CarboScen

Analysis of carbon outcomes in landscape scenarios

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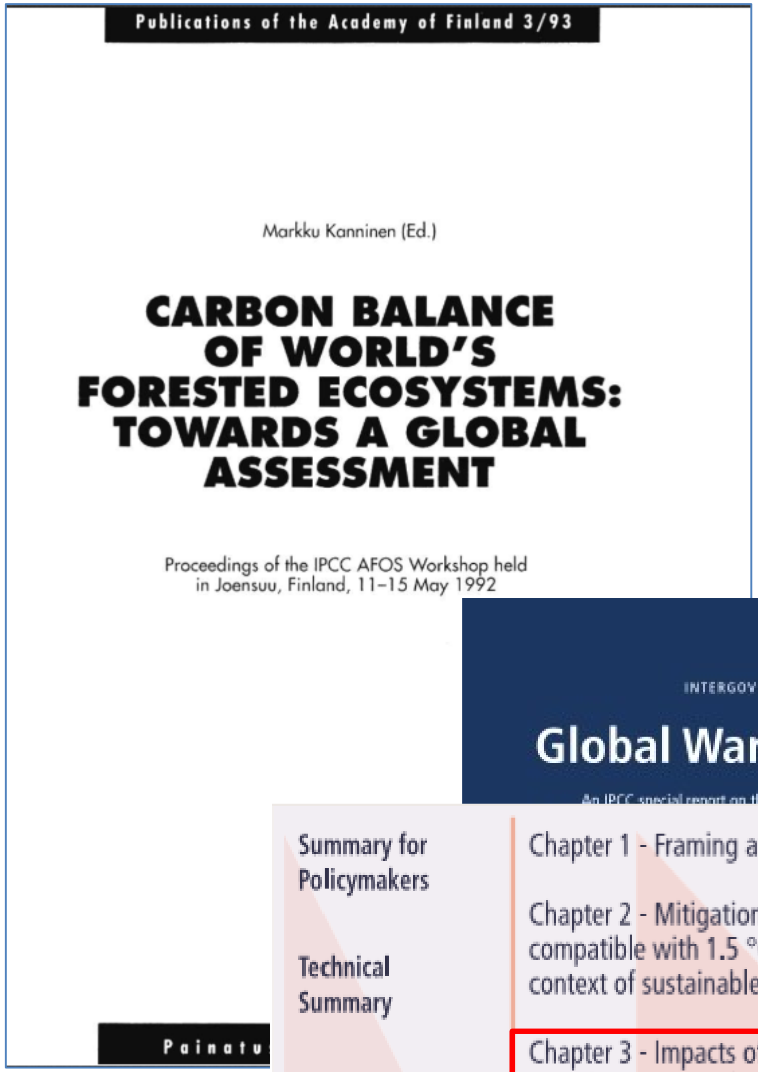
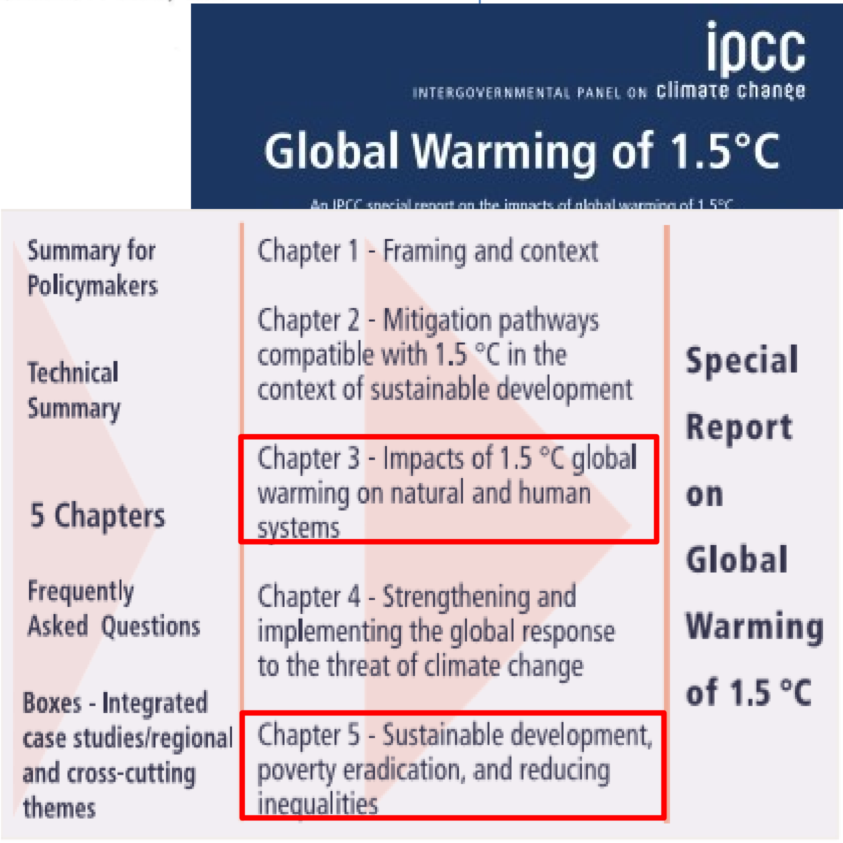
My background

- Over quarter of century of international research on forests, land use and climate change
- Research and policy advice at various levels: national (Finland), regional (Europe, Central America) and global (CIFOR, IPCC, UNFCCC)
- Focus of this presentation:
  - Land use (AFOLU, LULUCF)
  - Global
  - Mitigation and adaptation
  - Climate-resilient sustainable development

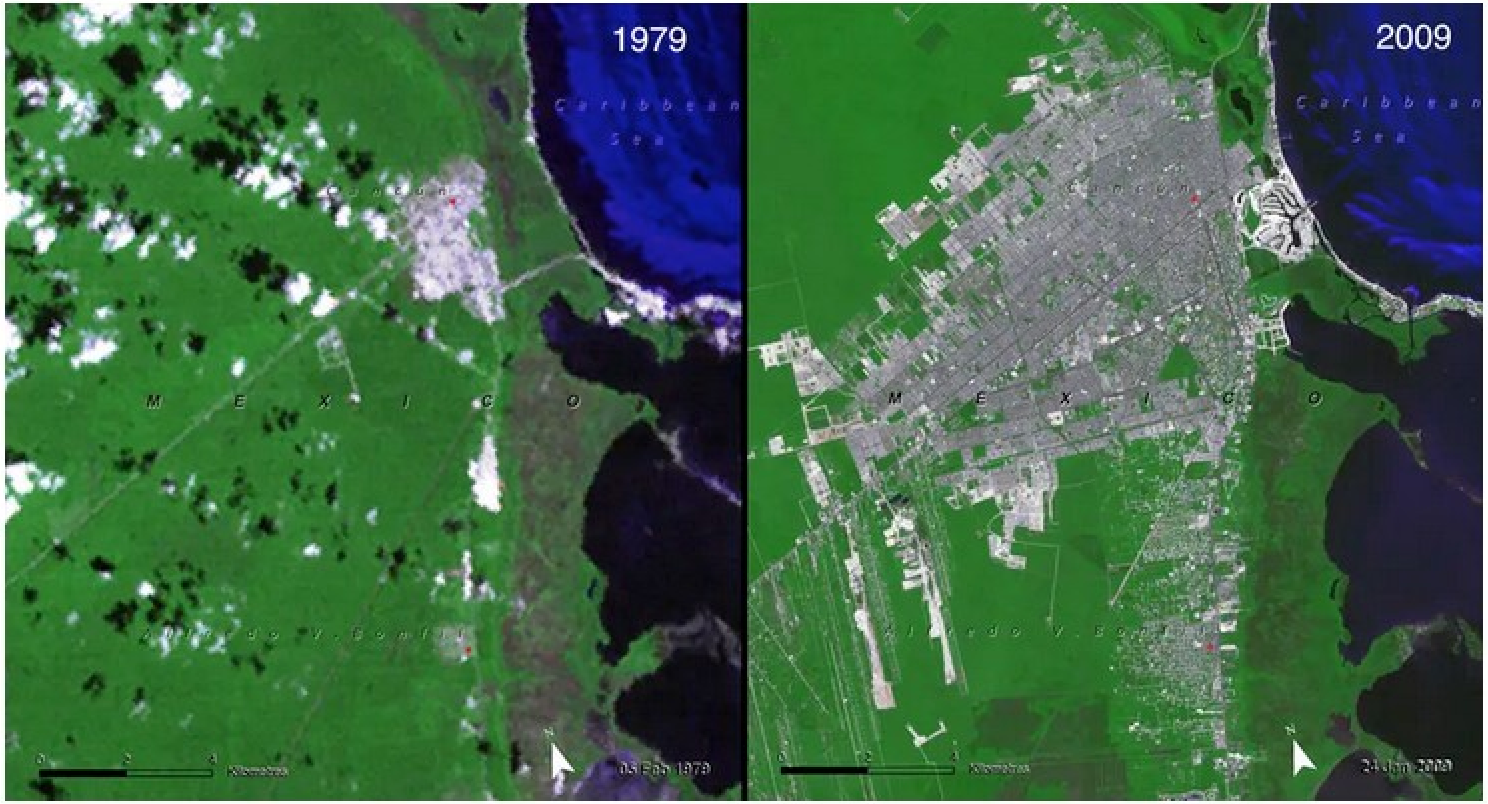
1993



2018



Changes in landscapes



Cancun in Yucatan,
Mexico 1979 and 2009

Changes in landscapes

Disappearing glaciers

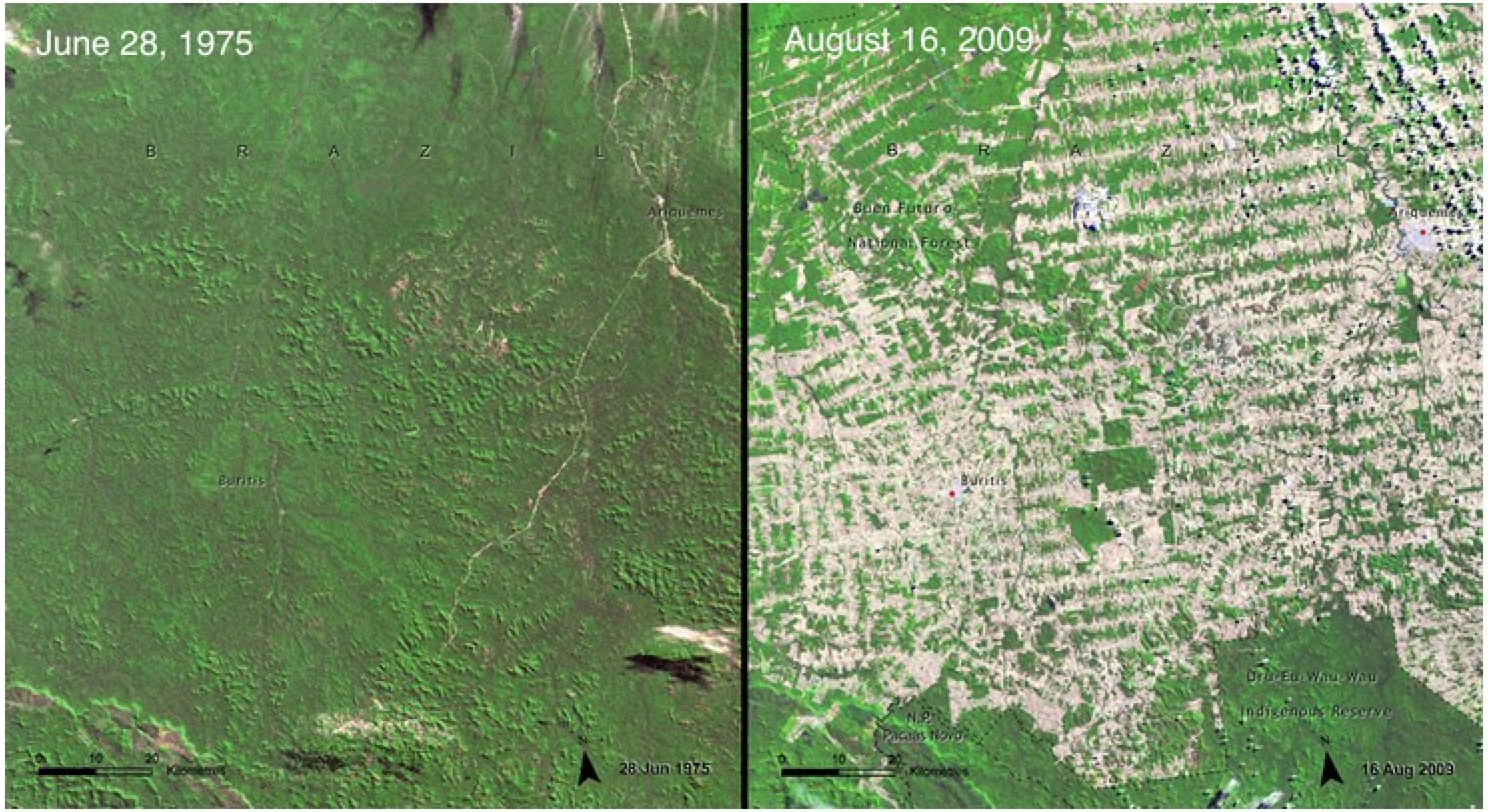
Changes in landscapes

Urbanization

Changes in landscapes

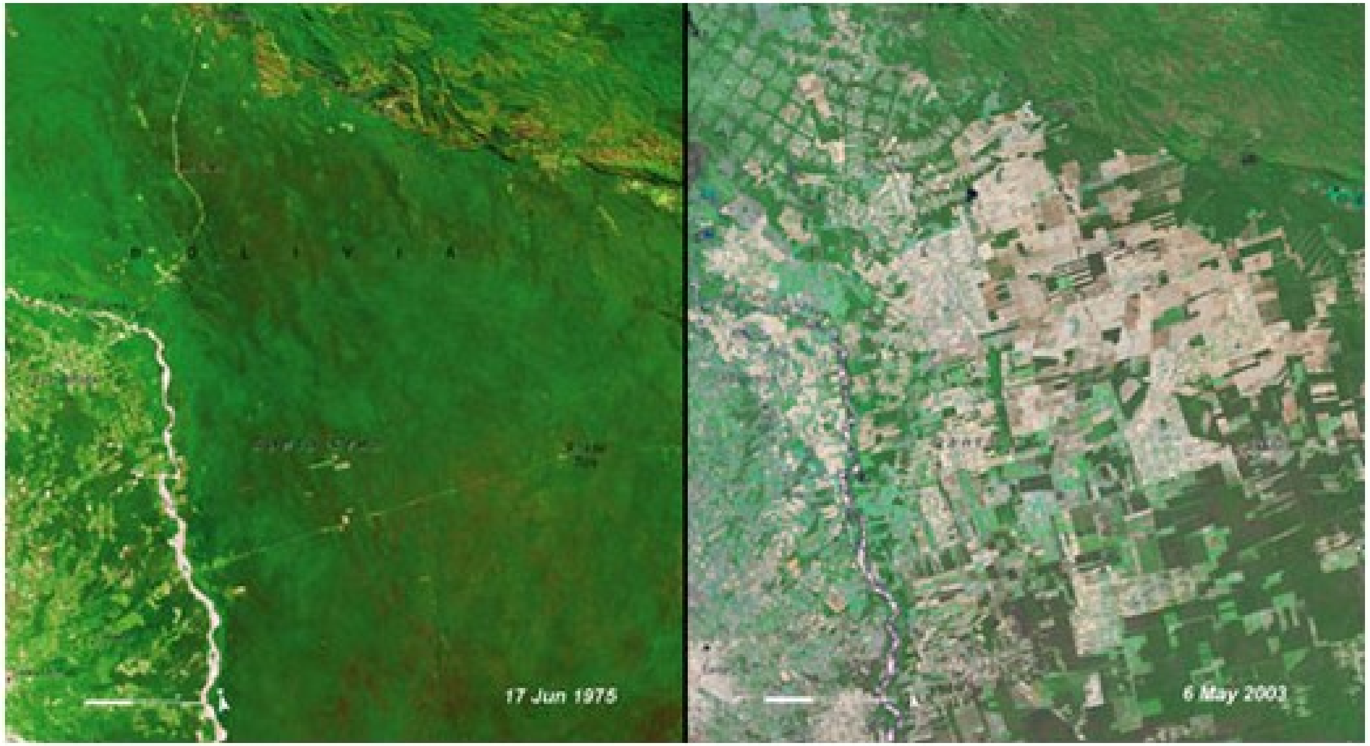
The Paraguay-Parana River before and after the construction of the Yacyreta Dam in 1985

Changes in landscapes



Rondônia in western Brazil 1975 and 2009

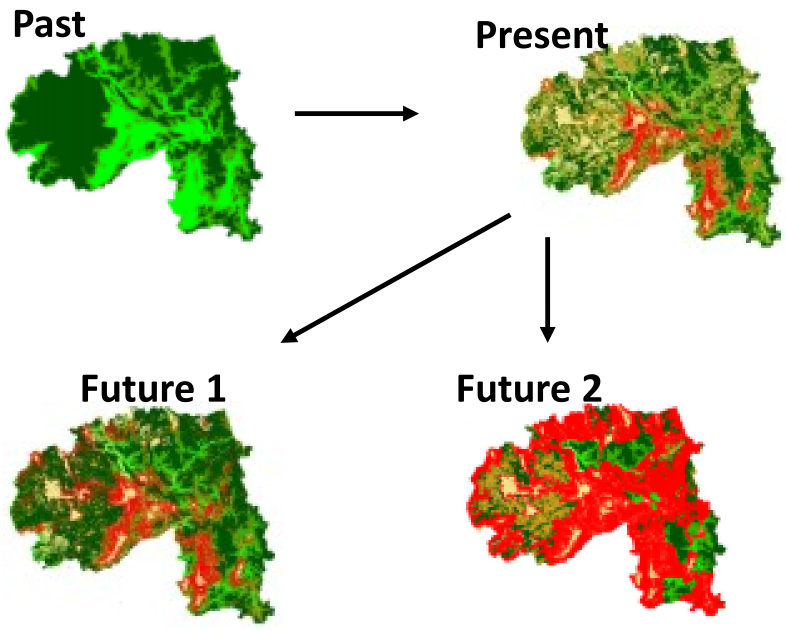
Changes in landscapes



Deforestation in Bolivia
1975 and 2003

How much carbon in a landscape in the future?

