Impact of forest management on organic carbon sequestration in soils

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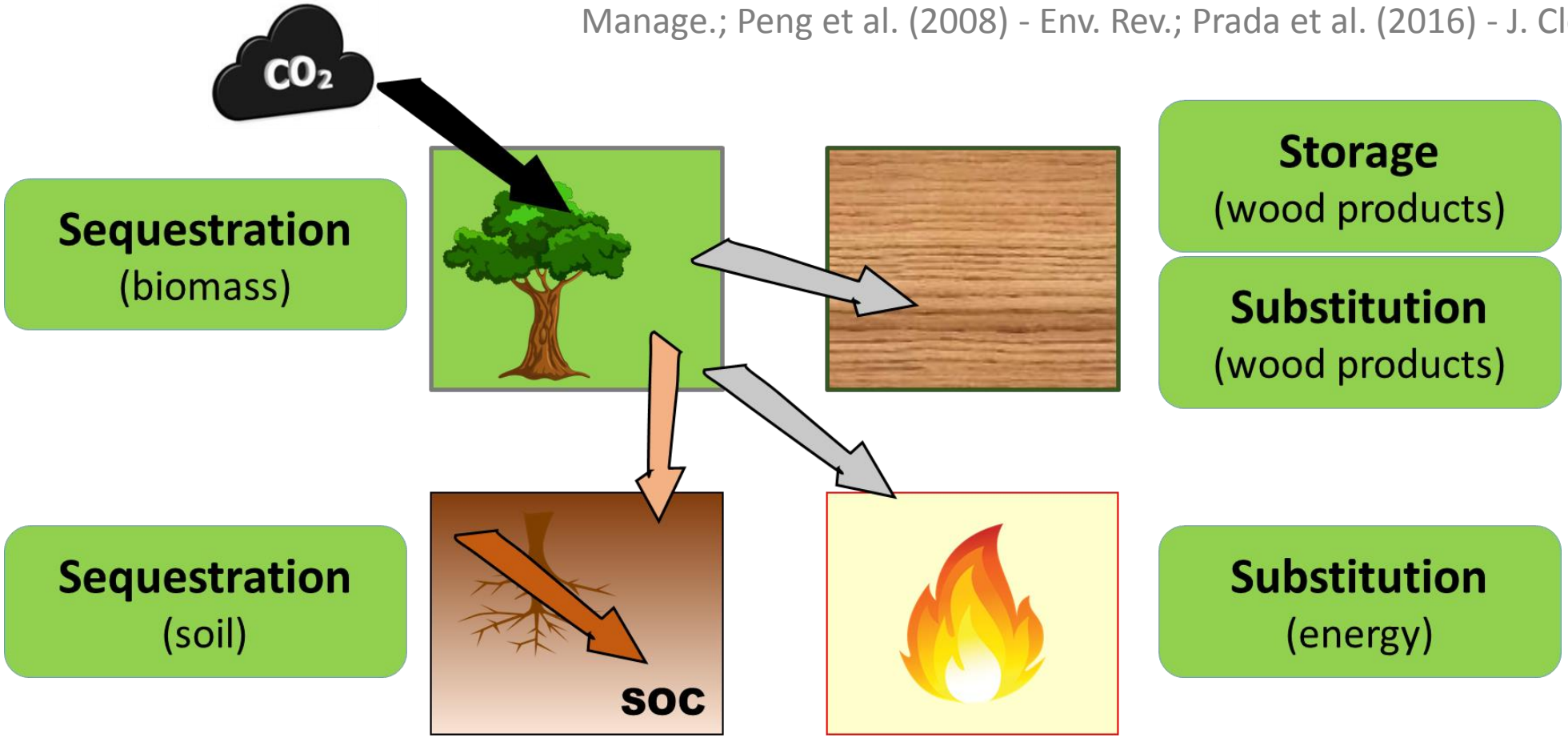
Presentation available at:
www.researchgate.net/profile/Laurent_Augusto

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.]

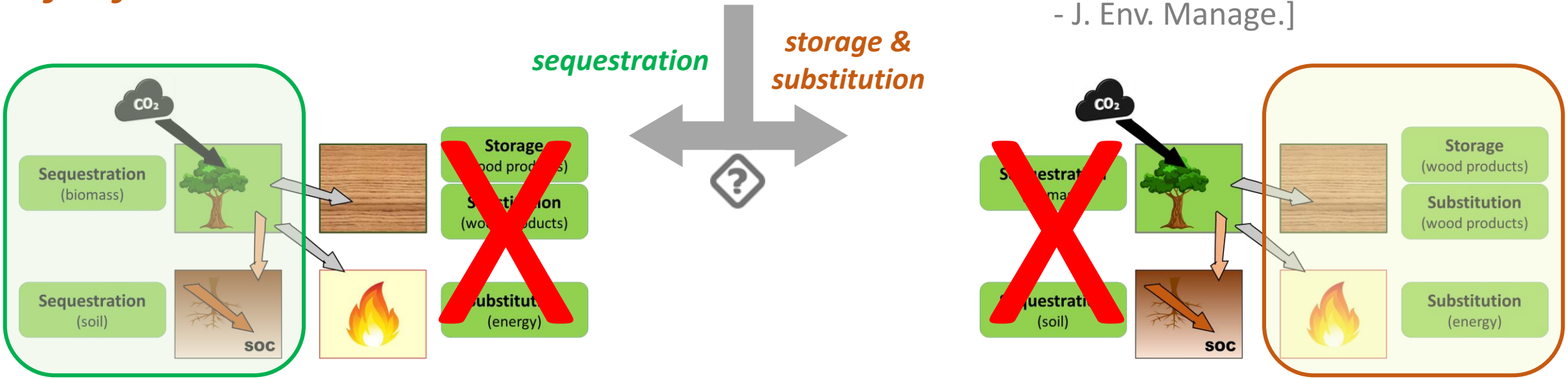


But determining what is the best strategy to optimize mitigation is hotly debated.

[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

[adapted from Taeroe et al. (2017) - J. Env. Manage.]



