Impact of forest management on organic carbon sequestration in soils

Laurent Augusto

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INRA
SCIENCE & IMPACT

Presentation available at:
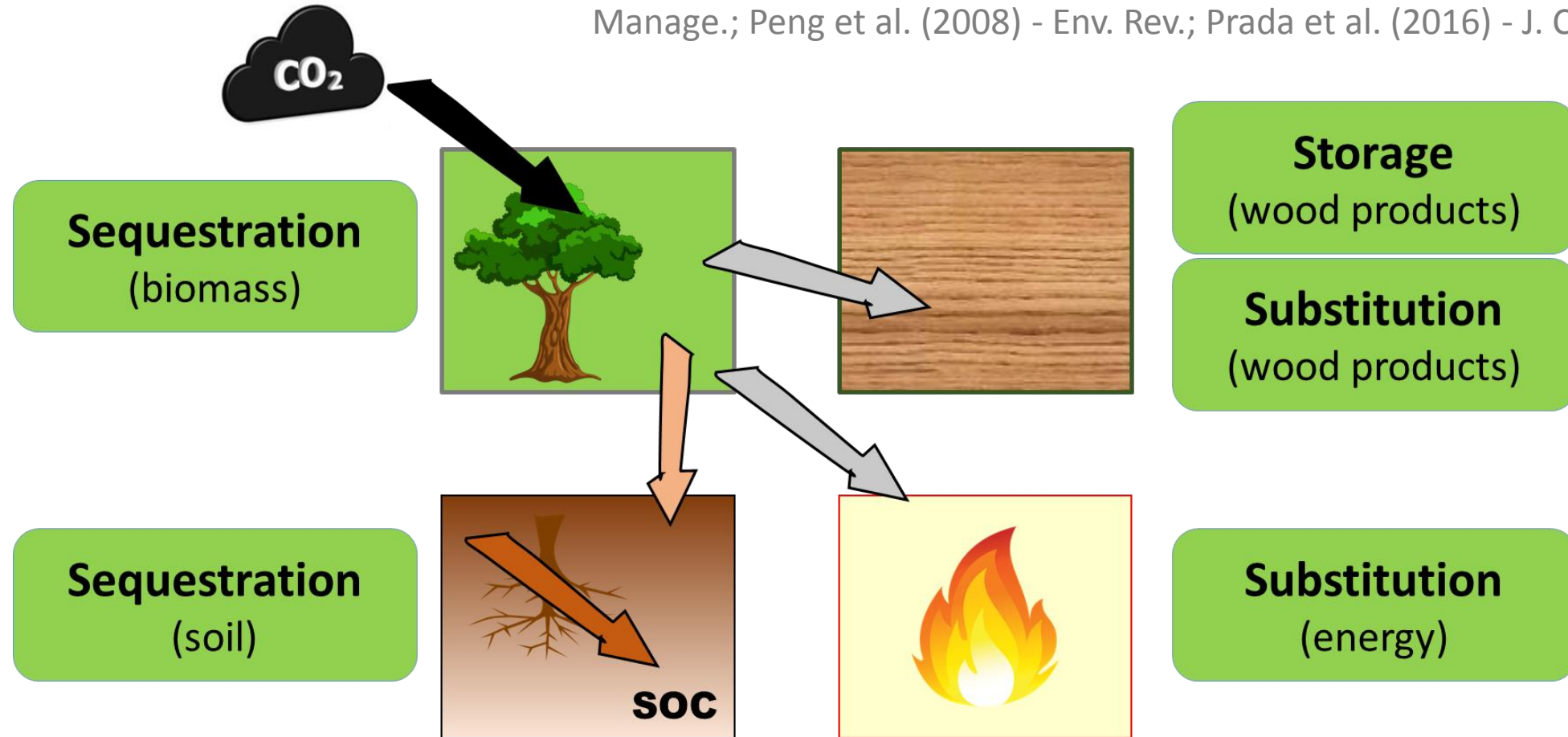www.researchgate.net/profile/Laurent_Augusto

125TH ANNIVERSARY CONGRESS 2017

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Freiburg, Germany

Forests play a major role in climate change mitigation because of their role in carbon (C) cycle. [Liski et al. (2002) - For. Ecol. Manage.; Markewitz (2006) - For. Ecol. Manage.; Peng et al. (2008) - Env. Rev.; Prada et al. (2016) - J. Cleaner Prod.]
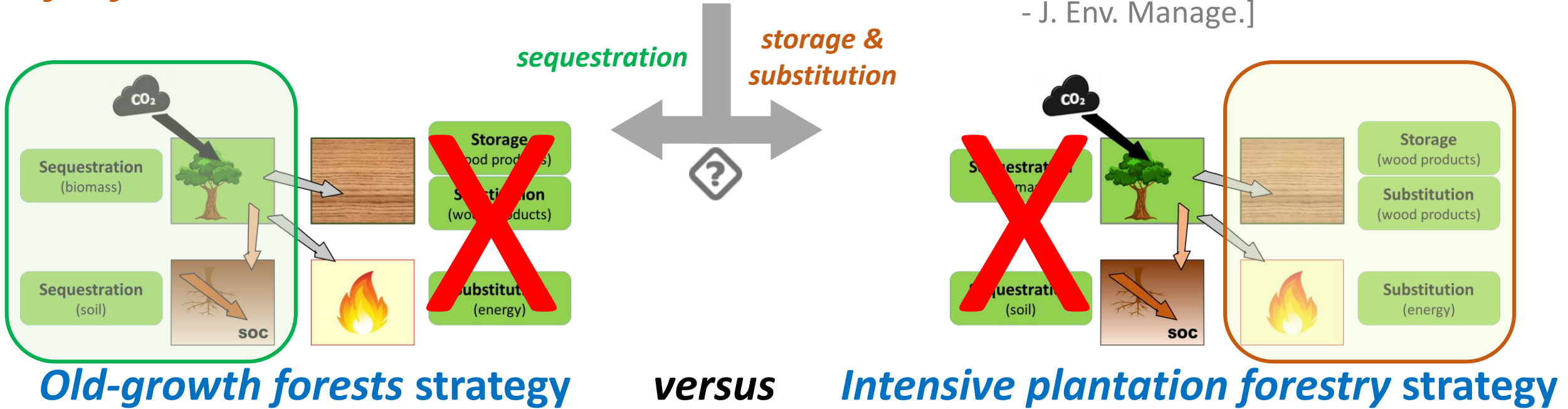

But determining what is the best strategy to optimize mitigation is hotly debated. [Schulze et al. (2013) - Glob. Change Biol. Bioenerg.; Haberl et al. (2013) - Glob. Change Biol. Bioenerg.; Bright et al. (2013) - Glob. Change Biol. Bioenerg.; Bellassen & Luyssaert (2014) - Nature]
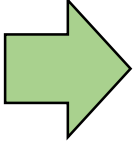
Question: "*Do forests best mitigate CO$_2$ emissions to the atmosphere by setting them aside for maximization of C sequestration or by management for fossil C substitution?*" ⇔ **The 3-S dilemma**

Old-growth forests strategy   *versus*   *Intensive plantation forestry* strategy

