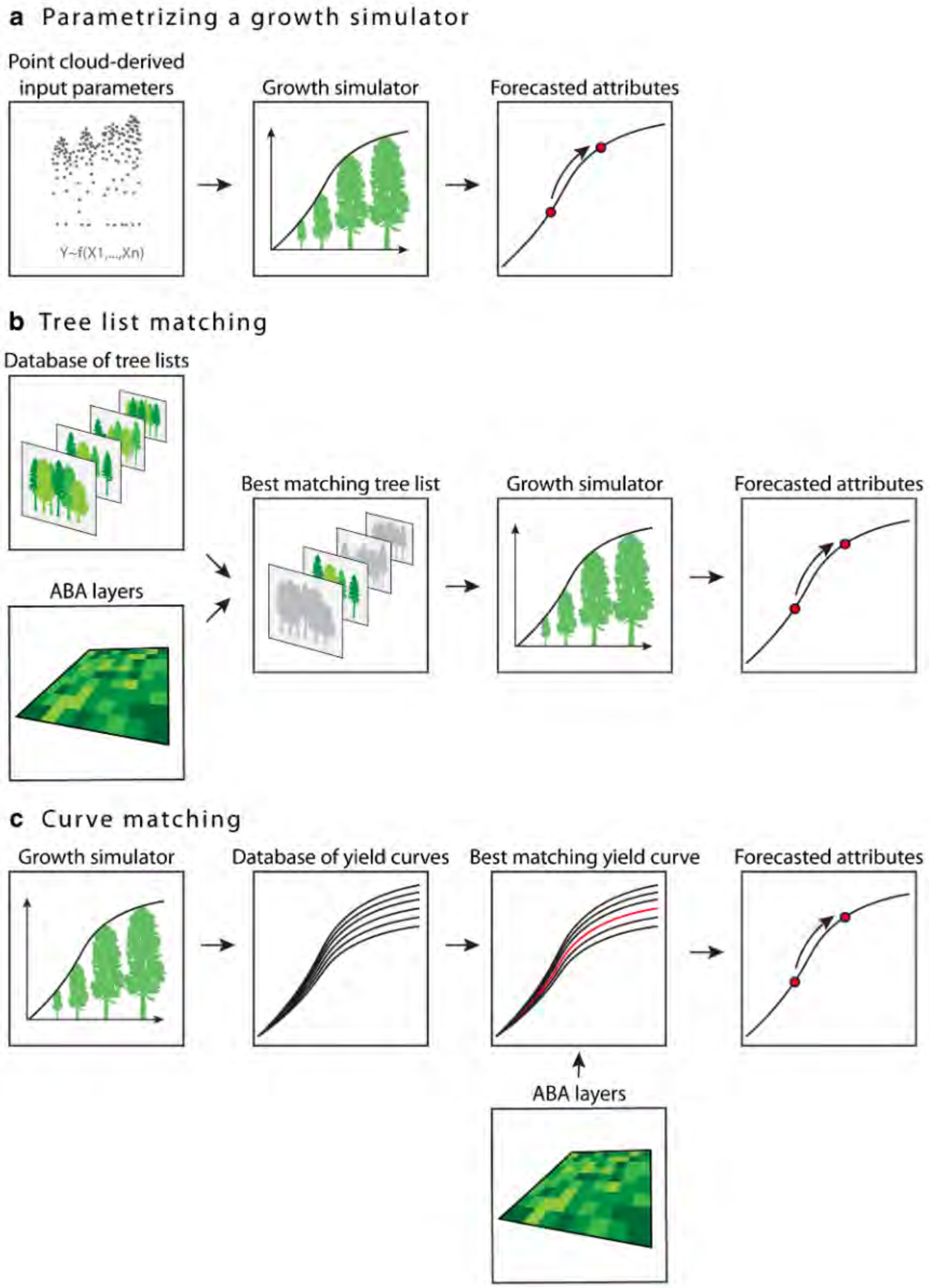

Approaches to integrate growth simulators with point cloud data

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Lamb, Sean M., David A. MacLean, Chris R. Hennigar, and Douglas G. Pitt. "Forecasting Forest Inventory Using Imputed Tree Lists for LiDAR Grid Cells and a Tree-List Growth Model." *Forests* 9, no. 4 (2018): 1–18. https://doi.org/10.3390/f9040167.

