Exploration and quantification of ecosystem thermodynamics and thermal buffering service of ecosystems

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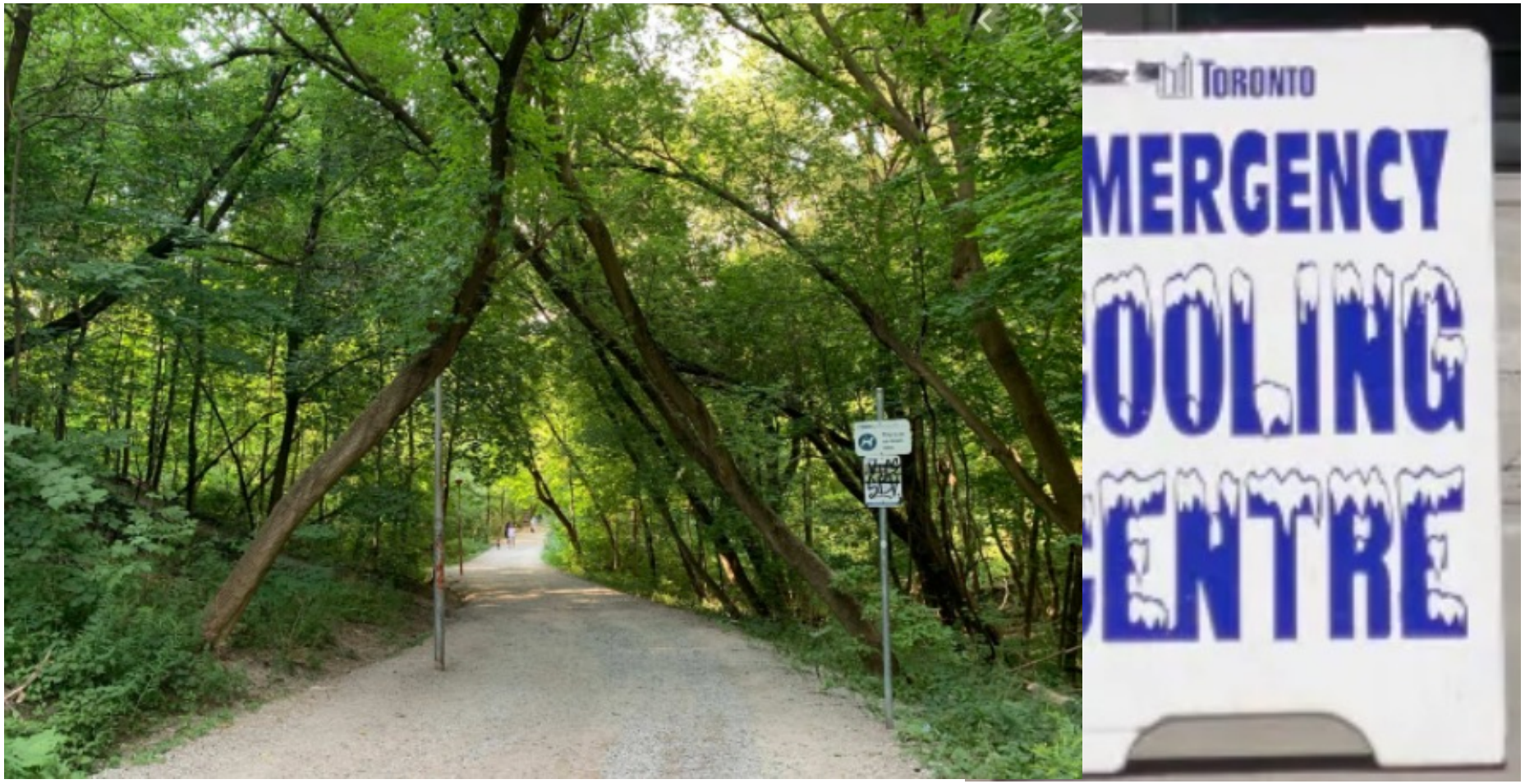
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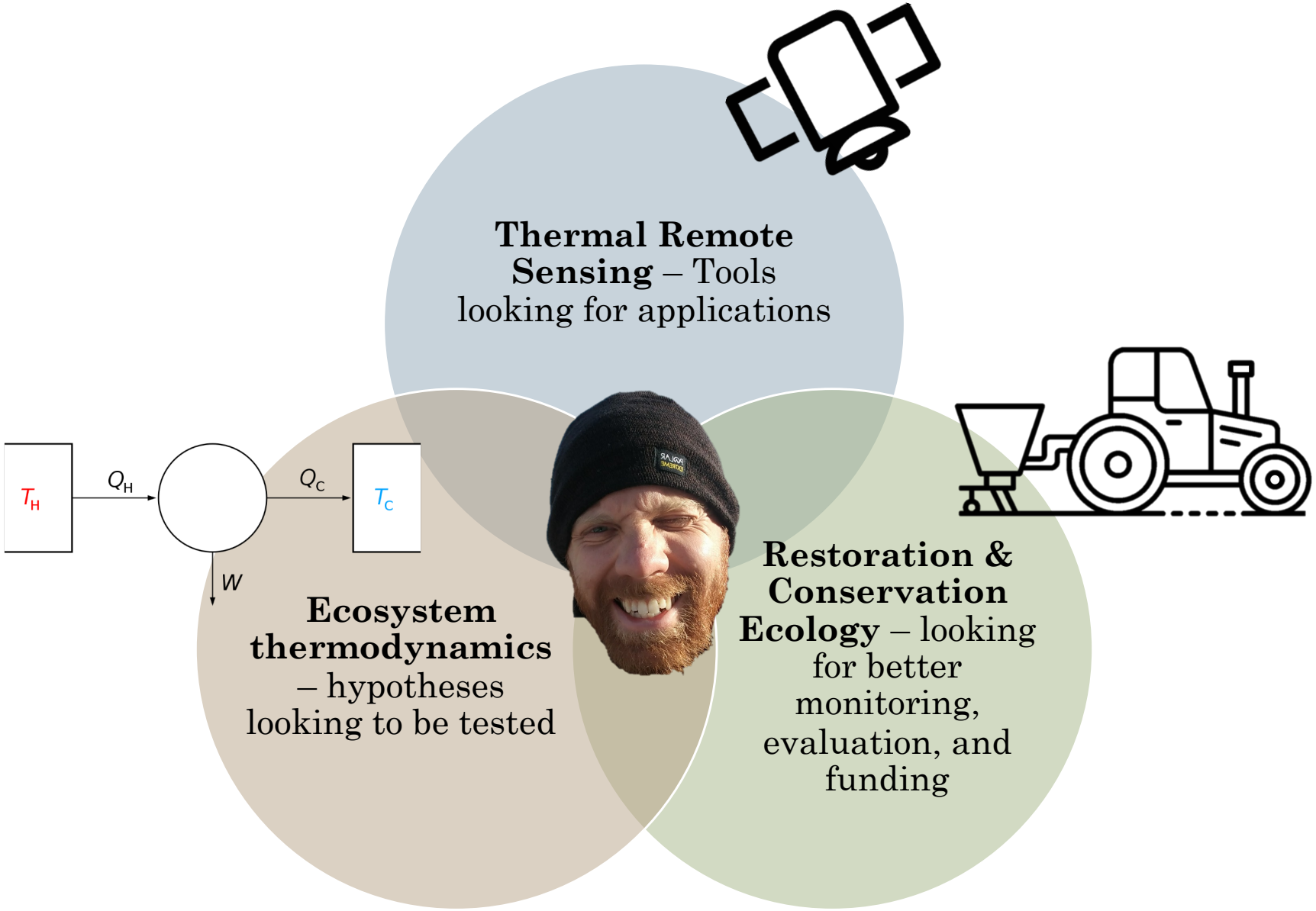
Thermal Remote Sensing – Tools looking for applications
T_H
Q_H
Q_C
T_C
W
Ecosystem thermodynamics – hypotheses looking to be tested
Restoration & Conservation Ecology – looking for better monitoring, evaluation, and funding

As ecosystems develop or mature, they should increase their total dissipation, and should develop more complex structures with greater diversity [...] If a group of ecosystems are bathed by the same amount of incoming energy [...] the most mature ecosystem would [...] have the coldest black body temperature. - *Schneider and Kay, 1994*