Question: "*Do forests best mitigate CO$_2$ emissions to the atmosphere by setting them aside for maximization of C sequestration or by management for fossil C substitution?*" ⇔ The 3-S dilemma
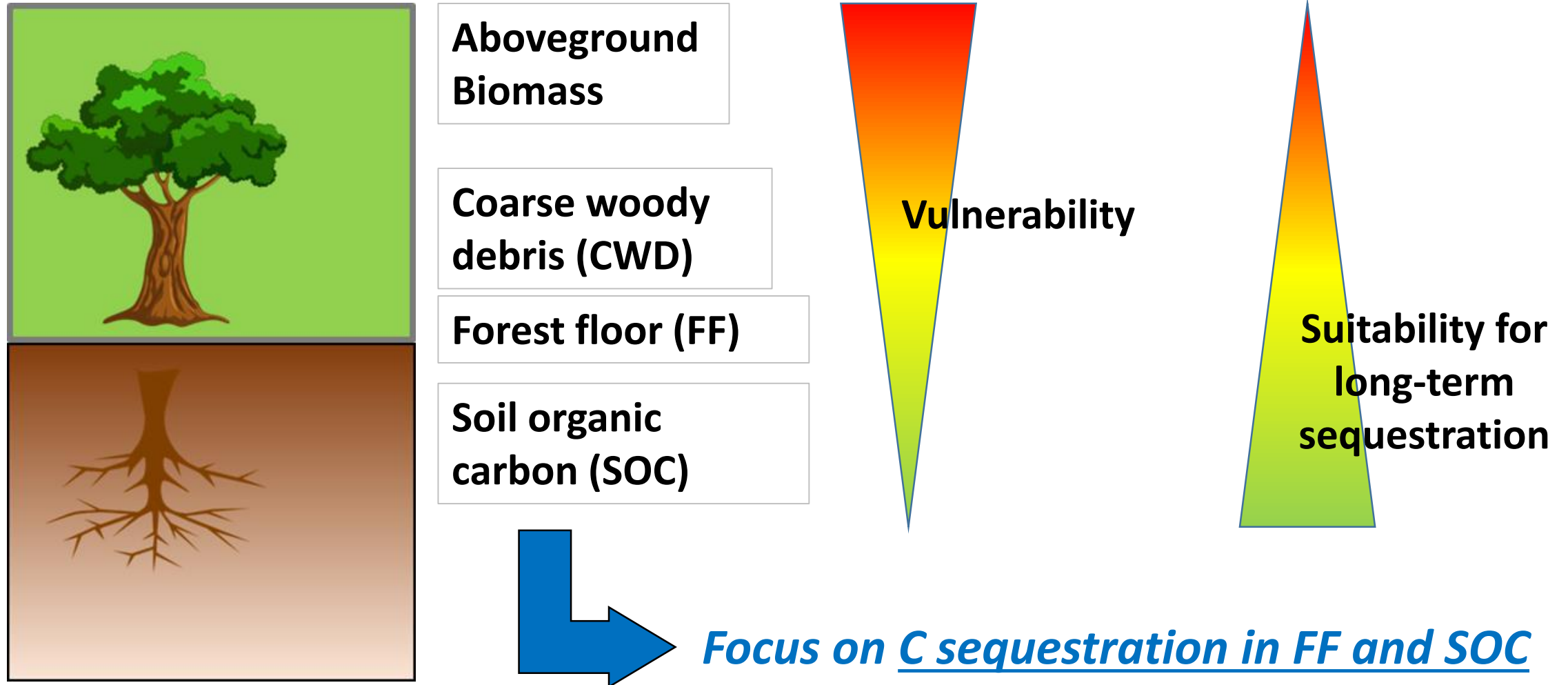
➡ **No unique answer because simulations are difficult to perform and are very sensitive to the many assumptions, or variables, needed** (energy conversion coefficients, type of fossil fuel considered during substitution, materials considered for wood products, assumptions about the long-term steady-state levels of C in old-forests)
[Taeroe et al. (2017) - J. Env. Manage.]

➡ **Probably different answers for different contexts, depending on climate, soils, regional economy, …**

⬇ *My focus is only on C sequestration in forests*

Forest carbon pools are not equally vulnerable to climate change or to disturbances (fires, windthrows, pests, droughts, forestry)

[Boerner et al. (2008) - For. Ecol. Manage.; D'Amato et al. (2011) - For. Ecol. Manage.; Jandl et al. (2007) - Geoderma; Johnson & Curtis (2011) - For. Ecol. Manage.; Thürig et al. (2005) - For. Ecol. Manage.; Reichstein et al. (2013) - Nature ; Wiesmeier et al. (2013) - For. Ecol. Manage.]

Aboveground Biomass

Coarse woody debris (CWD)

Forest floor (FF)

Soil organic carbon (SOC)

Vulnerability

Suitability for long-term sequestration

Focus on C sequestration in FF and SOC

My question:

"*Is it possible to maintain/increase soil carbon content while still harvesting biomass for storage/substitution processes?*"
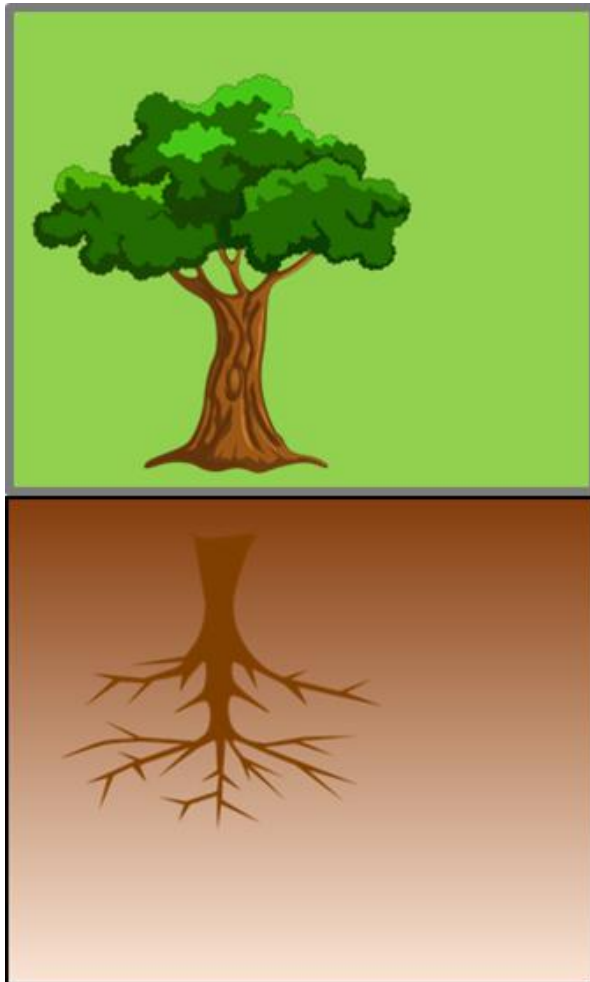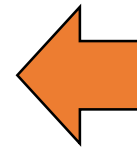
Aboveground Biomass

Coarse woody debris (CWD)

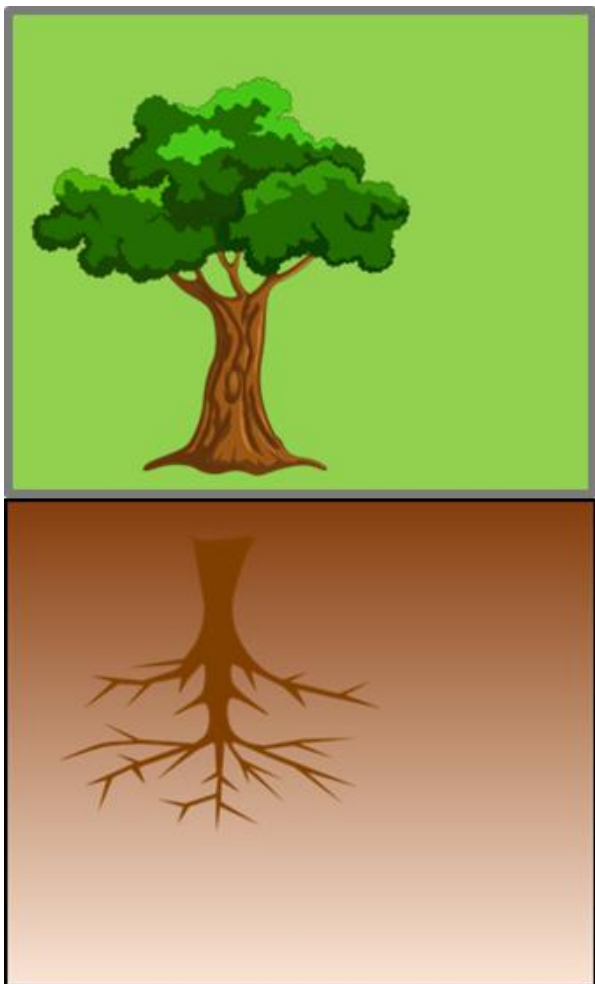**Forest floor (FF)**

Soil organic carbon (SOC)

Effects?

