Soil mapping applications in reforestation for climate change mitigation

C Bulmer

ITAC 2020

Vernon BC

Outline

Tree planting as a response to climate change

- billions of trees

The key role of soil in the global carbon cycle

- soil organic carbon (SOC): the largest pool of ecosystem carbon
- SOC stabilization mechanisms in different forest types
- example: Digital Soil Mapping with LiDAR

Putting it all together

1 material thickness
2 clay
3 inorganic carbonate
4 wetlands and wet areas

Tree planting as a response to climate change

Bastin *et al.*, *Science* **365**, 76–79 (2019) 5 July 2019

RESTORATION ECOLOGY

The global tree restoration potential

Jean-Francois Bastin[1]*, Yelena Finegold[2], Claude Garcia[3,4], Danilo Mollicone[2], Marcelo Rezende[2], Devin Routh[1], Constantin M. Zohner[1], Thomas W. Crowther[1]

The restoration of trees remains among the most effective strategies for climate change mitigation. We mapped the global potential tree coverage to show that 4.4 billion hectares of canopy cover could exist under the current climate. Excluding existing trees and agricultural and urban areas, we found that there is room for an extra 0.9 billion hectares of canopy cover, which could store 205 gigatonnes of carbon in areas that would naturally support woodlands and forests. This highlights global tree restoration as our most effective climate change solution to date. However, climate change will alter this potential tree coverage. We estimate that if we cannot deviate from the current trajectory, the global potential canopy cover may shrink by ~223 million hectares by 2050, with the vast majority of losses occurring in the tropics. Our results highlight the opportunity of climate change mitigation through global tree restoration but also the urgent need for action.

Canadian land mass = 0.99 billion hectares

Global emissions are about 10 gigatonnes of C each year (Wikipedia), and atmospheric C is increasing by about 4 gigatonnes per year

Right tree, right place, right purpose

The One Billion Trees Programme isn't just about numbers. We want to make sure the right trees are planted in the right places for the right purpose.

Right tree

We want to encourage both permanent and plantation forests made up of exotic and native tree species. The programme encourages the planting of native species to improve biodiversity.

Right place

We want to see trees integrated into the landscape to complement and diversify our existing land uses, rather than see large-scale land conversion to forestry. We also want trees planted to be suitable for the site and their intended use. To do this we need to align tree planting with local land-use and planting priorities and strategies.

Right purpose

We want to make sure tree planting is well-planned and considers the long-term maintenance and end-use of the trees. Commercial viability for production forests and protection for permanent forests should be thought through before planting. We also want to make sure plantings take local social, environmental, cultural and economic priorities into account.

New Zealand…

https://www.mpi.govt.nz/funding-and-programmes/forestry/one-billion-trees-programme/about-the-one-billion-trees-programme

... and sites with high potential for sequestering carbon above ground, but also belowground as **soil organic carbon**

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Tree planting as a response to climate change

- 2,000,000,000 trees

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- SOC accumulation / stabilization in different forest types
- example: Digital Soil Mapping with LiDAR

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  - **average ~ 10-12 kg/m^2 of SOC (0-100 cm depth)**
  - **organic soils in wetlands are hotspots of carbon accumulation (~ 60 kg/m^2)**
  - **forest floors are vulnerable to disturbance and rebuild quickly after reclamation / reforestation**
  - **large amounts of soil organic carbon occur in subsoils >20cm deep**

- **SOC stability: the key to successful carbon sequestration**
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  - **SOC associated with mineral particles is protected from decomposition by both physical and chemical mechanisms**
  - **SOC fractions in grassland / arbuscular hardwoods vs conifers and ectomycorrhizal hardwoods**
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- **Spatially explicit information to guide management**
  - **Digital soil mapping with LiDAR**
  - **SOC accumulates in the wetter parts of the landscape**
  - **soil thickness is strongly affected by topography**
  - **inorganic carbon present in soils derived from limestone, and**
  - **Inorganic carbon accumulates in lower horizons of grasslands and dry forests**

The key role of soil organic carbon: stocks

Global soil organic carbon map

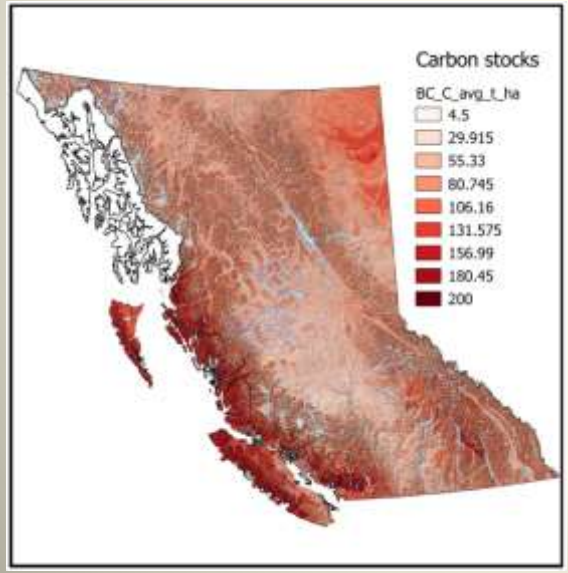
http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data-new/global-soil-organic-carbon-gsoc-map/en/