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

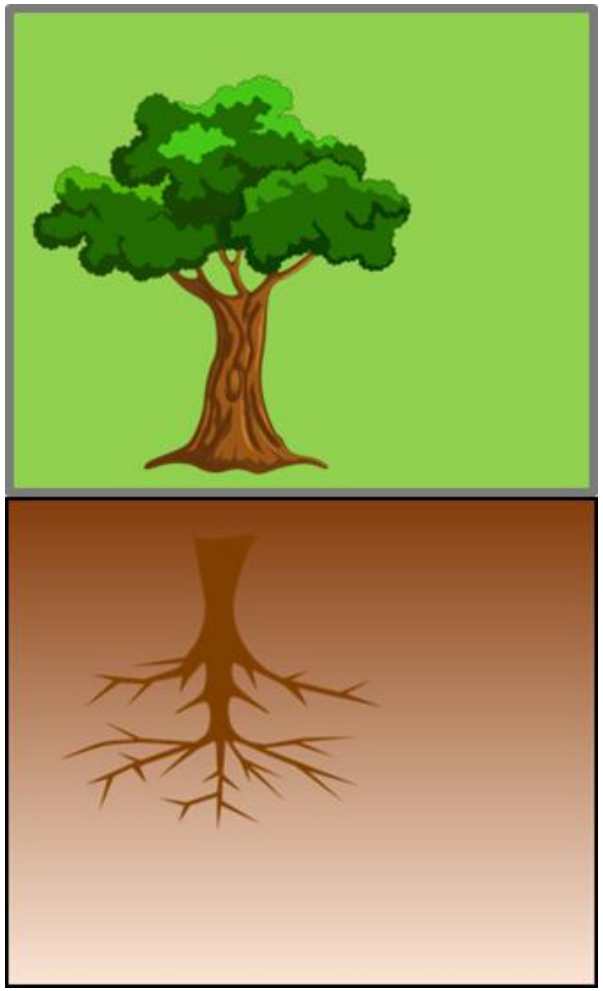
No unique answer because simulations are difficult to perform and are very sensitive to the many assumptions, or variables, needed
(energy conversion coefficients, type of fossil fuel considered during substitution, materials considered for wood products, assumptions about the long-term steady-state 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)

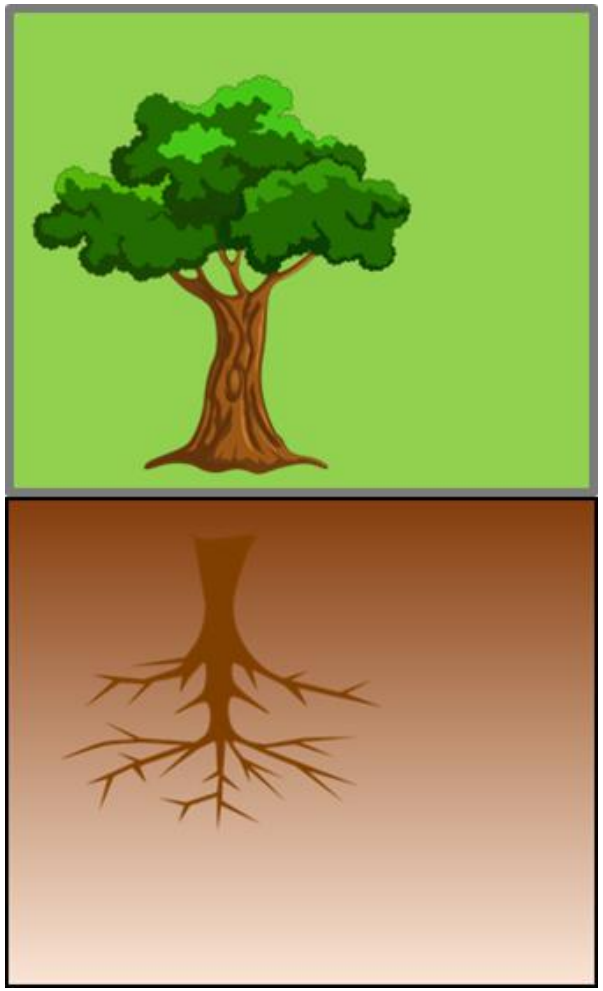
Vulnerability

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)

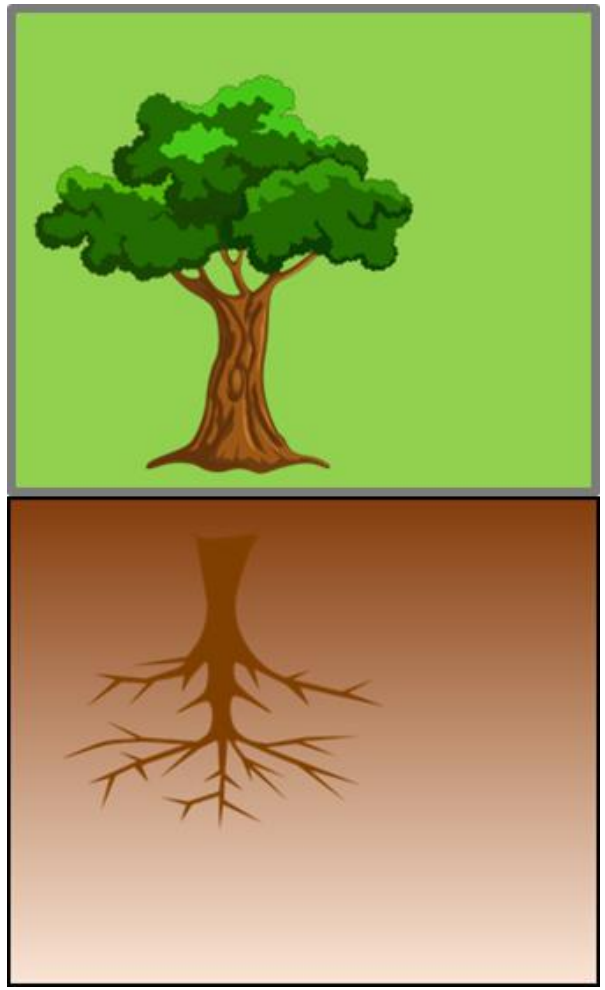
Effects?