Future scenarios of landscapes



- REDD+ policy maker:
  - Policy options – impacts in terms of emissions and sequestration
- Land-user planner:
  - Improving rural livelihoods – carbon outcomes of different schemes
- Investment advisor:
  - Carbon outcomes of investment options

Example graph from Li et al. 2008

Measuring REDD+ performance

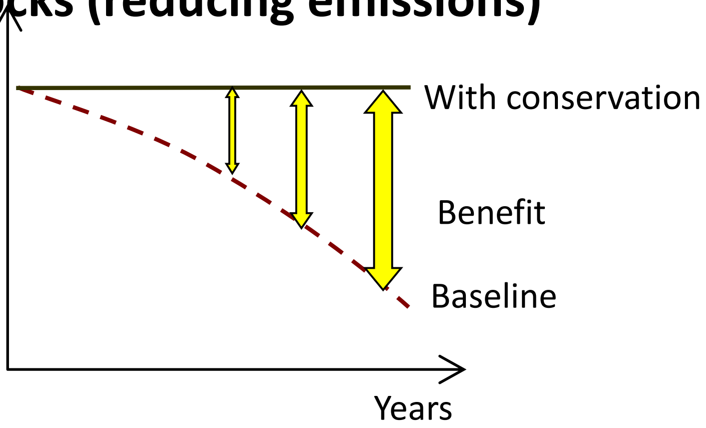
- What are we measuring?
  - Inputs, process, outputs, outcomes, impact
- Effectiveness (outcomes, impact)
  - The amount of emissions reduced or removals increased by REDD+ actions
- Approaches
  - An *ex post* evaluation of the effectiveness
    - Changes in forest carbon stocks (MRV) compared to a reference-level (business-as-usual baseline)
  - An *ex ante* evaluation of the effectiveness
    - Modeling and scenario-creation to analyze alternative futures ("carbon outcomes") based on different land use policies

How can forests mitigate climate change?

1) Avoiding losses of carbon stocks (reducing emissions)

Reducing deforestation and degradation

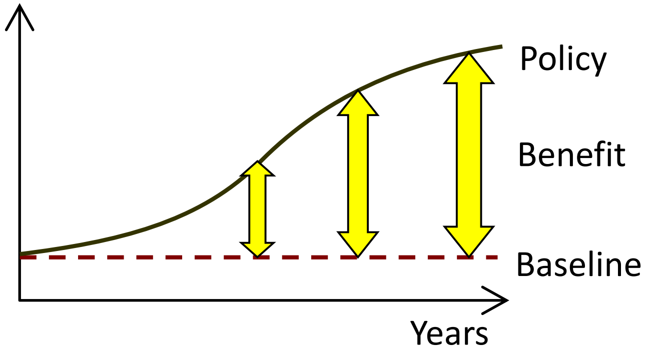
Applying other REDD+ activities



2) Increasing carbon stocks (carbon dioxide removal from atmosphere)

Creating plantations

Developing agroforestry



3) Producing biomaterials and bioenergy through substitution

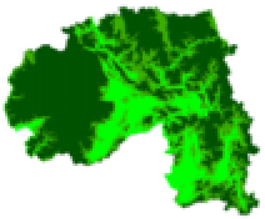
Forest

Energy

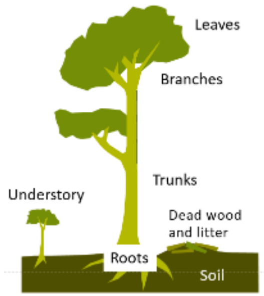
How to quantify ecosystem carbon when land-uses are known?

$$C_{tot} = D_c \times Area$$

Area (Hectares)



Carbon density per unit area (Mg C /ha)



Example 1		Example 2	
1 Ha		1 000 Ha	
1 x 100	100 Mg C /ha	1 000 x 50	50 000 Mg C /ha
100 Mg C /ha		50 Mg C /ha	

How to quantify ecosystem carbon when land-uses are known?

- When carbon densities (D_c) of a given land use are known, just multiply these with the area to get the total carbon pool (C_{tot}):
  $C_{tot} = D_c \times Area$

But there are two additional points to consider

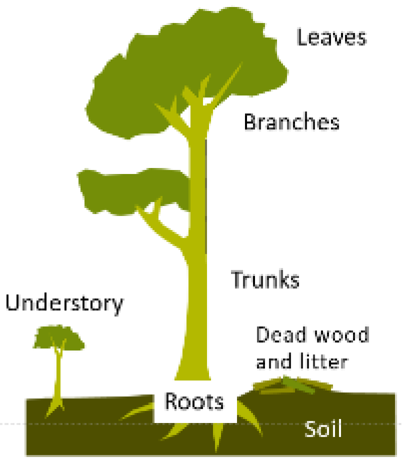
- First, land-use is changing constantly

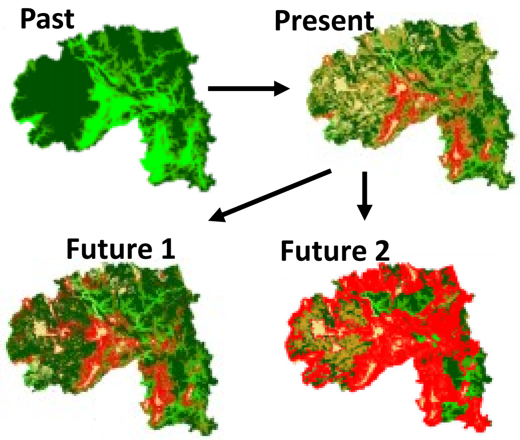
- Second, carbon densities do not change suddenly when a land-use change happens

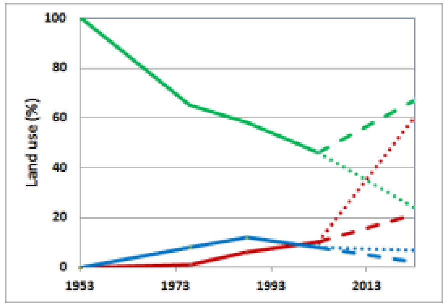
CarboScen tool
Carbon analysis at landscape scale

Carbon data for different land uses → Scenarios of land use change → Carbon outcomes in different land use scenarios

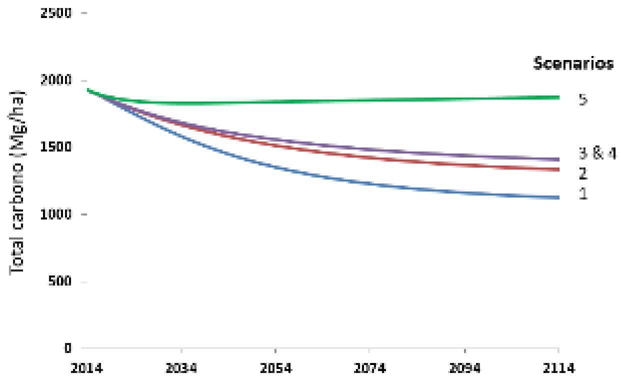
IPCC Carbon pools, grouped as
- Above-ground
- Below-ground
- Soil







In each scenario
- Total carbon
- By land-use
- By pool
  - Above-ground
  - Below-ground
  - Soil



CarboScen tool

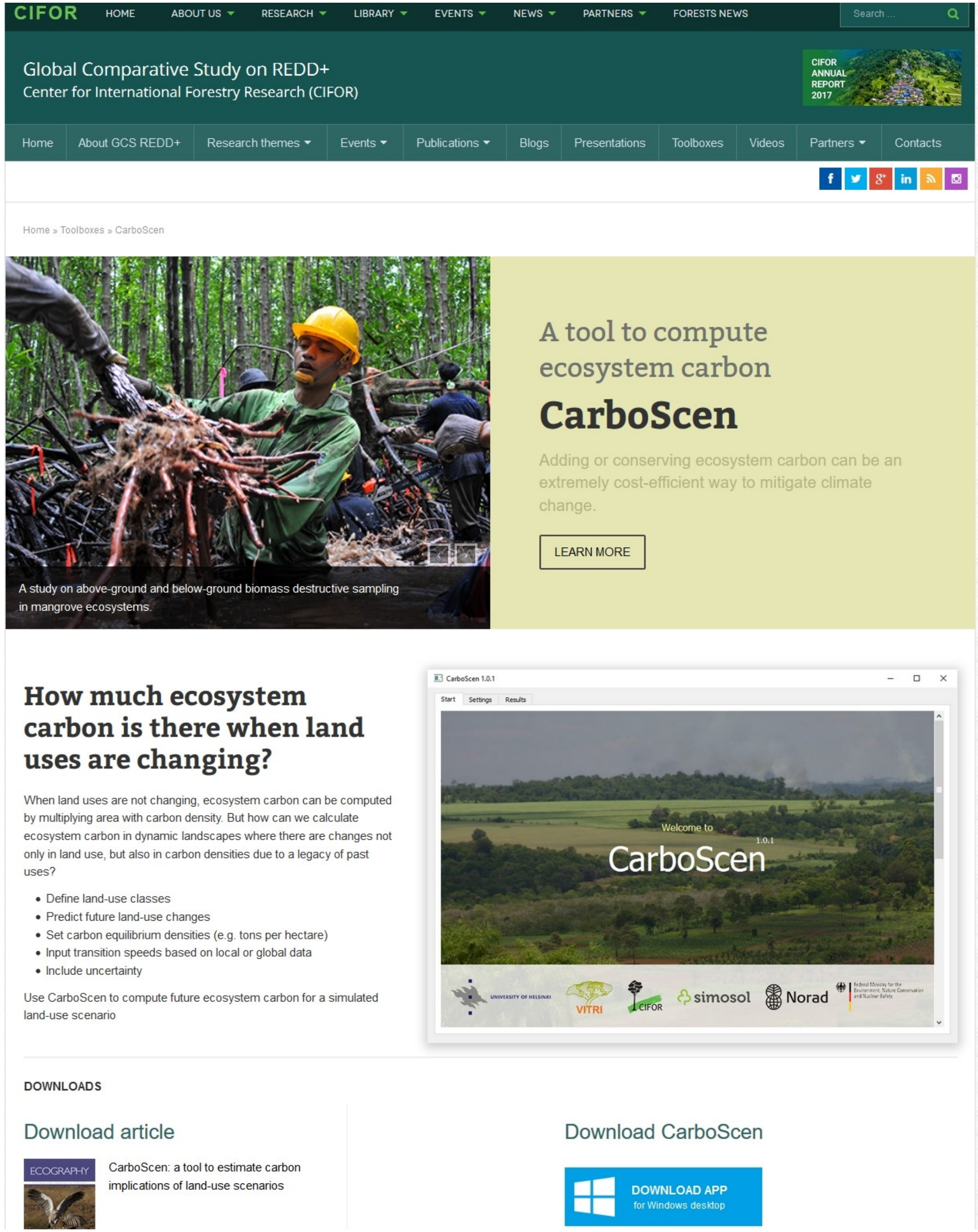
- A tool for estimating carbon outcomes in landscapes
- Characteristics
  - Starting point: Unlimited number of land use classes
  - User inputs data on carbon pools (C densities) for each land use class (based on inventory, literature, default values, etc.)
  - User generates land use scenarios
  - The tool assumes that carbon density asymptotically approaches a equilibrium value, which is set for the land-use type in question (result of a global meta-analysis)
- Useful for estimating carbon outcomes (i.e. changes in carbon contents) of land use change scenarios
- Suitable for participatory planning and rapid *ex ante* assessment of carbon outcomes of REDD+ and other land use policies

Software available in CIFOR web site

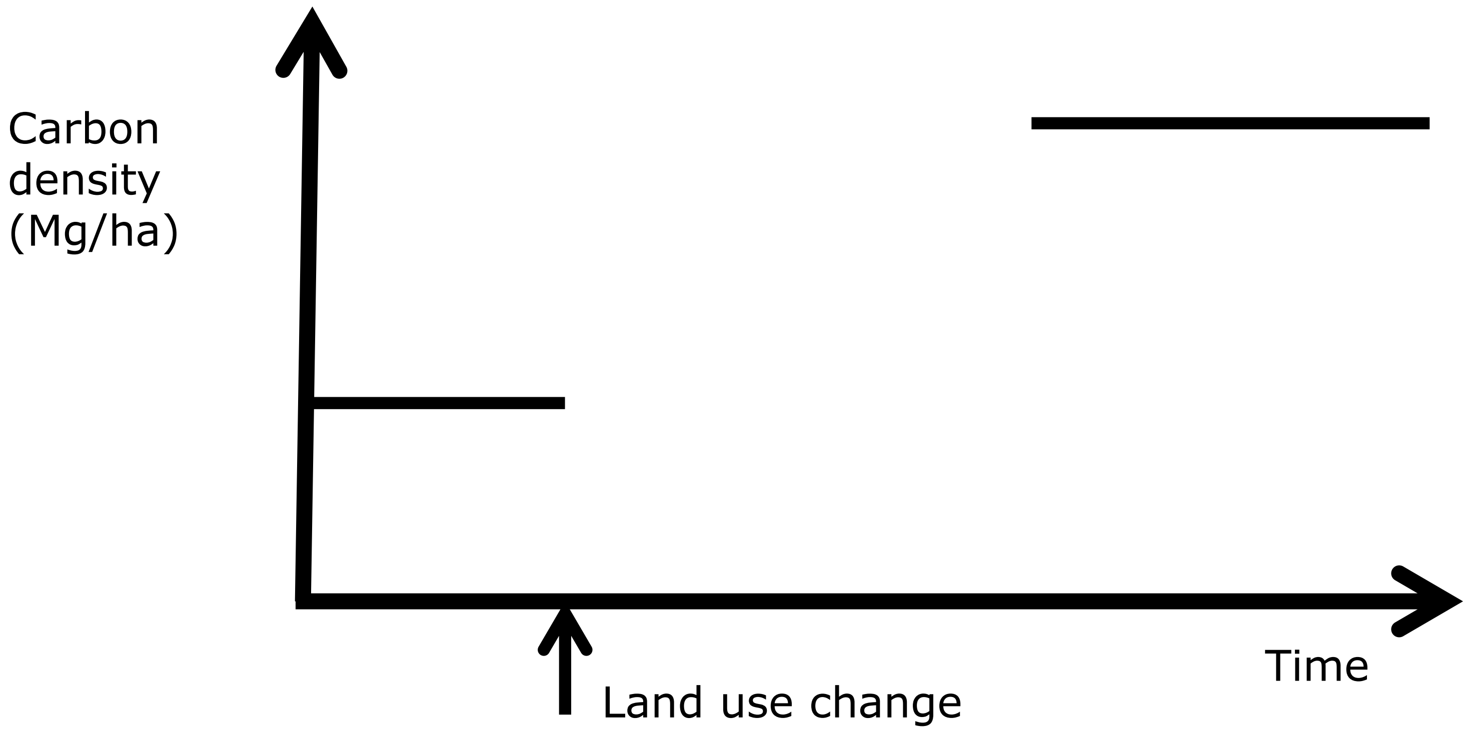
https://www2.cifor.org/gcs/toolboxes/carboscen/

Paper published in Ecography (open access)

http://dx.doi.org/10.1111/ecog.02576



How CarboScen works?