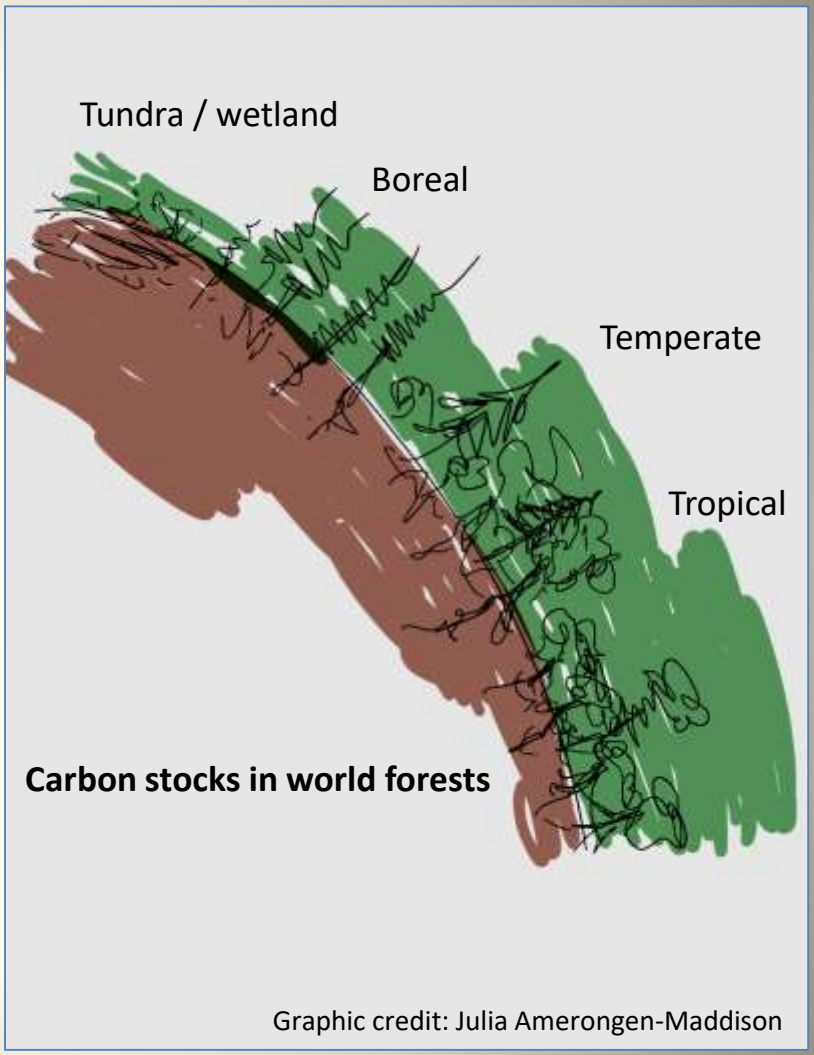
BC average:
75 tonnes / ha

IDFxh2 average:
47 tonnes / ha

ICH average:
70 tonnes / ha

CWH average:
125 tonnes / ha





Graphic credit: Julia Amerongen-Maddison

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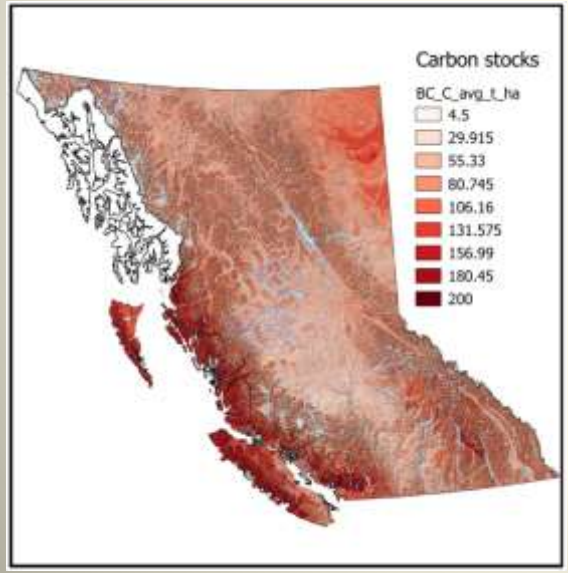

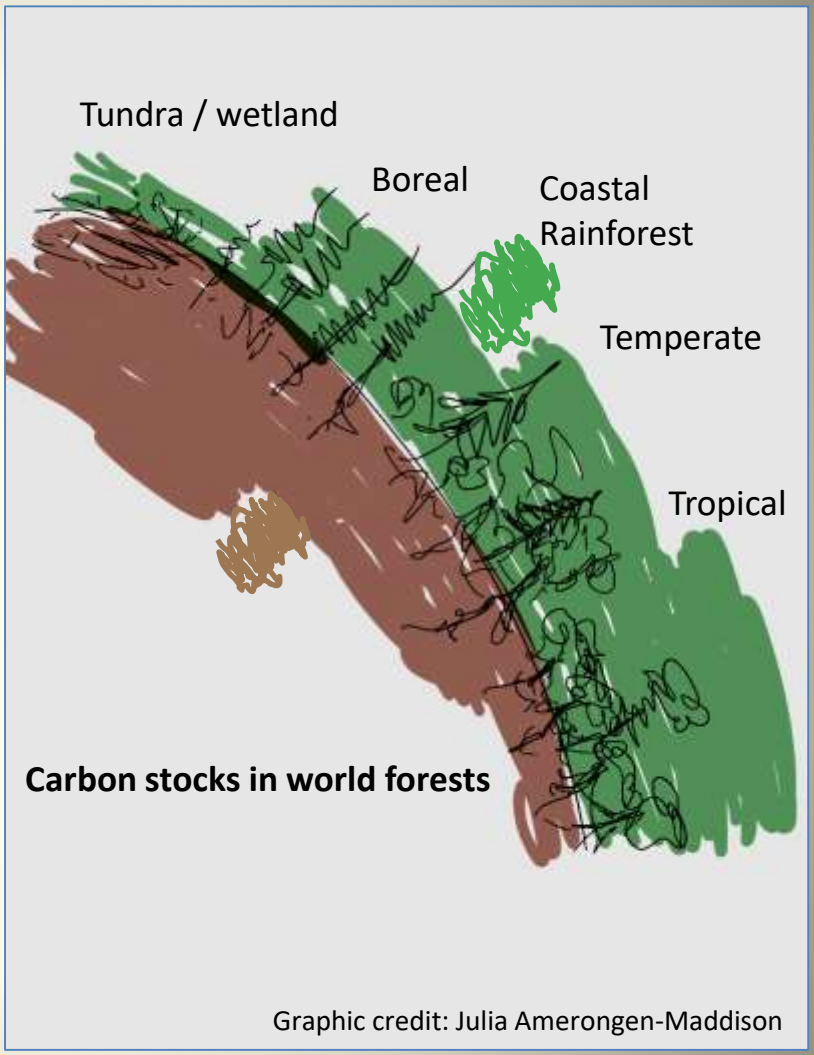

The key role of soil organic carbon: stocks

Tundra / wetland

Global so

http://www.fao.org/global-soil-
new/global-soil-organic-carbon-

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IDFxh2 average:
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Averaging 432 cubic metres per hectare (m^3/ha), the forests along Canada's west coast have the highest density of wood volume, more than three times the national average of 136

Global Change Biology

TRY – a global database of plant traits

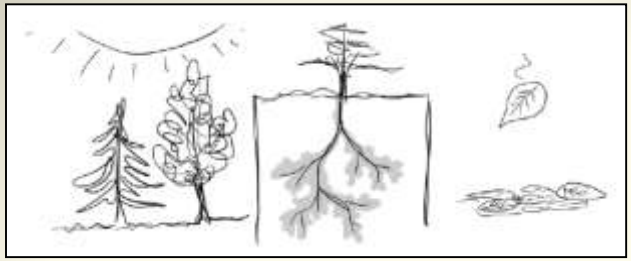
Common name	Species	Wood density [$t \cdot m^{-3}$]	Carbon content [$C \cdot t^{-1}$]
Douglas fir	*P. menziesii*	0.4533	0.5280
Norway spruce	*P. abies*	0.3700	0.4980
Maritime pine	*P. pinaster*	0.4140	0.5212

Trees "mid volume" →

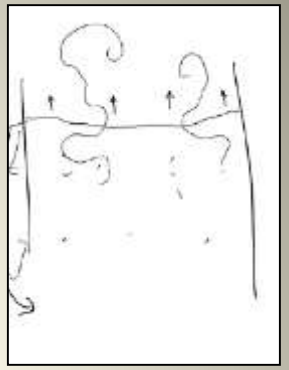
280 m^3 / ha x .4533 t /m^3 * .528 C t/t = 67.0 t / ha