Foresters' tools:

- thinnings
- clear-cuts
- intensity of harvests
- rotation length
- tree species

Thinnings (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)

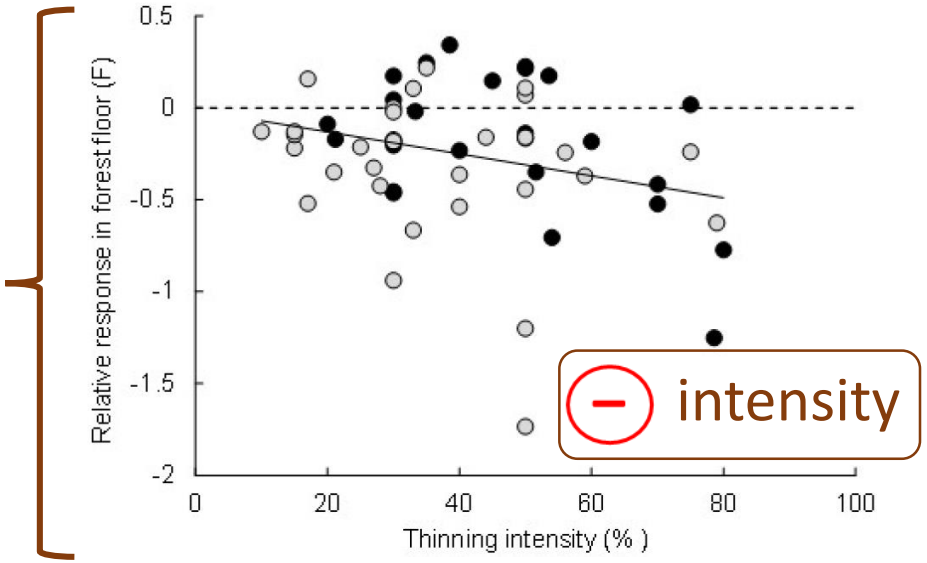
↘↘ to ➔

Forest floor (FF)

➔ or ↘

Soil organic carbon (SOC)

no significant effect



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

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.]

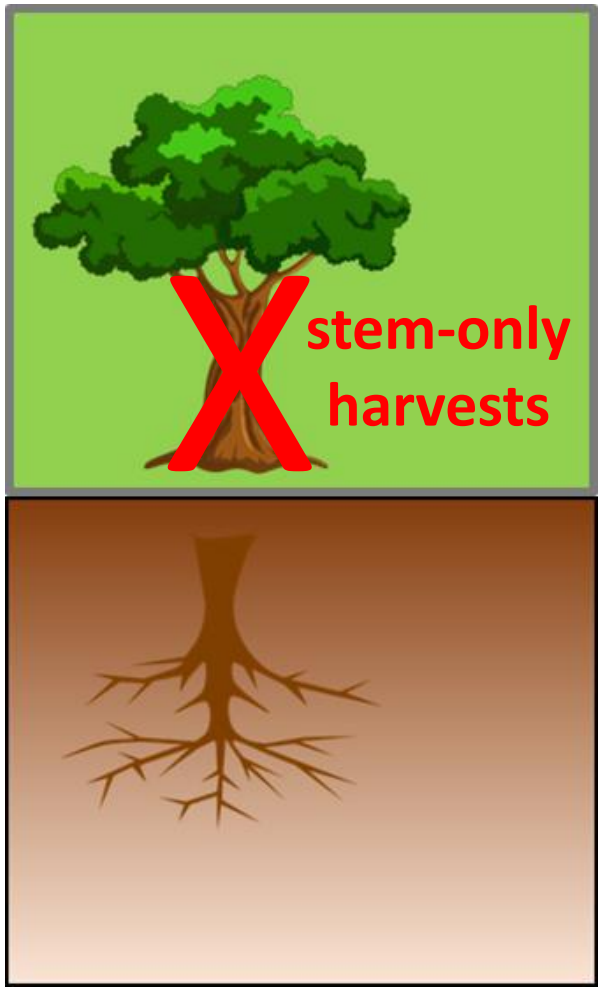
Conclusions:

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

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

Clear-cut (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.]



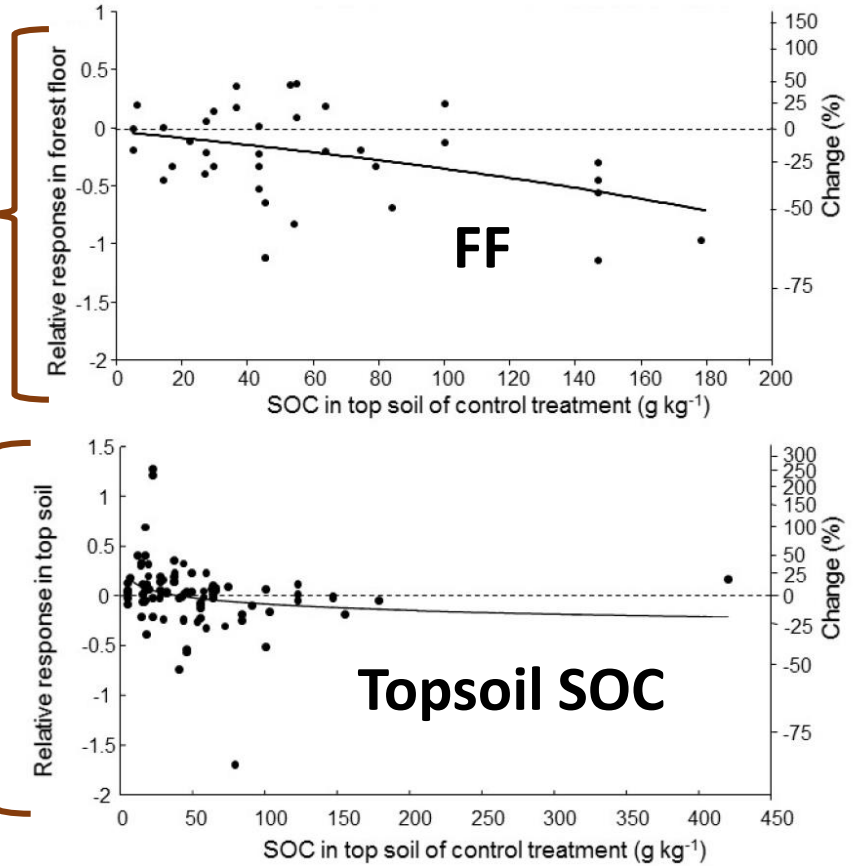
Coarse woody debris (CWD) ↘↘

↘↘ or →, (−) initial C pool

Forest floor (FF)

Topsoil (SOC)