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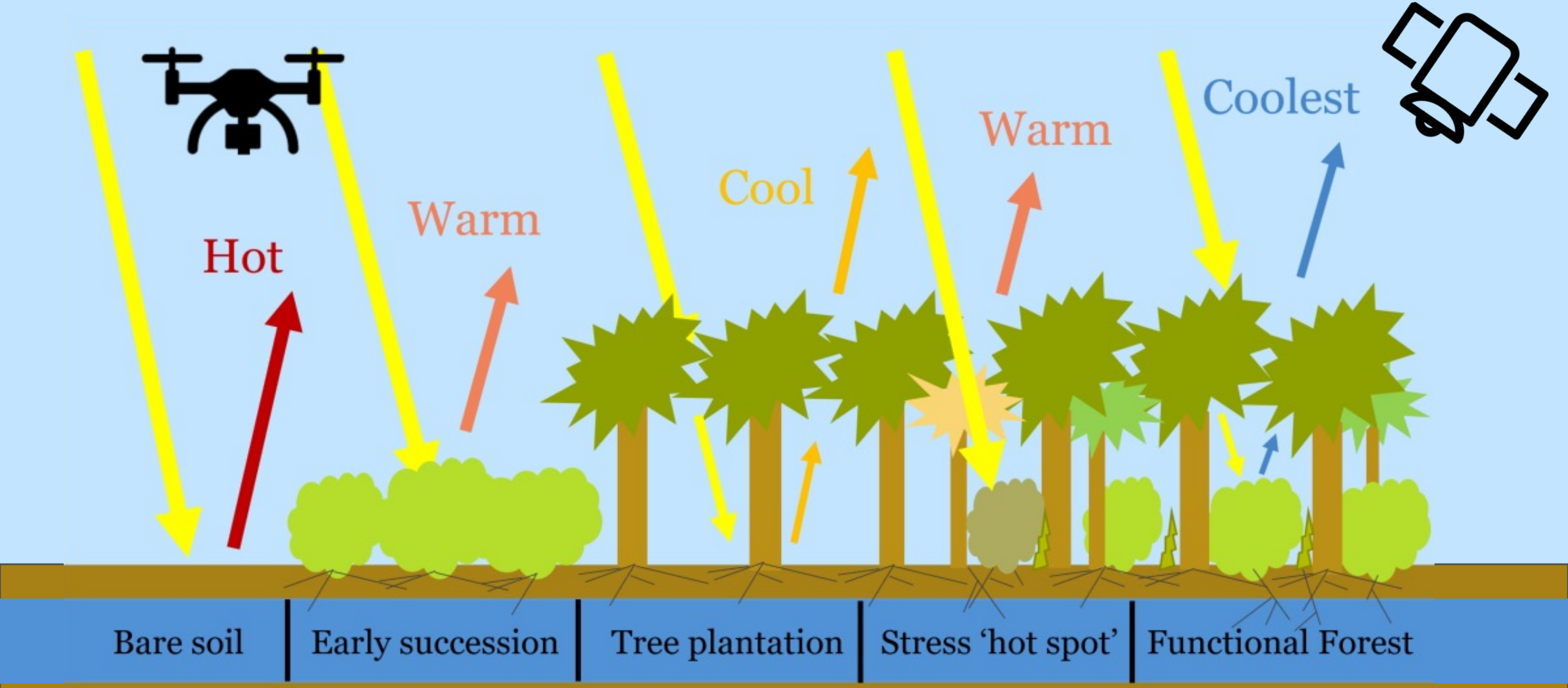
As plants use energy, less is re-emitted as sensible heat



Energy use: Transpiration, photosynthesis, respiration, physical heat capacity

Why ECOSTRESS is important for restoration and conservation

1. **Ecosystem services of thermal buffering**

2. **Monitoring for adaptive management**

Restoration & conservation monitoring

- Restoration and conservation needs decades of monitoring, for scattered and hard to access areas
- Current on ground measures are slow and expensive
- Current remote sensing can not accurately tell how diverse, complex or stressed an ecosystem is

Study 1: Biodiversity and temperature in an agriculture to oak-woodland restoration using Landsat and ECOSTRESS