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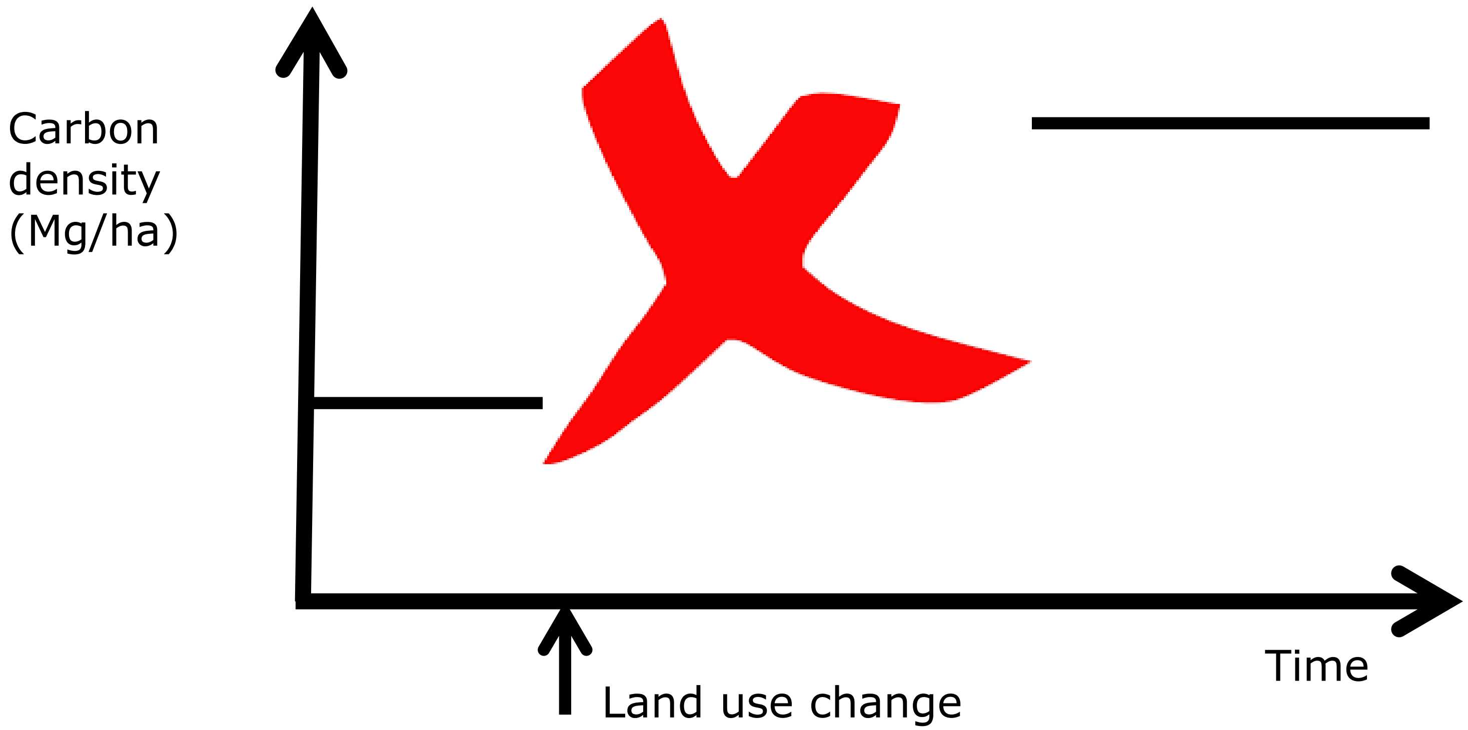
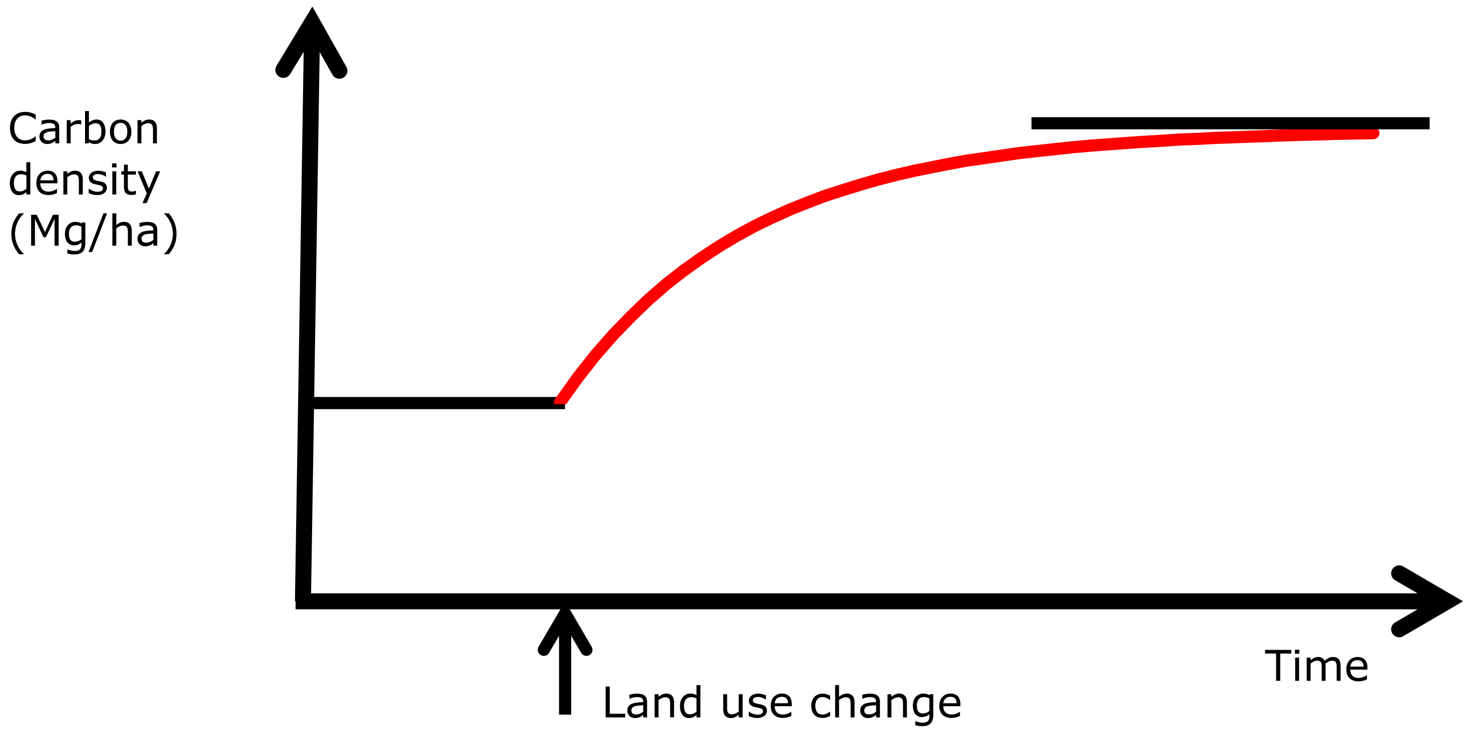
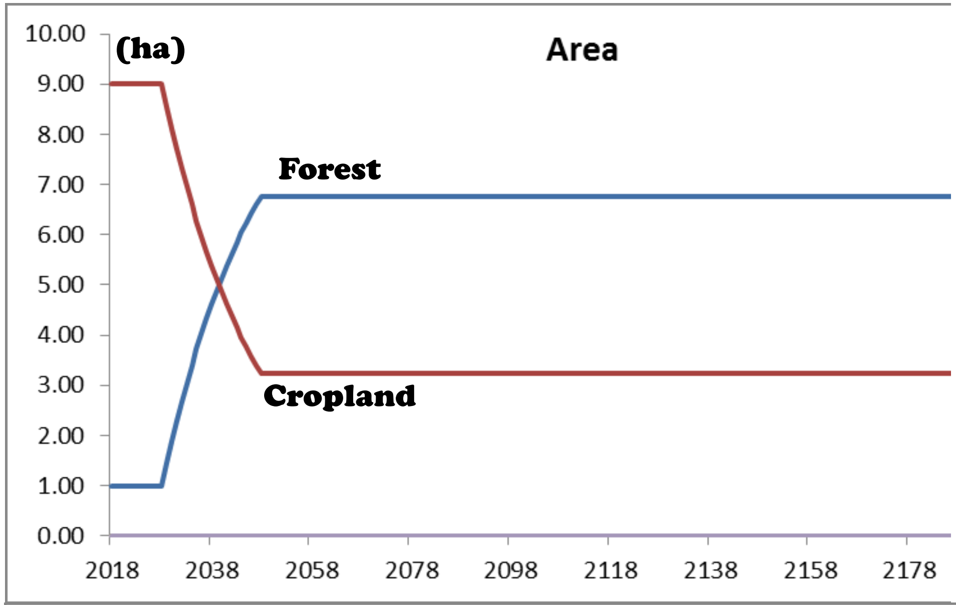


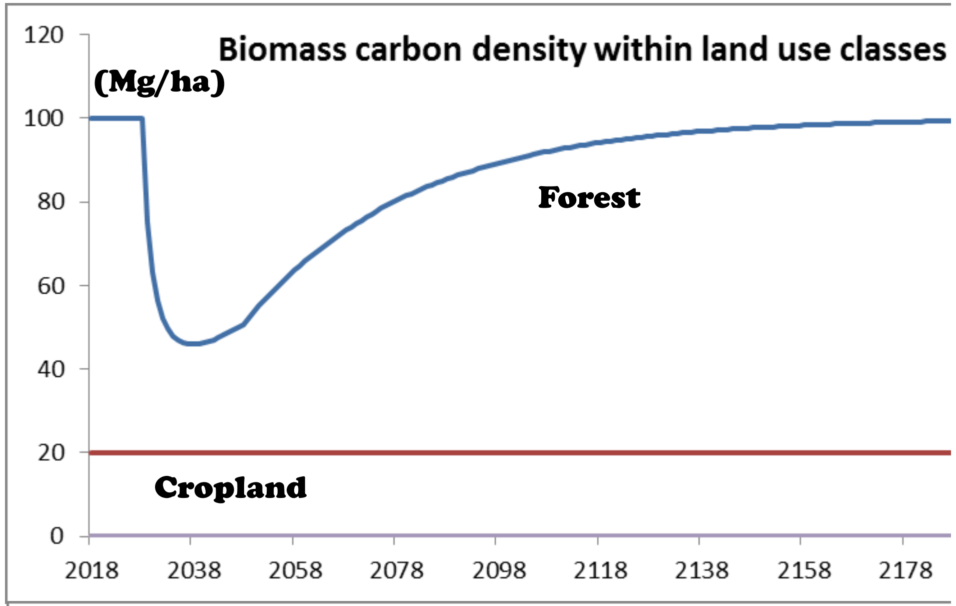
How CarboScen works?

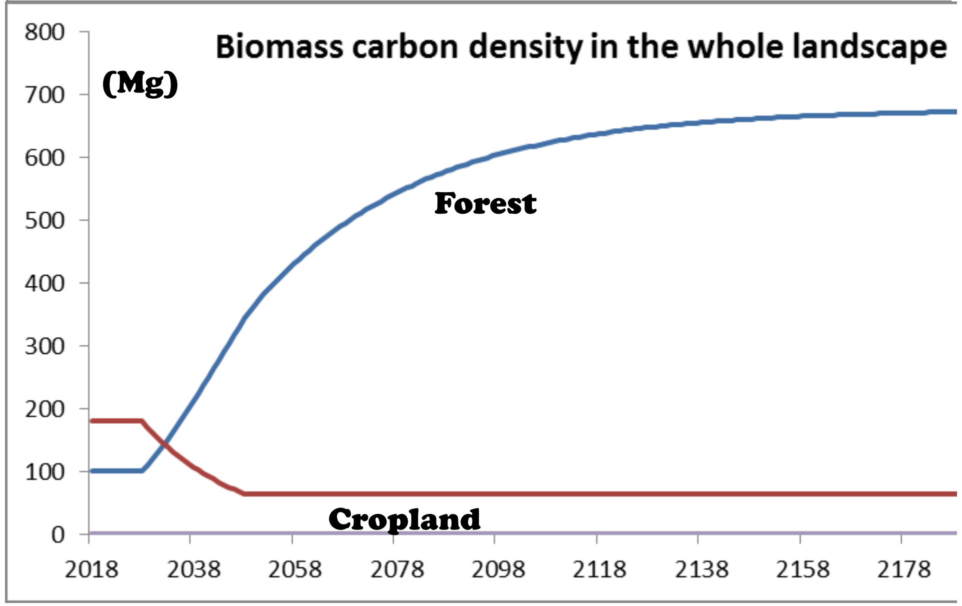


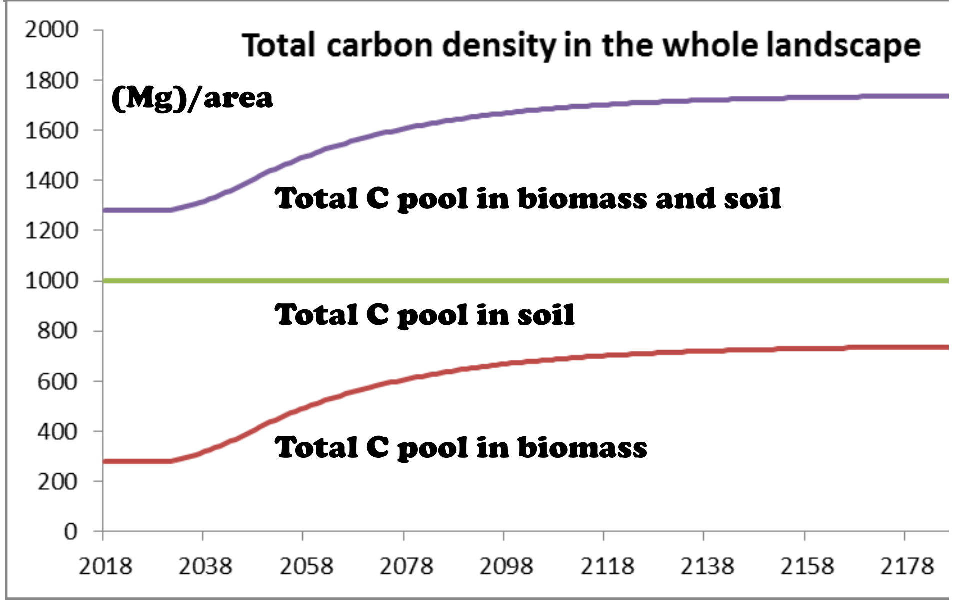
Assumption: Carbon density approaches the new equilibrium at a rate, which is a fixed proportion of the remaining difference per unit time

Simplest case: two land-uses







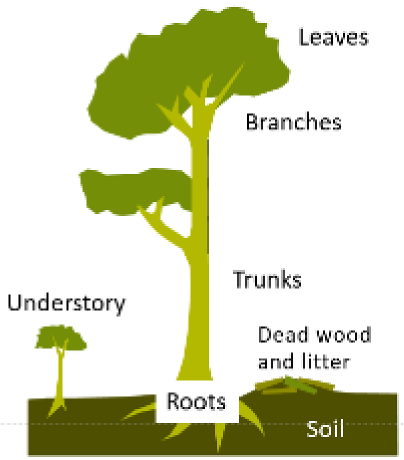


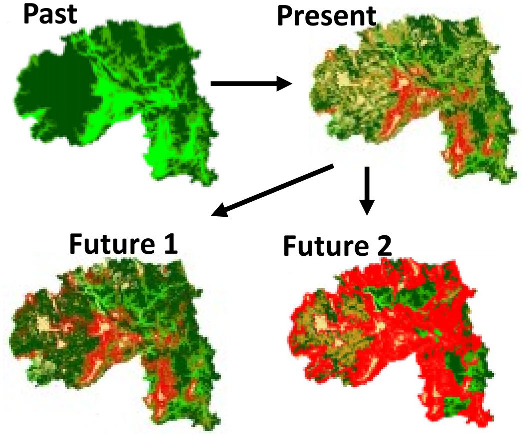
CarboScen tool
Carbon analysis at landscape scale

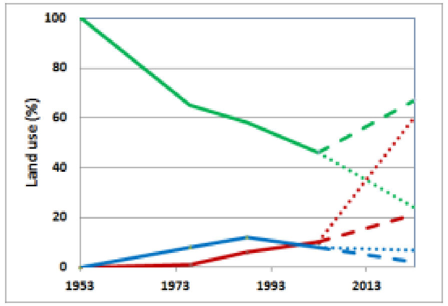
Carbon data for different land uses → Scenarios of land use change → Carbon outcomes in different land use scenarios

IPCC Carbon pools, grouped as

- Above-ground
- Below-ground
- Soil

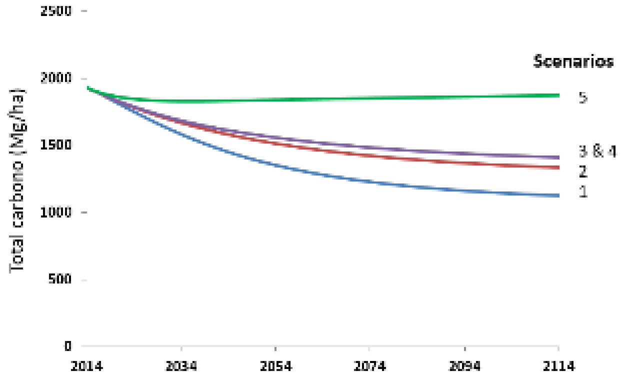




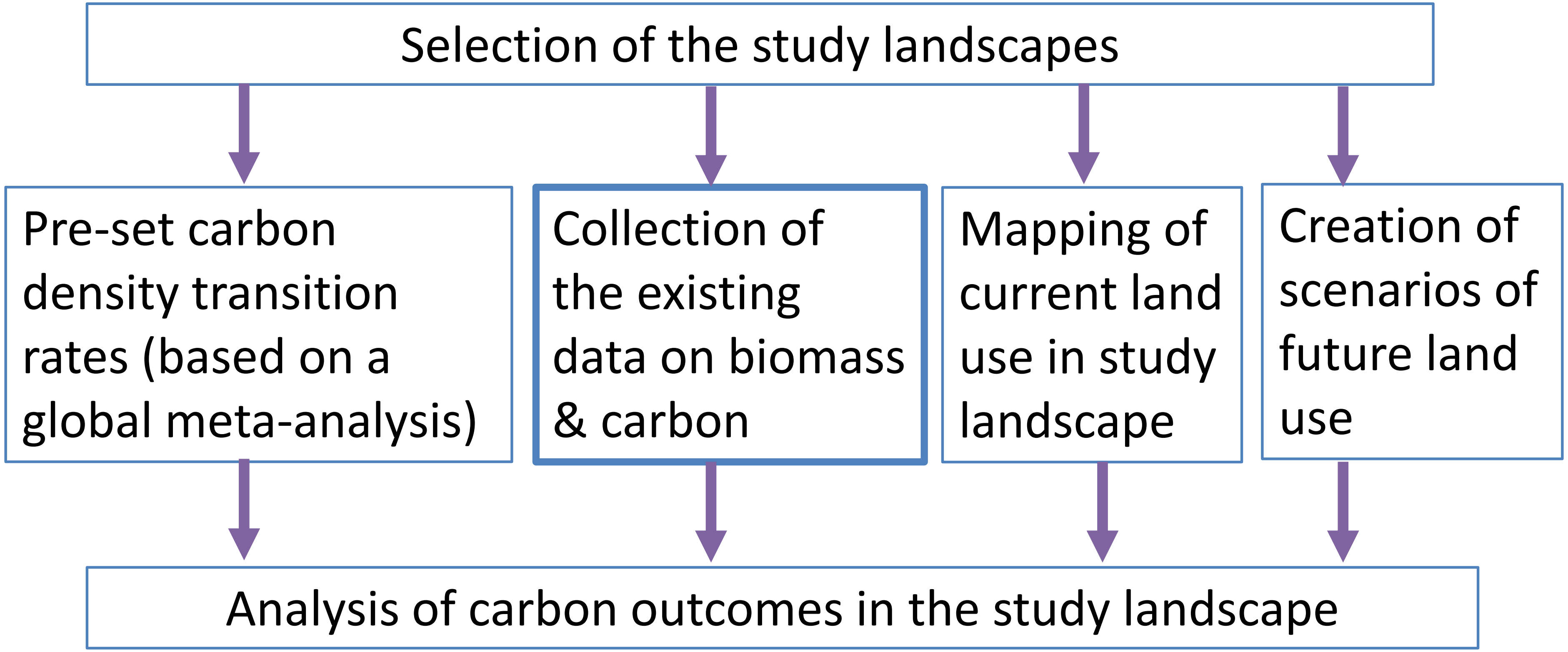


In each scenario

- Total carbon
- By land-use
- By pool
  - Above-ground
  - Below-ground
  - Soil



