High-resolution Mapping the Carbon Debts from Harvesting Beetle-killed Lodgepole Pine (Pinus contorta)

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The expansion of MPB induced mortality in CO, WY, ID, and MT from 2000 to 2012.

**Ideal bioenergy feedstock?**
- No cultivation
- Better C balance
Carbon impacts of salvage logging?
Explore the **carbon debts** due to salvage logging and the **payback time**
Lodgepole pine-dominated FIA plots

Forest Vegetation Simulator (FVS)

No harvest scenario
Harvest scenario

C debt over time
Payback time

Spatial input raster layers of the study region
Random Forest surrogates

Maps of C debt and payback time

METHOD OVERVIEW
Lodgepole pine-dominated FIA plots

Forest Vegetation Simulator (FVS)

No harvest scenario
Harvest scenario

C debt over time
Payback time

Forest Vegetation Simulator (FVS)

Lodgepole pine-dominated FIA plots

- Evaluate FVS’s growth models:
  FVS tends to overpredict growth of lodgepole pine, spure, fir, and aspen in the study region

- Calibrate FVS’s growth model
  - Calibrate Lodgepole pine (LP) (100% LP chronosequence)
  - Calibrate Spuce-fir (100% S/F chronosequence)
  - Calibrate mixed LP forest (>65% LP species composition)

Maps of C debt and payback time

Live Basal Area (m$^2$ ha$^{-1}$)

- Payback time
- C debt over time
- No harvest scenario
- Harvest scenario
- FIA chronosequence (>65% LP species composition)
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Random Forest metamodels

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C debt over time

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Carbon debt Calculation

Total Stand Carbon (MgC/ha)

There is a payback

\[ C \text{ debt (t)} = (\text{Total C of harvested stand} - \text{Total C of no harvest stand}) \text{ at time t} \]
**Payback time Calculation**

Linear interpolation between the last negative and the first positive C debts.

Carbon debt curve:
- **y=0**
- Year after harvest

Payback time $t_{pb}$:
- $t_{n-1}$
- $t_n$

Mathematical expression:
- Payback time calculation: Linear interpolation between the last negative and the first positive C debts.
- $t$: 10 year increment

Data sources:
- Lodgepole pine-dominated FIA plots
- Forest Vegetation Simulator (FVS)
- No harvest scenario
- Harvest scenario
- C debt over time

Maps of C debt and payback time:
- Random Forest metamodels
Forest Vegetation Simulator (FVS)

Lodgepole pine-dominant FIA plots

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Inputs

1. Years after harvest
2. Aspect
3. Slope
4. Elevation
5. Dead biomass
6. Total biomass (AG)

Target/Input

FVS’s modeled C debts

FVS’s modeled Payback time

Target

Surrogate model of C debt

Surrogate model of Payback time

Raster layers of predicted C debt over time

Raster layer of predicted payback time
Forest Vegetation Simulator (FVS)

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Spatial input raster layers of the study region

Random Forest surrogates

Topography (SRTM):
- Slope
- Aspect
- Elevation

Total biomass layer
- FIA data
- Landsat
- Climate
- Geomorphometry

Dead biomass layer
- FIA data
- Biomass
- Bark beetle mortality
RESULTS

1. FVS model Calibration
2. Stand characteristics vs. C debt and payback time
3. Random forest surrogate model of C debt
4. Mapping of C debts for the study region
We fit the model to the 40 to 150 age portion of the FIA chronosequences because:

- Early aged FIA plots did not appear to be even-aged.
- Older aged plots had small sample size.

FVS MODEL CALIBRATION

- FVS default model
- FIA mean
- Calibrated FVS

**Total Stand Carbon**

**Living Basal Area**

**Dead Basal Area**

**Trees per Hectare**

**Quadratic Mean Diameter (cm)**

Calibrated Fit to 40 to 150 years: RMSE = 1.03, RMSE % of Mean = 16.5%, Bias = -0.11
CARBON DEBT OVER TIME

Color by Payback time (years)
- Max (199.6)
- Min (3.9)
- No payback (∞)

150 plots: Payback
288 plots: No payback
INPUTS VS. CARBON DEBT

Carbon debt (MgC/ha) vs. Year

Carbon debt (MgC/ha) vs. Aboveground carbon (MgC/ha)

Carbon debt (MgC/ha) vs. Standing dead carbon (MgC/ha)

Carbon debt (MgC/ha) vs. Slope

Carbon debt (MgC/ha) vs. Elevation (ft)

Carbon debt (MgC/ha) vs. Aspect
Surrogate Model of Carbon Debt

Spatial Model evaluation stats:
\[ R^2 = 0.97 \]
\[ \text{RMSE} = 5.6 \text{ Mg C/ha} \]

Surrogate Model Variable Importance

Spearman’s Rank correlation

- Aboveground biomass: +0.52
- Year after harvest: -0.35
- Dead biomass: +0.25
- Elevation: +0.11
- Aspect: +0.04
- Slope: +0.03
LANDSCAPE AVERAGE OF CARBON DEBT

Average C debt (Mg C/ha)

Years after harvest

0 20 40 60 80 100

0 -10 -20 -30 -40 -50 -60 -70 -80 -90

Years after harvest
MAPPING OF CARBON DEBT

Year 0

Year 50

Year 100

North Park

Middle Park

Front Range

C Debt (MgC/ha)

-124

-93

-62

-31

0

8.3

C Debt (MgC/ha)

-124

-93

-62

-31

0

8.3

C Debt (MgC/ha)

-124

-93

-62

-31

0

8.3
1. Mapping of payback time due to salvage logging

2. Clearcut vs. Slash-and-burn?

3. Spatial optimization of feedstock harvest for biofuel production

4. Life cycle and supply chain assessment
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