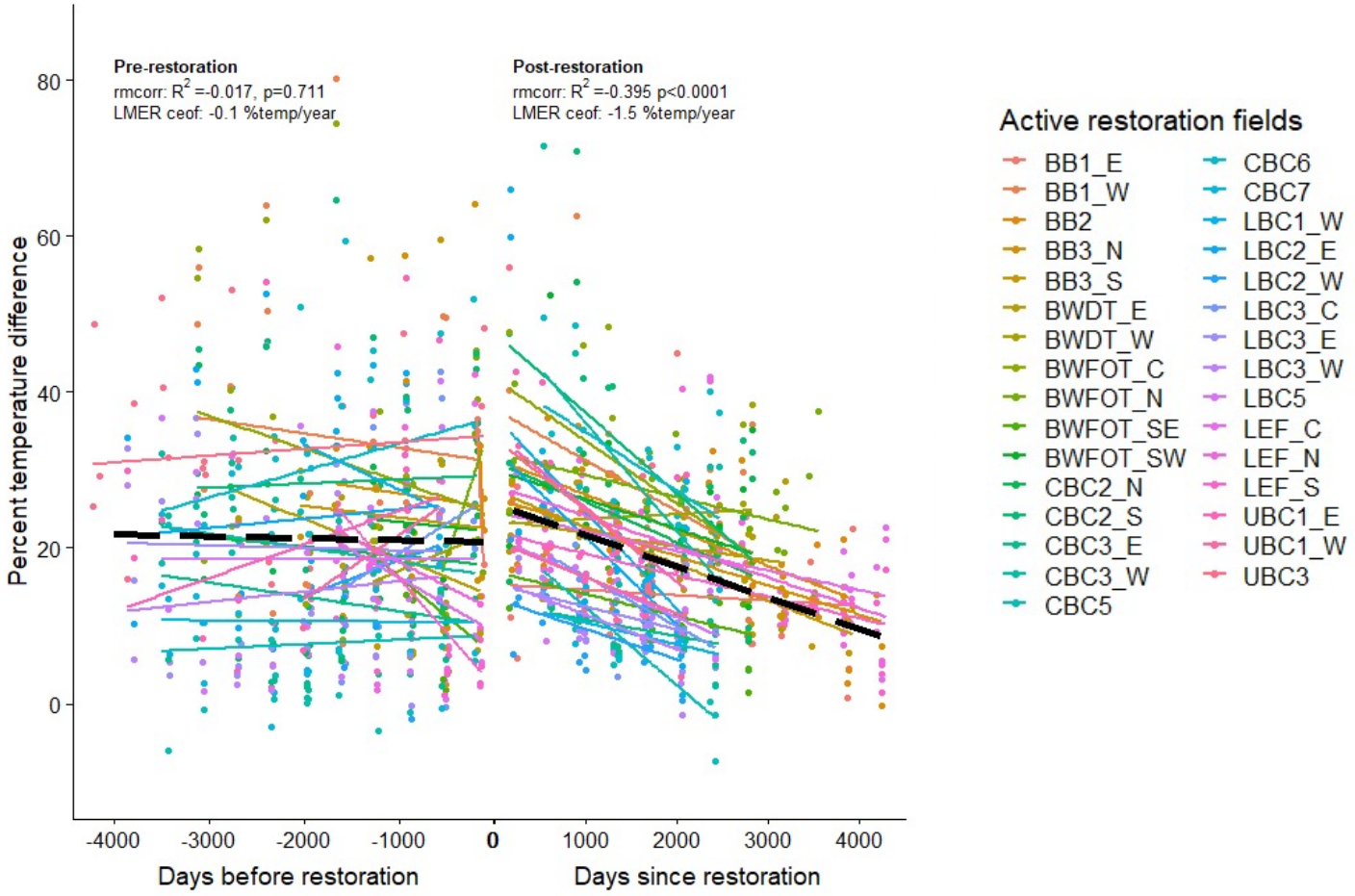
Photo-credit: Mary Gartshore

Study project and sites

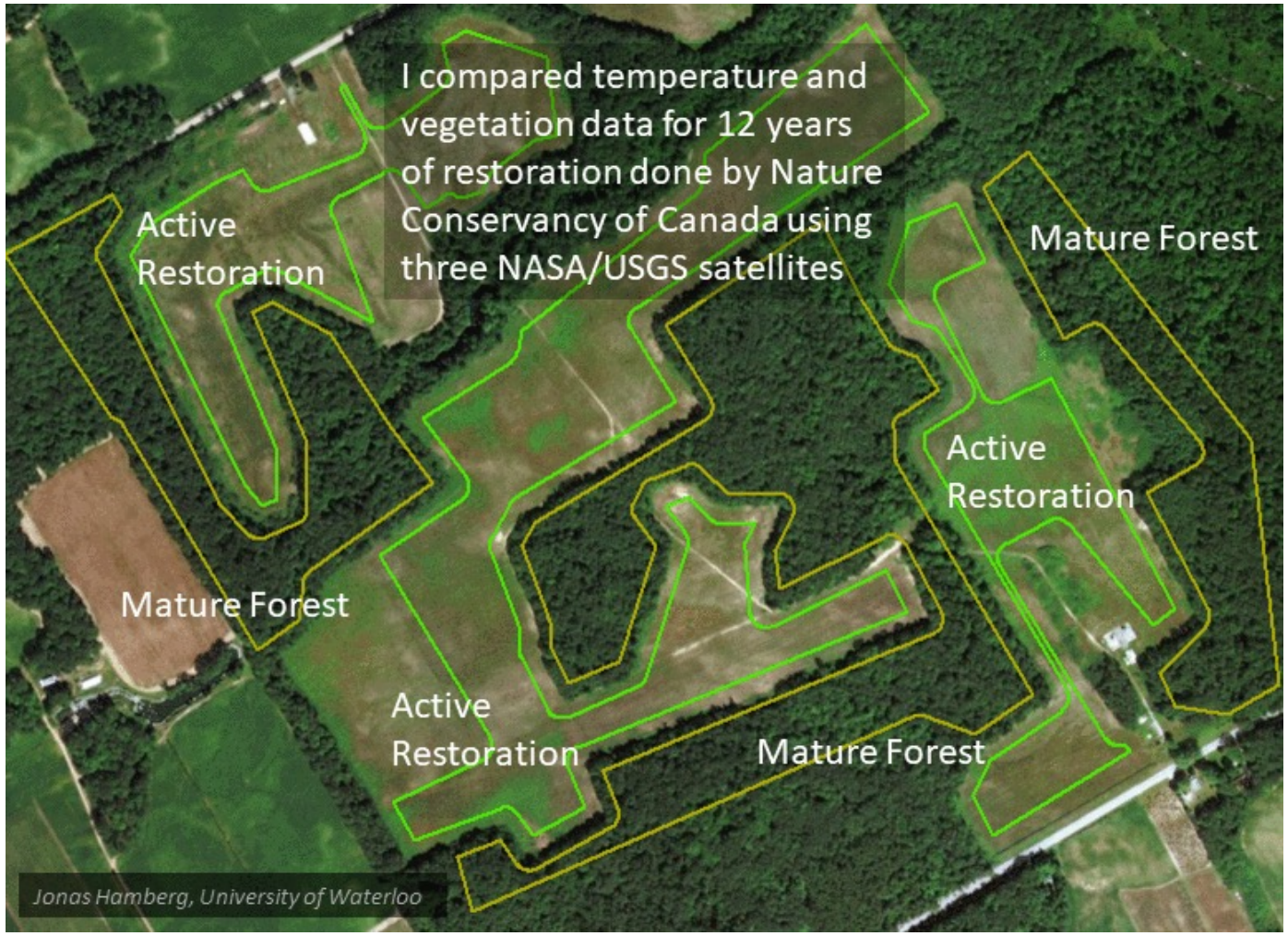
May 2006

July 2018

Google maps base layer

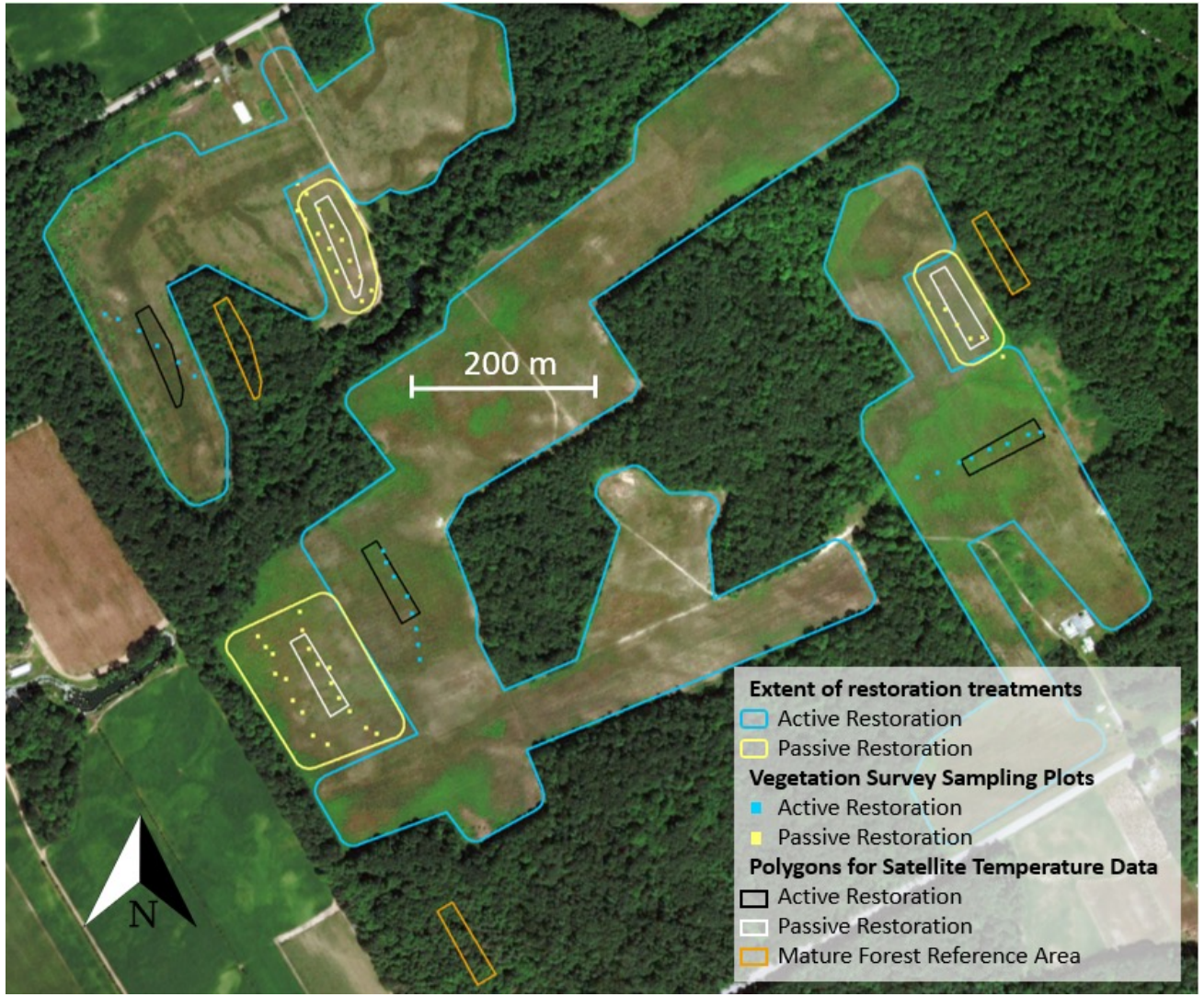


Mean temperature decrease -1.5 p.p. per year.
Equals approximately -4.5 °C in 12 years on a summer day