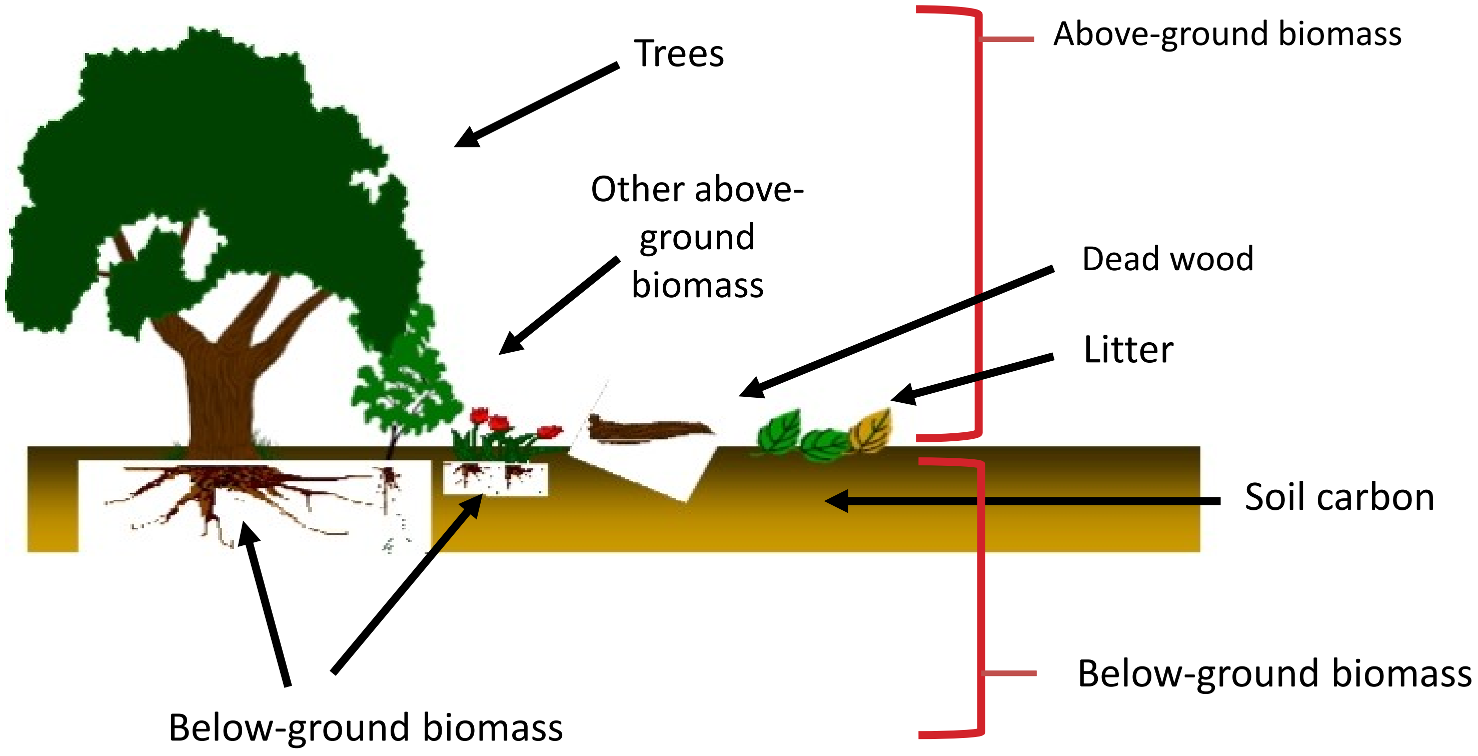
CarboScen - steps



Carbon pools (stocks, reservoirs)

The five IPCC carbon pools:

(1) Aboveground biomass (AGB)
(2) Belowground biomass (BGB)
(3) Litter
(4) Dead wood
(5) Soil organic carbon (SOC)

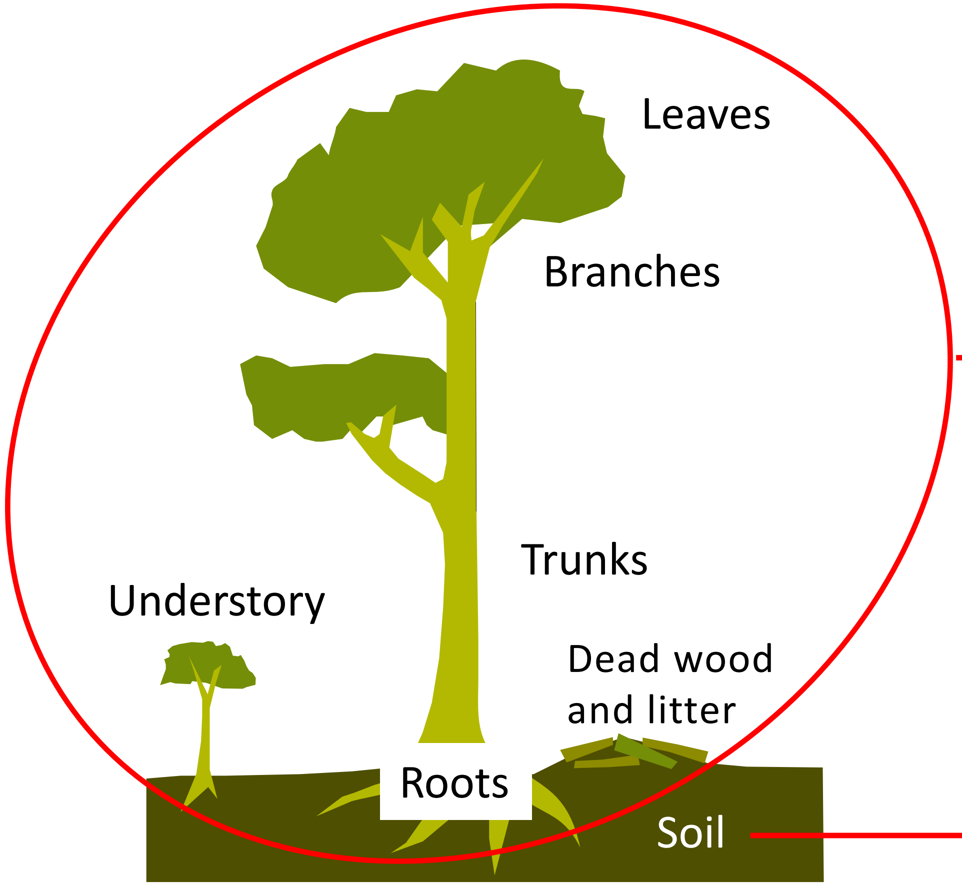


(IPCC, GPG 2003)

Carbon stocks of forests

- Mg C/ha
- Tons of C/ha

Total carbon stock =
Biomass carbon stock +
Soil carbon stock

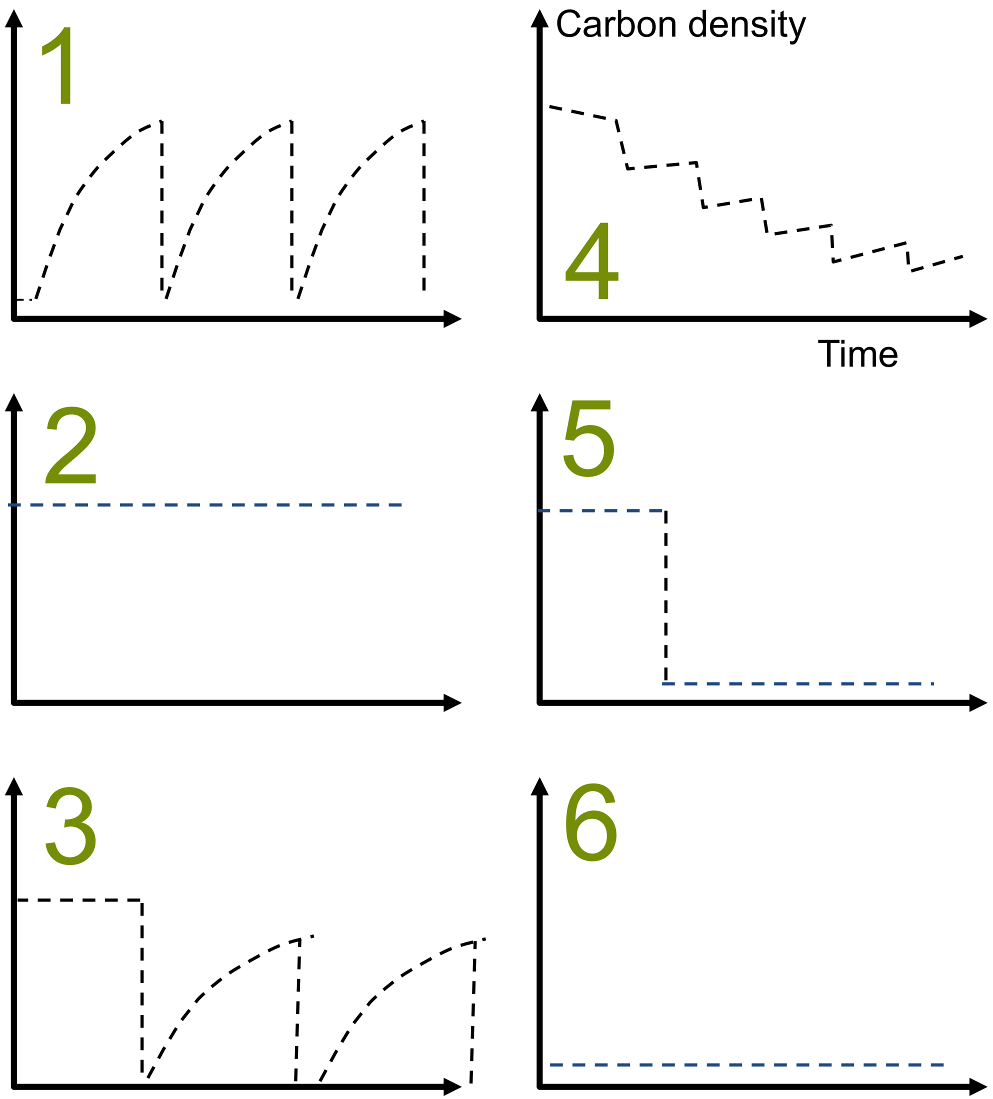


Biomass carbon stock
= Aboveground biomass C stock

Soil carbon stock
= Belowground C stock

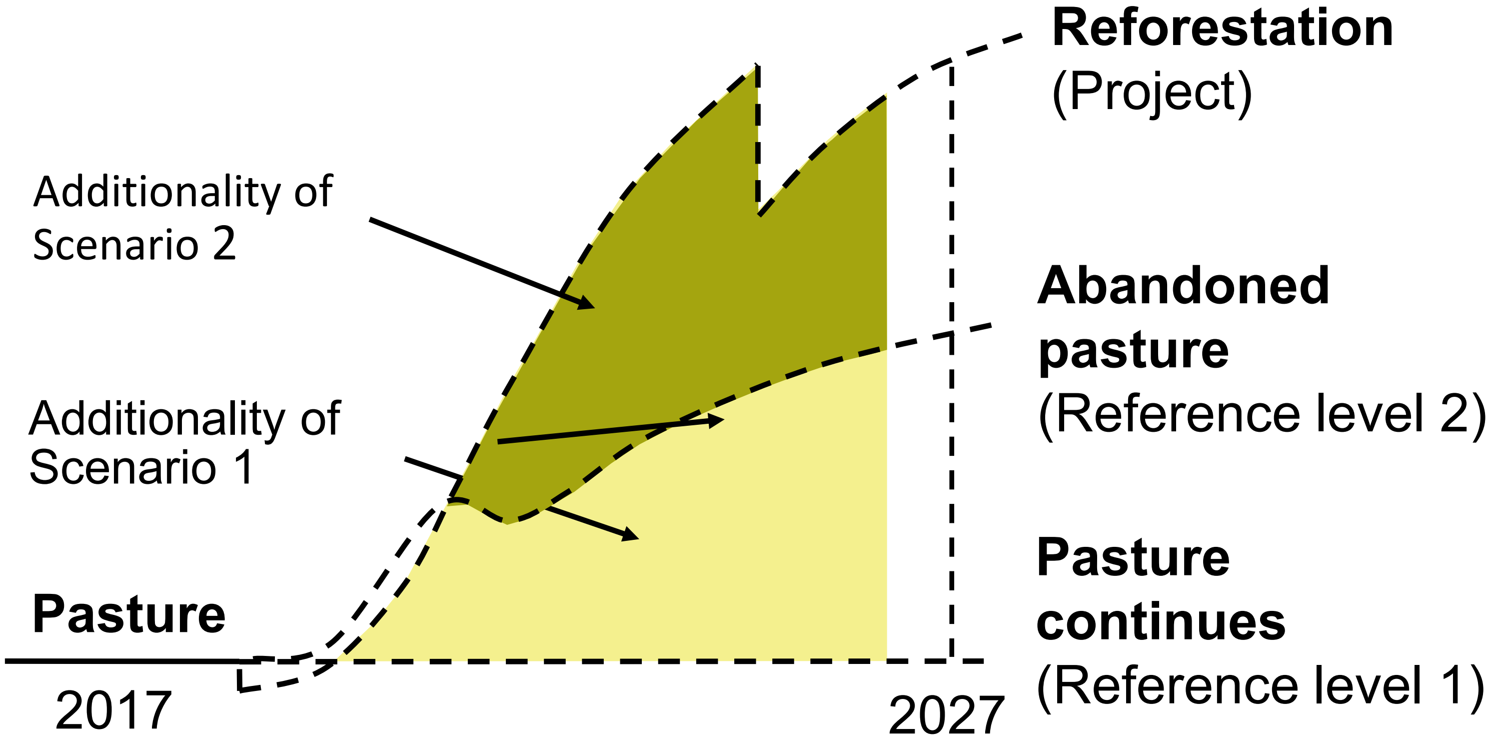
Quiz

Which figure represents the simplified evolution of aboveground carbon stocks in the following cases?

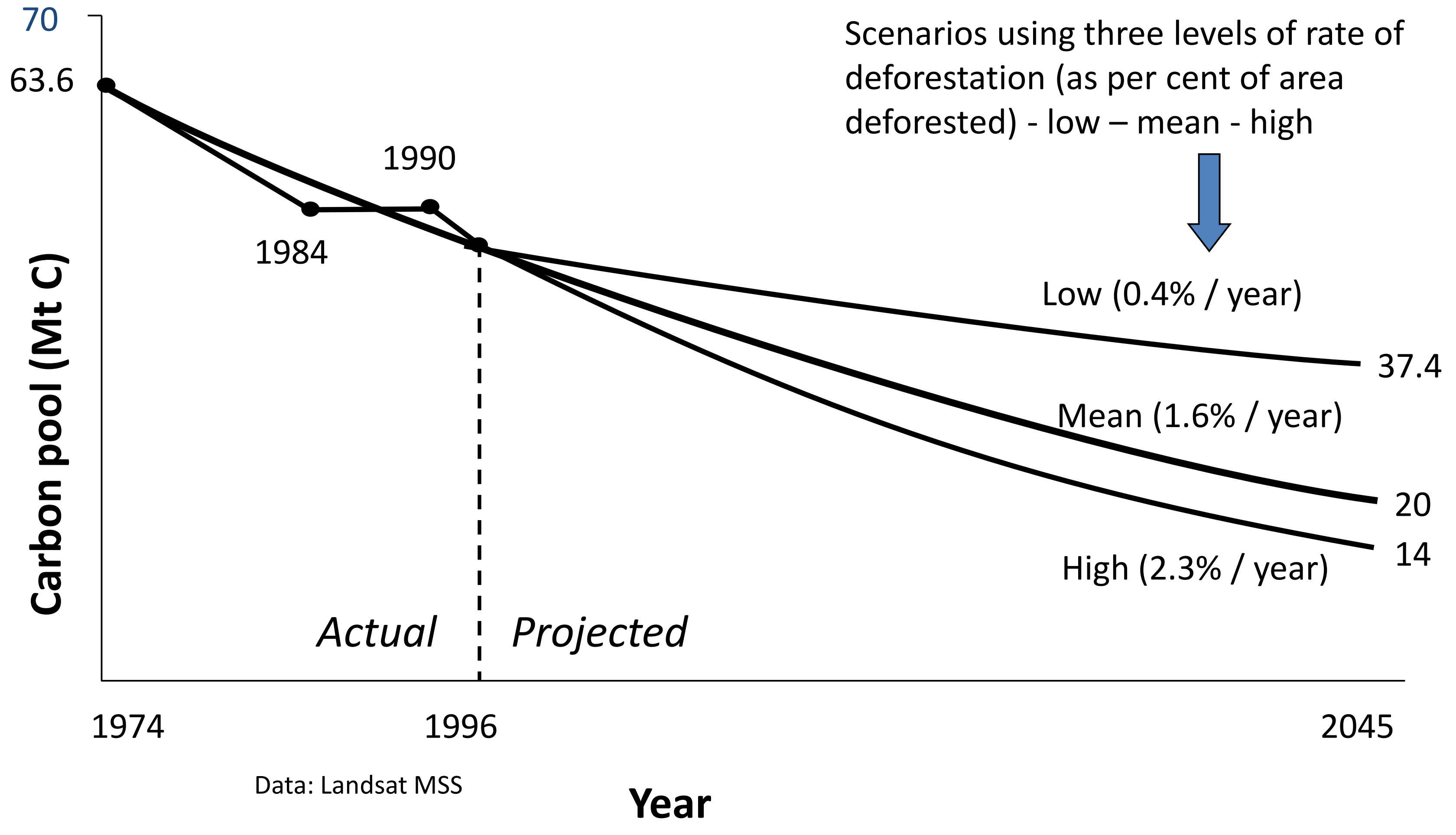


6	Non-forested land
5	Forest conversion to non-forested land use (deforestation)
4	Unsustainably managed forest (forest degradation)
1	Plantation established on non-forested land and harvested regularly
3	Forest converted to a plantation
2	Conserved primary forest

Reference level and additionality in a reforestation of pasture lands



Total C stock (past and projected) in 300 000 ha forest area of Chiapas, Mexico



(Brown et al., 2007)

From where to get carbon density data?