↘ or →, (−) initial C pool

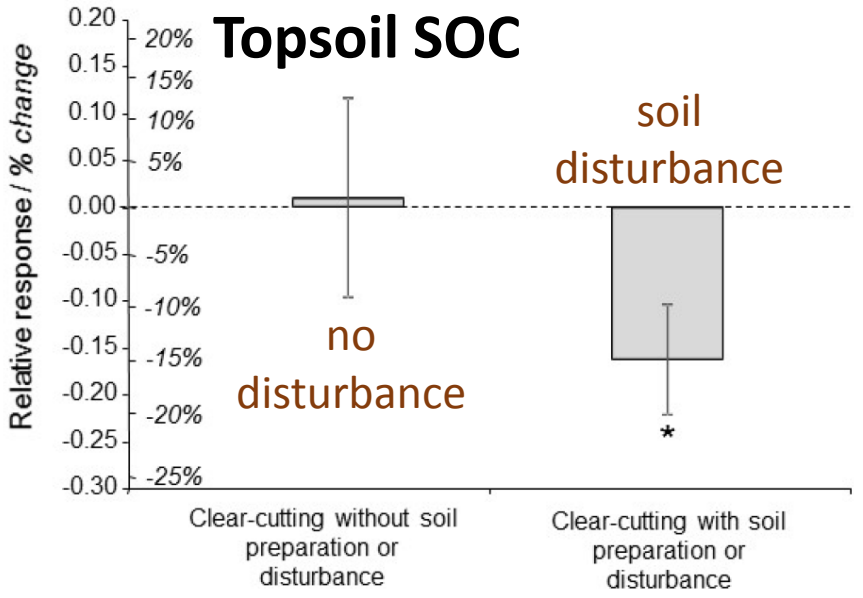


[Achat et al. (2015) - Sci. Reports]

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

Topsoil (SOC): losses mainly due to disturbances:

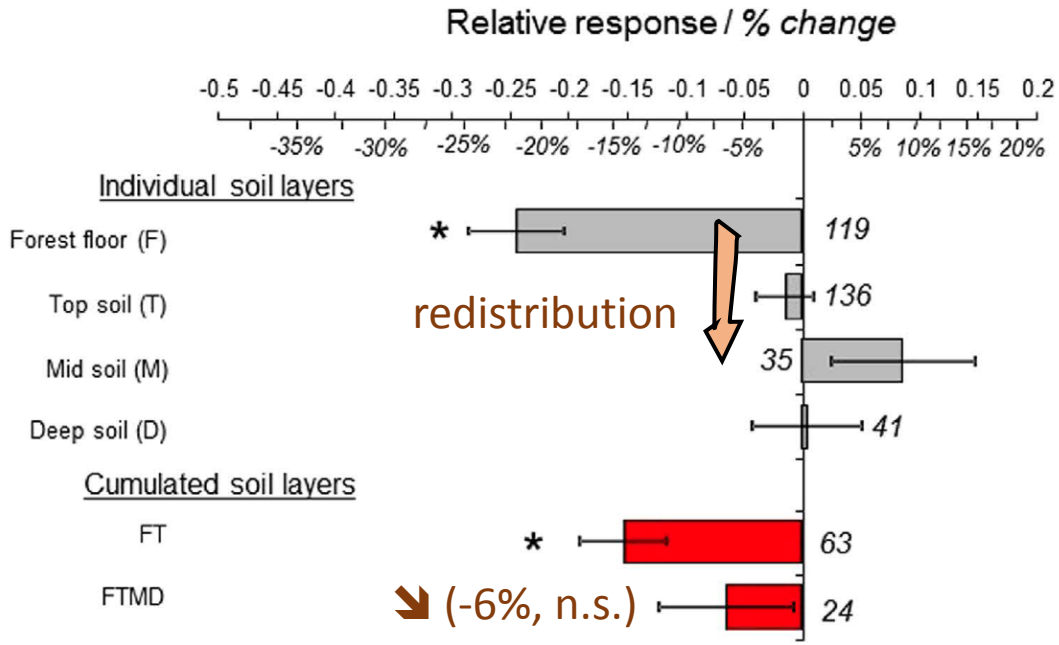
- **slash-and-burn** [Dean et al. (2017) - Glob. Change Biol.]
- **soil preparation** [Achat et al. (2015) - Sci. Reports; Johnson (1992) - Water Air Soil Pollution]



At the scale of the soil profile (FF + SOC):

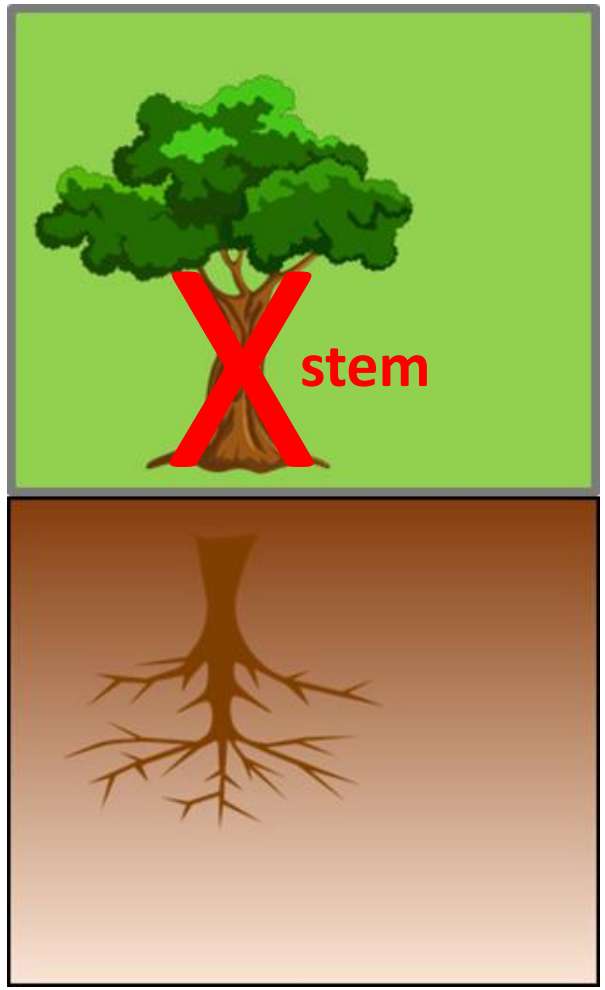
- **vertical redistribution**
- **no/low C losses**