Google maps base layer

Comparing temperature to biodiversity and biomass



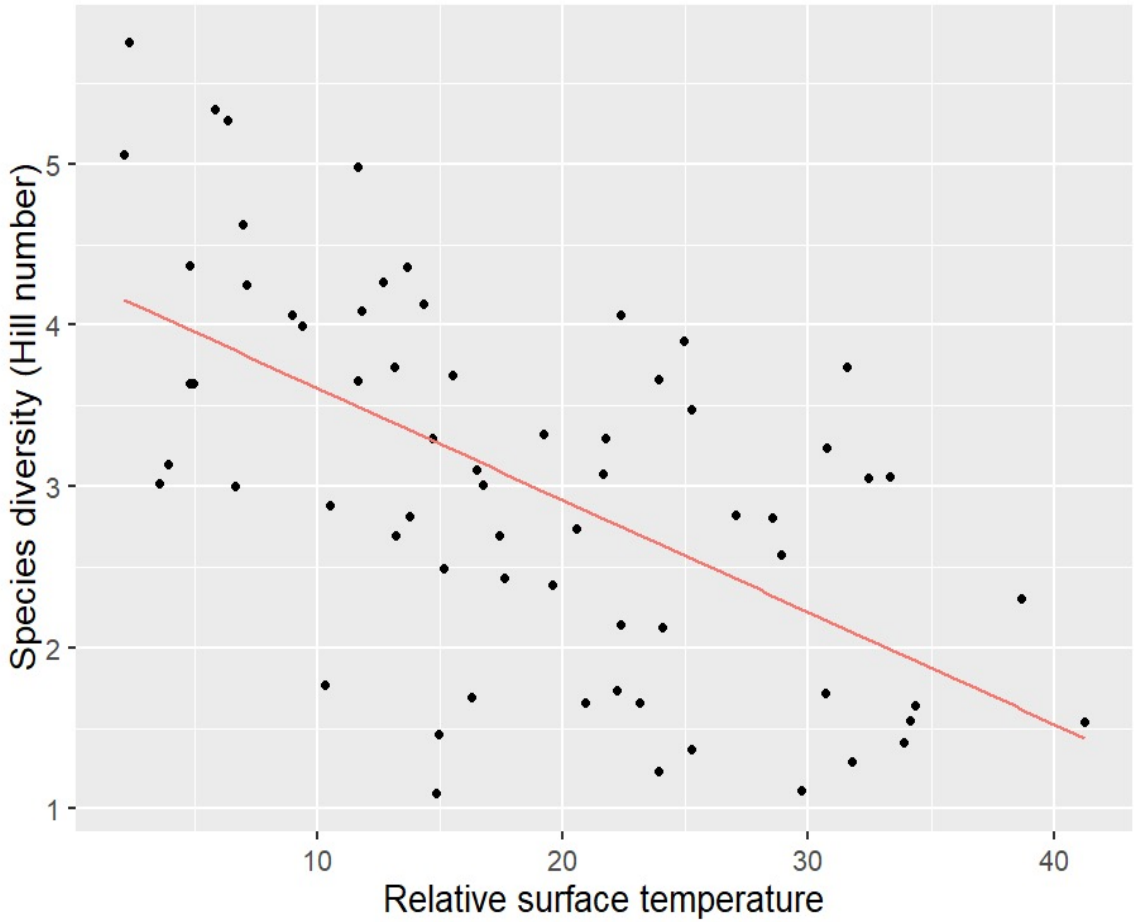
Google maps base layer

59 2x2m plots
In three fields
surveyed for all plants
by professionals 2007-2017

Three areas (yellow) were unseeded controls

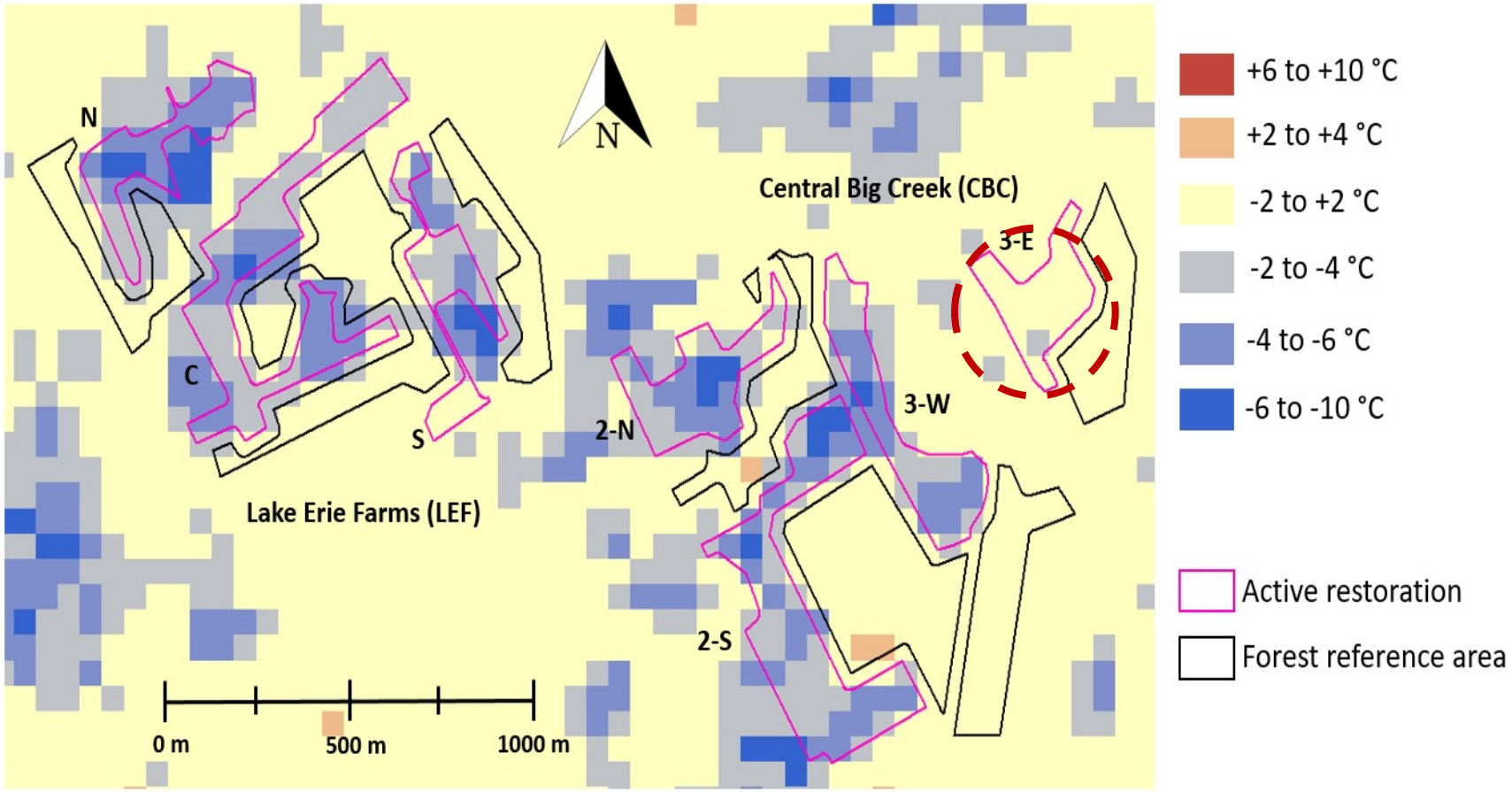
3 paired areas were compared

When controlling for biomass, total plant cover and canopy cover – Each new species decreases temperature by about 0.5 °C



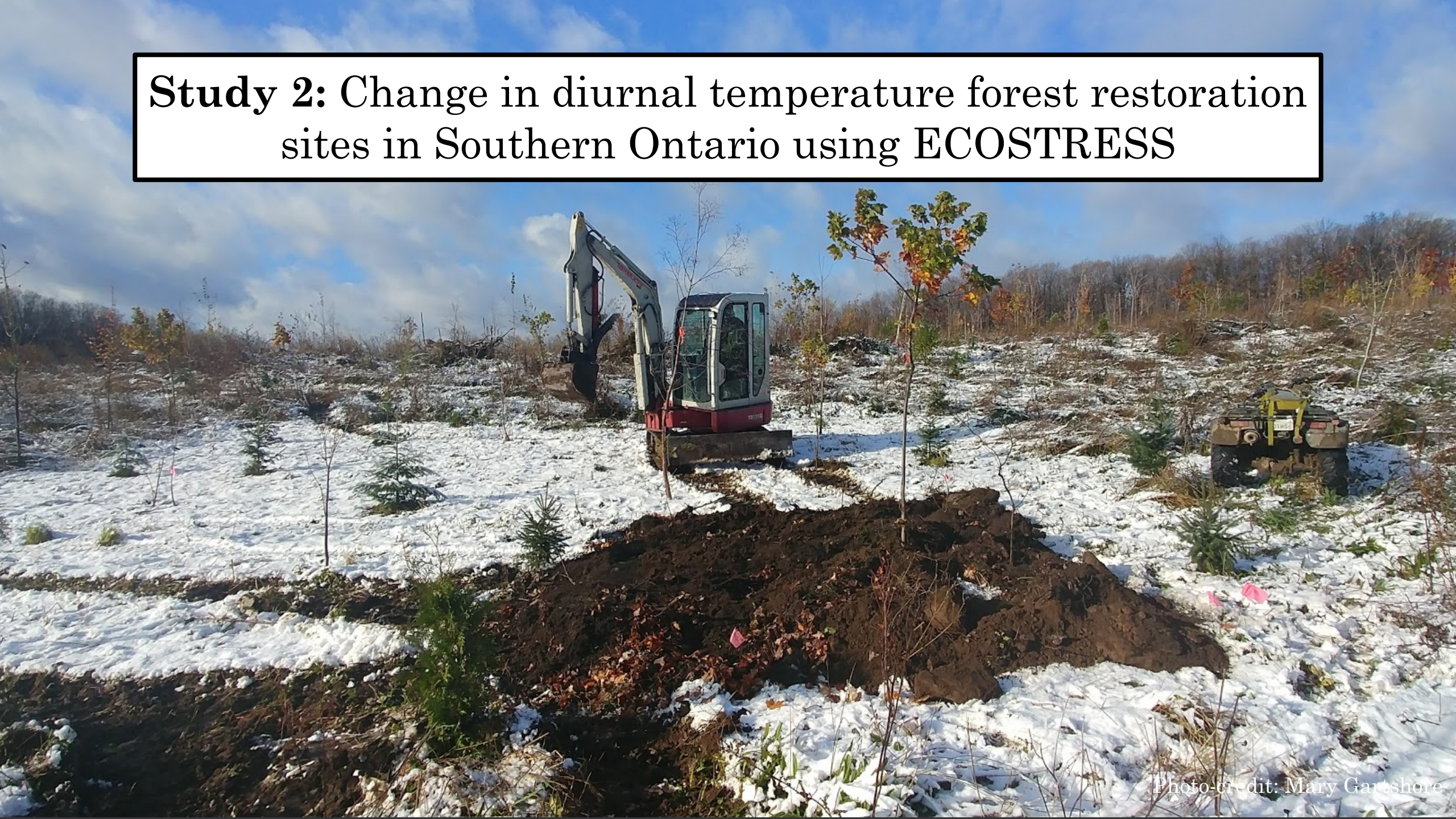
Thermal monitoring and evaluation through mapping