Foresters' tools:
- **thinnings**
- **clear-cuts**
- **intensity of harvests**
- **rotation length**
- **tree species**

<u>Thinnings</u> (or shelterwood): large, and consistent, literature

[Achat et al. (2015) - Sci. Reports; Bravo-Oviedo et al. (2015) - For. Ecol. Manage.; Cheng et al. (2013) - Sci. World J.; Hoover (2011) - Carbon Balance Manage.; Jandl et al. (2007) - Geoderma; Jurgensen et al. (2012) - SSSAJ; Kim et al. (2016) - iForests; Noormets et al. (2015) - For. Ecol. Manage.; Novak & Slodicak (2004) - J. For. Sci.; Powers et al. (2011) - For. Ecol. Manage.; Powers et al. (2012) - Ecol. Appl.; Ruiz et al. (2016) - Mitig. Adapt. Strateg. Glob. Change; Scott et al. (2004) - Environ. Manage.; Skovsgaard et al. (2006) - Scand. J. For. Res.; Vesterdal et al. (1995) - For. Ecol. Manage.; Zhou et al. (2008) - Biogeosciences]

Trees

stand biomass: ↘↘ to ↘
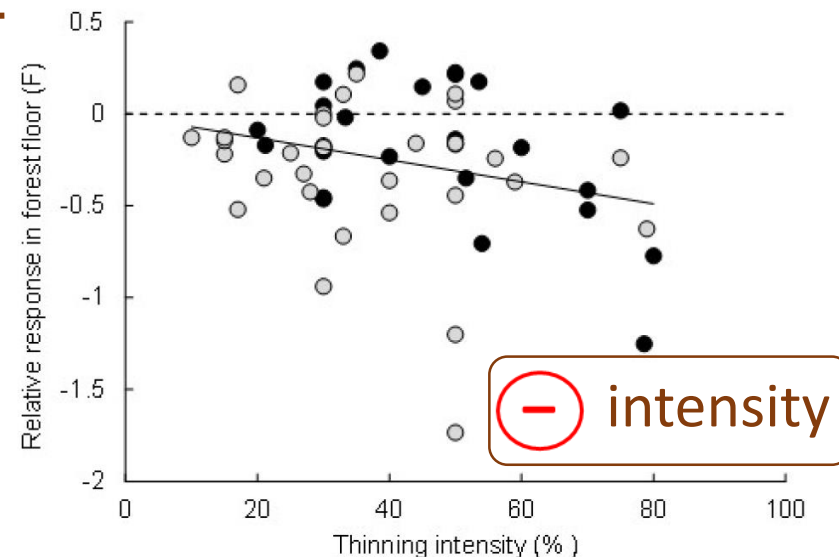growth of remaining trees → to ↗↗

Coarse woody debris (CWD)

↘↘ to →

Forest floor (FF)

→ or ↘

⊖ intensity

Soil organic carbon (SOC)

no significant effect

[Achat et al. (2015) - Sci. Reports]

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**After a thinning a SOC ↘ might be expected:**
- reduced C inputs (litterfall)
- enhanced SOC decomposition?

← **compensation effects**

- rapid recovery of litterfall flux
  (period length = f (intensity))
- ↗↗ understory biomass
- incorporation of harvest residues

[Achat et al. (2015) - Sci. Reports; Jandl et al. (2007) - Geoderma; Jimenez et al. (2011) - Forestry; Novak & Slodicak (2004) - J. For. Sci.; Zhou et al. (2008) - Biogeosciences; Zhou et al. (2016) - Env. Sci. Pollut. Res.]
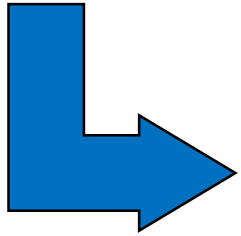
Conclusions:

➤ *"Thinnings don't affect the forest floor, provided that the cutting intensity is low or moderate."*

➤ *"Thinnings don't quantitatively affect the SOC pool."*

<u>Clear-cut</u> (SOH = stem-only harvest): large, and fairly consistent, literature

[Achat et al. (2015) - Sci. Reports; Berg et al. (2009) - Can. J. For. Res.; Busse et al. (2009) - Soil Biol. Biochem. ; Hoover (2011) - Carbon Balance Manage.; Jandl et al. (2007) - Geoderma; Johnson (1992) - WASP; Johnson & Curtis (2011) - For. Ecol. Manage.; Nave et al. (2010) - For. Ecol. Manage.; Noormets et al. (2015) - For. Ecol. Manage.]
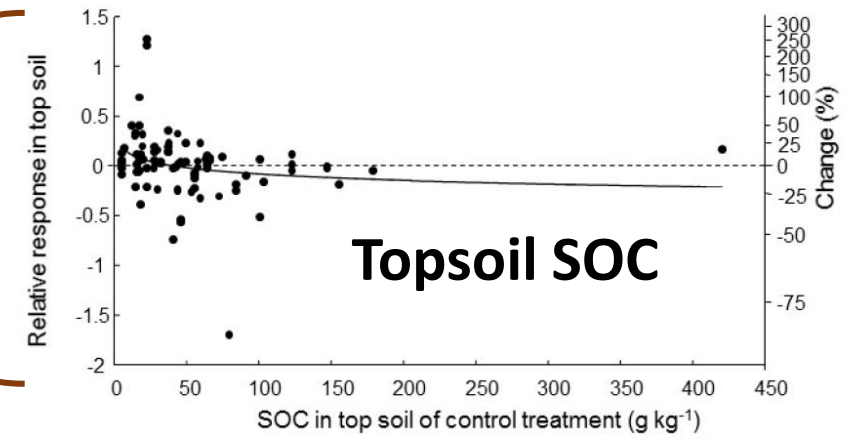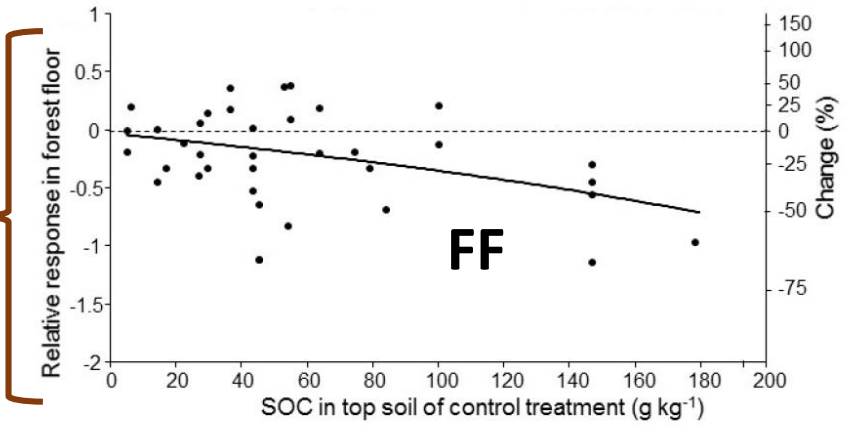

Coarse woody debris (CWD)

stem-only harvests

or ➡, ⊖ initial C pool

FF
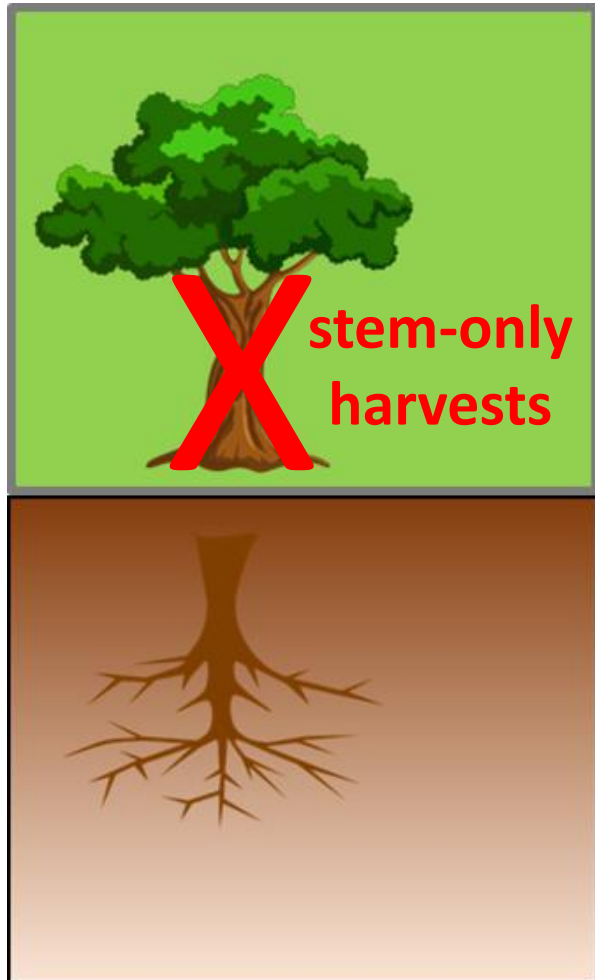
Forest floor (FF)