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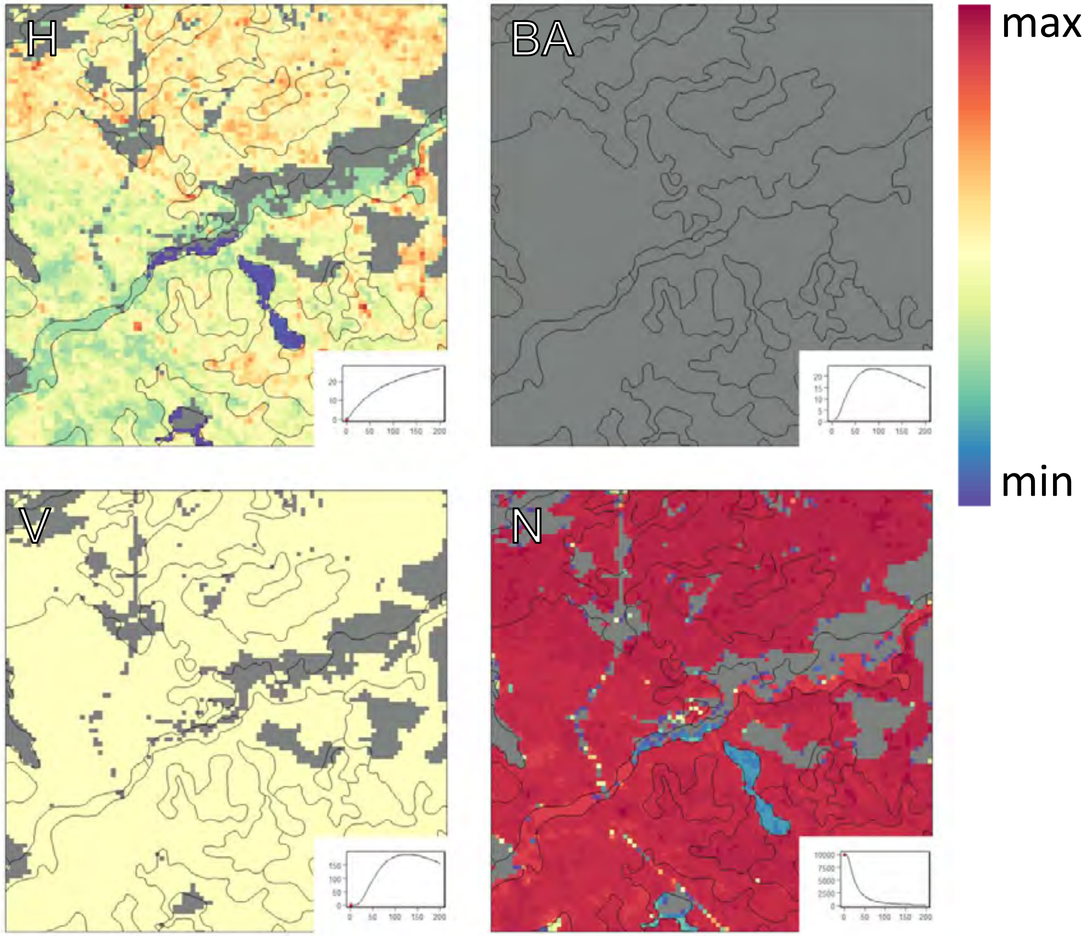
Yield curves matched at pixel-level