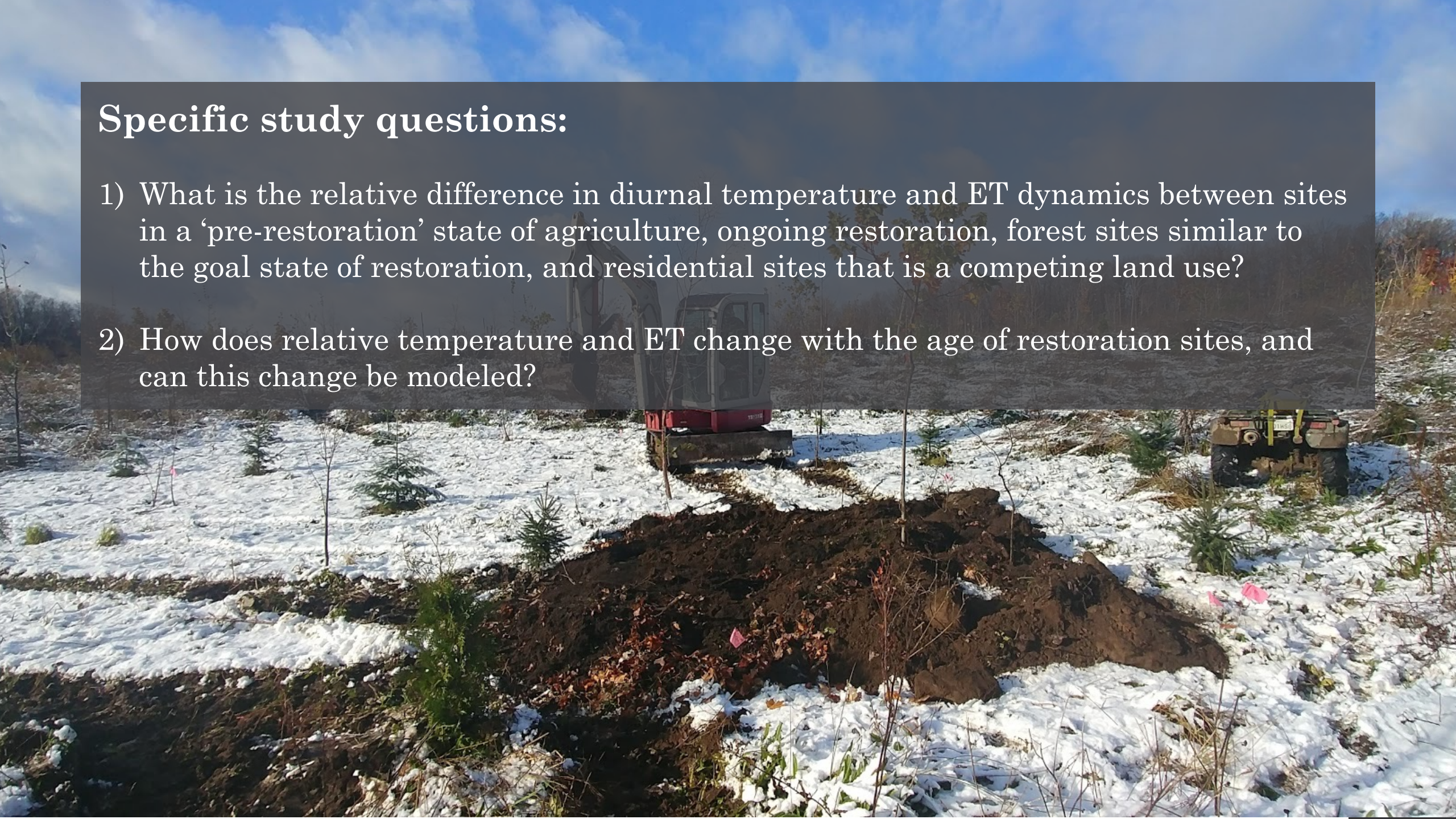
Mapping surface temperature change over time



Summer day-time temperature change 2014-2018

Study 2: Change in diurnal temperature forest restoration sites in Southern Ontario using ECOSTRESS





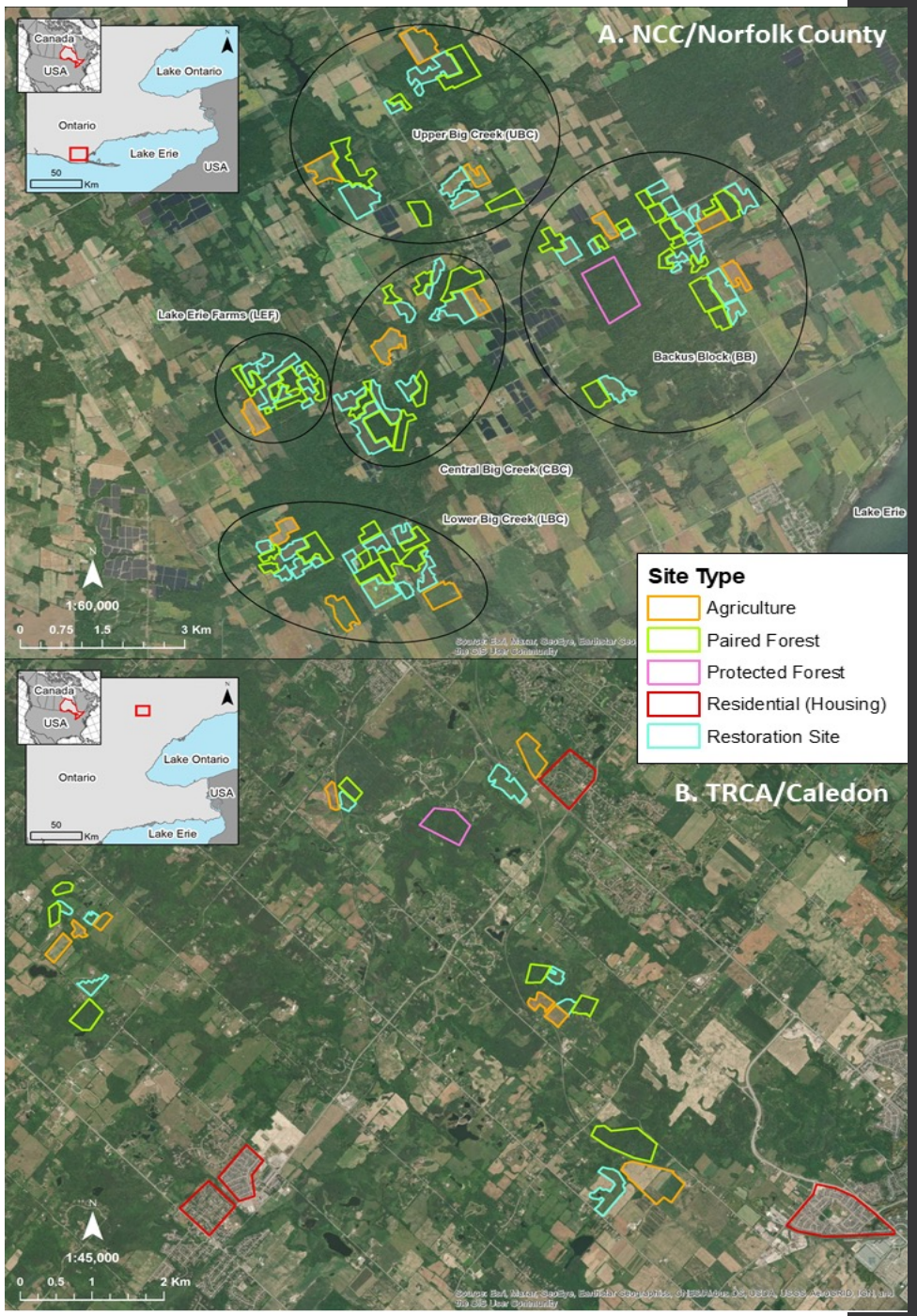
Specific study questions:

1) What is the relative difference in diurnal temperature and ET dynamics between sites in a ‘pre-restoration’ state of agriculture, ongoing restoration, forest sites similar to the goal state of restoration, and residential sites that is a competing land use?

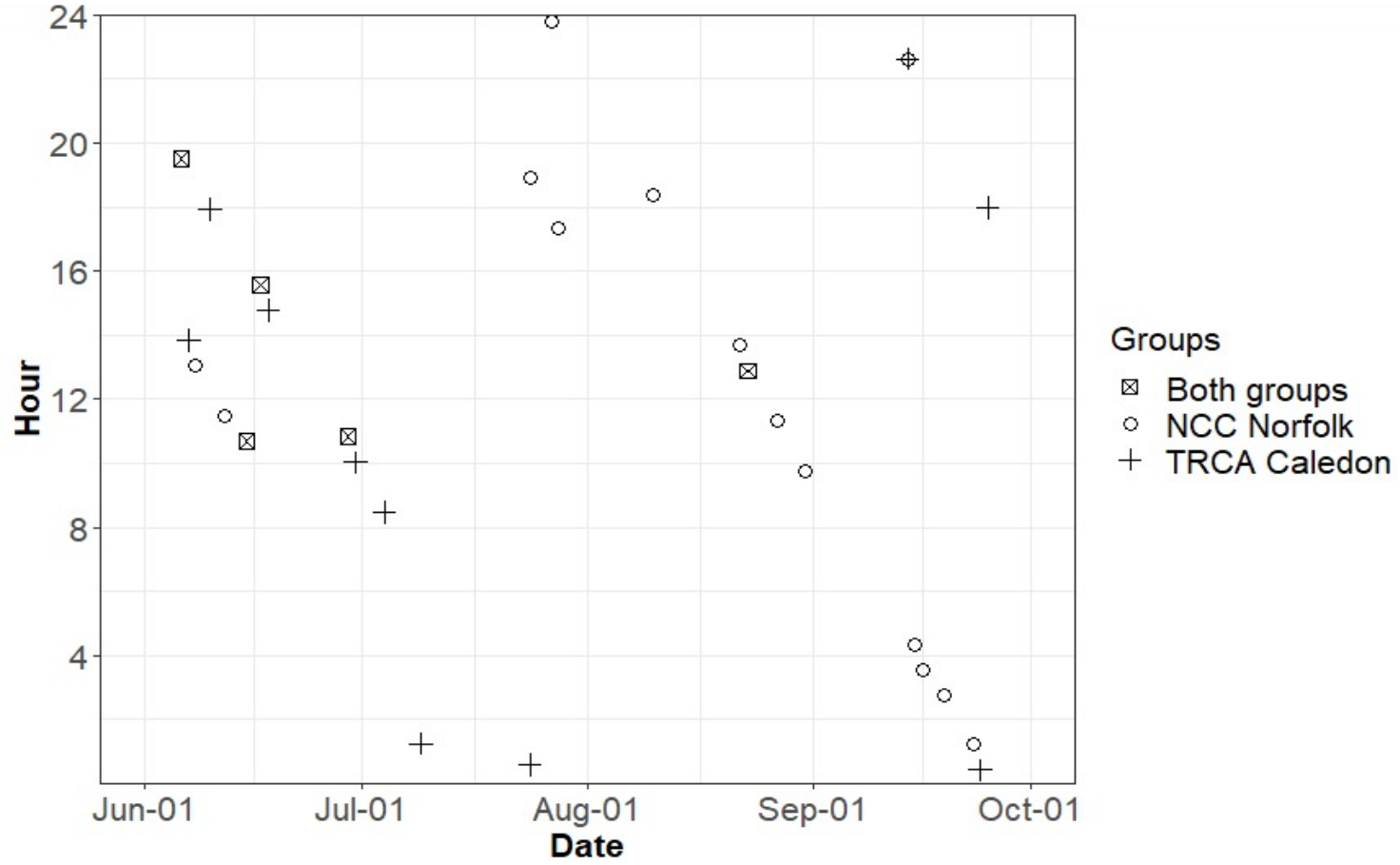
2) How does relative temperature and ET change with the age of restoration sites, and can this change be modeled?