Graphic credit: Julia Amerongen-Maddison

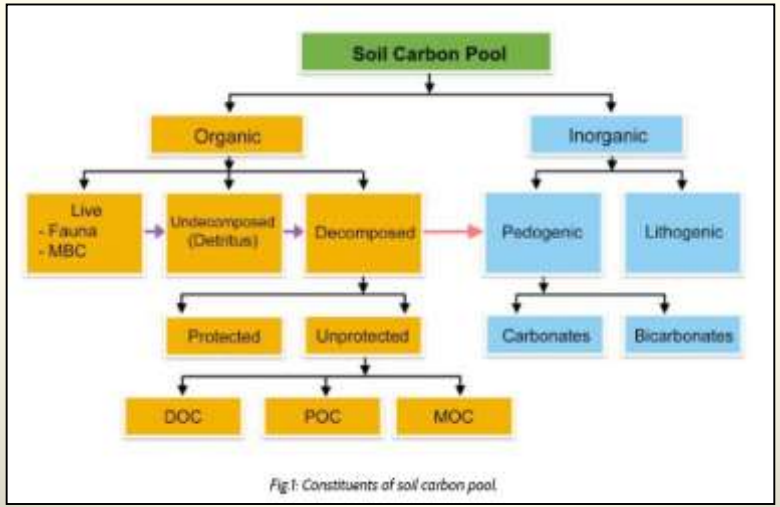
The key role of soil organic carbon: pools / stability



Additions: tree growth, roots, litter



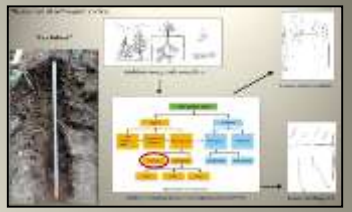
Losses: decomposition



Lal (2017). Global symposium on soil organic carbon 2017. FAO

Losses: leaching DOC

Graphic credit: Julia Amerongen-Maddison



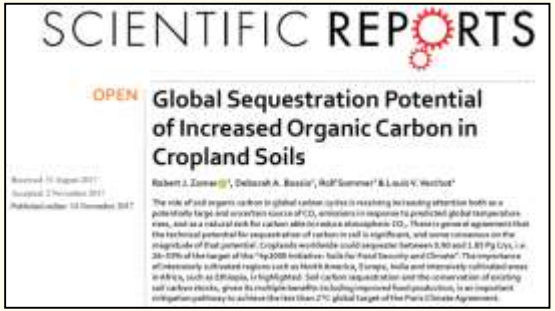
"Much effort in recent years to better understand processes of SOM accumulation and storage"

Global Change Biology

Carbon sequestration potential of soils in southeast Germany derived from stable soil organic carbon saturation

Wiesmeier et al. 2013

- High sequestration potential for grassland soils
- Forest soils already saturated



SCIENTIFIC REPORTS

OPEN

Global Sequestration Potential of Increased Organic Carbon in Cropland Soils

Zomer et al. 2017

- V. large opportunity, replace lost SOC on ag lands
- 4 per 1000 initiative
- Potential for **1-2 gigatonnes per year**

BIOGEOCHEMISTRY LETTERS

Beyond clay: towards an improved set of variables for predicting soil organic matter content

nature geoscience

ARTICLES

Soil carbon storage informed by particulate and mineral-associated organic matter

Cotrufo et al. 2017: carbon storage, N requirement, saturation

- **Mineral Associated C in grasslands and hardwood forests**
- **Particulate Organic C in ectomycorrhizal forests (conifers)**

soil systems

MDPI

The Case for Digging Deeper: Soil Organic Carbon Storage, Dynamics, and Controls in Our Changing World

Gross and Harrison 2019

- **More than 50 % of SOC pool is found deeper than 20cm**
- Deep SOC: dissolved organic carbon leaching
- **Deep SOC: its old, but not 'intrinsically stable'**