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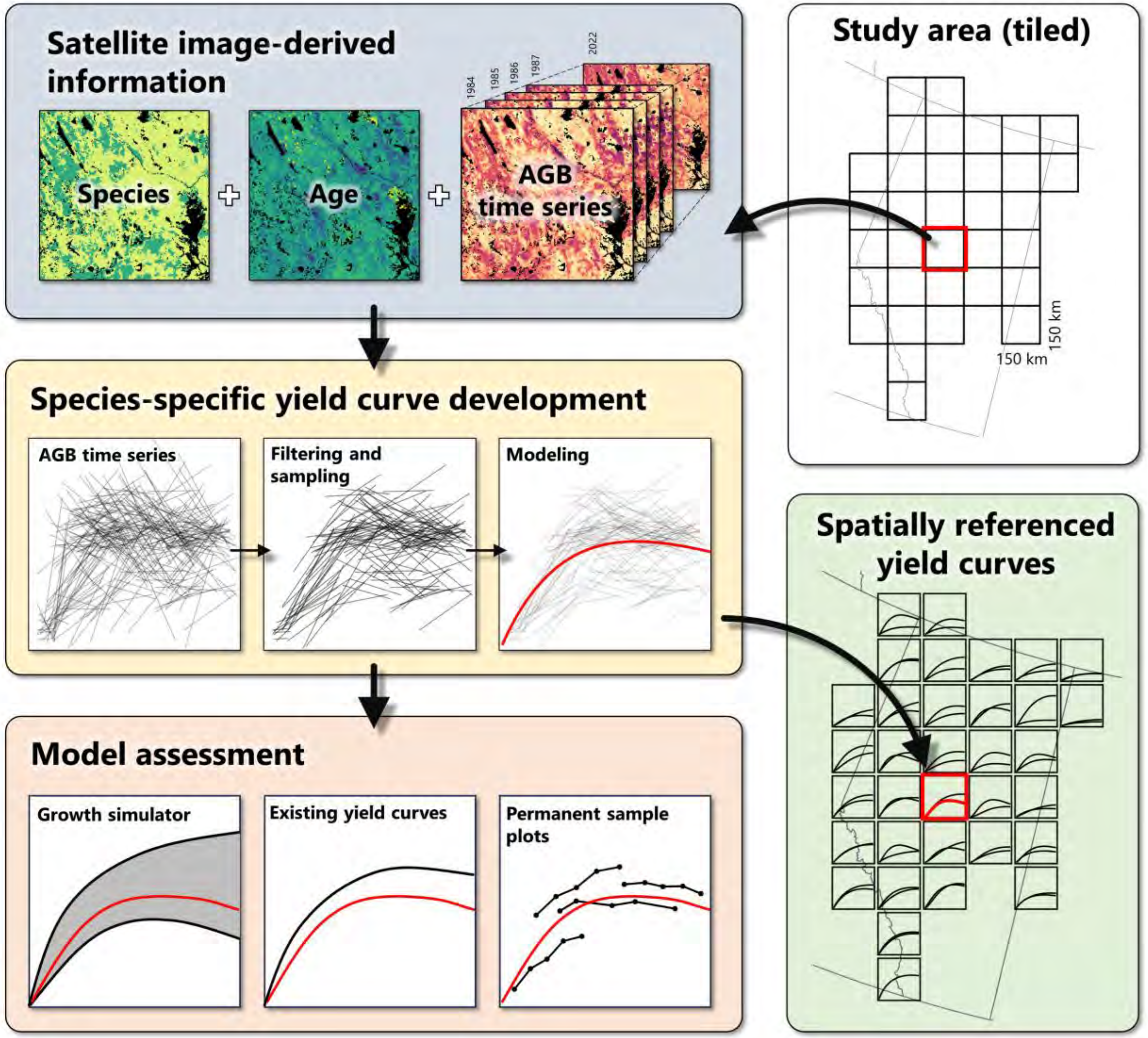
RS-driven growth and yield models



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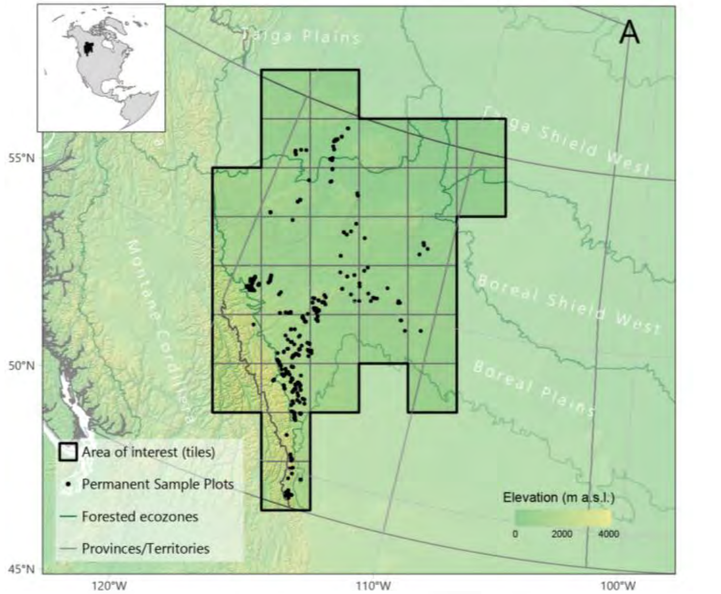