Methods

- Southern Ontario, Canada
- Two groups of sites:
  - NCC, Norfolk County
  - TRCA, Peel Region, Greater Toronto Area
- Initial restoration between 2007 and 2019
- Site size 2 – 31 ha
- Four site types:
  - Pre-restoration: Agriculture (24 sites total)
  - Reforestation (43 sites total)
  - Post-restoration: Mature forest (43 sites total)
  - Sub/Ex-urban residential (4 sites total)
- LST and ET relative to mature forest areas

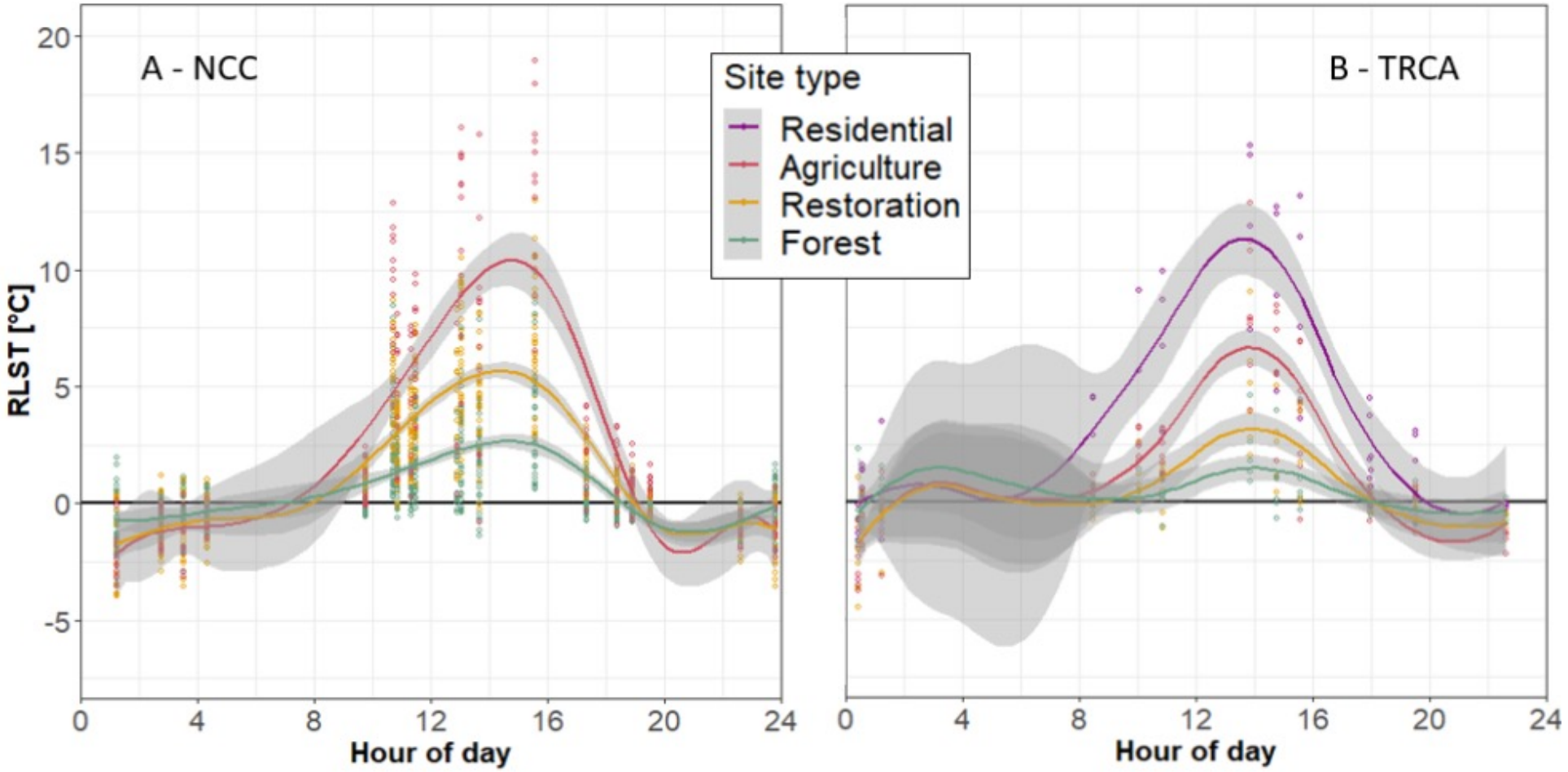


Date and hour of ECOSTRESS imagery/products used

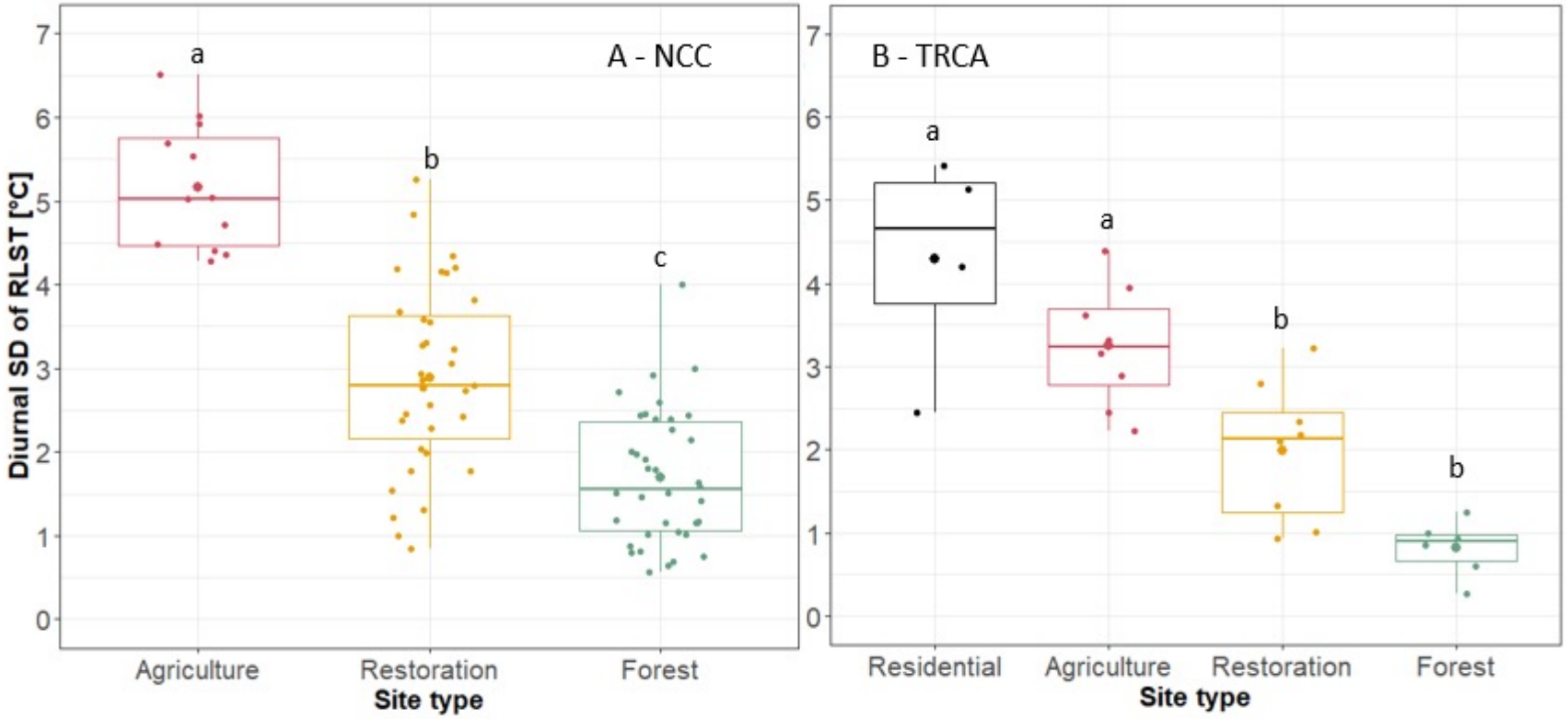


- June – September 2020
- NCC: 19 images (9 for ET), TRCA: 15 images

Results: Relative temperature by land cover type



Standard deviation of relative temperature by land cover type (thermal buffering)