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



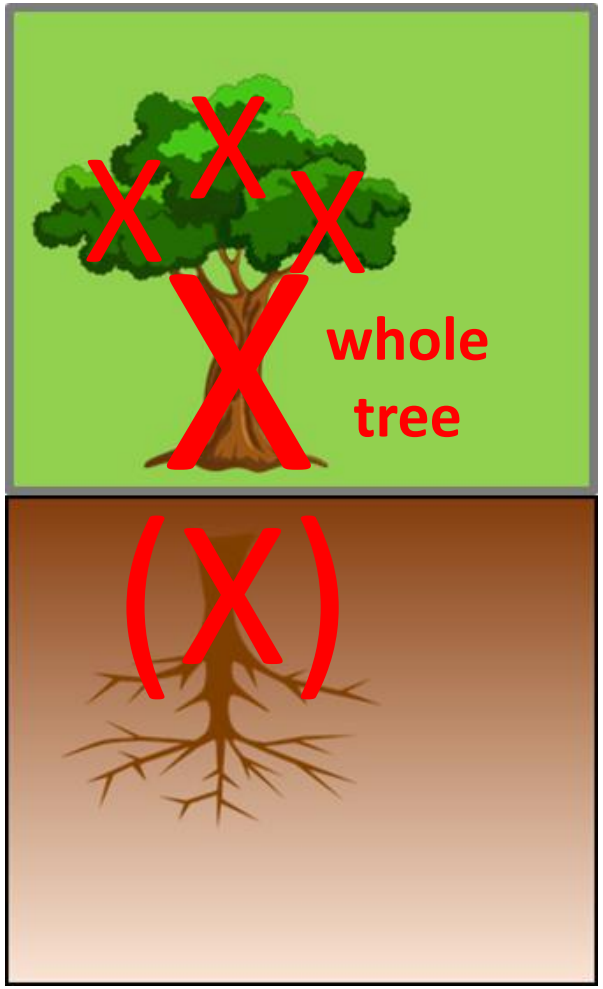
Clear-cut: large, and (fairly) consistent, literature

[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”

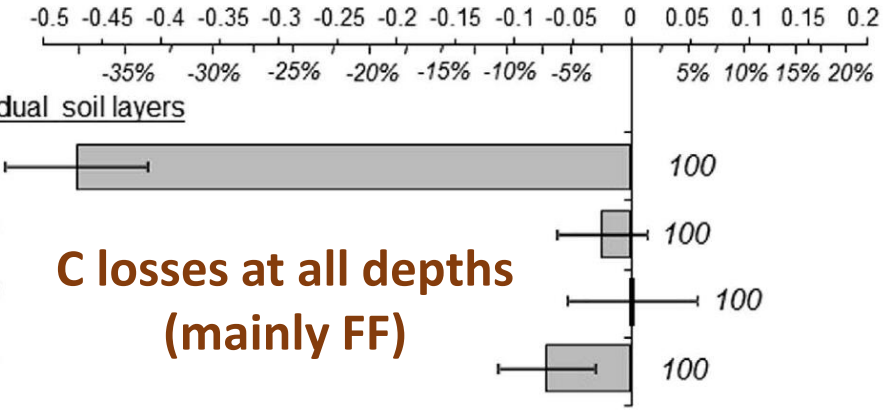


Coarse woody debris (CWD) ↘↘↘

Forest floor (FF) ↘↘

↘ -11%

All soil layers (SOC) ↘ or →



C losses at all depths (mainly FF)

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

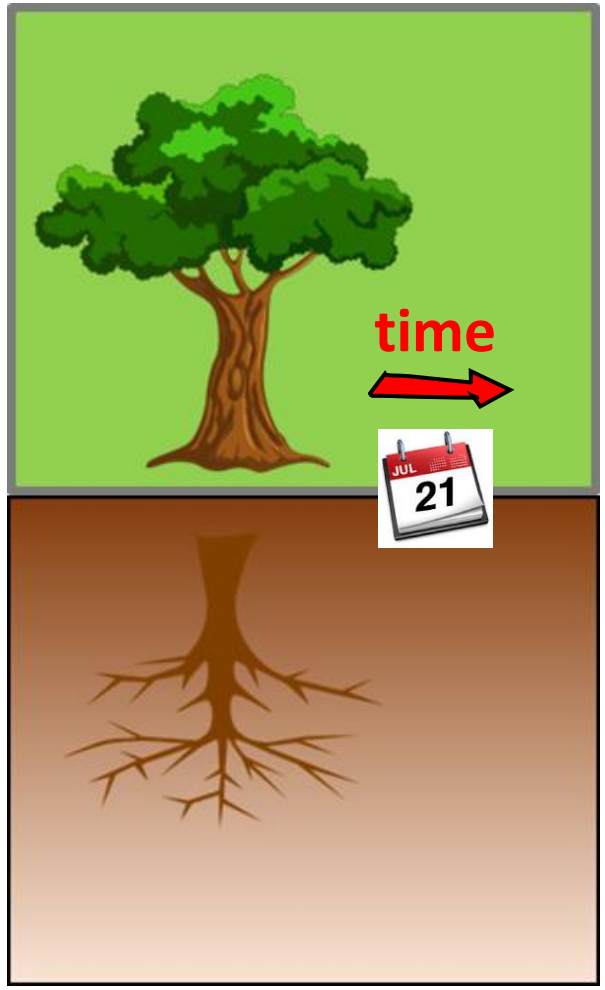
↘ (+) climate (MAT, ETR)