Topsoil (SOC)

or ➡, ⊖ initial C pool

Topsoil SOC

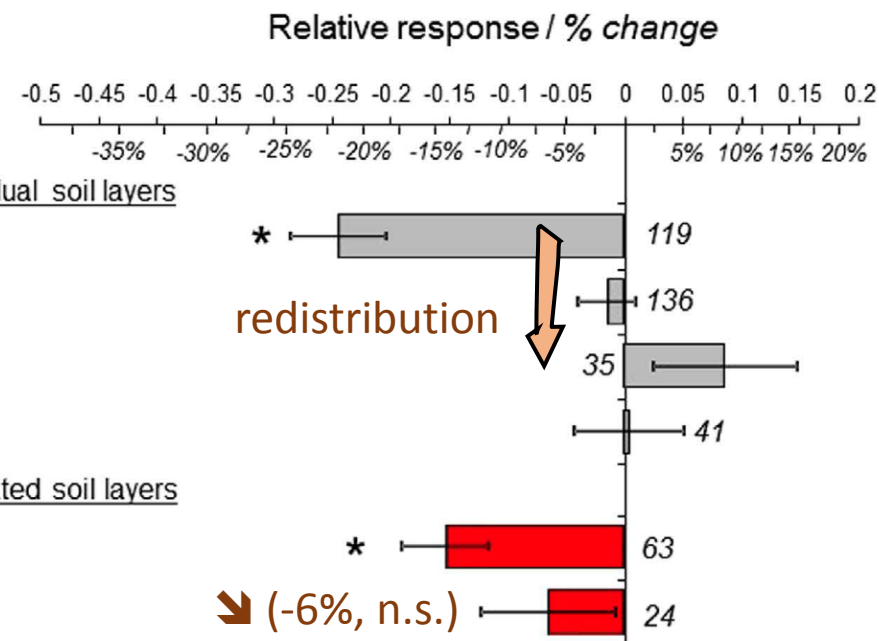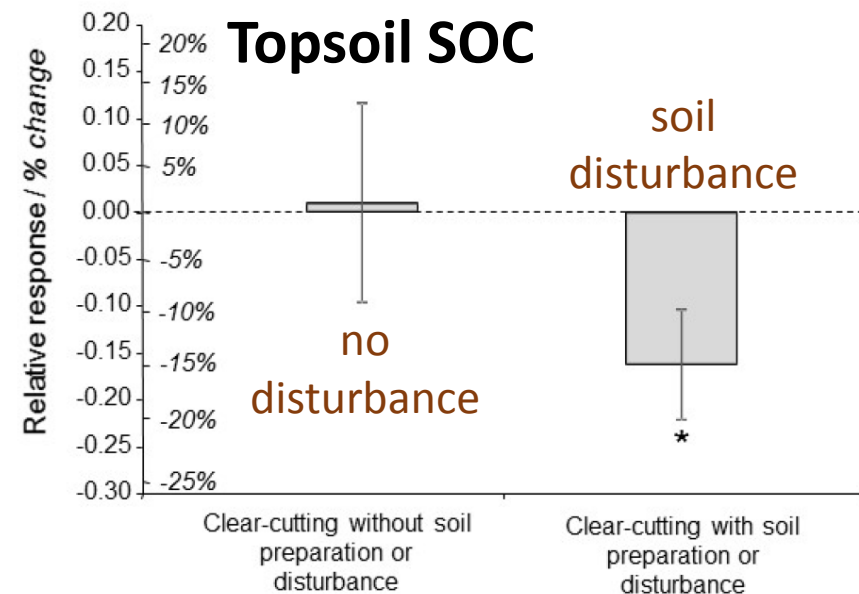[Achat et al. (2015) - Sci. Reports]

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Clear-cut: large, and (fairly) consistent, literature

Topsoil (SOC): losses mainly due to disturbances:
➢ **slash-and-burn** [Dean et al. (2017) - Glob. Change Biol.]
➢ **soil preparation** [Achat et al. (2015) - Sci. Reports; Johnson (1992) - Water Air Soil Pollution]

At the scale of the soil profile (FF + SOC):
➢ **vertical redistribution**
➢ **no/low C losses**
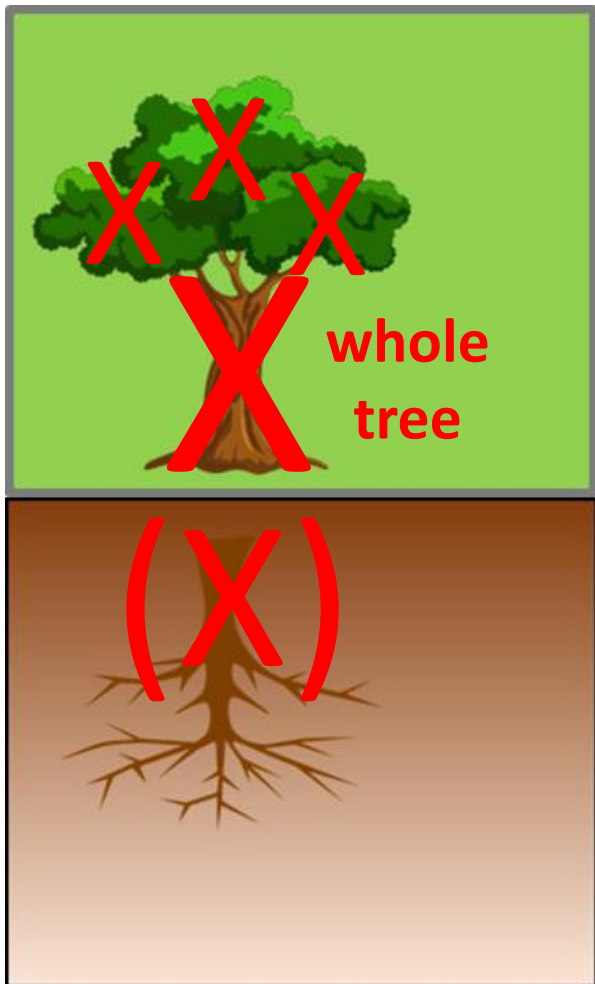[Achat et al. (2015) - Sci. Reports]

<u>Clear-cut</u>: large, and (fairly) consistent, literature

[Achat et al. (2015) - Sci. Reports; Berg et al. (2009) - Can. J. For. Res.; Busse et al. (2009) - Soil Biol. Biochem. ; Hoover (2011) - Carbon Balance Manage.; Jandl et al. (2007) - Geoderma; Johnson (1992) - WASP; Johnson & Curtis (2011) - For. Ecol. Manage.; Nave et al. (2010) - For. Ecol. Manage.; Noormets et al. (2015) - For. Ecol. Manage.]
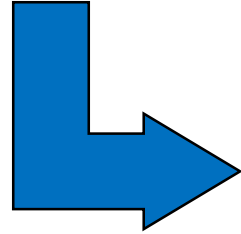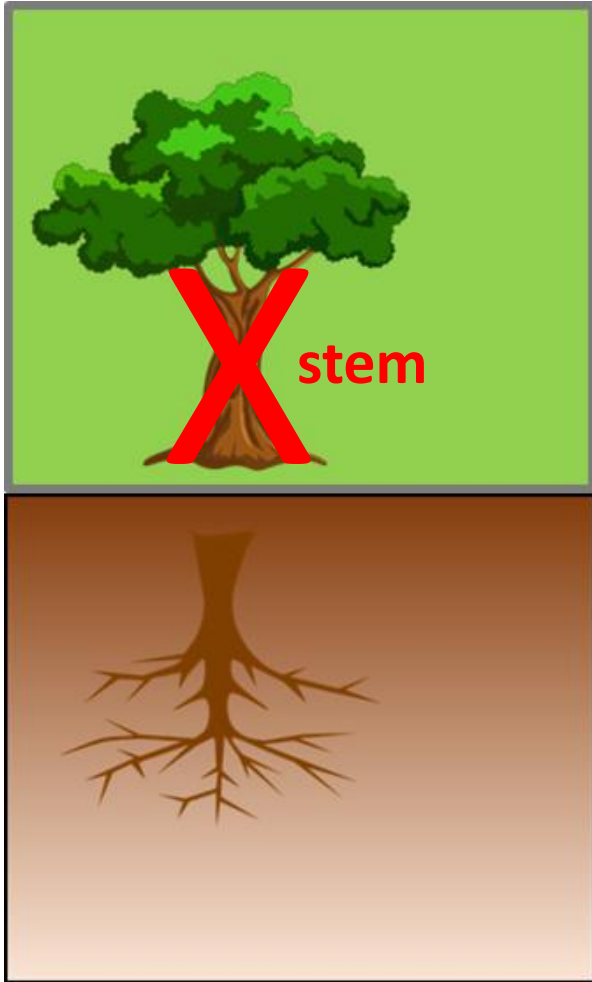
➢ **Clear-cuts based on stem-only harvests generally don't affect soil C sequestration, provided that soils are not disturbed.**