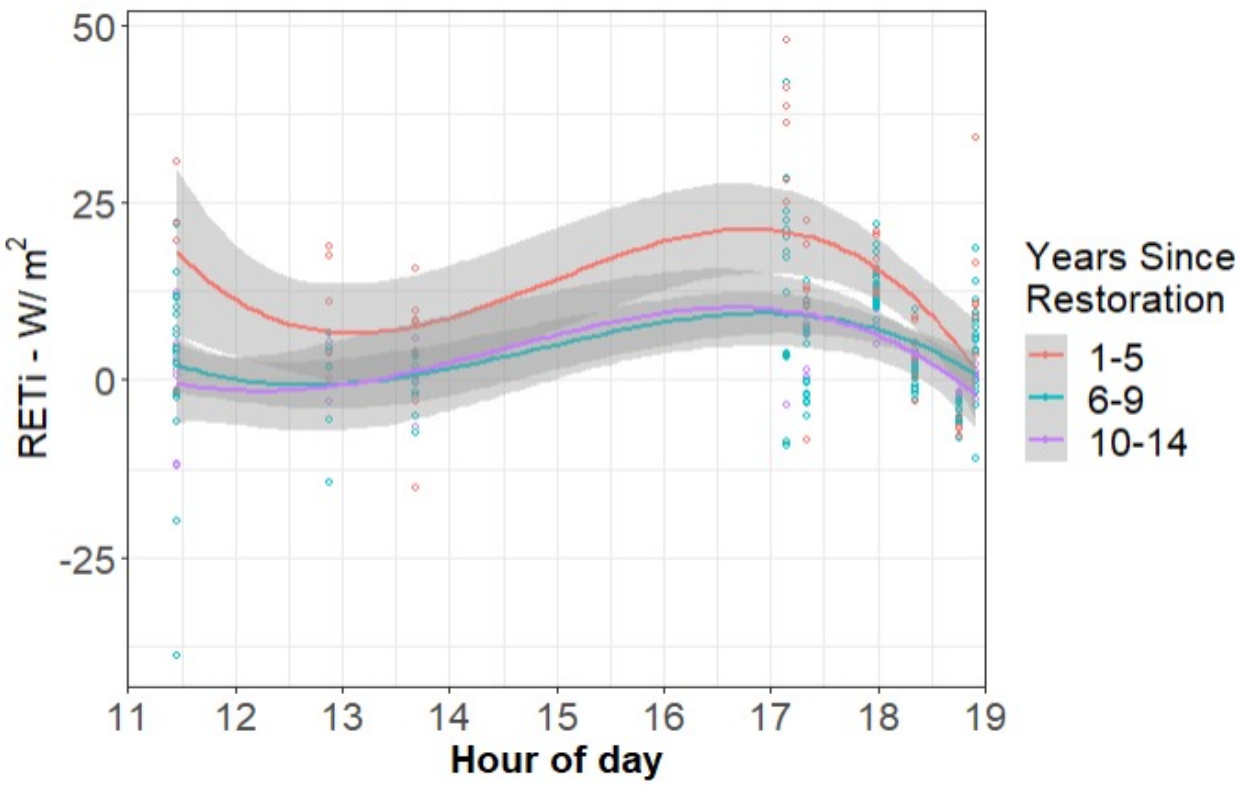
Mixed-effects linear regression model of relative temperature for restoration sites

	RLST (C°)			
	Coefficient	p-value	Std. error	DF. (K-R)
Years Since Restoration	-0.094	**0.038**	0.043	29.8
Restoration area size (ha)	0.067	**0.002**	0.020	30.6
Hours from 2 pm peak	-0.605	**<0.001**	0.040	30.6
Constant	3.319	**<0.001**	0.500	34.1
Observations (fields)	402 (35)			
Marginal/Conditional R^2	0.37/0.57			

0.1 °C relative decrease by year since restoration at NCC sites

~32 years to reach forest temp

Relative ET by years since restoration



	RETi – W/m²			
	Coefficient	p-value	Std. error	DF. (K-R)
Years Since Restoration	-0.784	**<0.001**	0.214	41.9
Restoration area size (ha)	0.257	**0.016**	0.103	43.2
Constant	7.682	**0.002**	2.393	42.1
Observations (fields)	241 (35)			
Marginal/Conditional R^2	0.11/0.16			

Relative instantaneous ET **decreased** by 0.8 W/m²

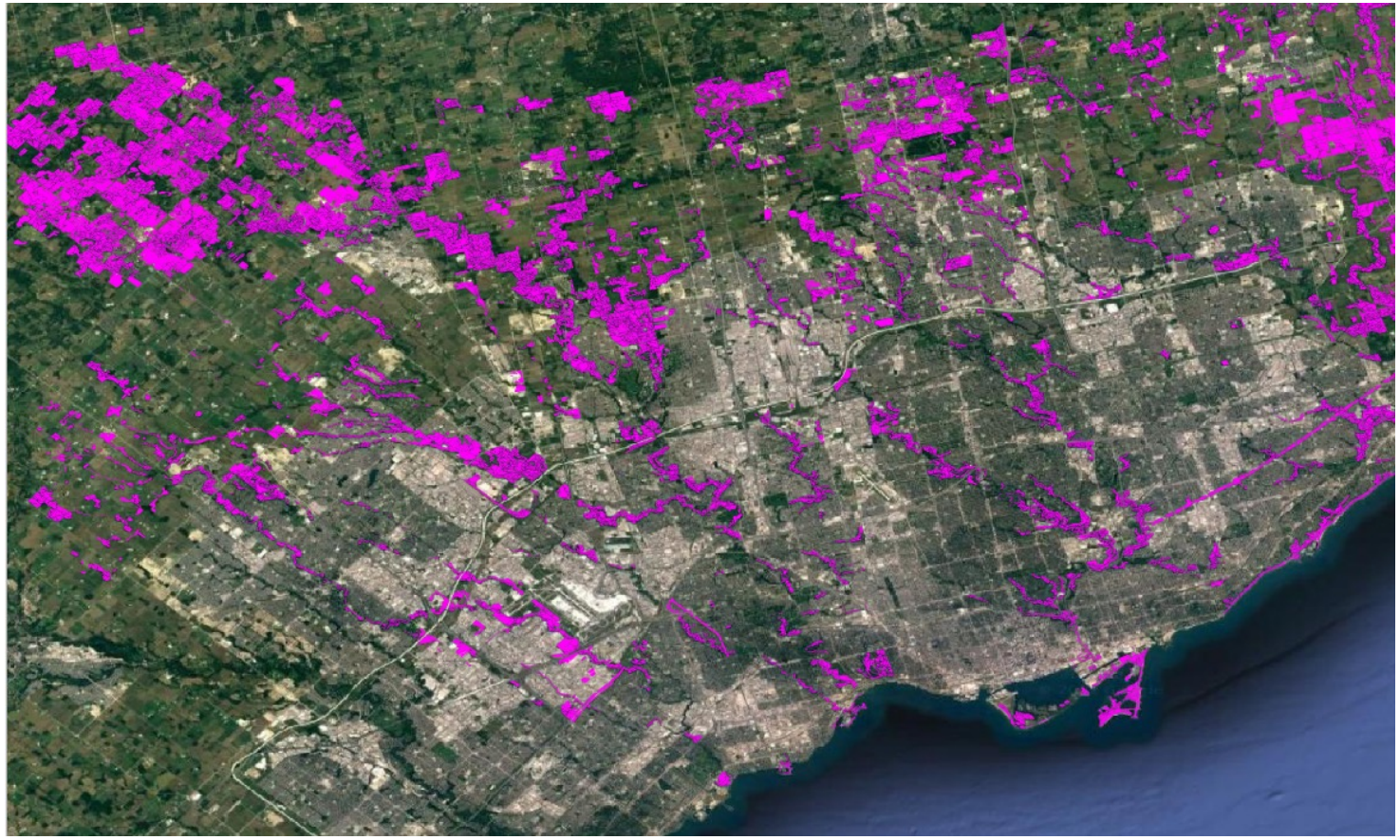
Implications for ECOSTRESS and SBG

- ECOSTRESS denser data than Landsat, higher resolution than MODIS, still limitations with sites < 5 ha
- Ecosystem service – summer temperature variation decreased substantially by restoration. Thermal buffering can be quantified.