➢ **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

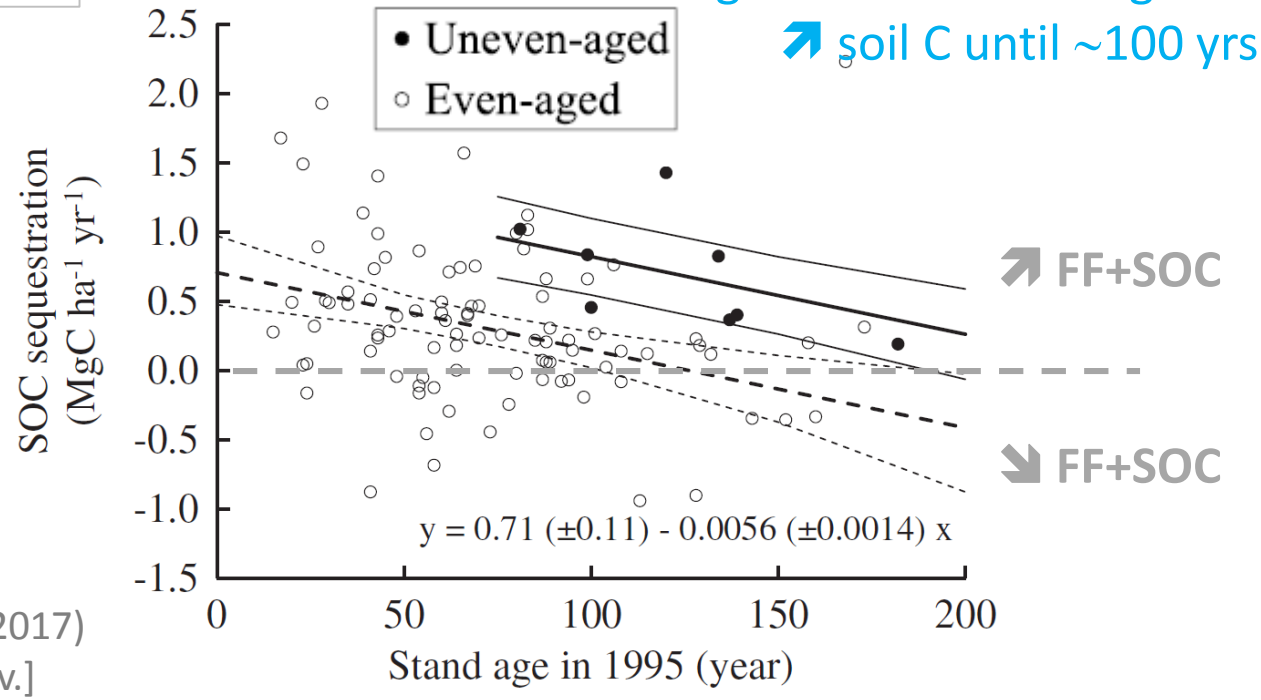
↗ (even in old-growth forests)

? mean effect of major disturbances
(fire, windthrow, pest, drought, …)

Forest floor (FF) + Soil (SOC)

inconsistent results: ↗ or →

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

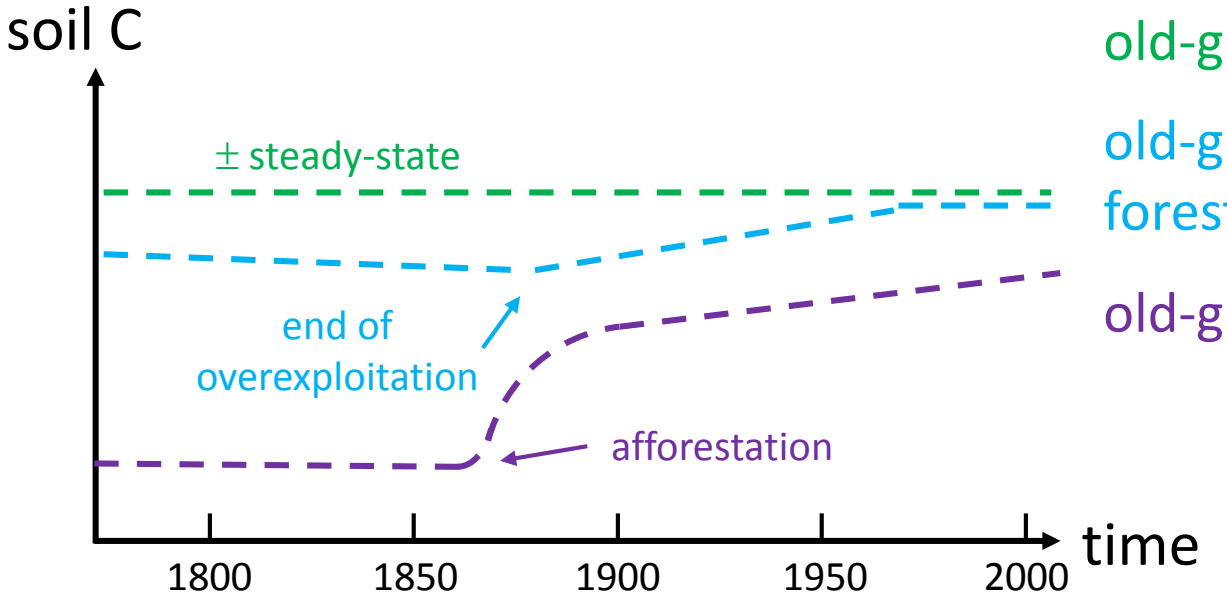


[Jonard et al. (2017) - Sci. Tot. Env.]

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

Hypothesis = the effect of old-growth forestry depends on forest history:

SOC = *f* (past-land use, past forestry, past disturbances)



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

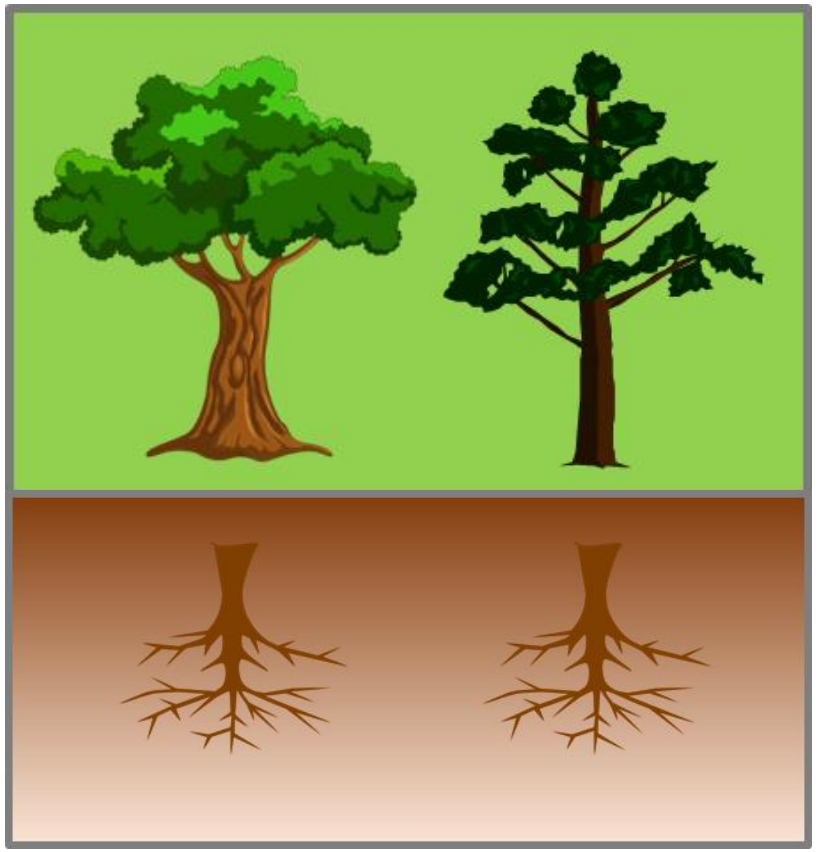
old-growth in ancient, but formally overexploited, forests (French network case?)