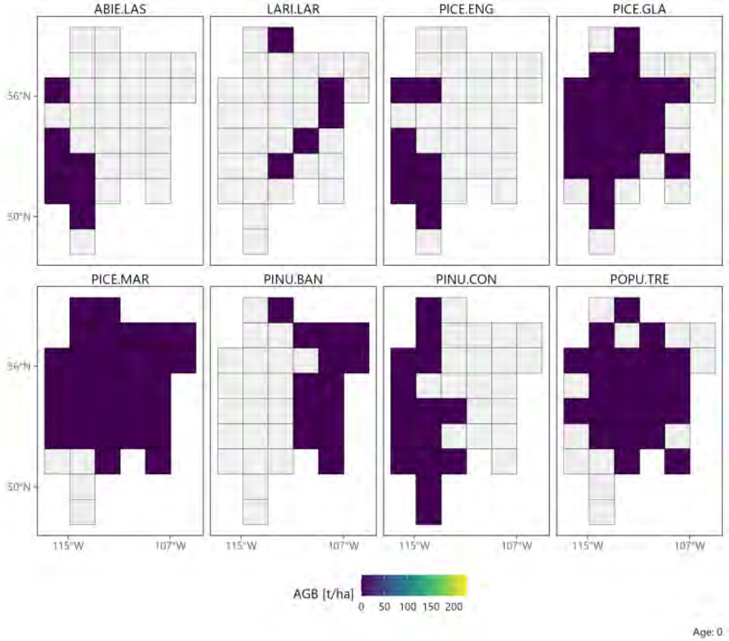

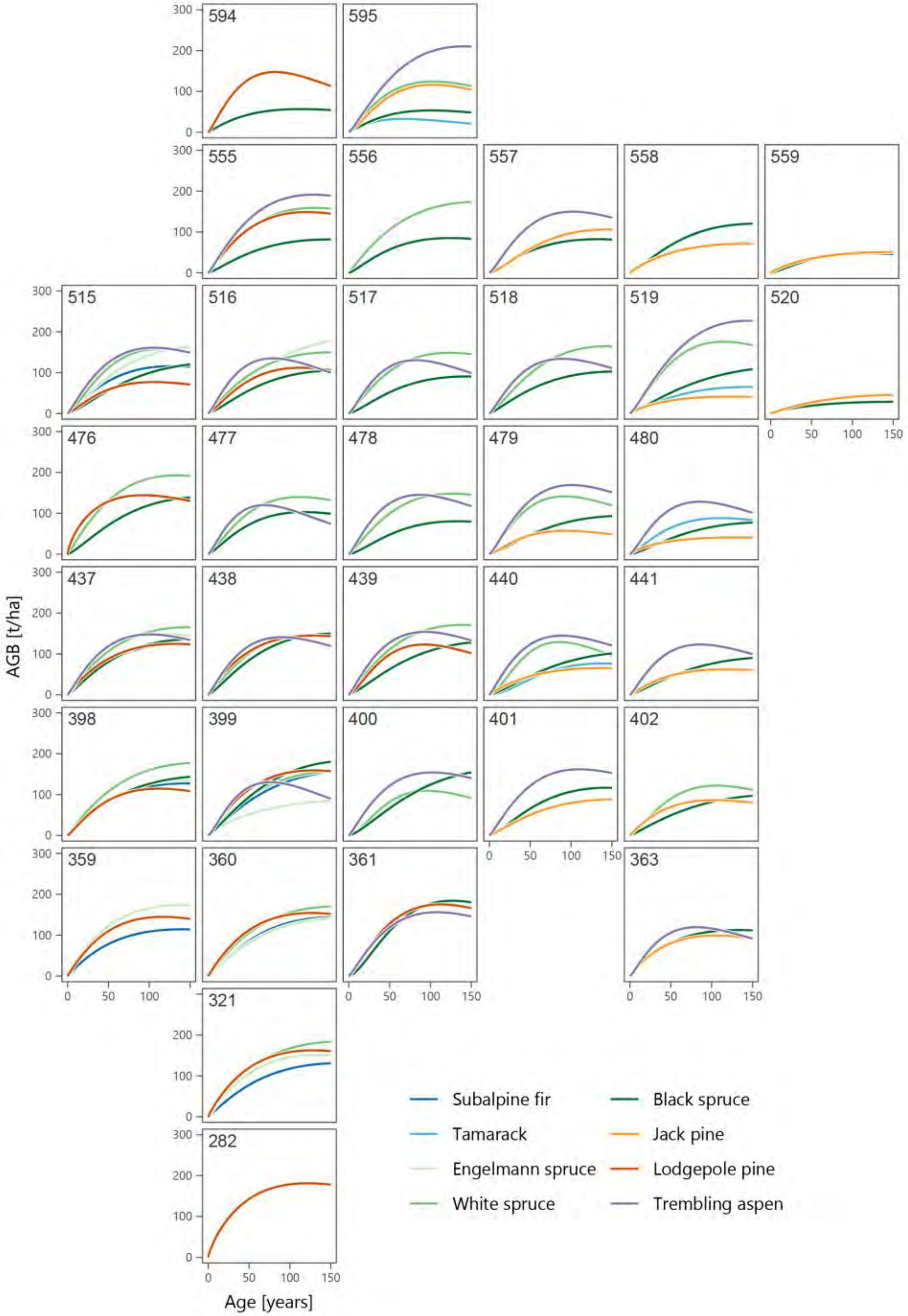

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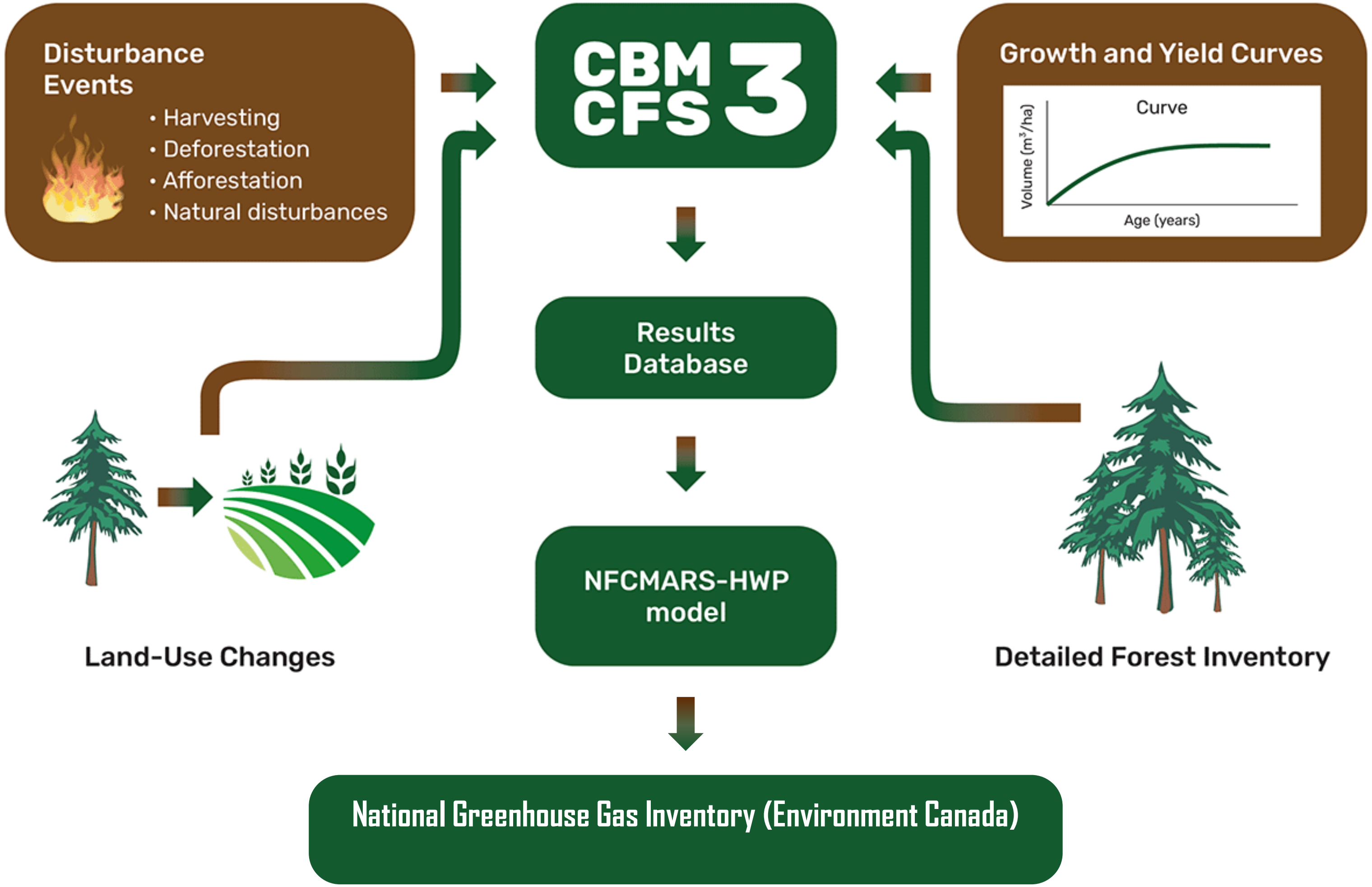
NFCMARS
National Forest Carbon Monitoring, Accounting and Reporting System



https://natural-resources.canada.ca/climate-change/climate-change-impacts-forests/carbon-accounting/13087