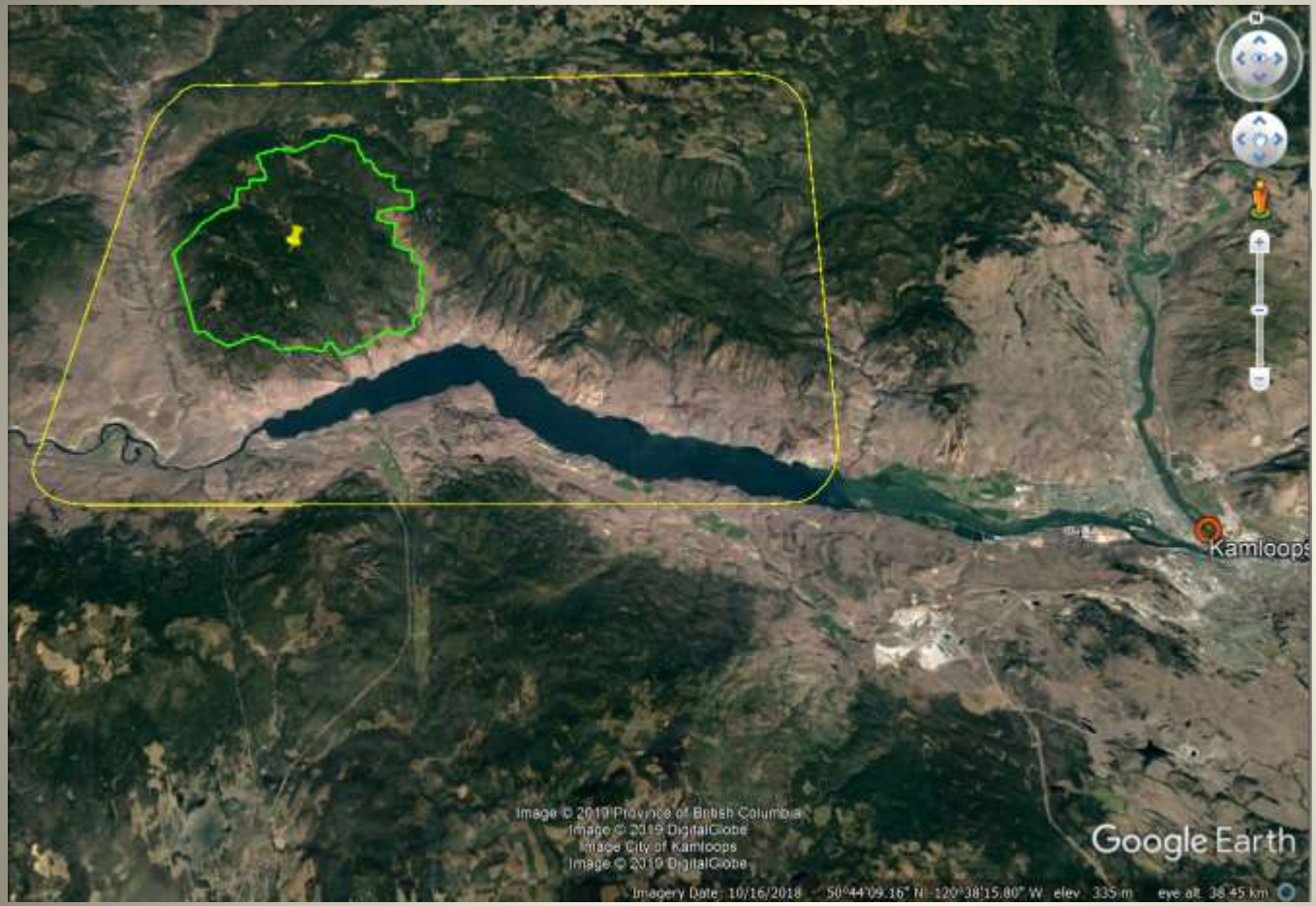
Eagle Hill Study Area

Canada
British Columbia

Montane
Cordillera
Ecozone

50° 50.3’ North
120° 51.4’ East

Soil mapping



Thompson Plateau physiographic area

Elevation **(yellow box)**
320 – 1600 masl

Elevation **(green area)**
900 – 1450 masl

MAT: 7 C
MAP: 305mm

Bunch grass
Ponderosa pine
Douglas – fir
Lodgepole pine

Photo: E. Koopmans

Photo: A. Arbour

Photo: A. Arbour

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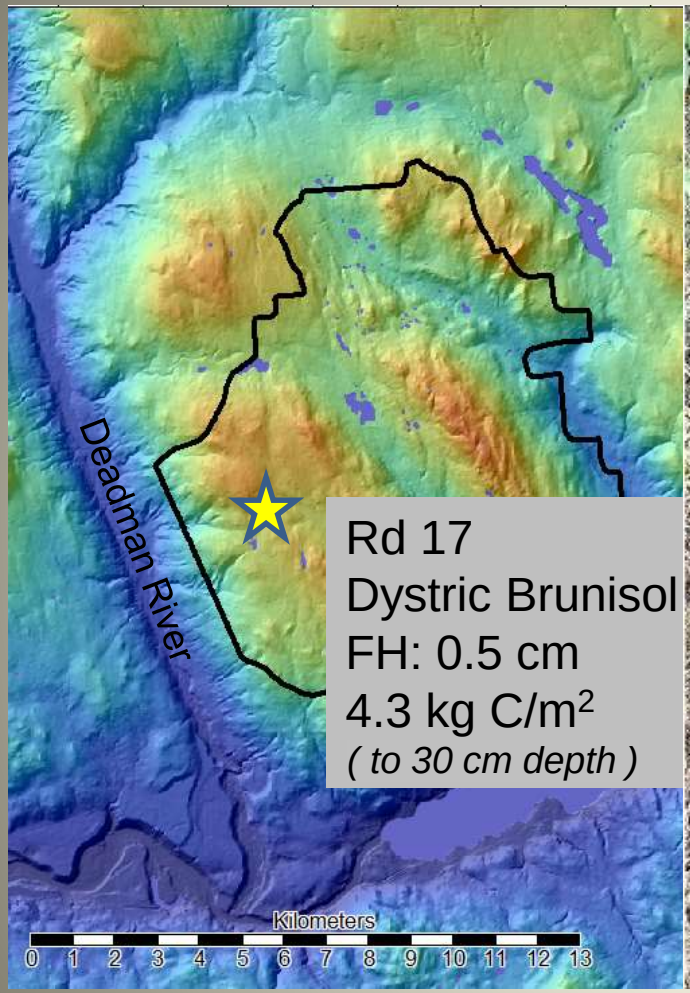
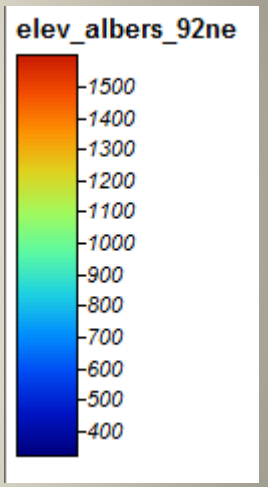
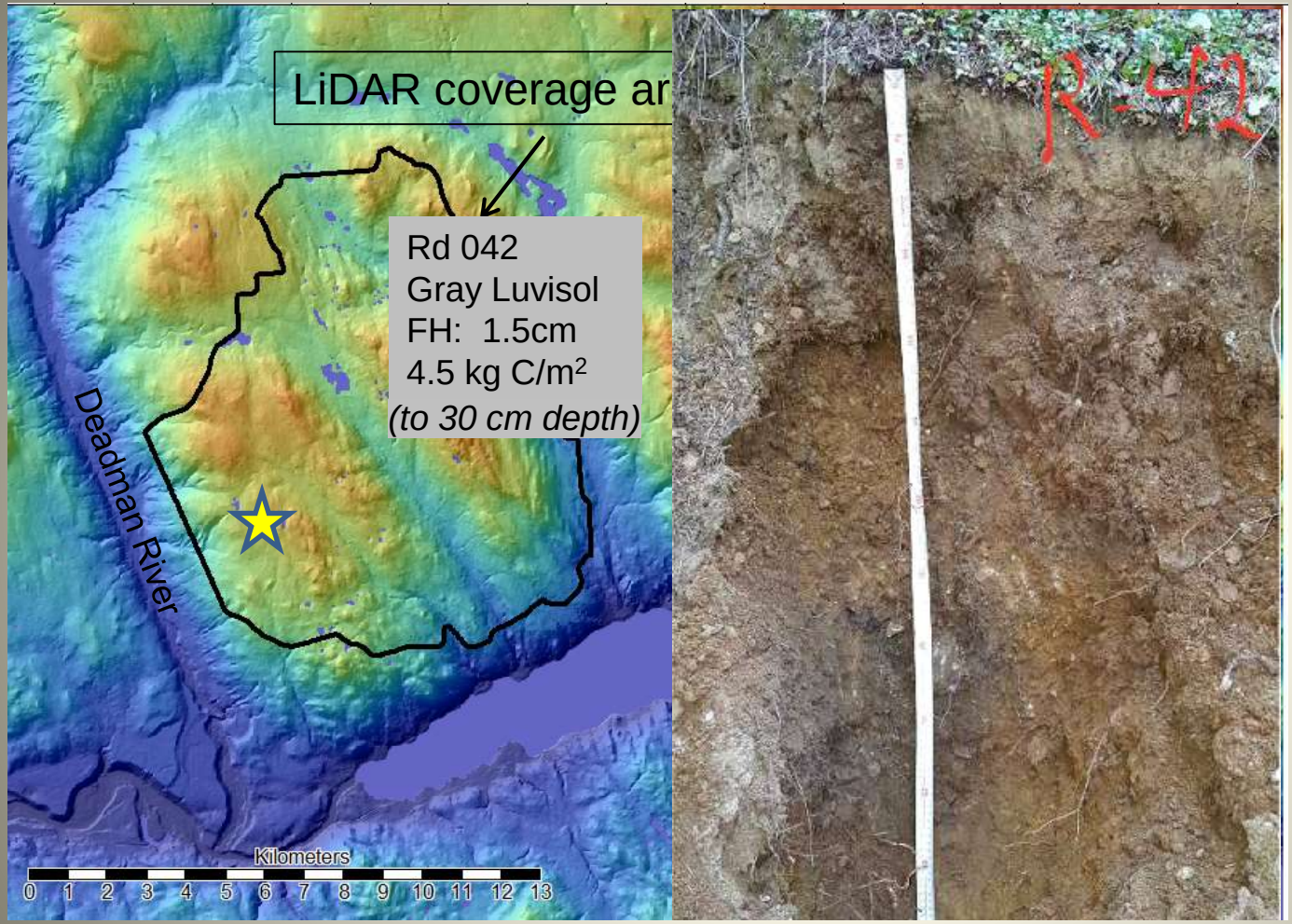
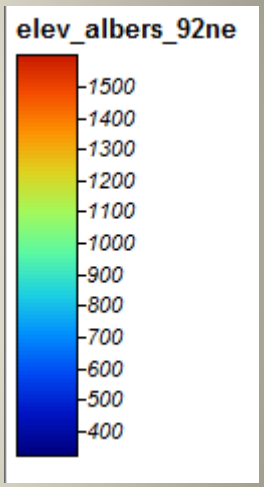