➢ **Risk of C loss increases with the initial size of the C pool.**

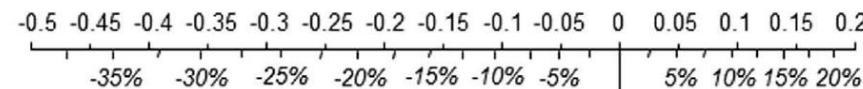# Intensive harvests: "whole-tree harvests"

Coarse woody debris (CWD) ↘↘↘

Forest floor (FF) ↘↘

↘ -11%

All soil layers (SOC) ↘ or →

Individual soil layers

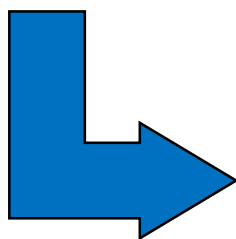Forest floor (F)
Top soil (T)
Mid soil (M)
Deep soil (D)

**C losses at all depths (mainly FF)**

[Achat et al. (2015) - Sci. Reports]

↘ ⊕ climate (MAT, ETR)

> **Intensive harvests negatively affect soil C pools.**

> **The C budget of fuelwood is reduced by SOC losses, but may remain slightly positive.** [Pukkala (2014) - For. Policy Economics]

Rotation length (→ "old-growth"): not so clear

[Ji et al. (2017) - Sci. Reports; Leuschner et al. (2014) - Ecosystems; Luyssaert et al. (2008) - Nature; Naudts et al. (2016) - Science; Seely et al. (2002) - For. Ecol. Manage.; Wang (W.) et al. (2013) - For. Ecol. Manage.; Zhou (G.) et al. (2006) - Science]
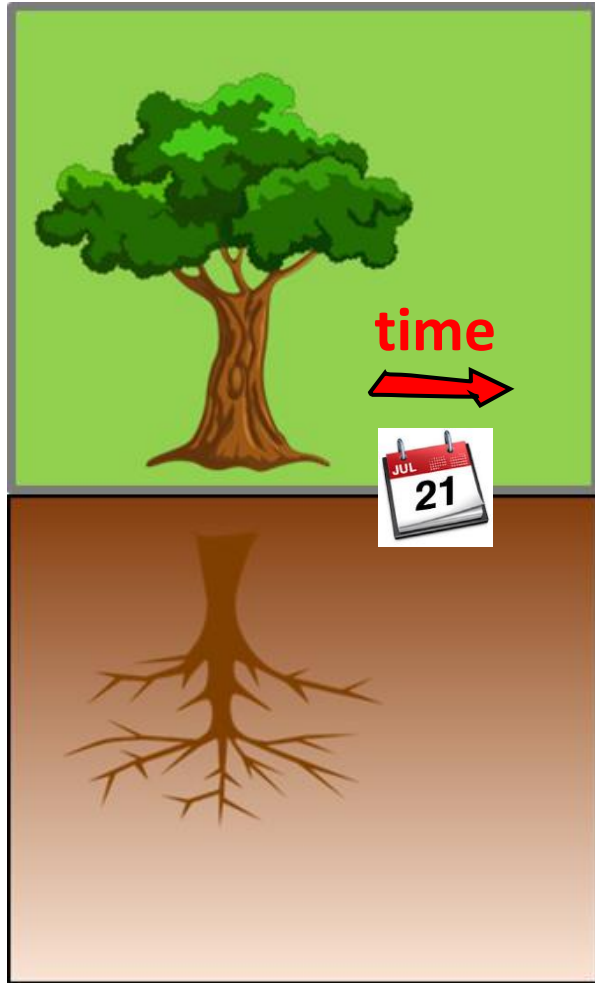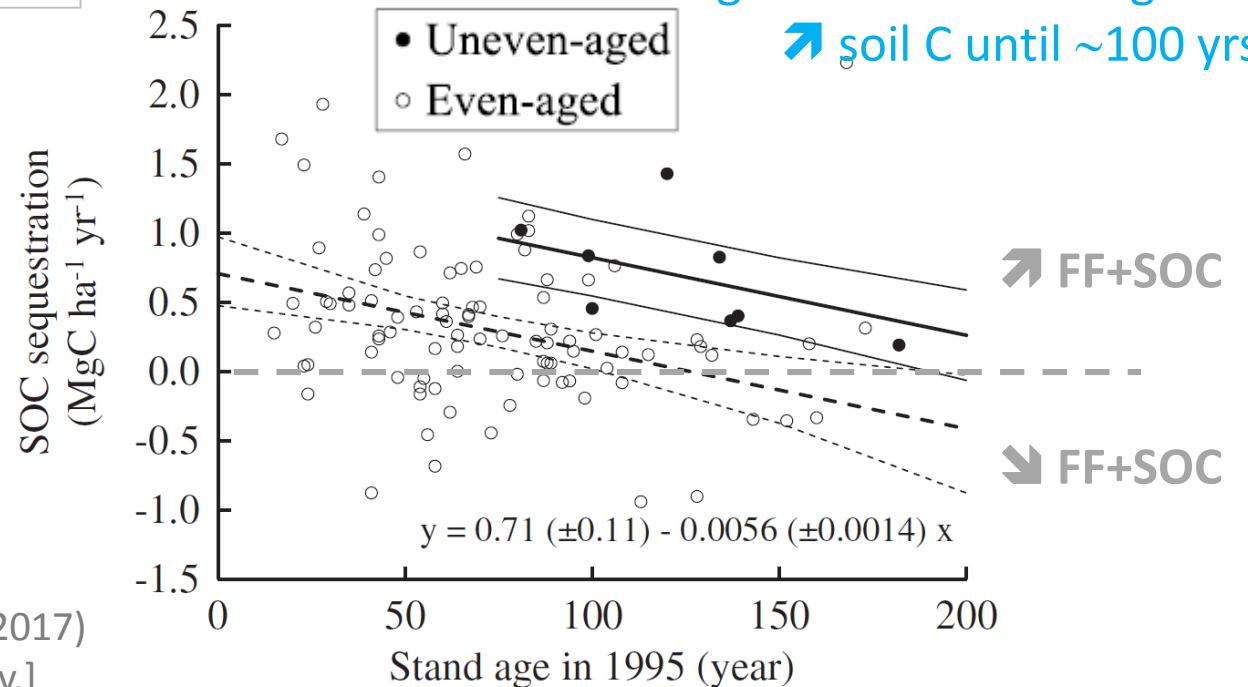
Biomass

↗ (even in old-growth forests)

❓ mean effect of major disturbances
(fire, windthrow, pest, drought, ...)