Best option – local data

Additional data collection might be needed

Literature, global data banks

San Martin, Peru


Lowlands – agriculture dominating


Coffee


Highlands – natural forest and coffee expansion


Shaded coffee - agroforestry

Carbon data base - example

Carbon data for the landscape

- User collects from carbon inventories, various projects, data bases, and literature

L1 — DBH limit (cm)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	**Land use class**	**C data on biomass**	**Notes on C density (Units and other relevant)**	**Unit (1 =**	**Corrected**	**BGB (1 =**	**Corrected**	**CWD (1 =**	**Corrected**	**Litter (1 =**	**Corrected**	**DBH lim**	**Corrected**	**Exact wording on land use class in**	**Reference (Harvard Style)**	**Credits and status of the Information**	**Soil C weight (not takin**	**Biomass C weight (not takin**	**Notes on Weight**	**Biomass C density (Mg/ha)**	**Biomass C weight**
2	Agriculture and Pastures	335	Units: Mg/ha DBH>5 cm AGB, only. Woody debris and BGB not included.	2	##	2	##	2	##	1	##	5	##	Complejos de chacras y purmas	Córdova, A. (2013) E-mail to Harold Gordillo, 02 October.	Data available. Credits should be respected	-	1	Location is in the Region	172.6	1
	Agriculture and Pastures	262	Units: Mg/ha DBH>5 cm	2	##	2	##	2	##	1	##	5	##	Complejos de chacras	Córdova, A. (2013) E-mail to Harold	Data available.	-	1	Location is in the Region	135.8	1
321														piedemonte andino							
322	Shrub and Bamboo Vegetation	11	Units: TnC/ha DBH>5cm C in AGB and BGB. C in woody debris not included.	1	11	2	11	1	31	1	11	5	16	Paca	Recavarren, P., Delgado M., Angulo, M., León, A., Castro, A. (2011). Proyecto REDD en Áreas Naturales Protegidas de Madre de Dios. Insumos para la elaboración de la linea base de carbono. Asociación para la Investigación y el	Data available. Credits should be respected	-	45	Almost identical area and condictions where the study was conducted	15.8	45

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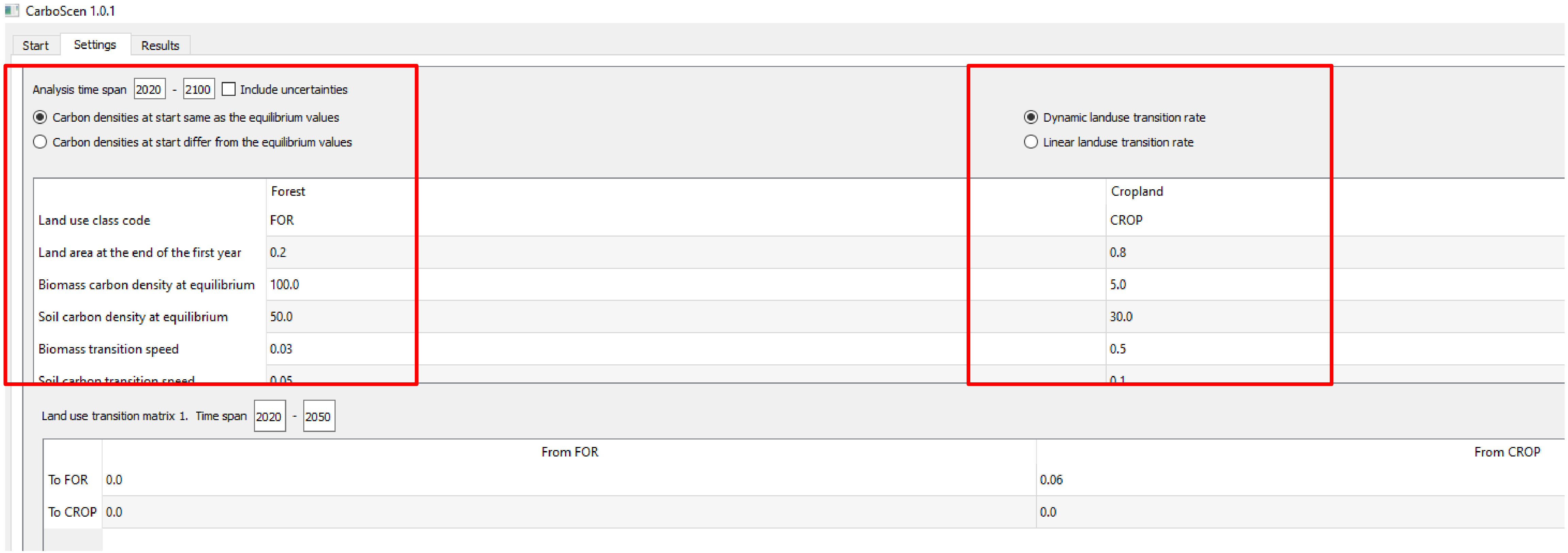
Carbon data - San Martin, Peru

Land use class	Biomass Carbon Density (Mg/ha)	Soil Carbon Density (Mg/ha)
Upper montane forest	157	76
Lower montane forest	149	59
Pre-montane forest	123	41
Palm forest in wetlands	99	57
Paramo (subalpine forest)	25	76
Mixed agriculture	20	20
Pasture	11	30
Rice cultivation	8	30
Coffee	11	30
Shaded coffee (agroforestry)	71	40

CarboScen user interface

Carbon stock & transition speed values



CarboScen - steps

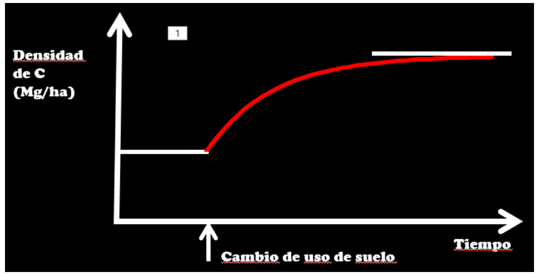
Selection of the study landscapes

- Pre-set carbon density transition rates (based on a global meta-analysis)
- Collection of the existing data on biomass & carbon
- Mapping of current land use in study landscape
- Creation of scenarios of future land use

Analysis of carbon outcomes in the study landscape

Parameter for the transition rate (rate of change) of carbon density is more challenging to obtain

Transition rate (parameter f):
Is the proportion of the remaining difference between the current carbon density and the future equilibrium carbon density that happen annually



Global data needed for most landscapes

Accumulation of above-ground biomass with increasing stand age

Carbon density in a given land use at a given moment of time (p_c) can be calculated from:

$$p_c = p_s + (p_e - p_s)(1 - e^{-ft})$$

where:

p_s = initial carbon desity

p_e = equilibrium carbon desity

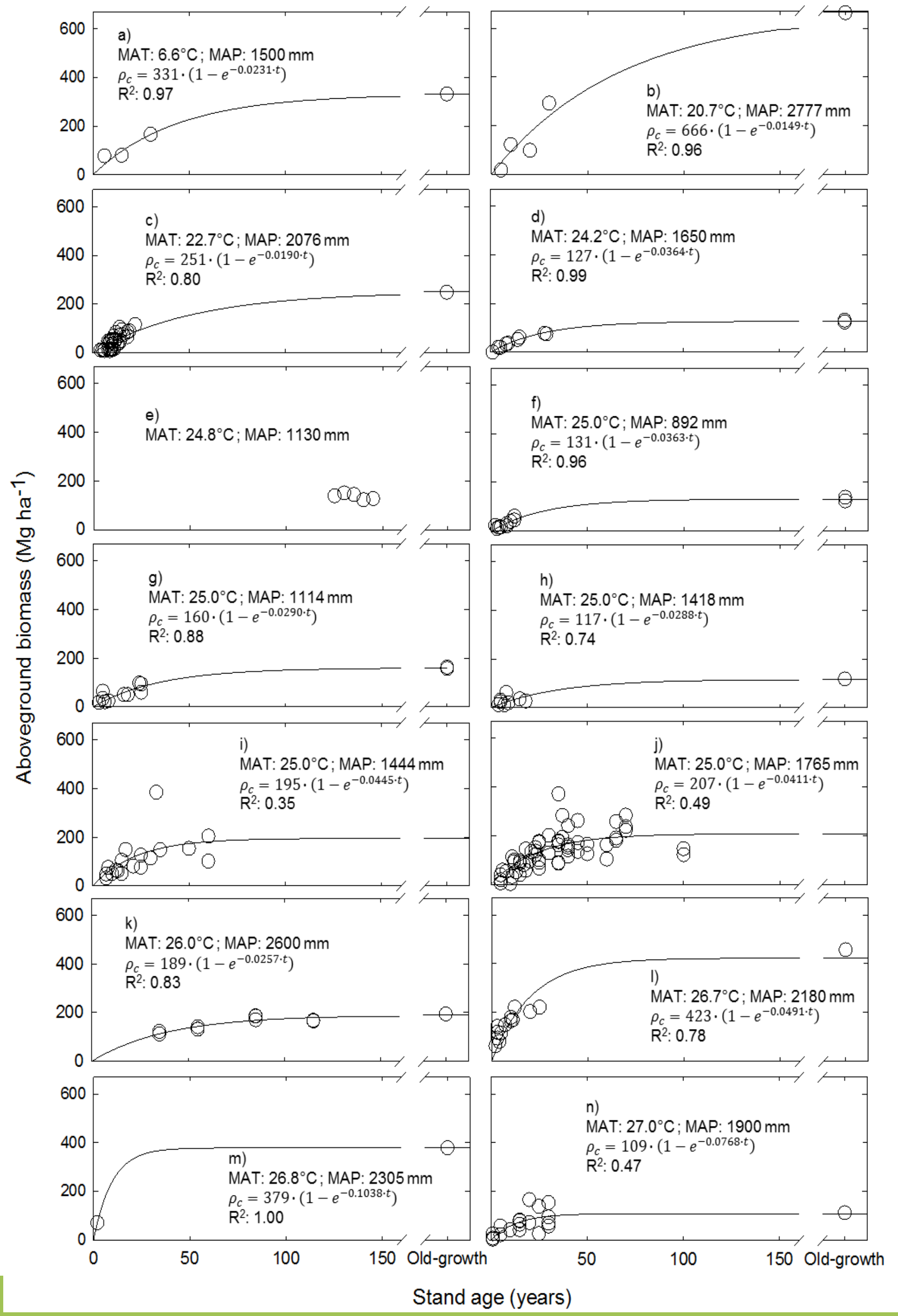
e = Euler's number

f = parameter on transition rate

t = time since the start of the period

Biomass data from 14 landscapes around the world

(Larjavaara et al. 2017 - Appendix 1)



Cool climate

Hot climate

The transition rate (f) of soil carbon density is even more challenging

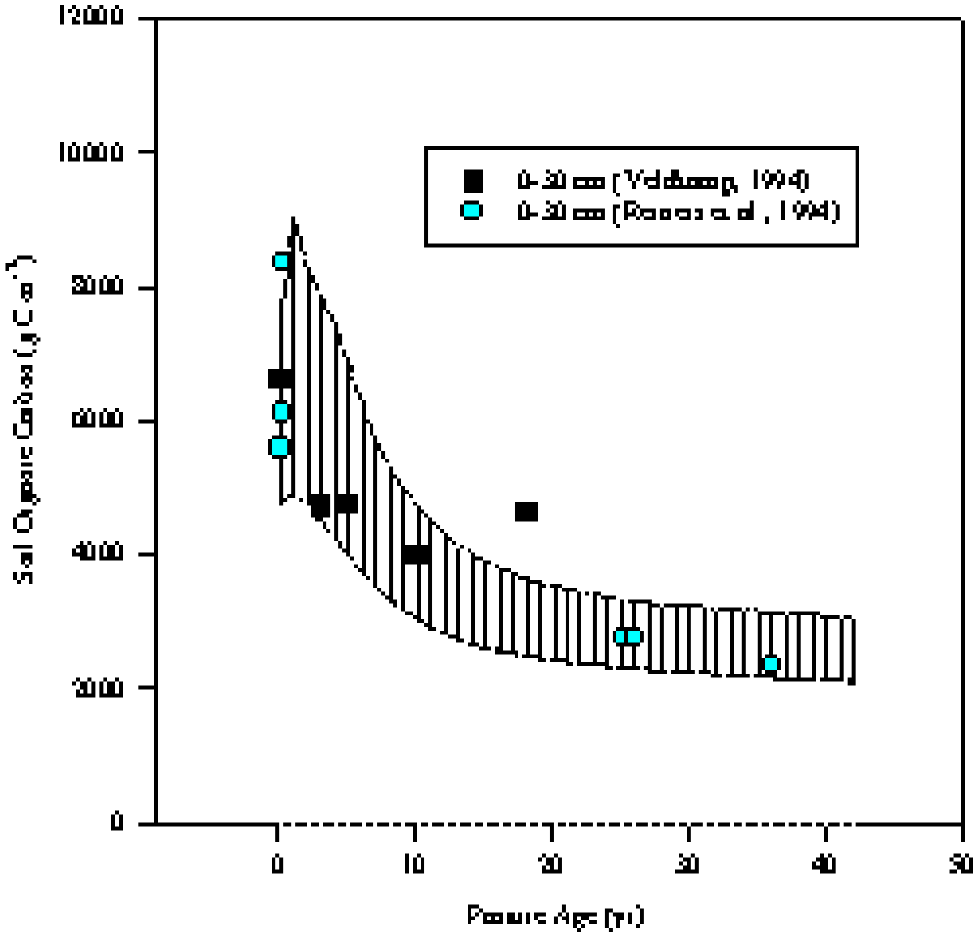
Table: Values of parameter f with standard deviations, coefficient of variation, and the number of chronosequences for each conversion type

⇩

Conversion type	f	SD	CV	n
Cropland to forest	0.056	0.067	120	7
Forest to cropland	0.073	0.055	75	71
Cropland to grassland	0.073	0.061	84	3
Grassland to cropland	0.151	0.149	99	3
Average/total	0.074	0.061	82	84

Soil carbon pool after conversion from forest to pasture in Costa Rica

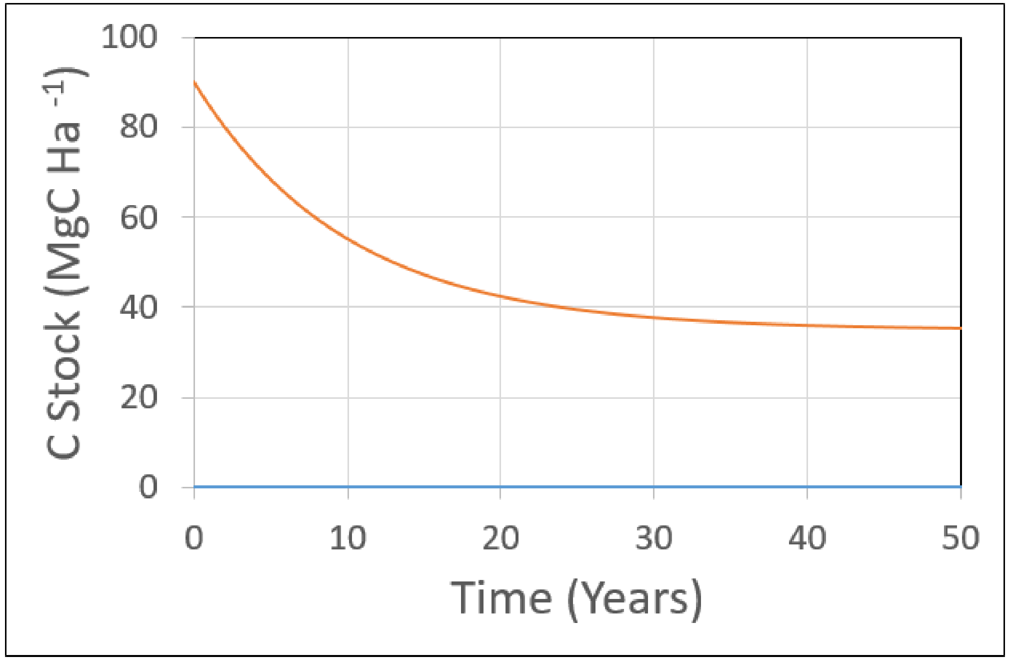
Soil organic carbon SOC (Mg ha^{-1}) after conversion



(Veldkamp, 1994)

Soil carbon pool after conversion - CarboScen

Rate of change of carbon density in biomas and in soil



Parameters

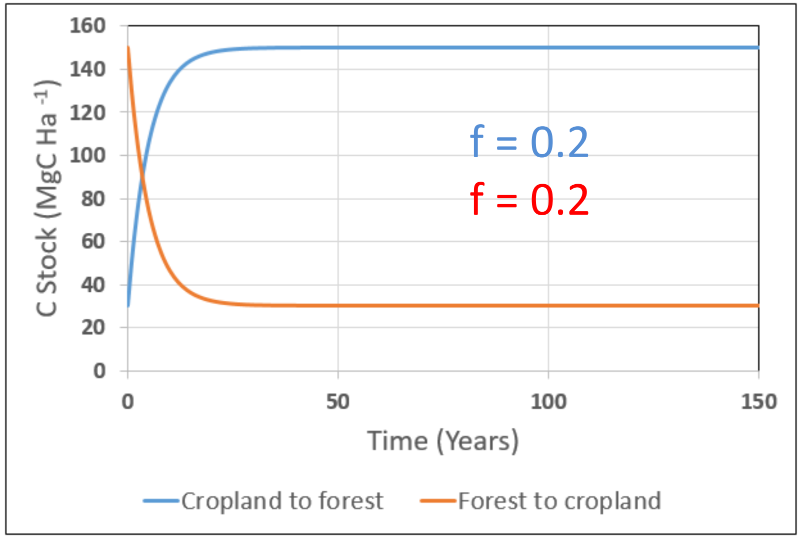
Pc =	Carbon density at a given moment
Ps =	Initial carbon density
Pe =	Equilibrium carbon density
f	Transition rate parameter