Deadman River
Rd 17
Dystric Brunisol
FH: 0.5 cm
4.3 kg C/m2
(to 30 cm depth)
Kilometers
0 1 2 3 4 5 6 7 8 9 10 11 12 13


#17


elev_albers_92ne
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400


LiDAR coverage ar
Rd 042
Gray Luvisol
FH: 1.5cm
4.5 kg C/m2
(to 30 cm depth)
Deadman River
Kilometers
0 1 2 3 4 5 6 7 8 9 10 11 12 13
R-42


elev_albers_92ne
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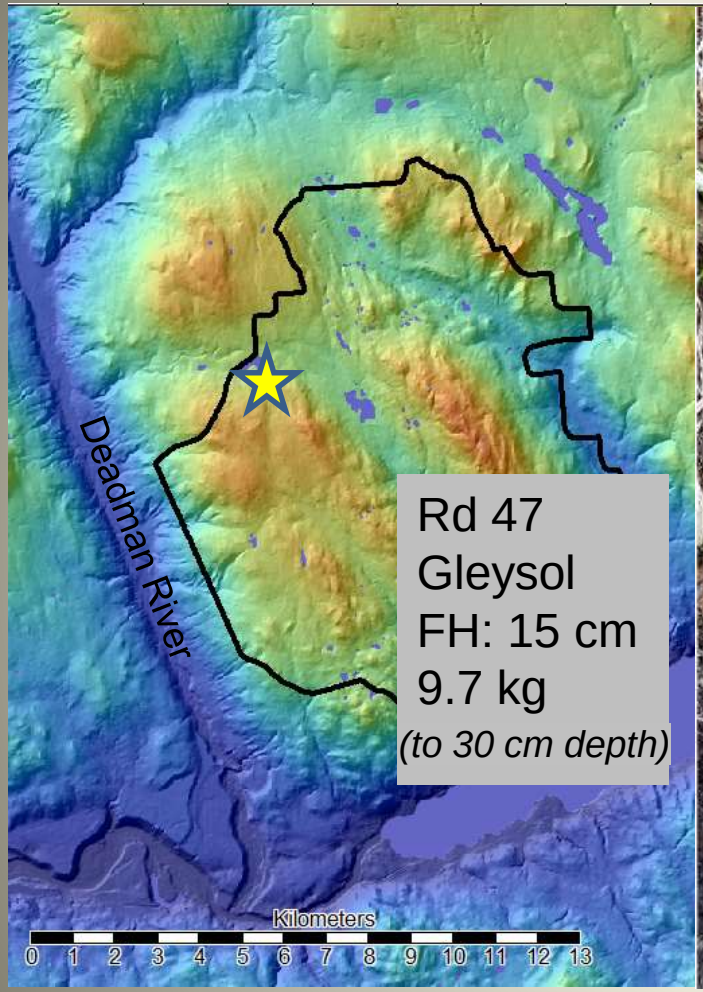
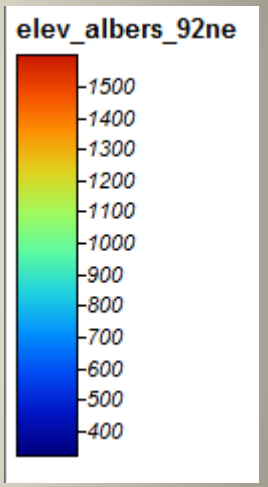

Deadman River
Rd 47
Gleysol
FH: 15 cm
9.7 kg
(to 30 cm depth)
Kilometers
0 1 2 3 4 5 6 7 8 9 10 11 12 13


#47


elev_albers_92ne
1500
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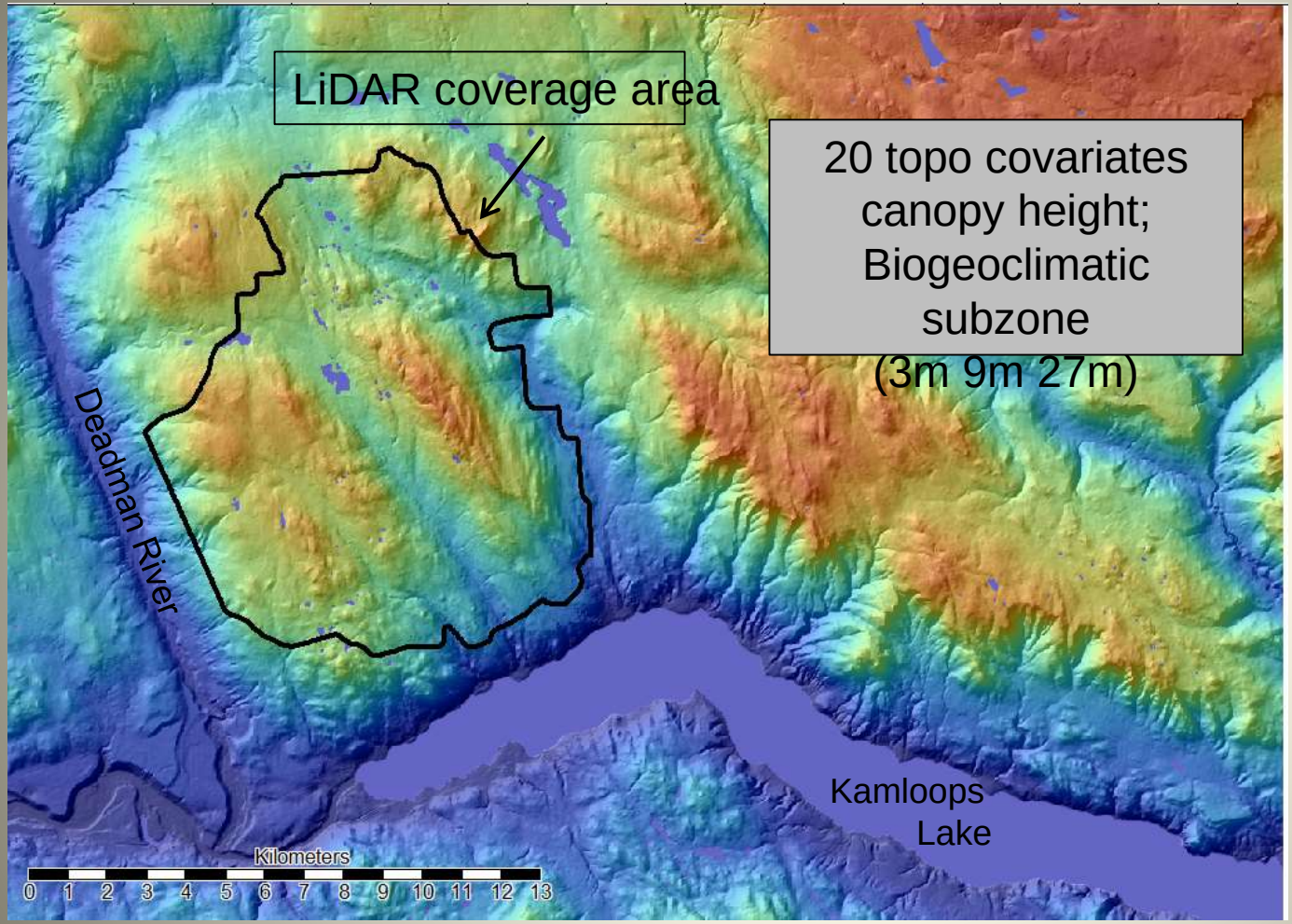
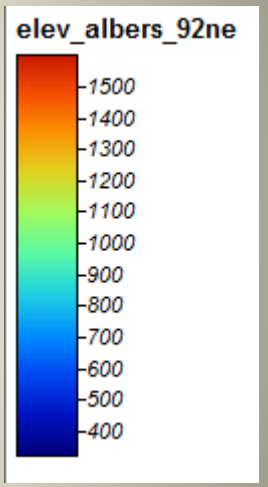