time

Forest floor (FF) + Soil (SOC)

inconsistent results: ↗ or →

e.g.French monitoring network:
↗ soil C until ~100 yrs

↗ FF+SOC

↘ FF+SOC
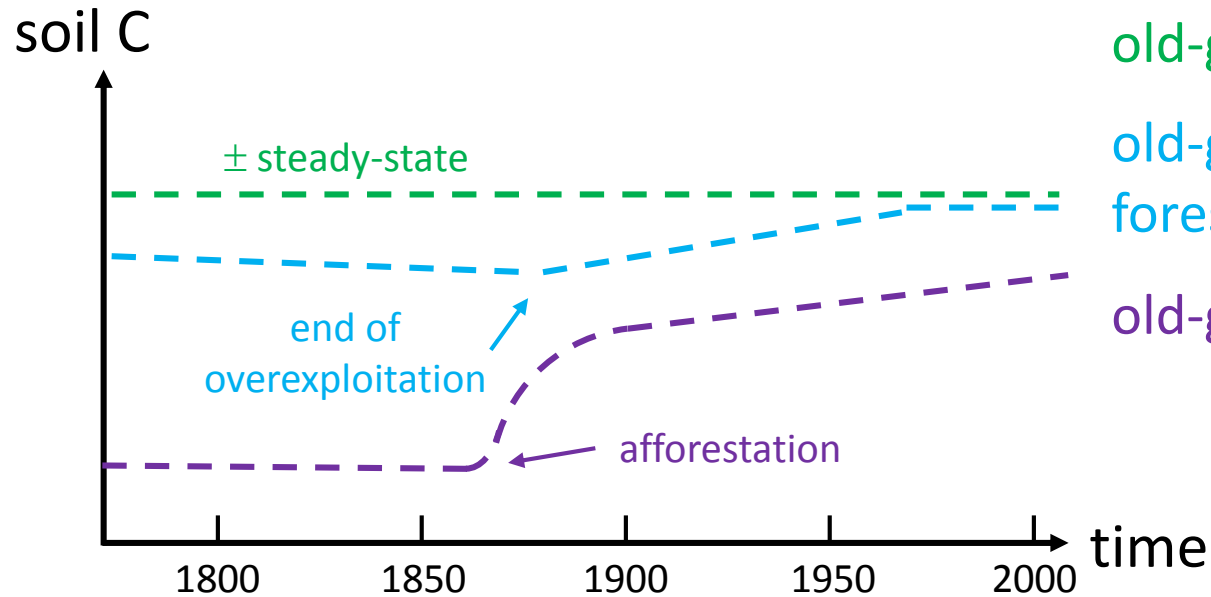
$y = 0.71\ (\pm 0.11) - 0.0056\ (\pm 0.0014)\ x$

[Jonard et al. (2017) - Sci. Tot. Env.]

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Rotation length (→ "old-growth"): not so clear

Hypothesis = the effect of old-growth forestry depends on <u>forest history</u>:
SOC = f (past-land use, past forestry, past disturbances)

soil C

± steady-state

end of overexploitation

afforestation

1800   1850   1900   1950   2000   time

old-growth in <u>ancient</u> (> 200 yrs), <u>undisturbed</u>, forests

old-growth in <u>ancient</u>, but <u>formally overexploited</u>, forests (French network case?)

old-growth in <u>recent</u> forests (< 200 yrs; formally croplands)

➢ **Increasing the rotation length –and tending toward old-growth forests– can improve soil C pools in the long-term (up to 50-100 yrs?).**

➢ **In the very long-term (> 100-200 yrs?), the incremental soil C sequestration may be negligible (depending of forest history?).**

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<u>Tree species</u> (identity & biodiversity): in brief ⇔ see other talks

[Augusto et al. (2014) – Ecol. Letters; Augusto et al. (2015) - Biol. Reviews; Boca et al. (2014) – SSSAJ; Brunel et al. (2017) - Sci. Total Env.; Dawud et al. (2016) - Ecosystems; Dawud et al. (2017) - Func. Ecol.; Gahagan et al. (2015) - For. Ecol. Manage.; Hulvey et al. (2013) - Nature Climate Change; Sullivan et al. (2017) - Sci. Reports; Wang (H.) et al. (2013) - For. Ecol. Manage.; Wiesmeier et al. (2013) - For. Ecol. Manage.]
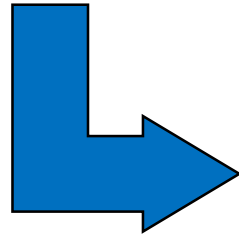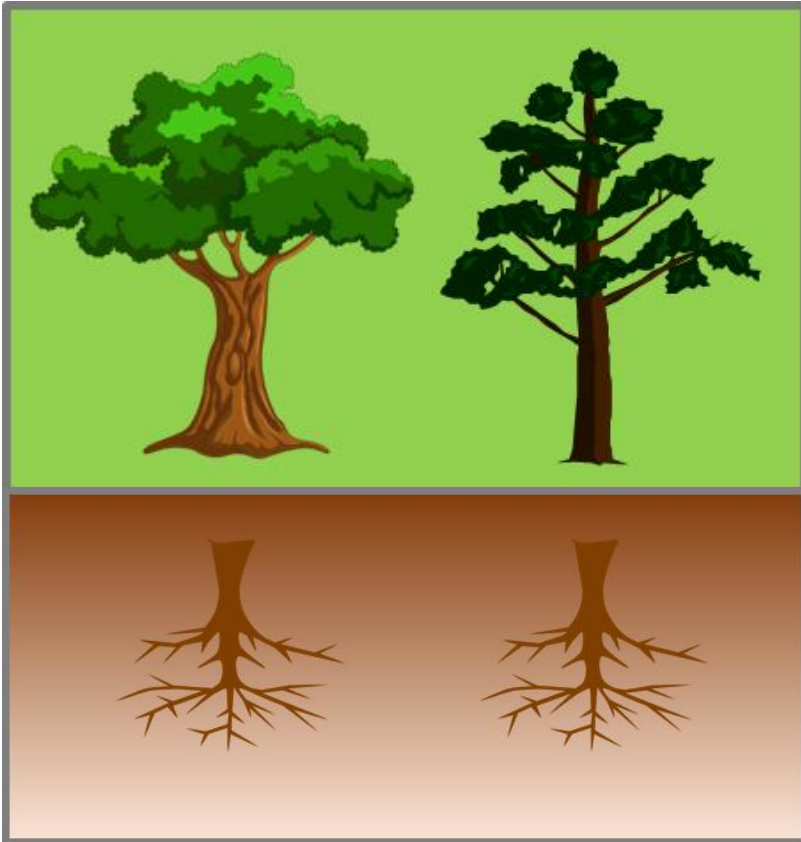
➤ **Many uncertainties remain.**

➤ **Species identity is generally a stronger driver than species diversity.**

➤ **Functional diversity (i.e. conifer, N-fixers, …) may better explain the observed trends than species diversity.**

Synthesis

Foresters' main tools:

- **thinnings** (SOH) — n.s. ⊗ initial size of C pools

- **clear-cuts** (SOH)
  - without soil disturbance — n.s. ⊗ initial size of C pools
  - with soil disturbance — ⊖

- **stand density** — ❓ - - - - - - - - research needed 🔒

- **intensive harvests** (WTH) — ⊖ ⊗ climate

- **rotation length** — ⊕ ⊗ forest history research needed 🔒

- **tree species**
  - identity — ❓
  - diversity — ❓ } - - - - - - research needed 🔒

**Sequestration** (soil)

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Personal proposal

My question was: "*Is it possible to maintain/increase soil carbon content while still harvesting biomass for storage/substitution processes?*"