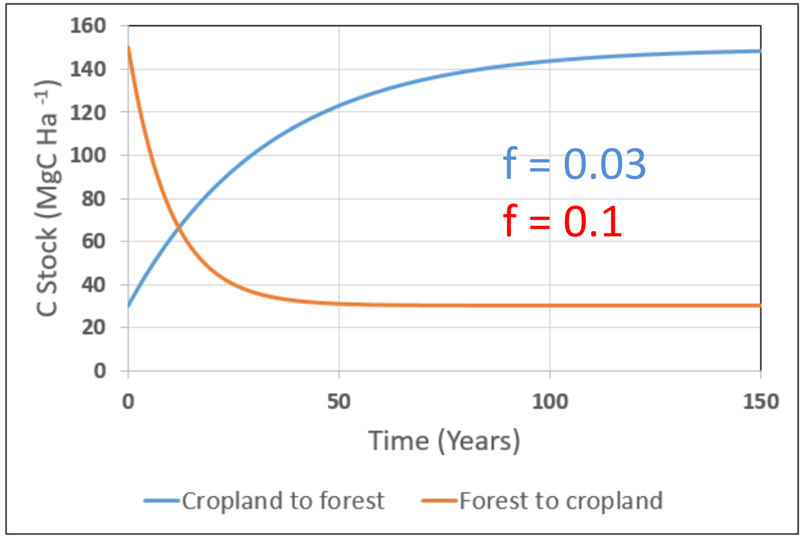
Ps	0
Pe	0
f	0.000
tau-Pe	0

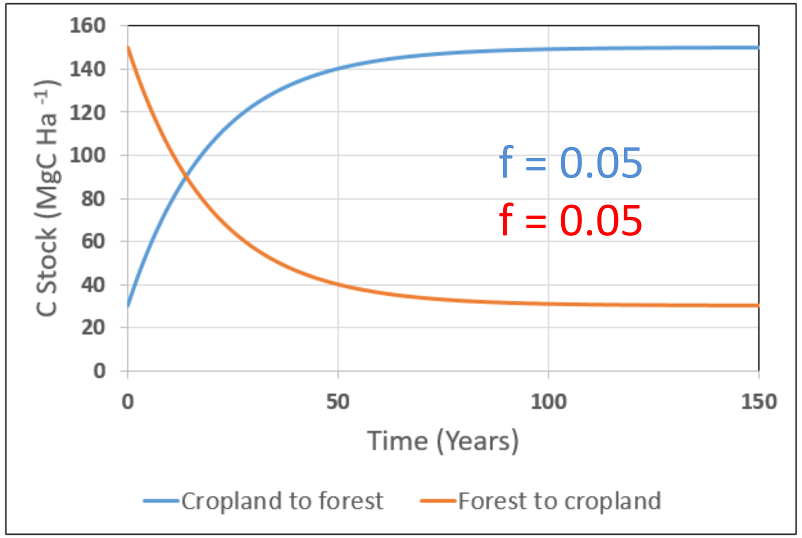
Ps	90
Pe	35
f	0.100
tau-Pe	14

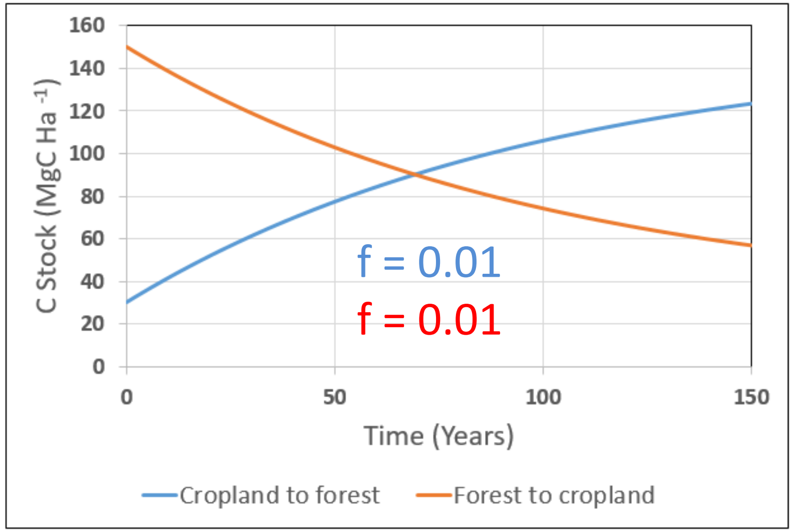
Veldkamp (1994) data parametrized in CarboScen

Carbon pools after conversion - CarboScen



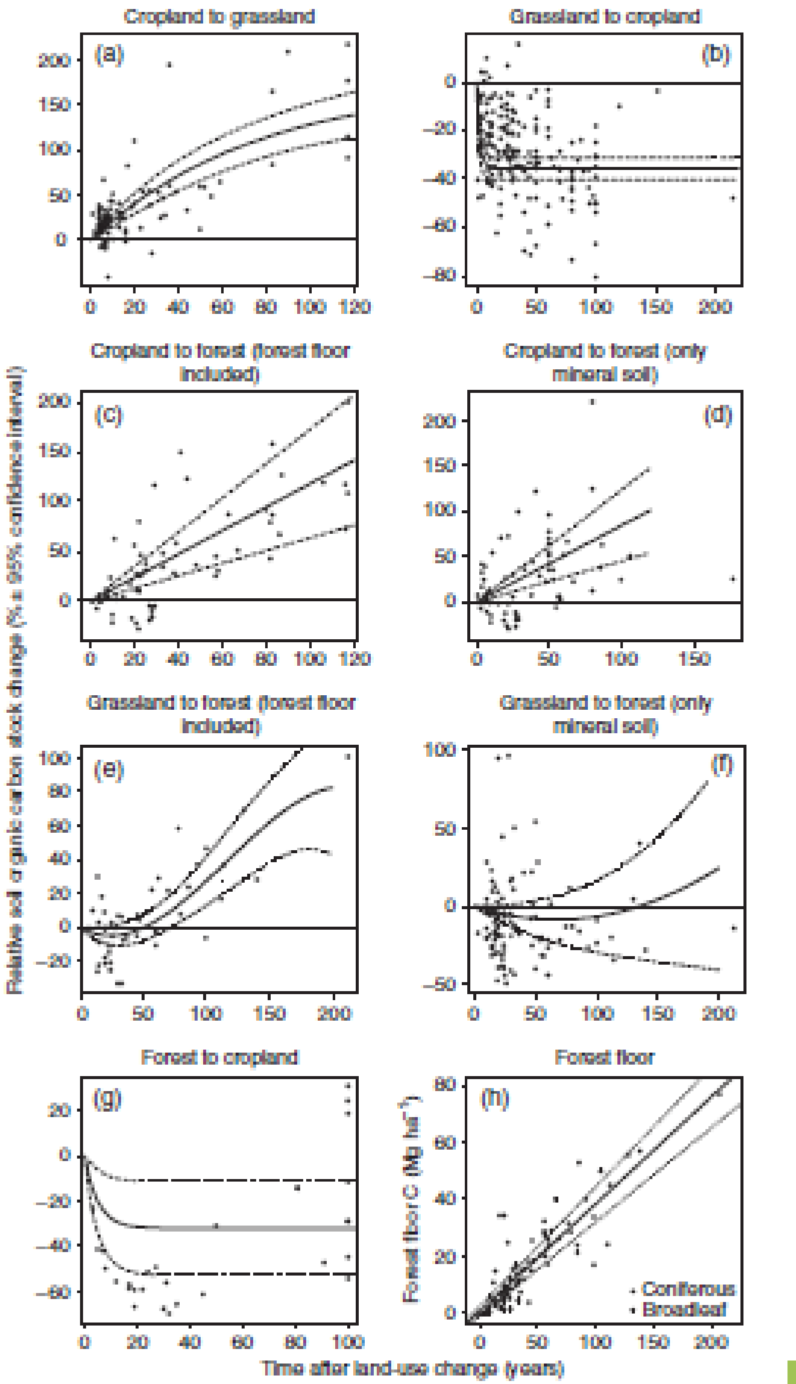






Existing data on soil carbon density transition rate is messy

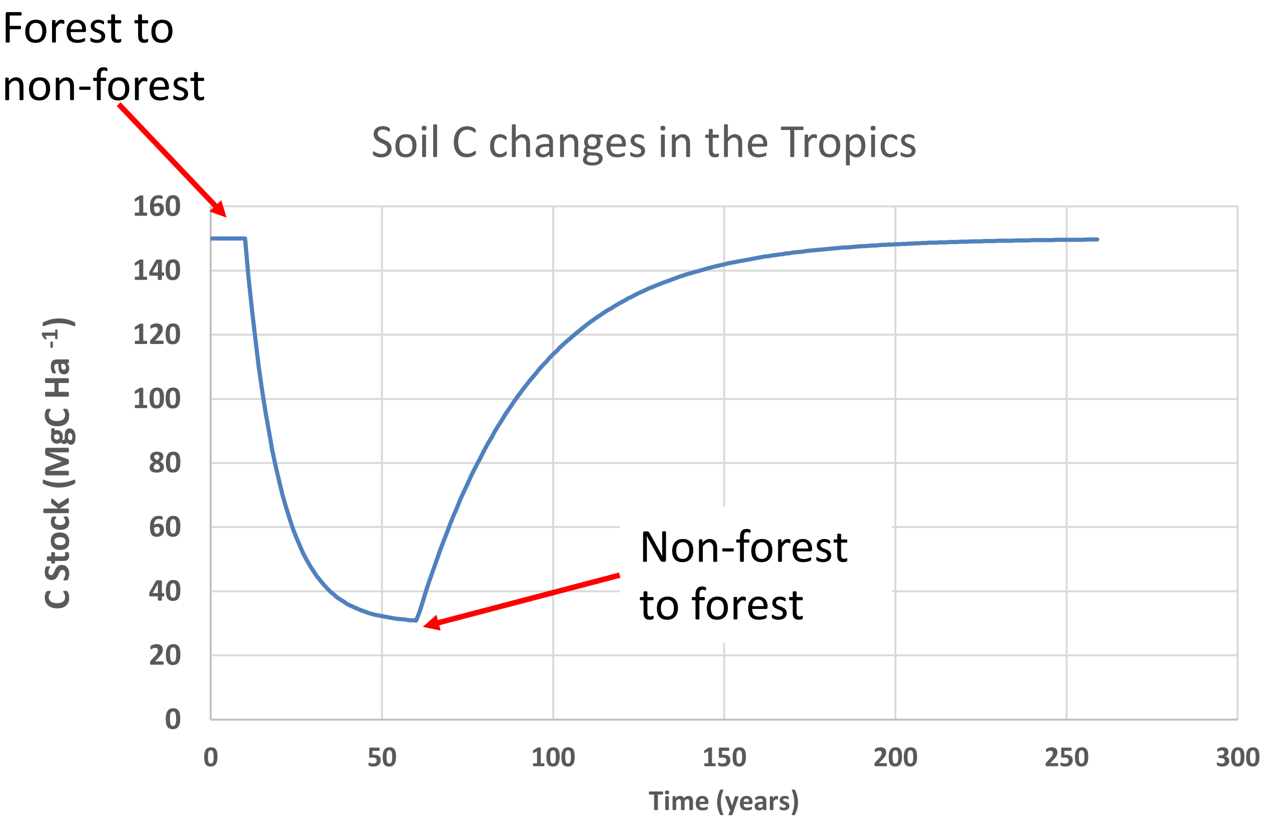
Few data and high uncertainty



(Poeplau et al. 2011)

Carbon transition rates after land use changes have different time constants

Carbon stock loss after deforestation is much faster than C stock recovery in restoration and/or plantation

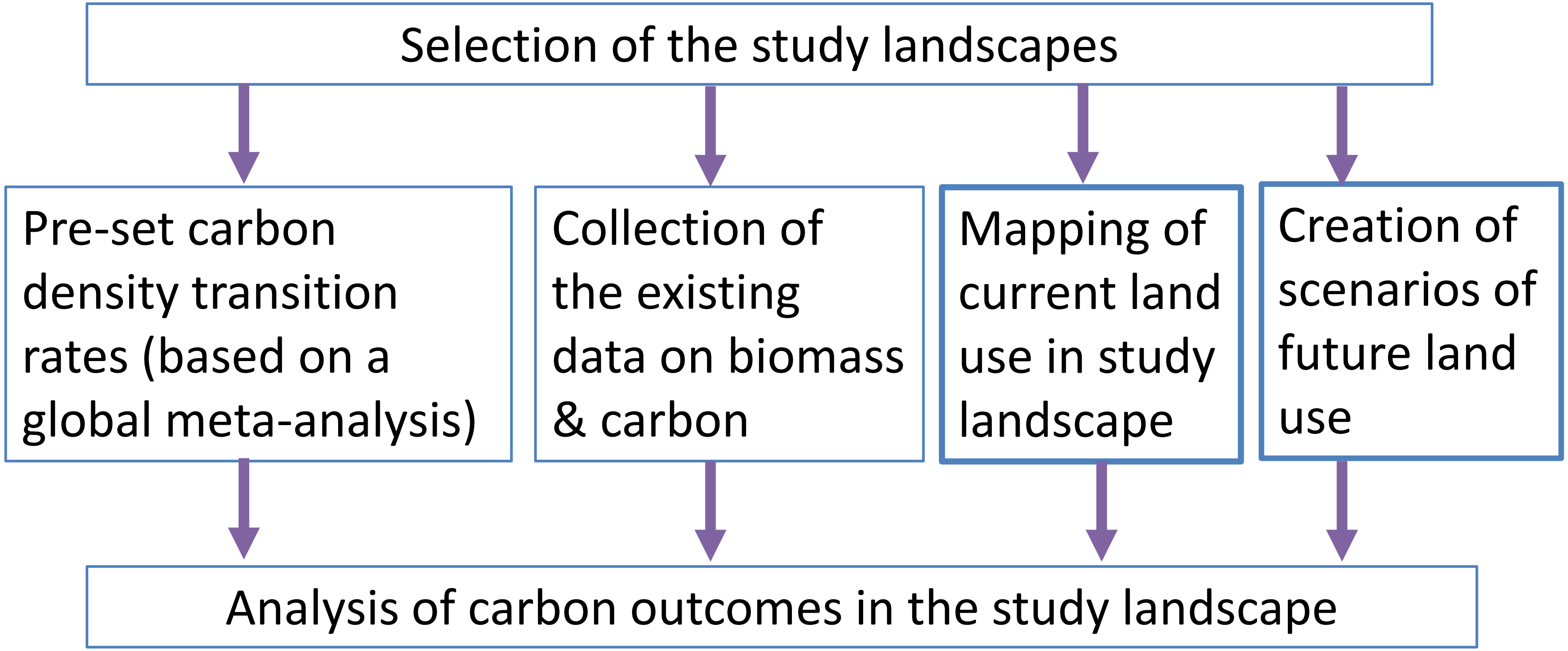


Example calculated with CarboScen tool
Data: Poeplau et al. 2011

CarboScen tool
https://www.cifor.org/gcs/toolboxes/carboscen/

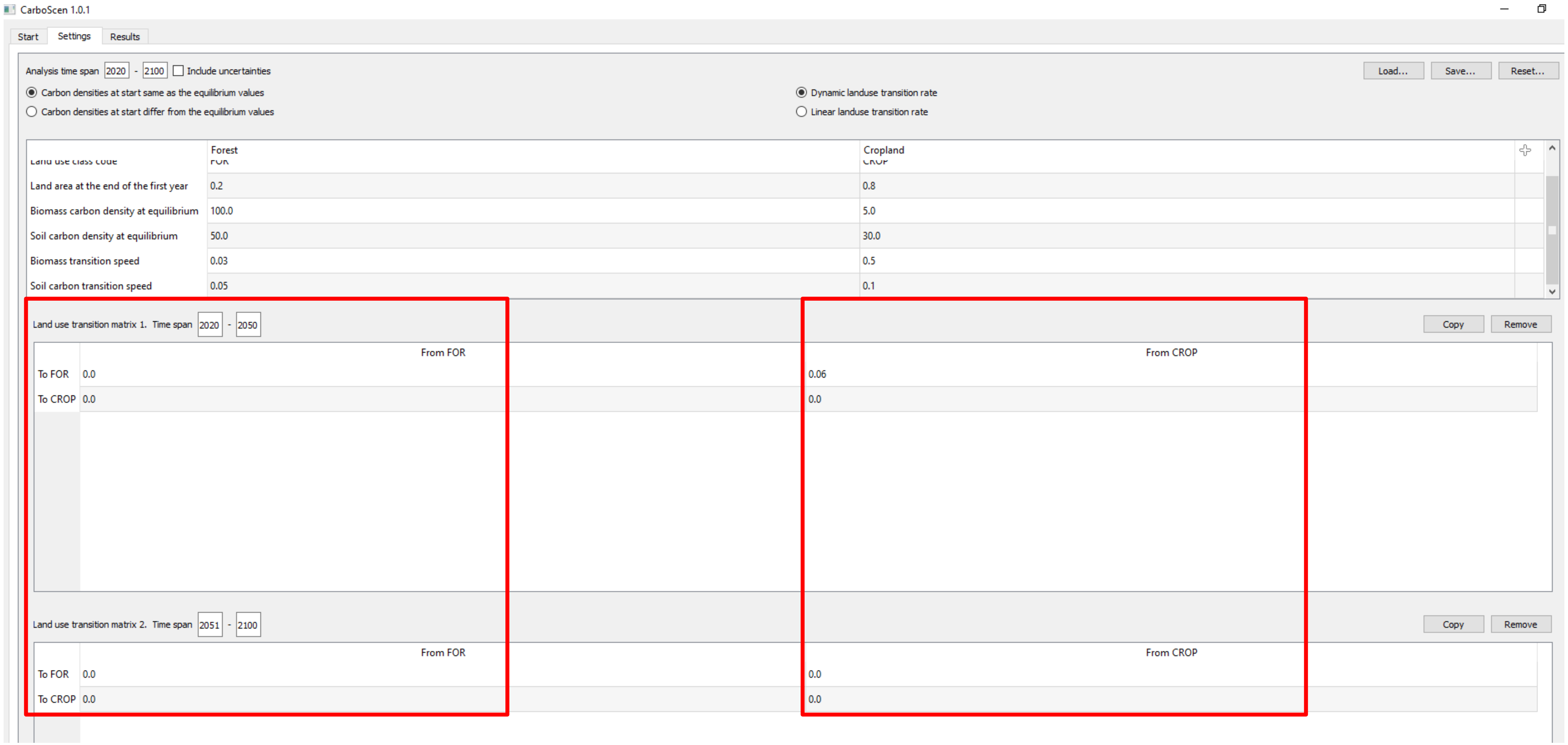
Larjavaara, M., Kanninen, M., Alam, S.A., Mäkinen, A., Poeplau, C. 2017. CarboScen: a tool to estimate carbon implications of land-use scenarios. Ecography 40, 894-900.