LiDAR coverage area
20 topo covariates
canopy height;
Biogeoclimatic
subzone
(3m 9m 27m)
Deadman River
Kamloops
Lake
Kilometers
0 1 2 3 4 5 6 7 8 9 10 11 12 13


elev_albers_92ne
1500
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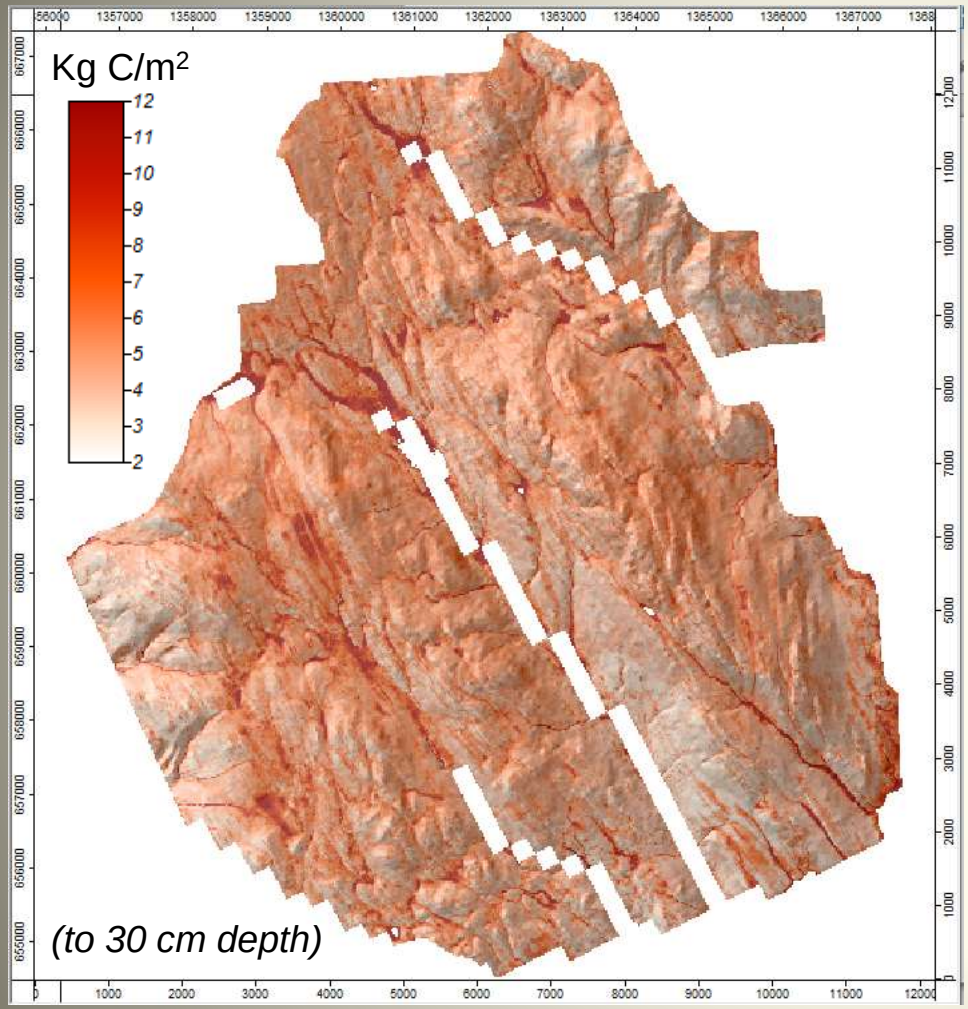
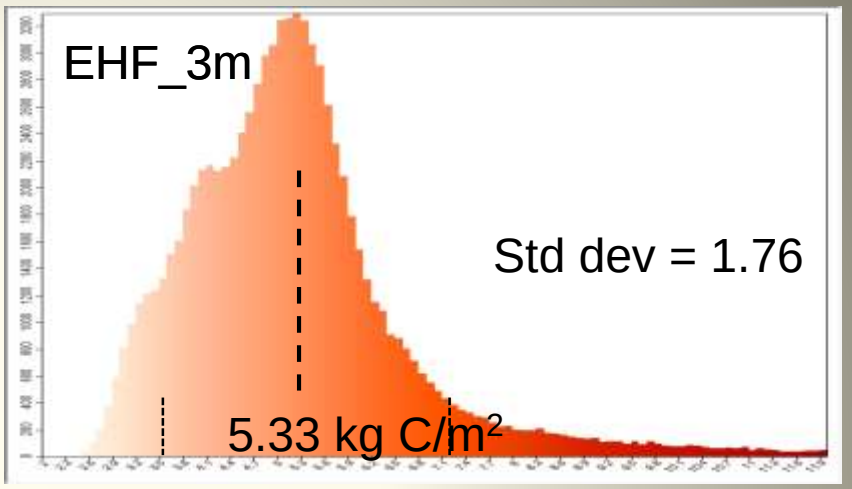
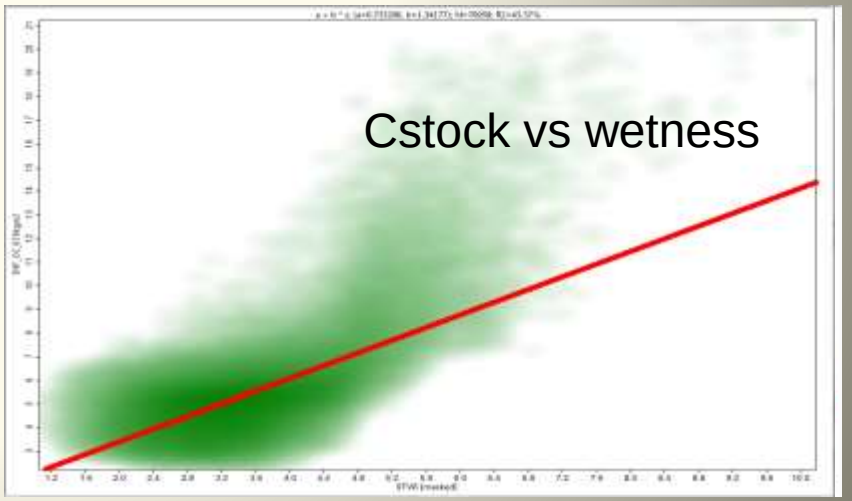