➤ **My answer is based on two premises:**

¤ **increment rate of soil C** increases with decreasing initial C pool size

¤ **soil C losses** increase with increasing initial C pool size

[Achat et al. (2015) - Sci. Reports; Boulmane et al. (2017) - Ann. For. Sci.; Cook et al. (2016) - For. Ecol. Manage.; Li et al. (2012) - New Phytol.; Moradi et al. (2017) - iForests; Poeplau et al. (2011) - Glob. Change Biol.; Smith et al. (1997) - Glob. Change Biol.; Wei et al. (2014) - Sci. Reports; Zheng et al. (2008) - For. Ecol. Manage.]
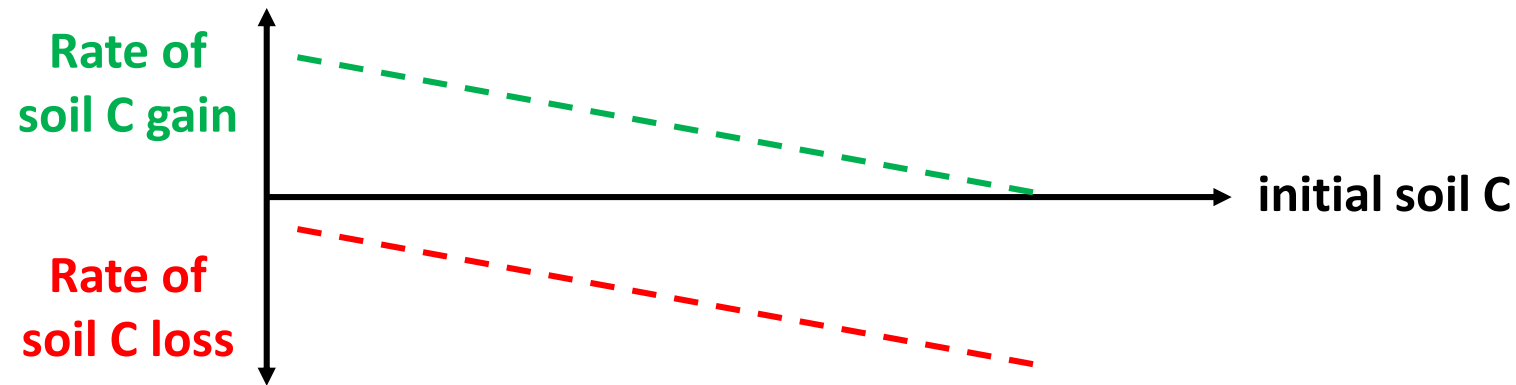
➤ **Proposal = "*when possible, win on all fronts*"** [≈ Bellassen & Luyssaert (2014) – Nature]

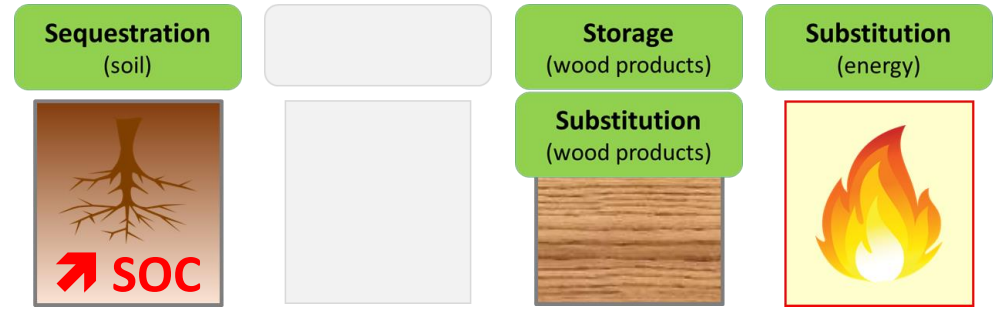⇔ in poor-C soils, increase soil C pool <u>and</u> harvest biomass.

in rich-C soils, maintain the soil C pool and maintain some harvests.

> **Poor-C soils** (e.g. afforested degraded soils)
>> ¤ **fast-growing species**
>> ¤ **intensive forestry**

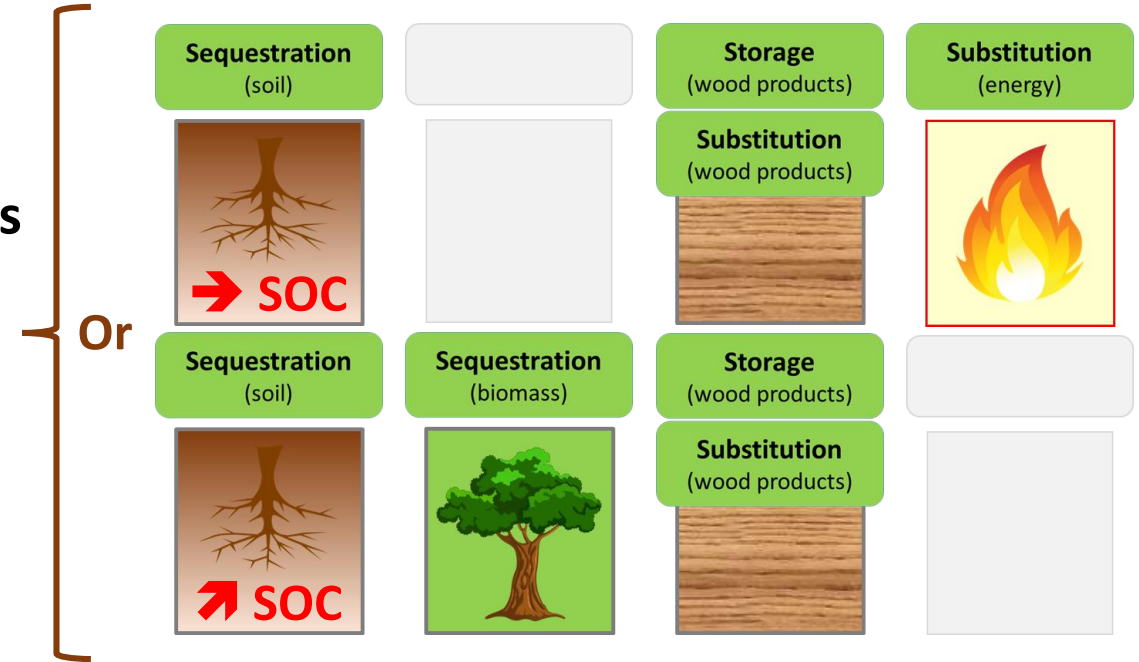[e.g. Boulmane et al. (2017) - Ann. For. Sci.; Cook et al. (2016) - For. Ecol. Manage.]

> **Intermediate-C soils** (e.g. ± disturbed forests)
>> ¤ **if intensive harvest, don't collect all biomass**
>> ¤ **increase soil fertility** (e.g. N-fixers)
>> ¤ **limit soil disturbances**

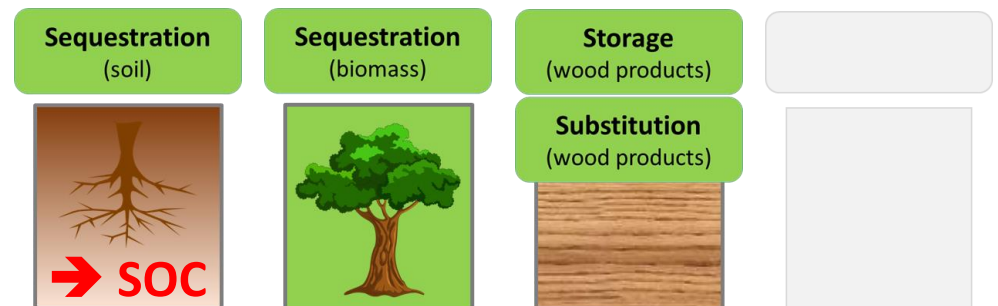[e.g. Janssens et al. (2010) - Nature Geosci.; Johnson & Curtis (2011) - For. Ecol. Manage.]