old-growth in recent 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?).**

Tree species (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

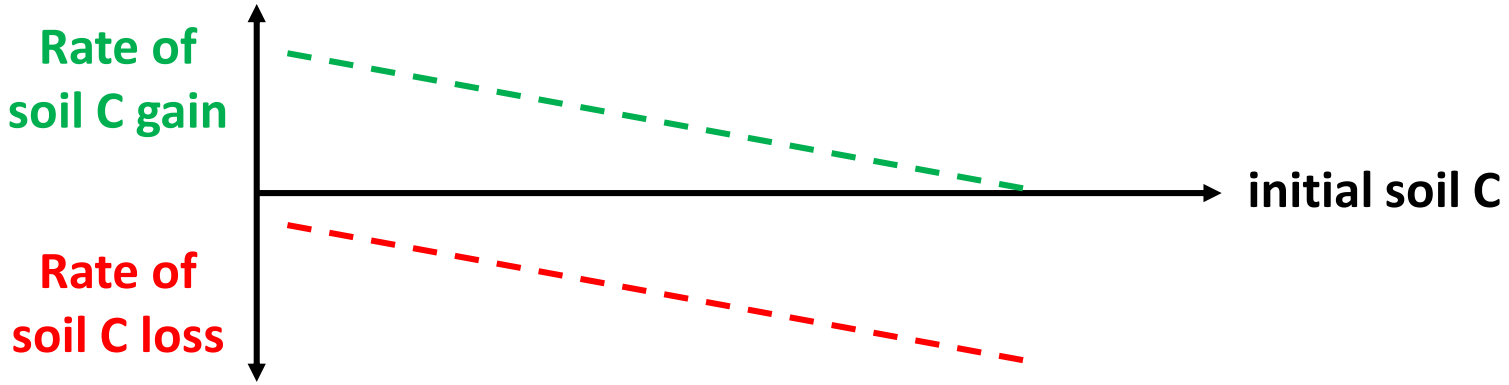
Sequestration (soil)

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]

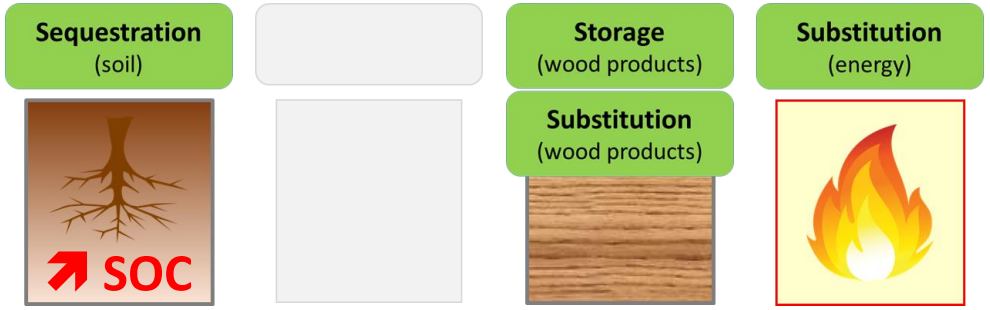
  ⇔ in poor-C soils, increase soil C pool and harvest biomass.

  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.]

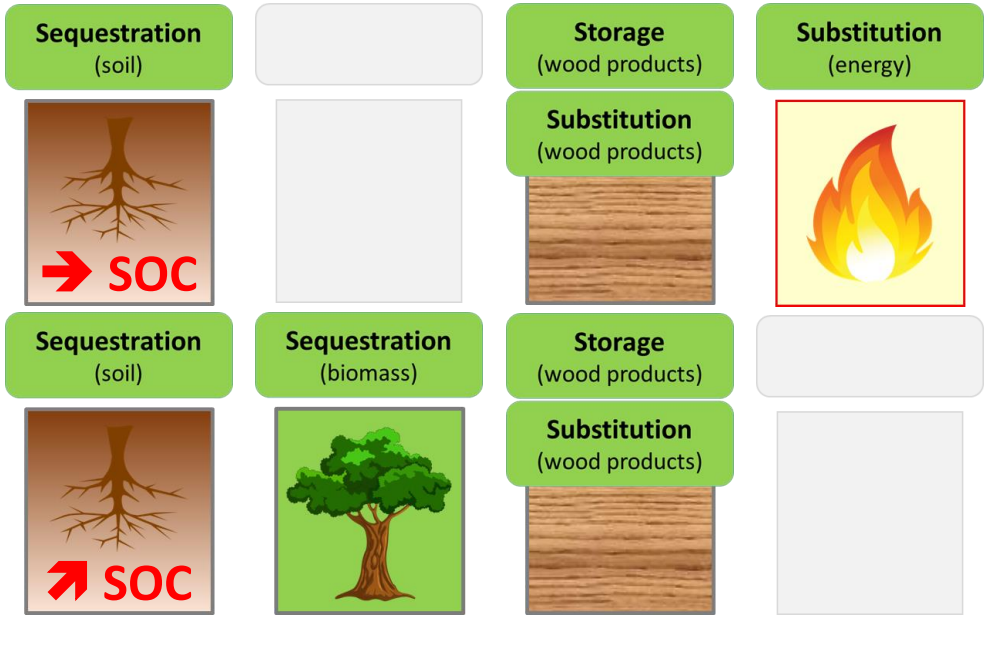


➢ **Intermediate-C soils (e.g. ± disturbed forests)**

- ¤ **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.]