Kg C/m²
12
11
10
9
8
7
6
5
4
3
2
(to 30 cm depth)


EHF_3m
Std dev = 1.76
5.33 kg C/m²


Cstock vs wetness

The key role of soil organic carbon

- **Overall, about half of total ecosystem carbon occurs in soil organic matter** **1**
  - **average ~ 10-12 kg/m^2 of SOC (0-100 cm depth)**
  - **organic soils in wetlands are hotspots of carbon accumulation (~ 60 kg/m^2)**
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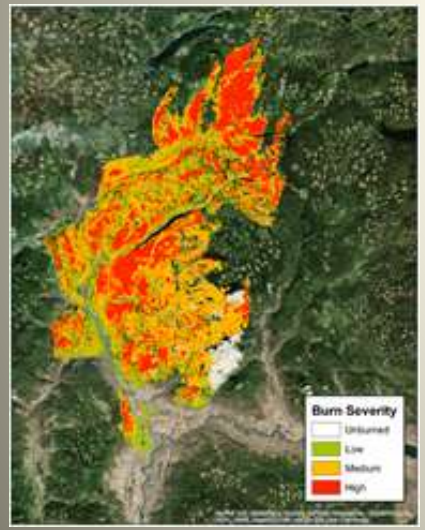
Fire

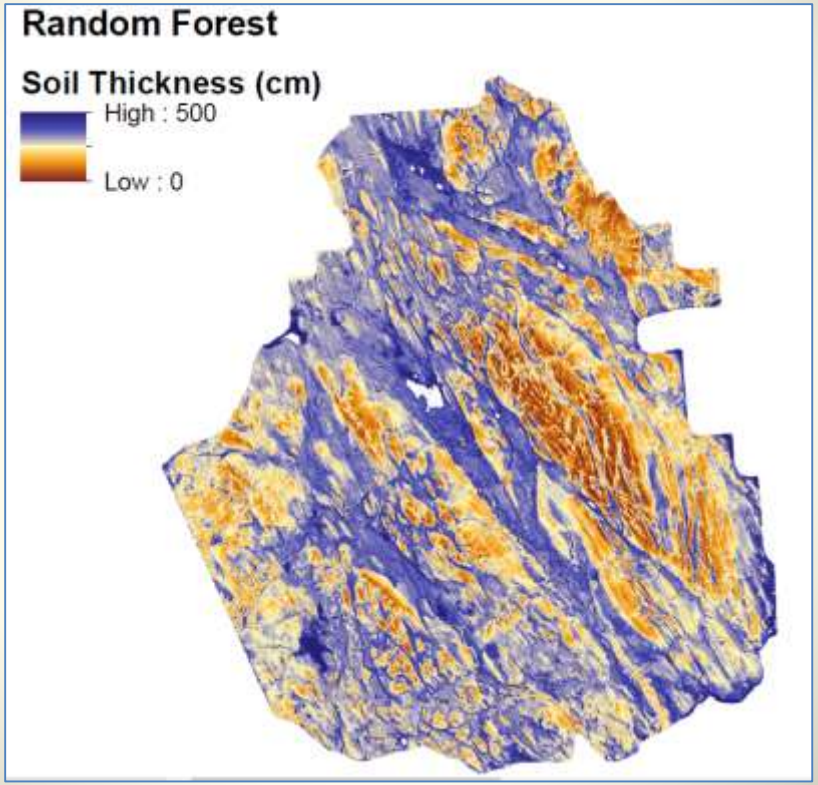
Soil Disturbance



Potential strategies for enhancing soil carbon:
afforestation, reforestation, retain slash, fertilization, hardwoods, … manage soil disturbance, manage fire, manage harvest rates

Material thickness

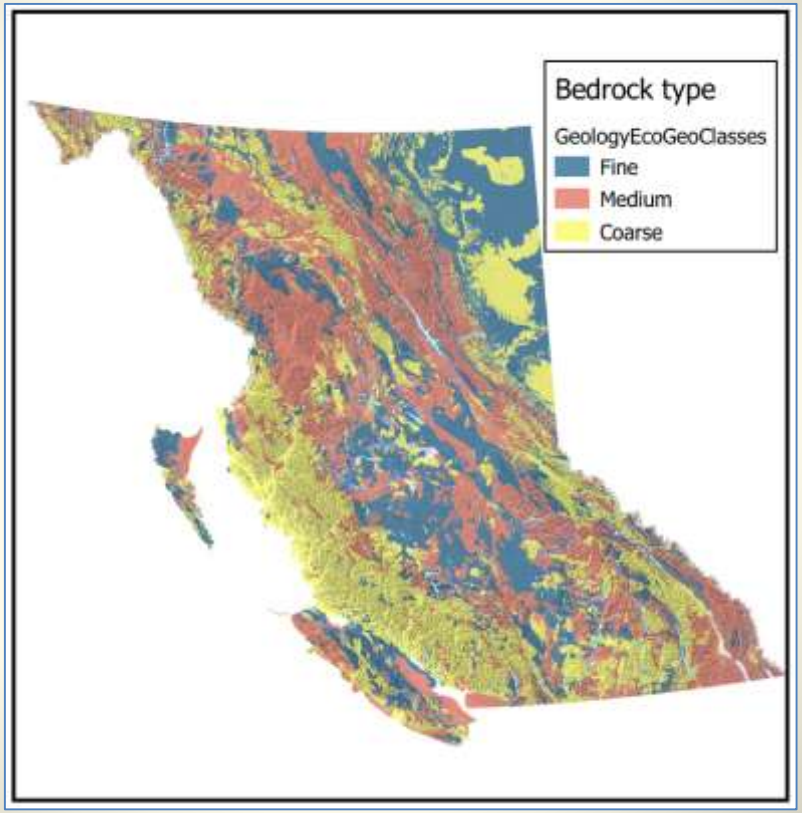
Topographic effects on productivity and soil carbon storage