CarboScen - steps

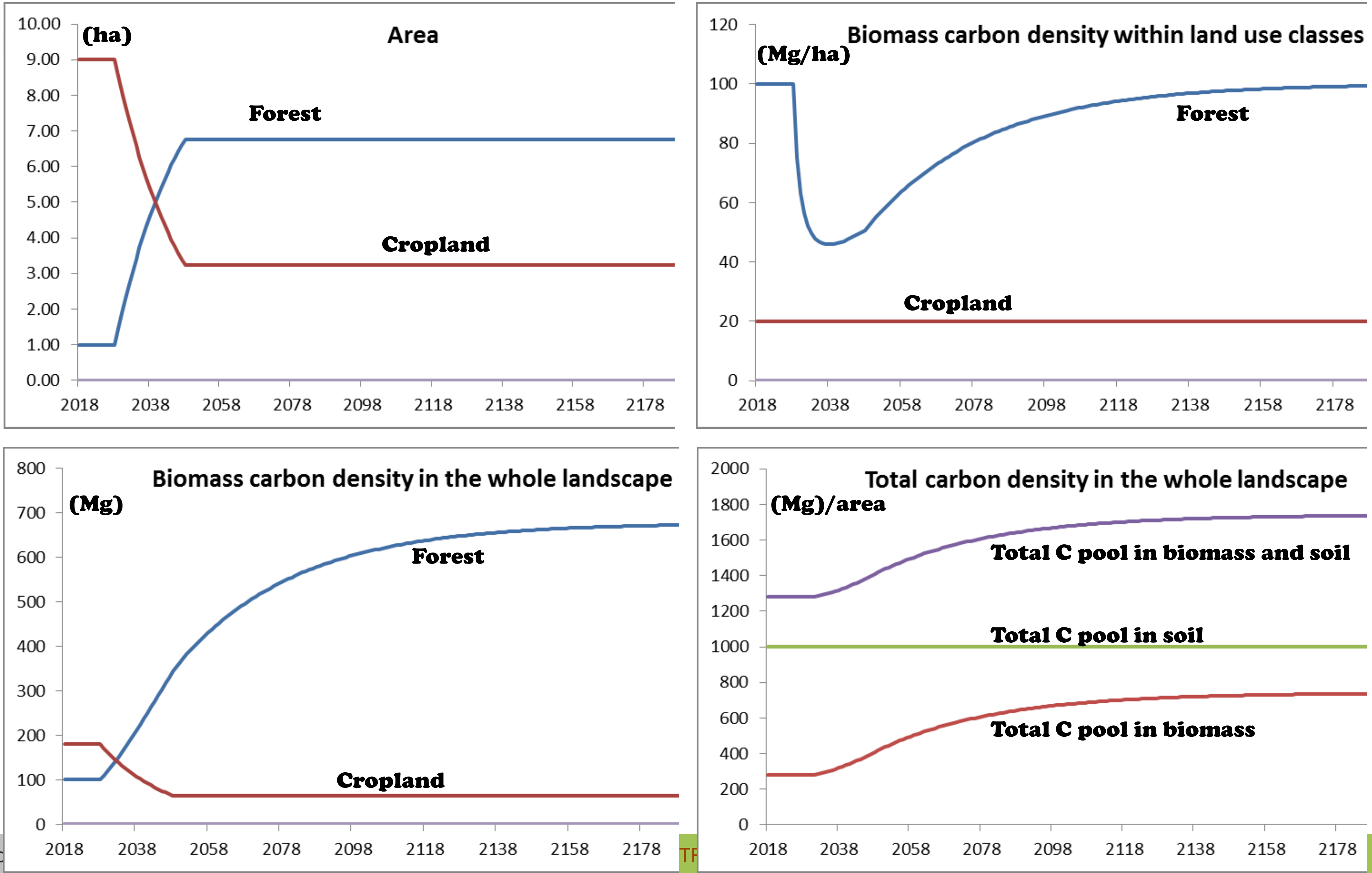


CarboScen user interface

Land use transition matrix



Simplest case: two land-uses

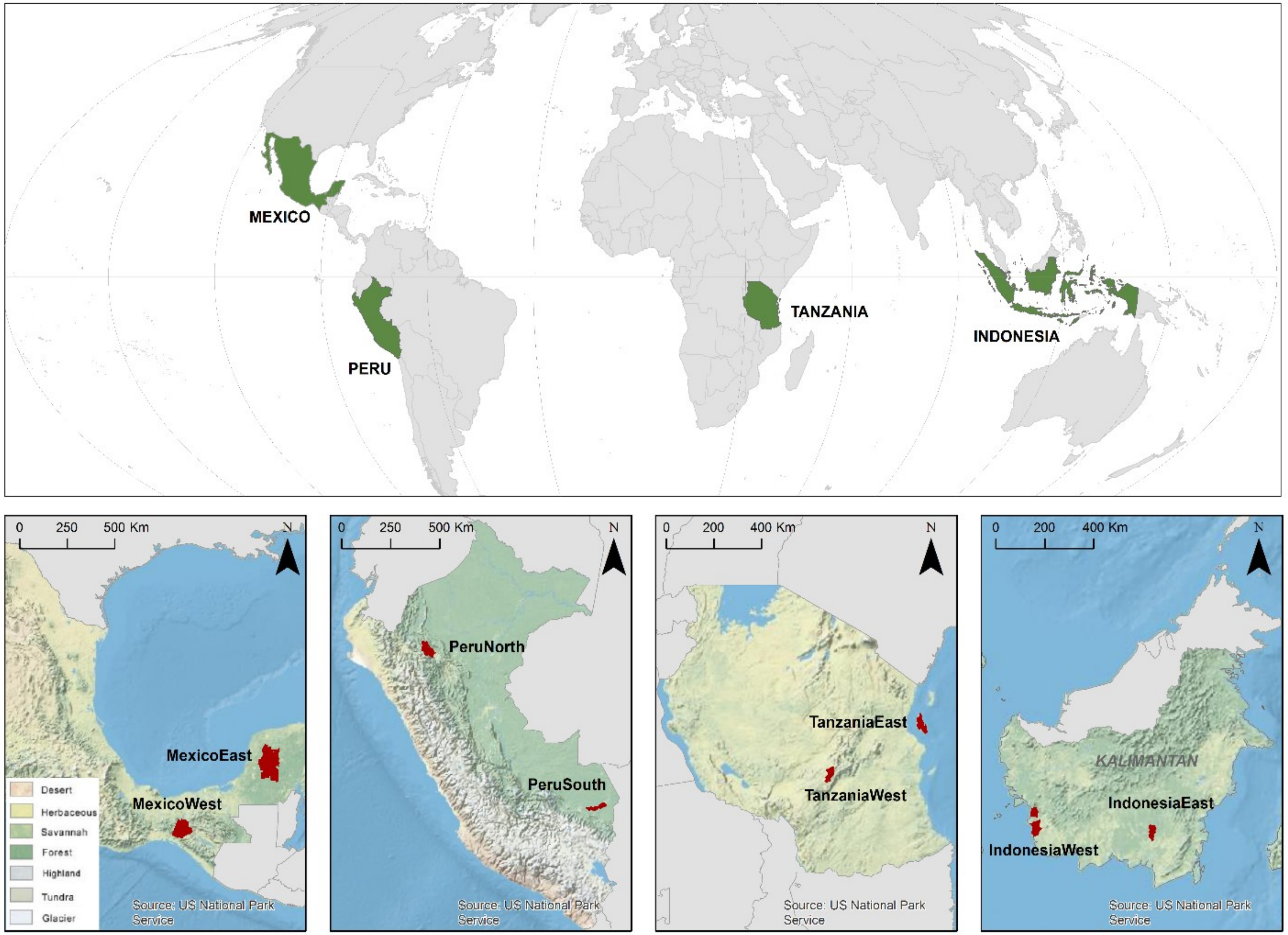


Carbon simulations in participatory workshops

CarboScen – example 1

- Participatory multi/stakeholder workshops to develop divergent future land use scenarios
- 4 continents, 4 countries, 8 landscapes, and 8 workshops
- In each workshop: 4 groups were given a task to visualize on maps the future of the landscapes with changing drivers of land-use change

Study landscapes



Mexico West (Chiapas)

Increasing carbon density of forested areas, and a significant afforestation of the area classified as ‘Pasture and savannah’

Mexico East (Yucatan)

Carbon increase resulted mainly from increase in carbon density of already forested areas and from some afforestation

Peru North (San Martin)

Significant conversion of “coffee” to “eco-coffee” (coffee agroforestry)

Peru South (Madre de Dios)

Increase in the carbon density of forested land, but, additionally, noteworthy afforestation was predicted on agricultural land

Tanzania West (Iringa)

Coniferous tree plantations on various open land-uses

Tanzania East (Zanzibar)

Modest increase in ecosystem carbon could result from forest tree plantations replacing coral rag scrub

Indonesia West (West Kalimantan)

Anticipated changes conserved some of the peat from oxidization due to aerobic decomposition or from fire, by afforestation and rising water table levels

Indonesia East (Central Kalimantan)

Anticipated changes conserved some of the peat from oxidization due to aerobic decomposition or from fire, by afforestation and rising water table levels

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Can conservation funding be left to carbon finance? Evidence from participatory future land use scenarios in Peru, Indonesia, Tanzania, and Mexico

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Carbon data - San Martin, Peru

Land use class	Biomass Carbon Density (Mg/ha)	Soil Carbon Density (Mg/ha)
Upper montane forest	157	76
Lower montane forest	149	59
Pre-montane forest	123	41
Palm forest in wetlands	99	57
Paramo (subalpine forest)	25	76
Mixed agriculture	20	20
Pasture	11	30
Rice cultivation	8	30
Coffee	11	30
Shaded coffee (agroforestry)	71	40

Participatory workshop in Peru

Developing land use scenarios

Scenarios

Factor of change	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Natural phenomena and climate change				
Government policies and programs, and alignment between levels of governance				
Commodity prices				
REDD+				

Scenarios

Factor of change	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Natural phenomena and climate change	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular
Government policies and programs, and alignment between levels of governance	Support for irrigated commercial agriculture	Integrated territorial (multi-sector) visión for land use	Support for adaptation measures and wáter management coordination among *ejidos*	Support for tourism and investment in industrial development in cities
Commodity prices	Commerical crop prices rise	Markets privilege organic and sustainably produced products	Commercial crop prices rise	All crop prices fall
REDD+	REDD+ does not materialize	REDD+ materializes with the commitment of the national government to support conservation	REDD+ materializes as a strategy to support local forest management and governance	REDD+ materializes as a strategy to support local forest management and governance

Scenarios

Factor of change	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***
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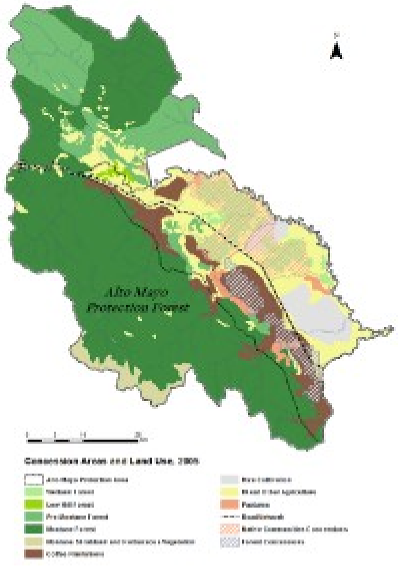
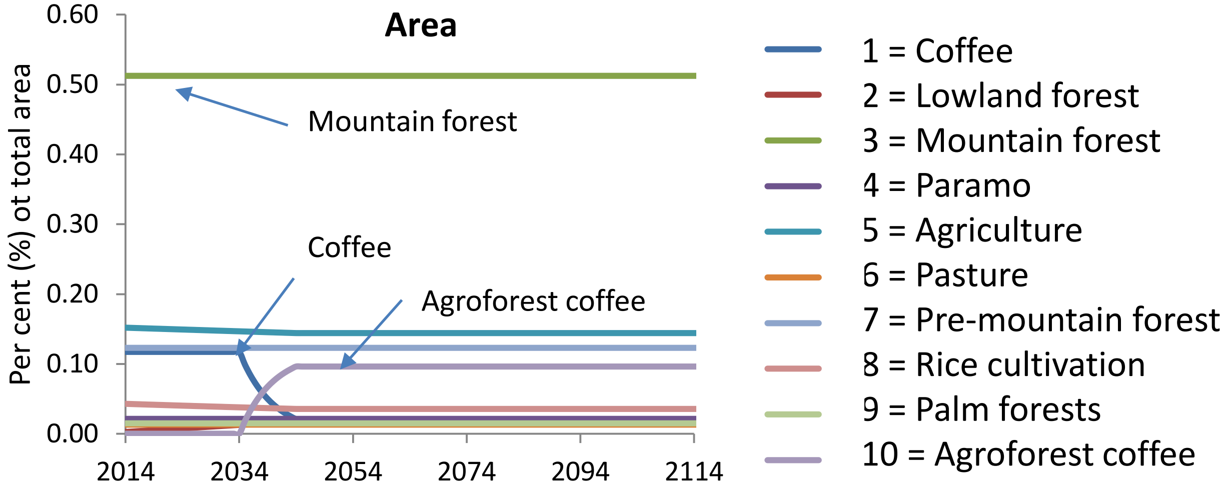
Participatory scenarios

- What is going to happen in the future?

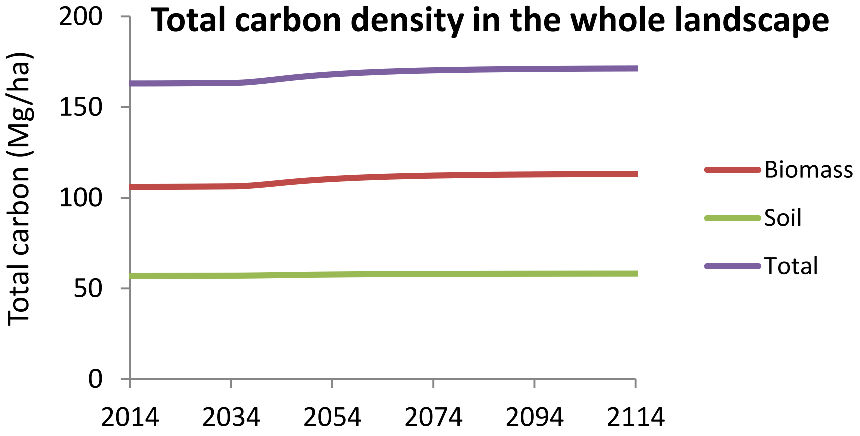
One land use scenario in San Martin, Peru:
"Forest conservation and agroforestry coffee"



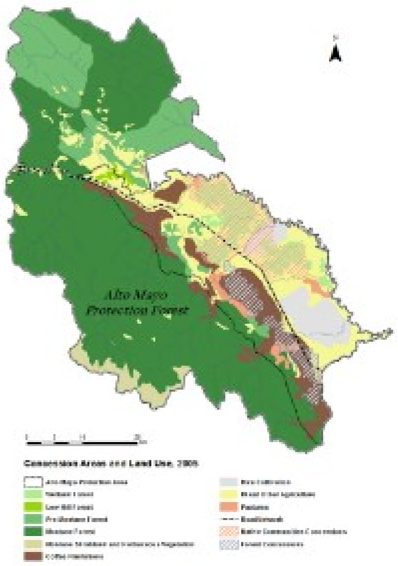


Total area of the landscape:
147 000 Has.

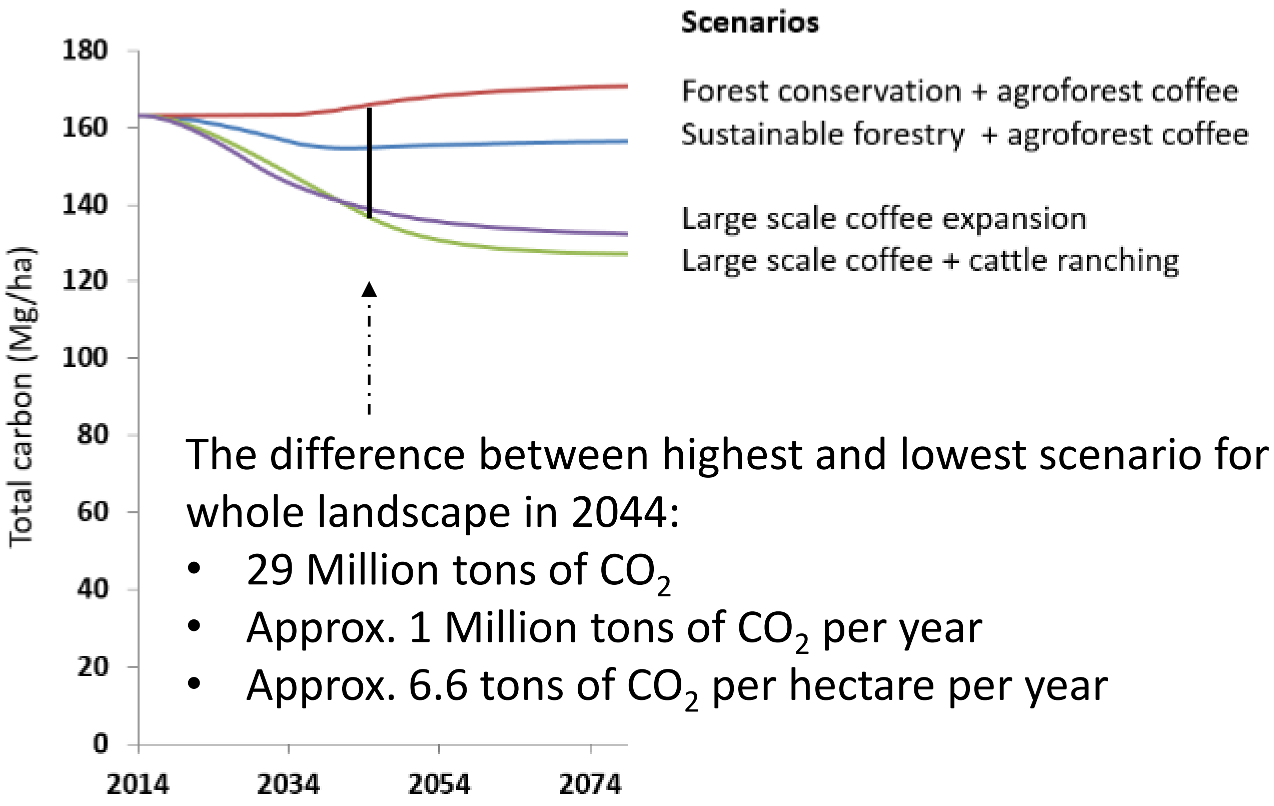
Scenario:
Forest conservation and agroforest coffee



Comparison of four scenarios in San Martin, Peru



Total area of the landscape:
147 000 Has.