Study 3: The thermal signature of Toronto region natural Landscapes – ECOSTRESS and Landsat

Photo-credit: Mary Gartshore

TRCA - Ecological Land Classification – Visited and classified 2000-2020



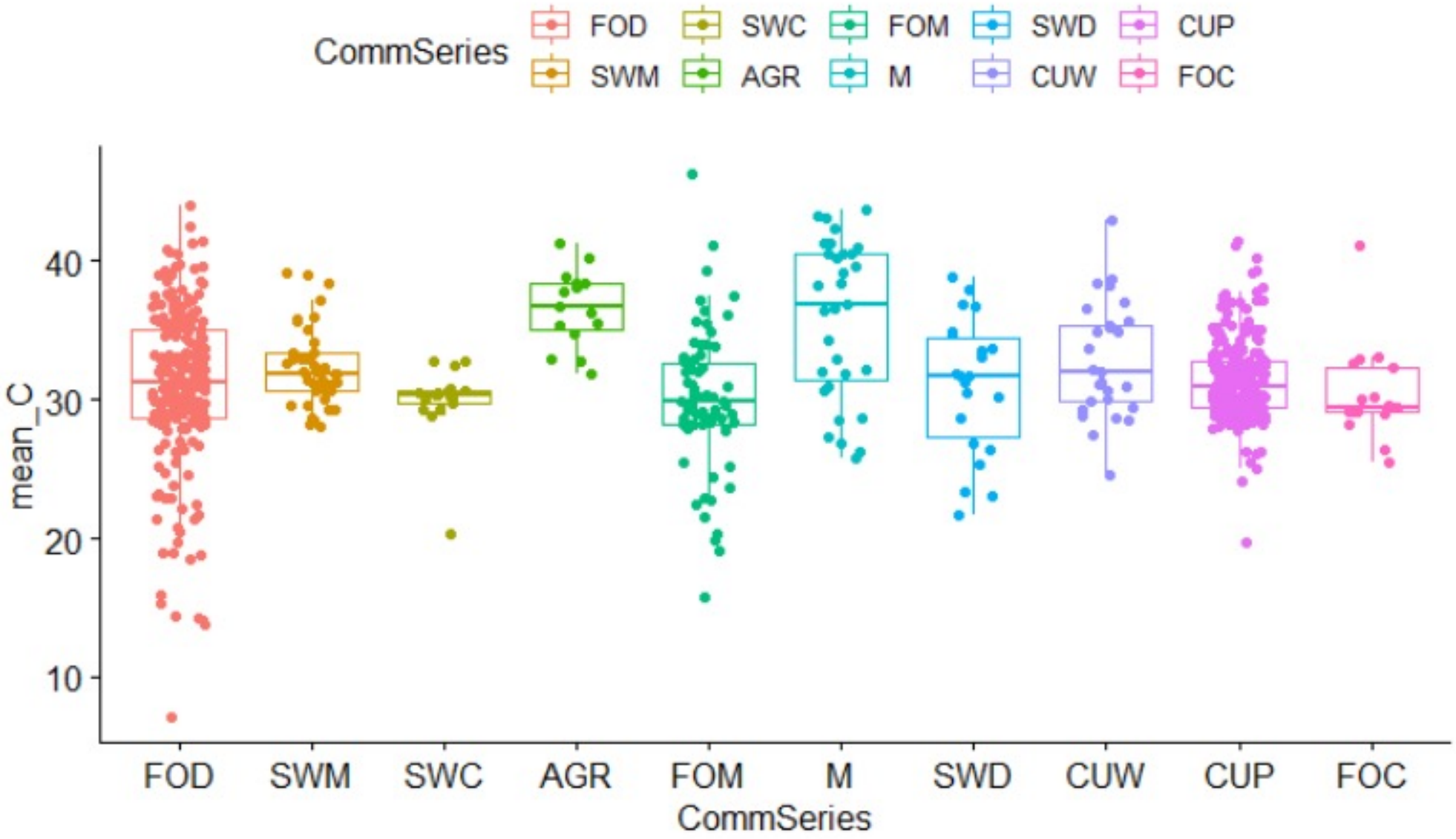
Forest	FO			- tree
Deciduous Forest	FOD			- dec cove
Fresh – Moist Oak – Maple – Hickory Deciduous Forest Ecosite	**FOD9**			- Re Red Hick mixtu - rep (terr - alm - mix char pulp Sens - hig and
Fresh – Moist Oak – Sugar Maple Deciduous Forest Type	FOD9-1		X	- Re - Wh Spot
Fresh – Moist Oak – Maple Deciduous Forest Type	FOD9-2		X	- Re Silve free - has - Sw flag
Fresh – Moist Bur Oak Deciduous Forest Type	FOD9-3		X	- Bu Bass - Se
Fresh – Moist Shagbark Hickory Deciduous Forest Type	FOD9-4		X	- Sh and - Blu - Wi pulp

Toronto and Region Conservation Authority

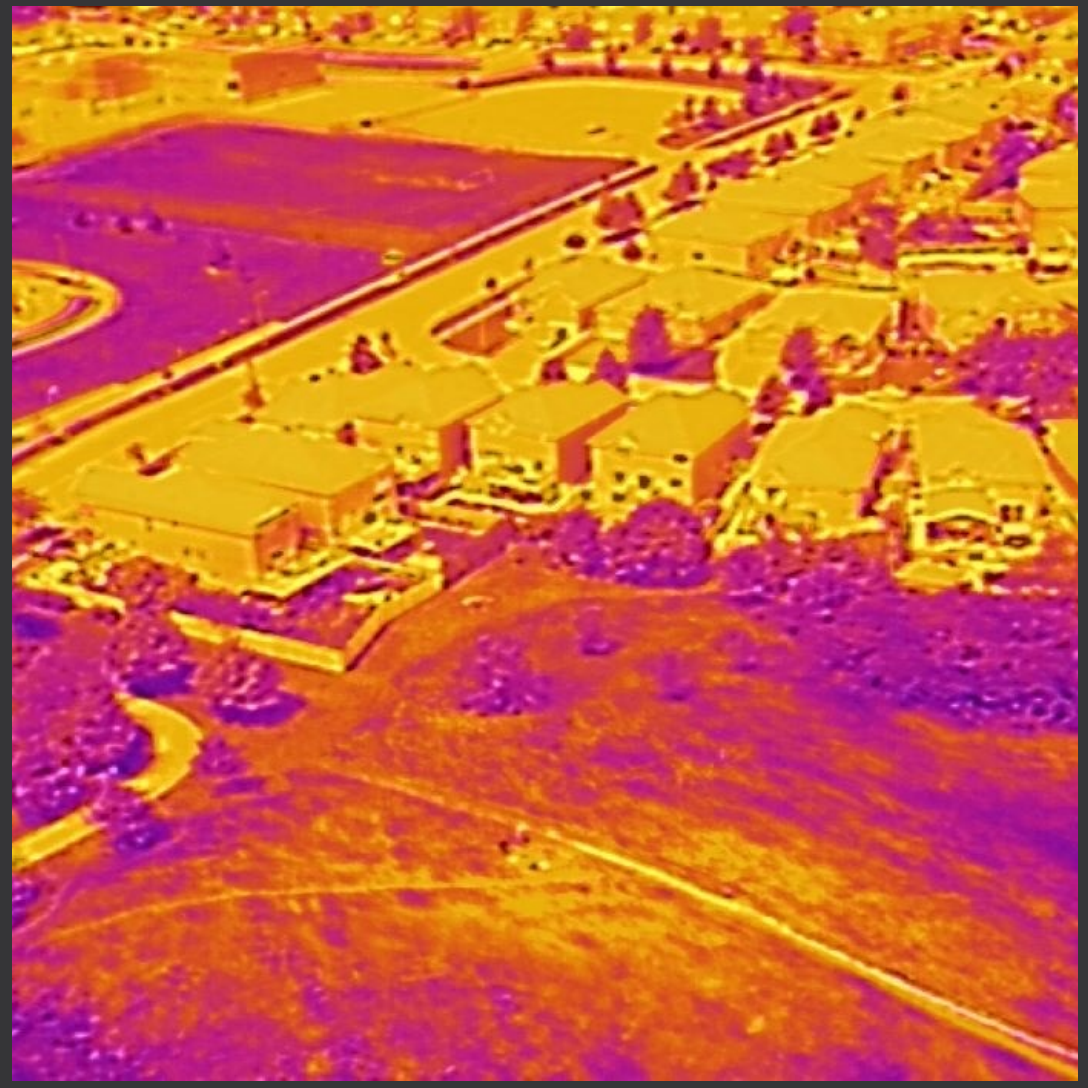
Size, fragmentation, height, location, vegetation type, and diversity

Variables	Variable type	Sources	Year selected (available from)	Expected effects:
Dependent				
Mean summer daytime LST / Relative LST if using multiple days – Full area and area – 50 m buffer	Continuous	ECOSTRESS	2021 (2018-)	
		Landsat 8	2021 (2013-)	
Independent				
Dominant canopy species[1]	Categorical	ELC data	2011-2021 (1996-)	?
ELC name/code[1]	Categorical	ELC data	2011-2021 (1996-)	?
Broadleaf/Coniferous[1]	Categorical	ELC data	2011-2021 (1996-)	?
Canopy density	Ordinal	ELC data	2011-2021 (1996-)	Neg.
Spread of exotics	Ordinal	ELC data	2011-2021 (1996-)	Pos.
ELC local rank/Area Score	Ordinal	ELC data	2011-2021 (1996-)	Neg.
Size of area	Continuous	ELC data	2011-2021 (1996-)	Neg.
Size to edge ratio	Continuous	ELC data	2011-2021 (1996-)	Neg.
NDVI (or similar)	Continuous	Landsat 8	2021 (2013-)	Neg.
% Surrounding natural areas	Continuous	TRCA Landuse or SOLRIS		Neg.
Fragmentation		Fragstat alt.		Pos.
Height of canopy from ground		LiDAR/DEM	2019	Neg.
Height of ground*		LiDAR/DEM	2019	Neg.
Northing* (also lake distance)		GIS		Neg.
Facing (N, S, W, E)*		LiDAR/DEM		S - Neg.

Very preliminary results



- PLANNER: Locate (sub)-urban ‘heat-deserts’ and hot watersheds for restoration planning
- MANAGER: Monitor restoration success and biodiversity based on temperature
- GRANT-WRITER: Show funders how your restoration decreases temperatures
- PUBLIC: Are you in a heat-desert? How far does someone have to walk to get to a cool greenspace on a 30°C day?
- Advocate for and plant more native and diverse greenery. Protect parks and street-trees as “cool islands”.



Thanks!

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