Thickness of productive soil

Clay content as a measure of soil carbon storage potential

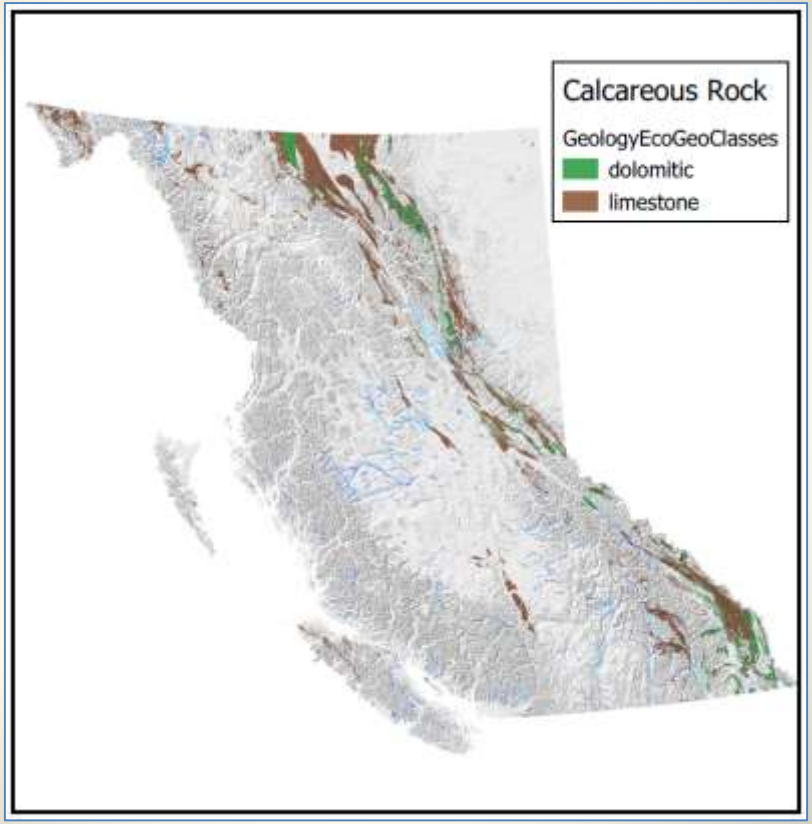
Clay – rich soil has more binding sites for mineral associated organic carbon



Bedrock weathering effects on soil particle size

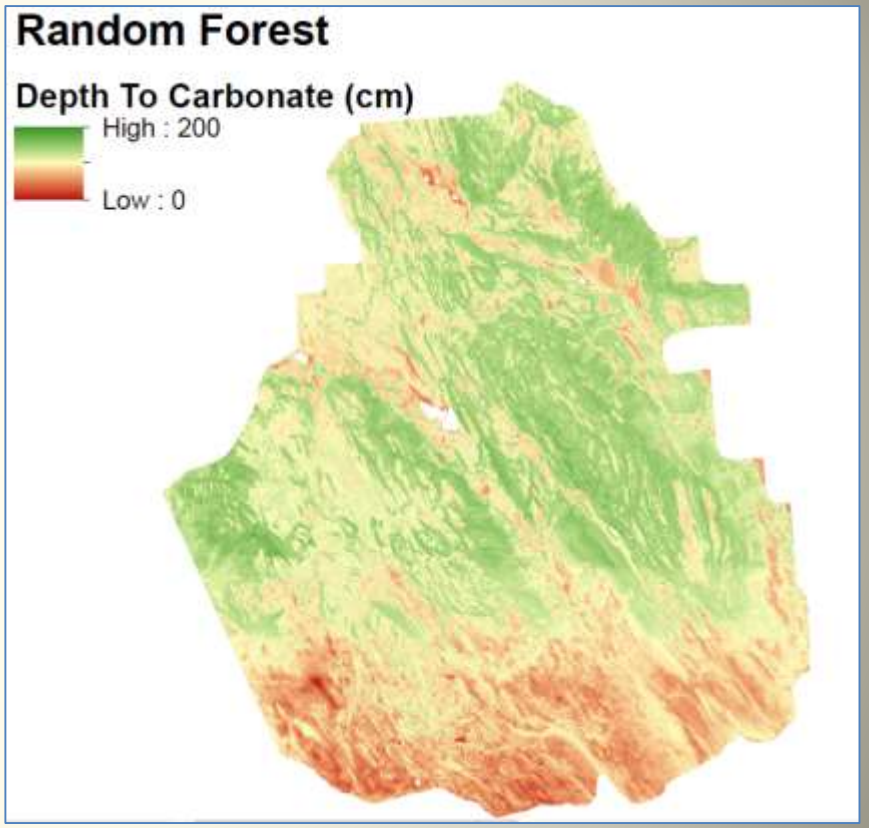
Inorganic carbon – from parent rock

Inorganic carbon derived from limestone complicates evaluation of SOC sequestration…



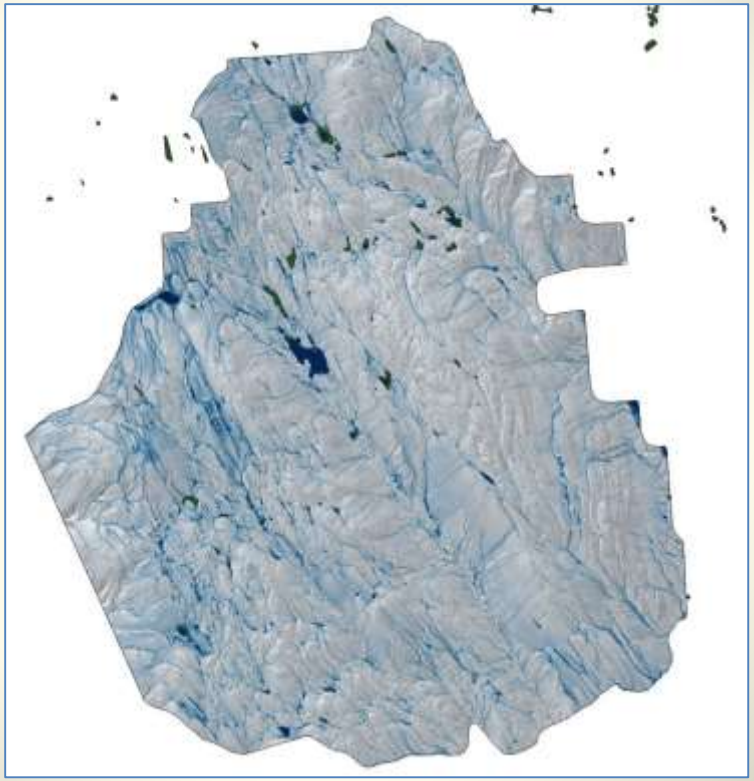
documenting benefits would require evaluation of inorganic C (not a deal breaker)

Calcareous subsoils contain lots of C, release is possible, restricts root growth…



Calcareous subsoils could become a source of atmospheric CO_2

Cost – benefit: mounding disturbs soil, likely releases C, but aids establishment.. (alternatives?)



Wetlands and Wetness index

Summary

soil organic carbon (SOC): the largest pool of ecosystem carbon

SOC accumulation / stabilization reflects a dynamic system of additions and losses

Put trees where they will grow well, and..

Consider factors that help meet objectives of maximizing ecosystem carbon

- material thickness (affects productivity and C storage)
- clay (potential effect on C storage)
- inorganic carbonate (an extra wrinkle)
- wetlands and wet areas (be careful)