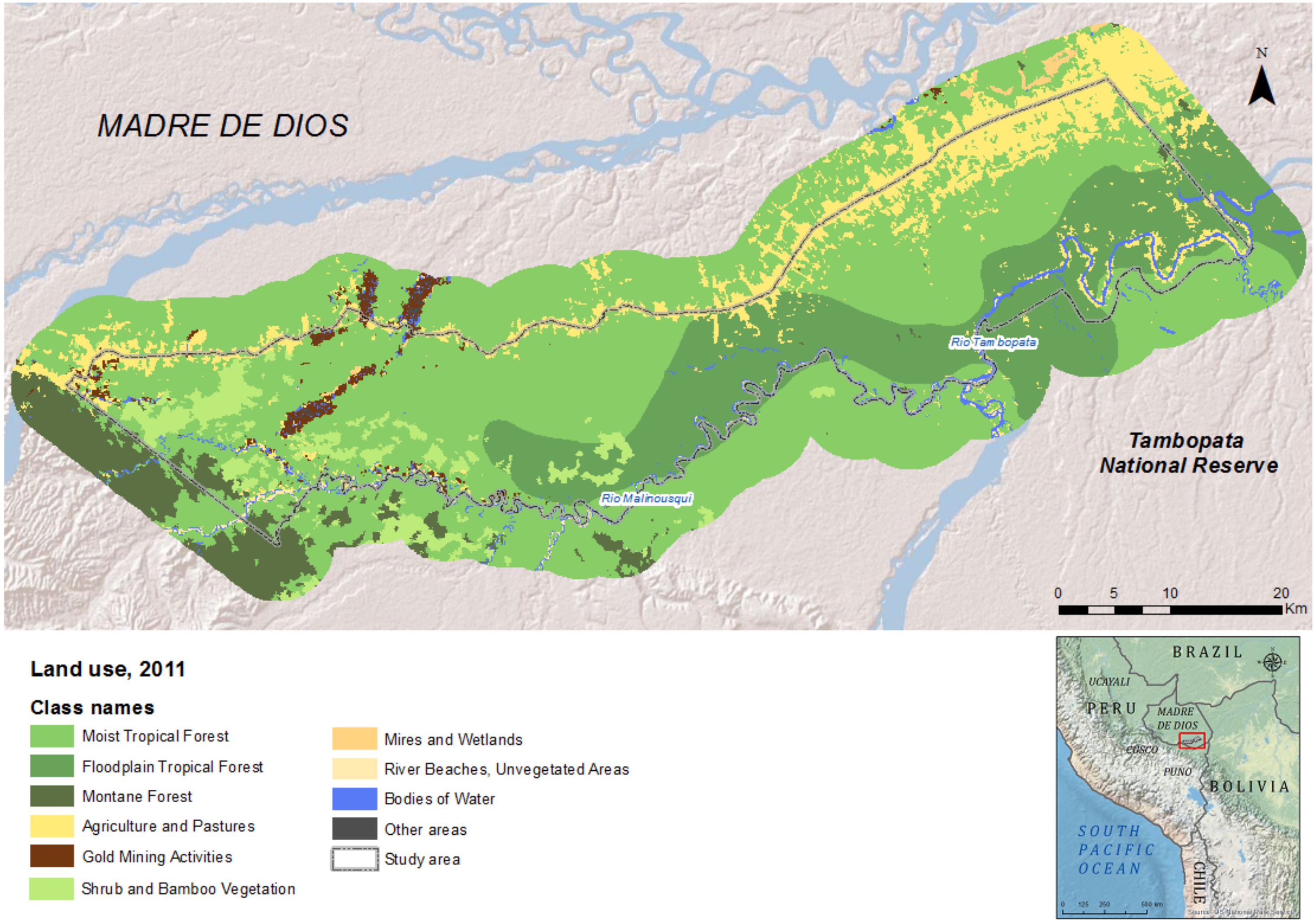


The difference between highest and lowest scenario for the whole landscape in 2044:

- 29 Million tons of CO_2
- Approx. 1 Million tons of CO_2 per year
- Approx. 6.6 tons of CO_2 per hectare per year

Madre de Dios, Peru

Total area of the landscape:
146 000 Has.



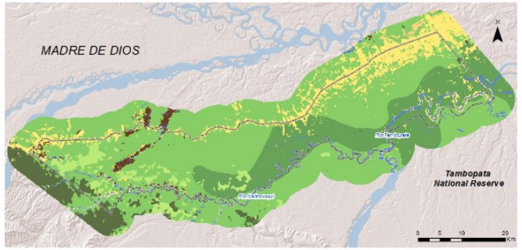
Local carbon data, Madre de Dios

Land us class	Carbon density of above-ground biomass (Mg/ha)	Soil organic carbon density (Mg/ha)
Agriculture and cattle raching	45.3	35.0
Bodies of water	11.4	5.0
Mining	5.0	5.0
Flooded tropical forest	153.3	50.0
Tropical forest	168.3	50.0
Mountain forest	181.5	60.0
Secondary vegetation and bamboo	120.6	55.0

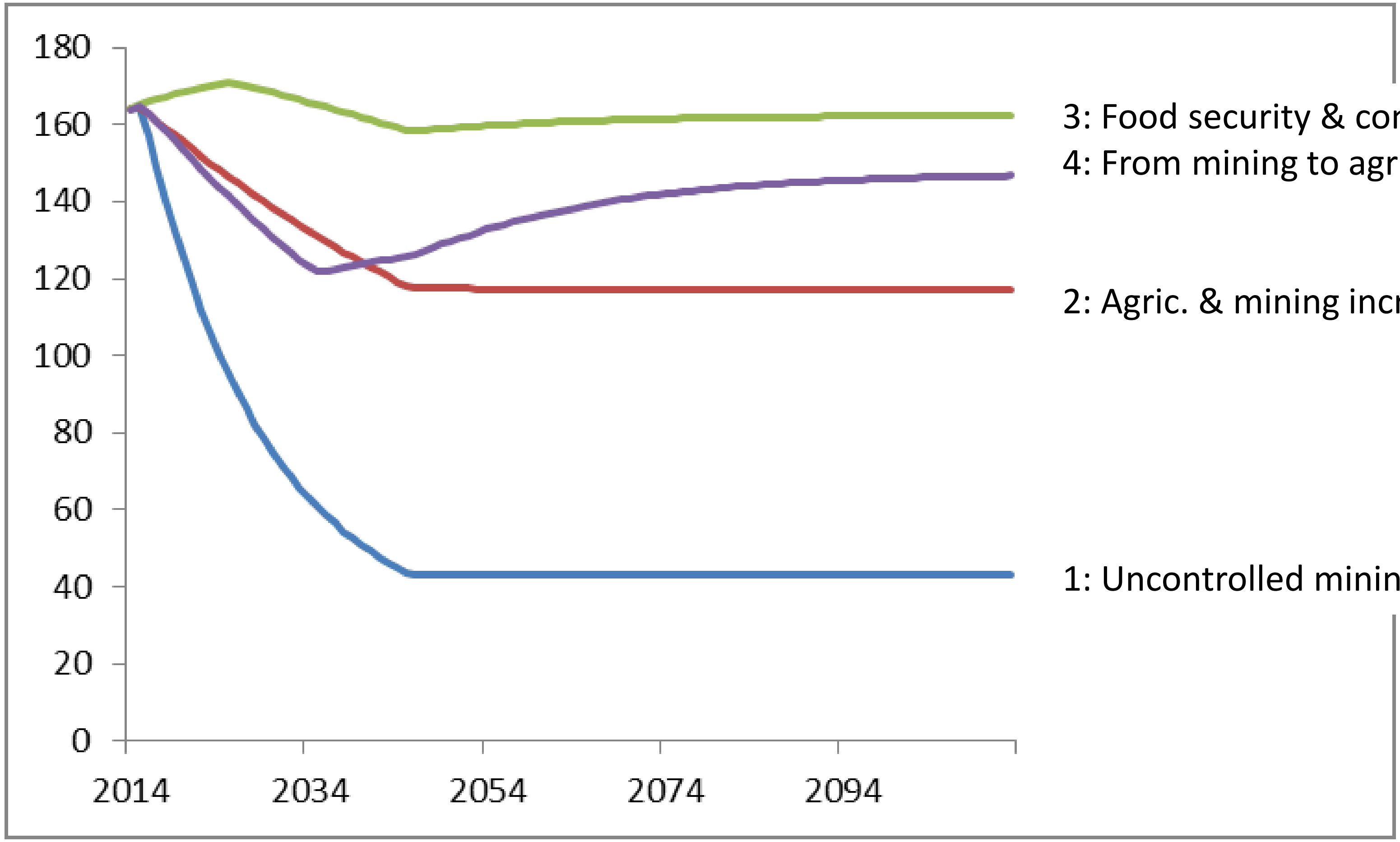
Participatory workshop in Peru

Developing land use scenarios

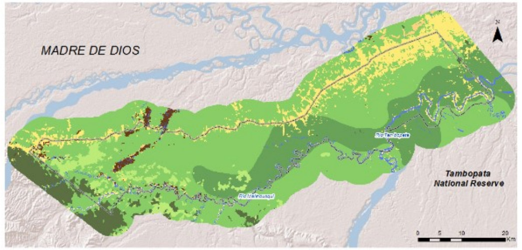
Four scenarios in Madre de Dios



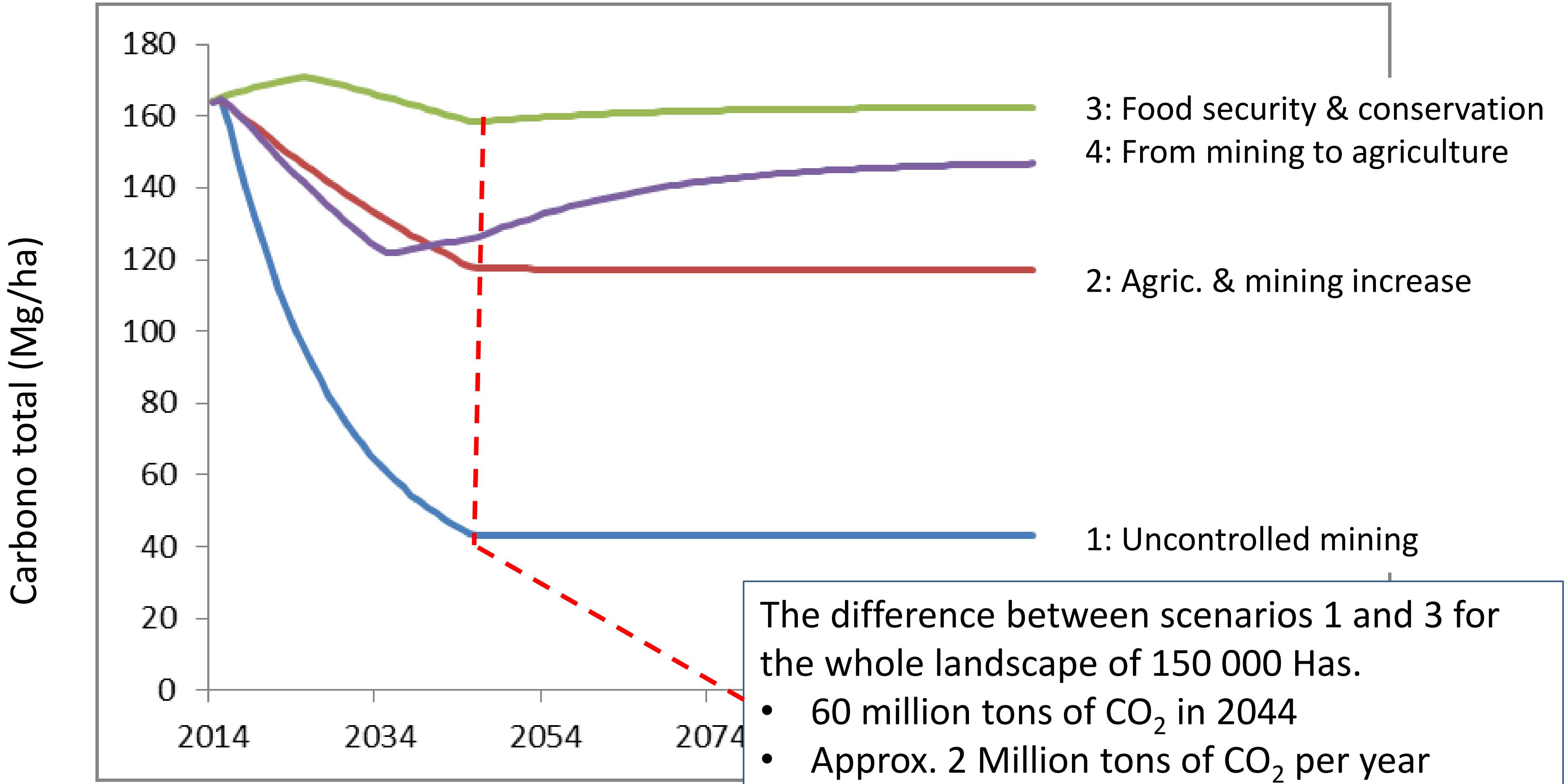
Total area of the landscape:
146 000 Has.



Four scenarios in Madre de Dios



Total area of the landscape:
146 000 Has.



The difference between scenarios 1 and 3 for the whole landscape of 150 000 Has.

- 60 million tons of CO_2 in 2044
- Approx. 2 Million tons of CO_2 per year
- Approx. 13 tons of CO_2 per hectare per year

Forest carbon data sets

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VITRI

Forest carbon data set from Rozendaal et al. 2022

Data for aboveground biomass carbon

Ecological zone	Continent	Successional stage	Mean AGB ($Mg\ ha^{-1}$)	SD ($Mg\ ha^{-1}$)	Median AGB ($Mg\ ha^{-1}$)	Method	# plots	# grid cells	Ref
Tropical rainforest	Africa	OGF	404.2	120.4	—	Weighted	451	—	[1–12]
		OSF	212.9	143.1	141.6	Grid cell	97	9	[5–7, 11, 13–16]
		YSF	52.8	35.6	56.3	Grid cell	83	9	[9–11, 14, 15, 17]
	America	OGF	307.1	104.9	—	Weighted	487	—	[3, 4, 9, 10, 18–21]
		OSF	206.4	80.4	208.3	Grid cell	328	26	[9, 10, 22–28]
		YSF	75.7	34.5	67.1	Grid cell	513	23	[9, 10, 14, 22, [illegible]]
	Asia	OGF	413.1	128.5	—	Weighted	192	—	[3, 4, 9, 10, 33–35]
		OSF	131.6	20.7	131.6	Grid cell	94	5	[9, 10, 36, 37
		YSF	45.6	20.6	50.6	Grid cell	88	7	[9, 10, 37–39
Tropical moist forest	Africa	OGF	236.6	104.7	—	Weighted	25	—	[1, 2, 16]
		SF	72.8	36.4	64.2	Grid cell	7530	52	[9, 10, 16, 40–47]
	America	OGF	187.3	94.0	—	Weighted	106	—	[3, 4, 9, 10, 18–21]
		OSF	131.0	54.2	112.4	Grid cell	185	17	[9, 10, 22–26]
		YSF	55.7	28.7	44.7	Grid cell	353	17	[9, 10, 22, 23, 25, 26]
	Asia	All	67.7[a]	93.4	31.9	Grid cell	322	36	[9, 10, 35, [illegible]]
Tropical dry forest	Africa	All	69.6	47.5	59.7	Grid cell	9410	47	[1, 2, 43, 44, 51–53]
	America	OGF	127.5	72.6	—	Weighted	12		[18–21]
		OSF	118.9	81.3	121.1	Grid cell	72	6	[9, 10, 22, 23, 54]
		YSF	32.2	24.2	32.1	Grid cell	44	5	[9, 10, 22, 23, 54, 55]
	Asia	All	184.6[b]	144.5	161.6	Grid cell	36	3	[9, 10, 35, 48 [illegible]]
Tropical shrubland	Africa	All	48.4	45.8	37.2	Grid cell	2626	17	[44, 57, 58]
	America	All	71.5	46.4	62.5	AGB map	—	216	[59]
	Asia	All	38.3	33.0	27.1	AGB map	—	1458	[59]
Tropical montane forest	Africa	All	190.0	131.2	218.9	Grid cell	2057	46	[1–4, 9, 10, 42–44, 47, 53, 60–68]
	America	OGF	195.0	95.6	—	Weighted	83	—	[3, 4, 9, 10, 18–21]
		OSF	184.4	111.0	177.7	Grid cell	21	8	[9, 10, 22, 23, 26, 69]
		YSF	75.9	51.1	74.9	Grid cell	114	8	[9, 10, 22, 23, 26, 69, 70]
	Asia	OGF	433.5[c]	147.5	—	Weighted	23	—	[3, 4, 9, 10, 3[illegible], 35]
		SF	66.4	61.0	48.5	Grid cell	329	19	[9, 10, 50, [illegible]]
Subtropical humid forest	Africa	All	54.1	20.6	52.4	AGB map	—	203	[59]
	America	All	84.5	42.9	91.5	AGB map	—	3906	[59]
	Asia	OGF	323.0	157.7	281.3	Grid cell	29	11	[9, 10]
		SF	[illegible]	[illegible]	[illegible]	Grid cell	[illegible]	14	[9, 10]
Subtropical dry forests	Africa	All	65.2	27.1	60.2	AGB map	—	650	[59]
	America	All	115.9	46.2	110.8	AGB map	—	330	[59]
	Asia	All	70.9	26.2	75.6	AGB map	—	223	[59]
Subtropical steppe	Africa	All	50.5	23.9	47.0	AGB map	—	147	[59]
	America	All	44.0	26.0	39.8	AGB map	—	2797	[59]
	Asia	All	41.6	24.7	39.9	AGB map	—	400	[59]
Subtropical montane forest	Africa	All	35.1	22.2	26.8	AGB map	—	681	[59]
	America	All	74.6	40.1	64.6	AGB map	—	1835	[59]
	Asia	OGF	250.2	59.4	247.5	Grid cell	115	17	[9, 10]
		SF	155.2	41.7	166.5	Grid cell	32	14	[9, 10]

The IPCC refers to montane forests as 'mountain systems'; old-growth forests are included as 'primary' forests (IPCC 2019). YSF: young secondary forest (⩽20 years old); OSF: older secondary forest (>20 years old); SF: all secondary forests; OGF: old-growth forest; All: all successional stages.

Carbon data – Nambak, Laos

Land use class	Biomass Carbon Density (Mg/ha)	Soil Carbon Density (Mg/ha)
Agriculture	10	80
Fallow	24	110
Logged forest	76	113
Pristine forest	161	95
Tree plantation	50	72

Hett e t al. 2011, Larjavaara et al. 2019

Carbon data – Thailand

Land use class	Biomass Carbon Density (Mg/ha)	Soil Carbon Density (Mg/ha)
Agriculture – coconut-cassava	100	30(*)
Agriculture – paddy rice	9	30(*)
Rubber plantation	70-90	60-160
Eculayptus plantation	60	30-70(*)
Home garden	140	30(*)

(*) Average “best guess”

Gnanavelrajah et al. 2008, Nizami et al. 2014, van Straaten et al. 2015

Thank you

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