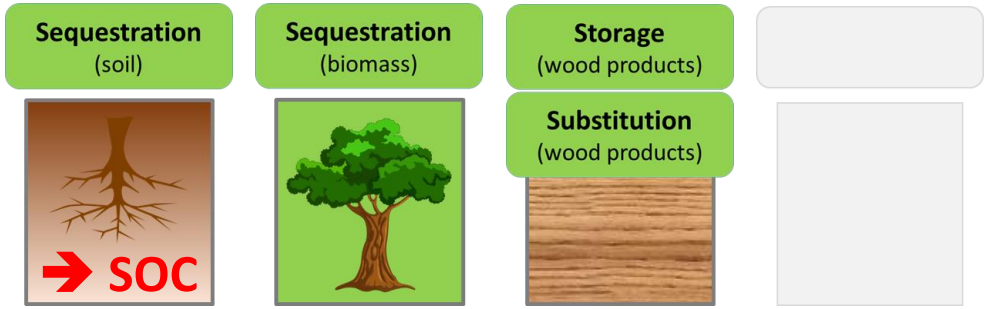
Or



➢ **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.]



in a nutshell

“when possible, win on all fronts”

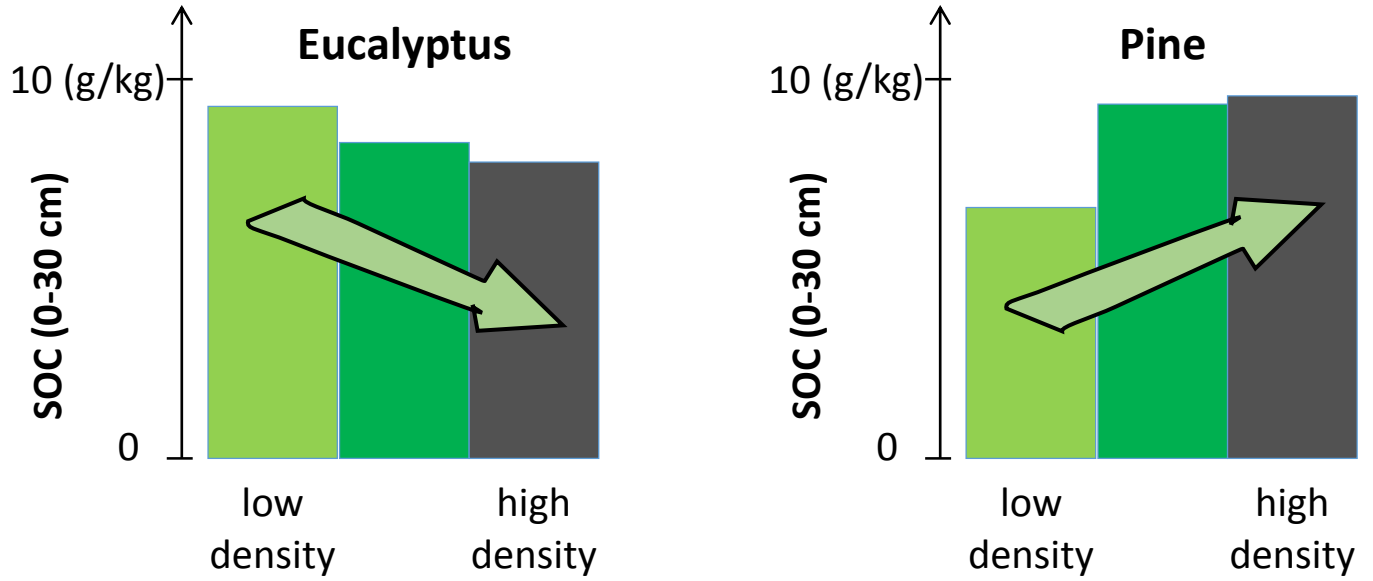
- **Use SOC as a management indicator**

- **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.

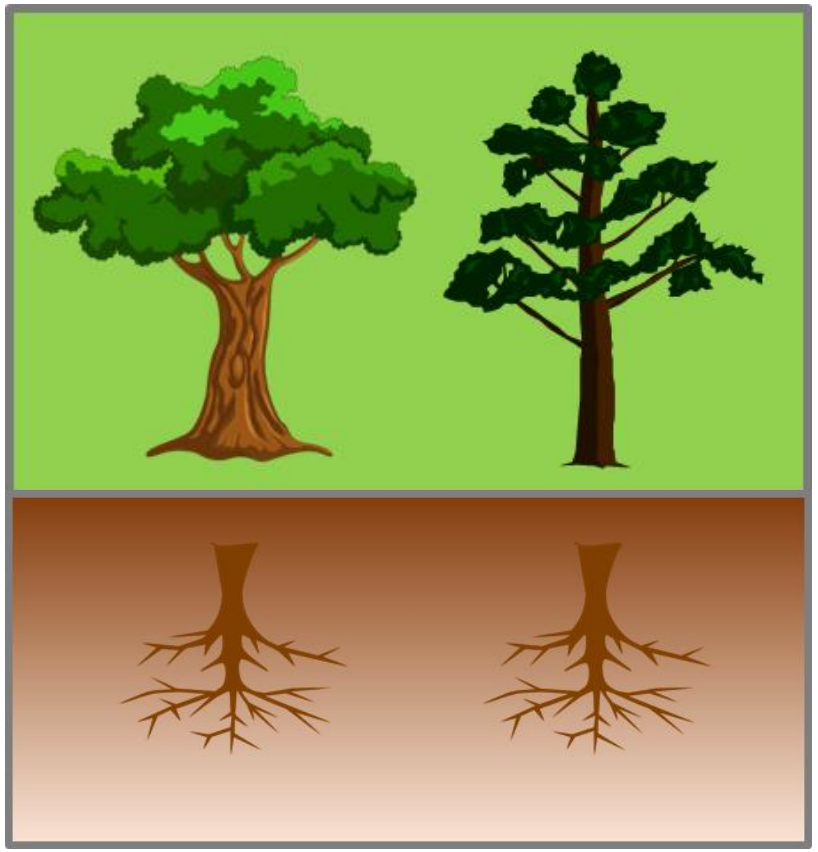


➢ **There are probably many density trials and many unpublished data, but there are not sufficiently published/visible.**

➢ **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.**

Tree species (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 ≥ conifers
poor sites: hardwoods ≤ 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

	Sequestration (soil)	Sequestration (biomass)	Storage (wood products) Substitution (wood products)	Substitution (energy)
Foresters' main tools:				
- 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			