> **Rich-C soils** (e.g. ancient forests)
>> ¤ **continuous-cover forestry**
>> ¤ **no soil disturbance during harvests**

[D'Amato et al. (2011) - For. Ecol. Manage.; Thornley & Cannell (2000) - Tree Physiol.]
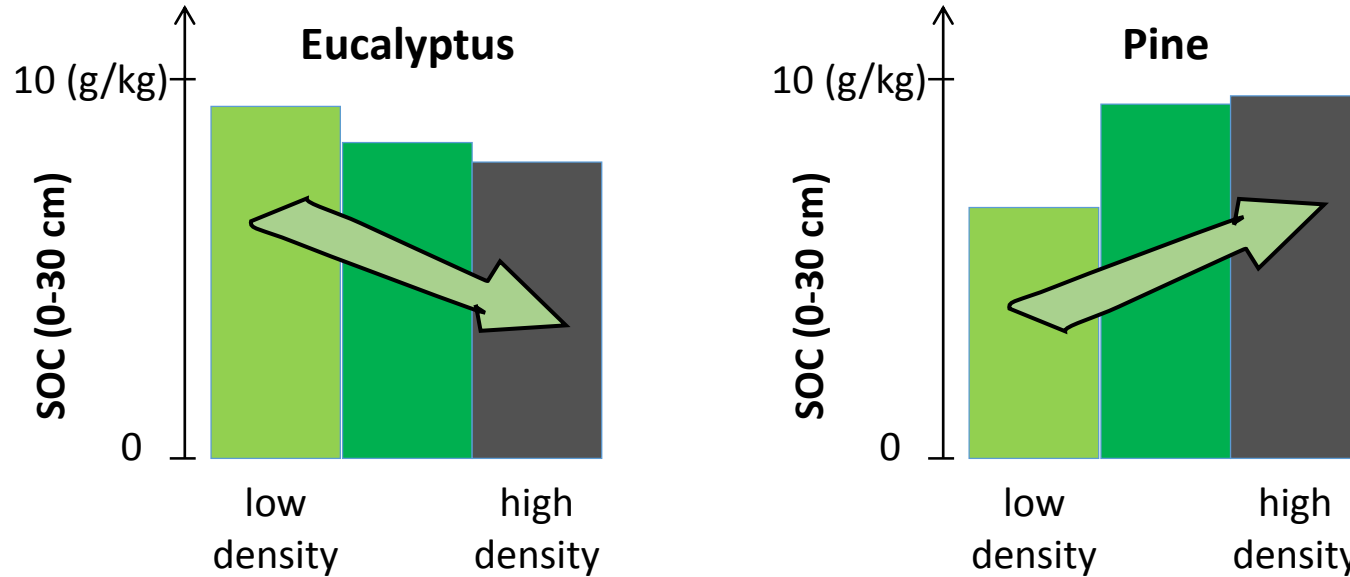
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"*when possible, win on all fronts*"

➢ **Use SOC as a management indicator**

➢ **Take into account:** **climate**

forest history

regional wood economy

Additional slides

Stand density: small, and inconsistent, literature

- **No effect:** Wang (W.) et al. (2013) - For. Ecol. Manage.

- **Conflicting results:** Hernandez et al. (2016) - For. Ecol. Manage.

> ➤ **There are probably many density trials and many unpublished data, but there are not sufficiently published/visible.**

> ➤ **The best trade-off of stand density between SOC sequestration and resistance/resiliency to drought stress** [Sohn et al. (2016) - For. Ecol. Manage.] **is still not well defined.**

<u>Tree species</u> (identity & biodiversity): **many uncertainties**

[Augusto et al. (2014) – Ecol. Letters; Augusto et al. (2015) - Biol. Reviews; Boca et al. (2014) – SSSAJ; Brunel et al. (2017) - Sci. Total Env.; Dawud et al. (2016) - Ecosystems; Dawud et al. (2017) - Func. Ecol.; Gahagan et al. (2015) - For. Ecol. Manage.; Hulvey et al. (2013) - Nature Climate Change; Sullivan et al. (2017) - Sci. Reports; Wang (H.) et al. (2013) - For. Ecol. Manage.; Wiesmeier et al. (2013) - For. Ecol. Manage.]
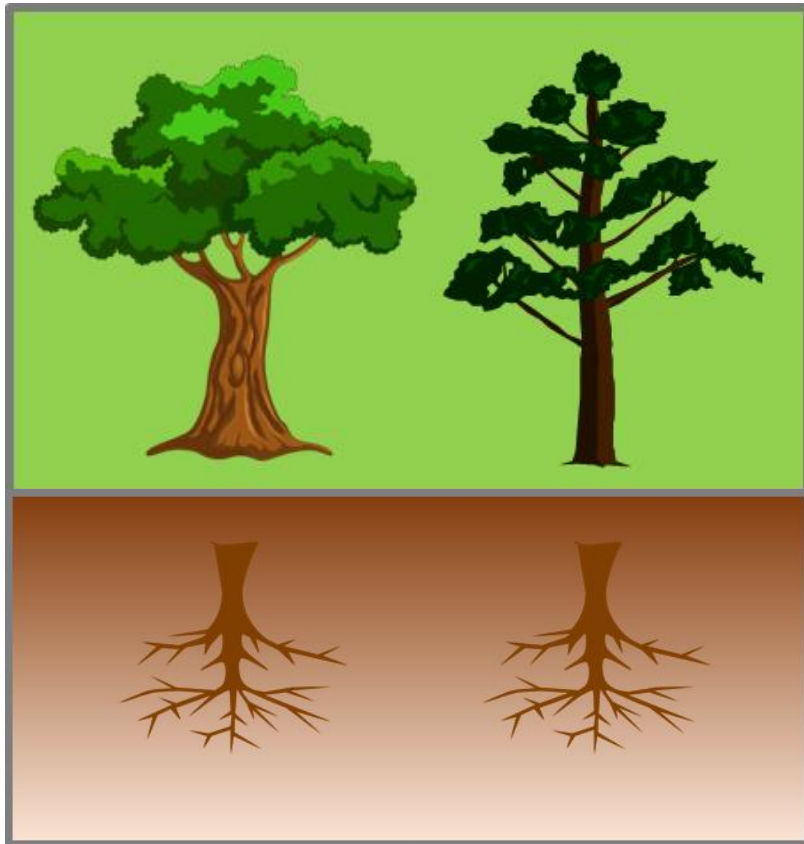
Biomass

rich sites: hardwoods $\geq$ conifers
poor sites: hardwoods $\leq$ conifers

biodiversity effect = inconsistent
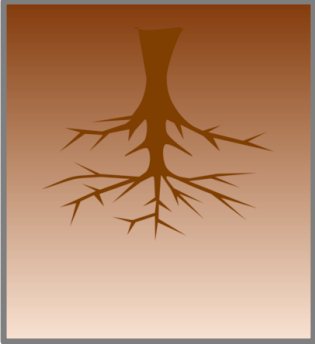*biodiversity effect = f (functional groups)*

Forest floor (FF)
and
Soil organic C

FF: hardwoods << conifers
but FF+SOC: ❓ no clear trend

biodiversity effect = inconsistent (↗ or ➡)
biodiversity effect = f (functional groups)

 # Synthesis

Foresters' main tools:

	Sequestration (soil)	**Sequestration** (biomass)	**Storage** (wood products) / **Substitution** (wood products)	**Substitution** (energy)
- thinnings (SOH)	**n.s.** (low-moderate intensity) ⚠ **initial size of C pools**	⊖	⊕	
- clear-cuts (SOH)	⚠ **initial size of pools**			
➤ without soil disturbance	**n.s.**	⊖ ⊖	⊕ ⊕	
➤ with soil disturbance	⊖			
- stand density	◇?			

Synthesis

Foresters' main tools:
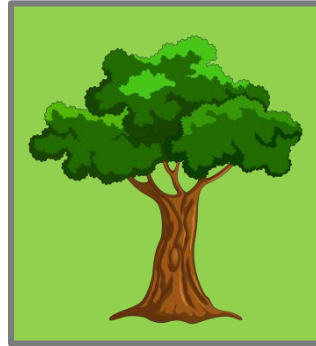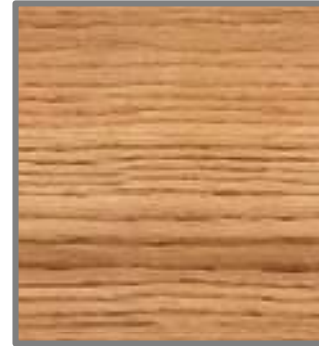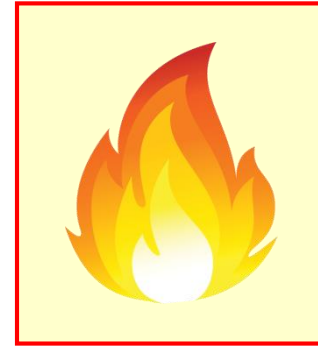
	Sequestration (soil)	Sequestration (biomass)	Storage (wood products) / Substitution (wood products)	Substitution (energy)
- intensive harvests (WTH)	⊖ ❗ climate	⊖ ⊖	⊕ ⊕	⊕
- rotation length	⊕ ❗ forest history	⊕ ❗ major disturbances		
- tree species ➢ identity ➢ diversity	◇? ◇? } research needed 🔒			