

# CarboScen

## Analysis of carbon outcomes in landscape scenarios

Markku Kanninen  
3.5.2023



# 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

Publications of the Academy of Finland 3/93

Markku Kanninen (Ed.)

## **CARBON BALANCE OF WORLD'S FORESTED ECOSYSTEMS: TOWARDS A GLOBAL ASSESSMENT**

Proceedings of the IPCC AFOS Workshop held  
in Joensuu, Finland, 11–15 May 1992

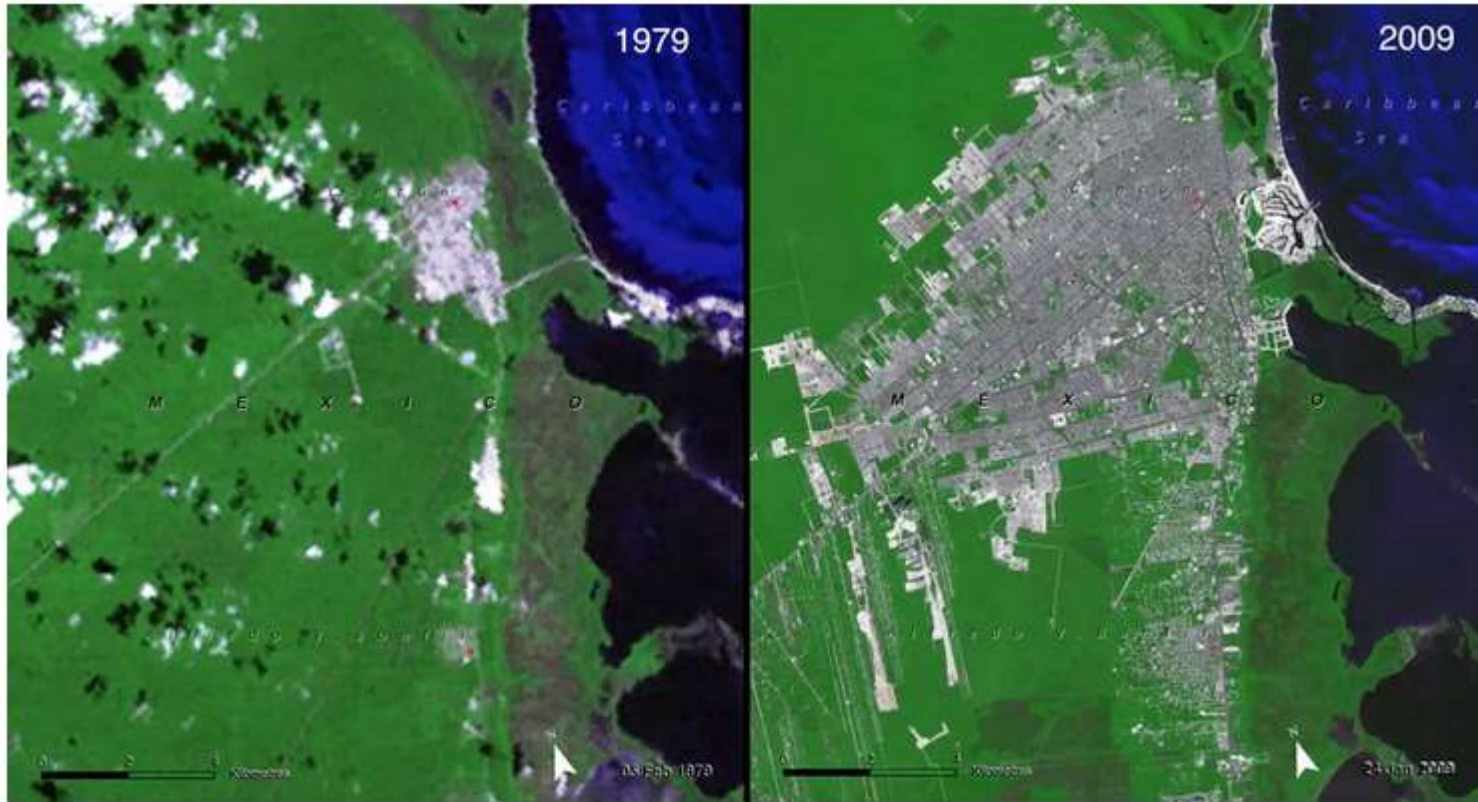
1993

2018



Summary for Policymakers	Chapter 1 - Framing and context	<b>Special Report on Global Warming of 1.5 °C</b>
Technical Summary	Chapter 2 - Mitigation pathways compatible with 1.5 °C in the context of sustainable development	
5 Chapters	Chapter 3 - Impacts of 1.5 °C global warming on natural and human systems	
Frequently Asked Questions	Chapter 4 - Strengthening and implementing the global response to the threat of climate change	
Boxes - Integrated case studies/regional and cross-cutting themes	Chapter 5 - Sustainable development, poverty eradication, and reducing inequalities	

# Changes in landscapes



Cancun in Yucatan,  
Mexico 1979 and 2009



# Changes in landscapes



Disappearing glaciers



# Changes in landscapes

Urbanization



2003



2005



2011



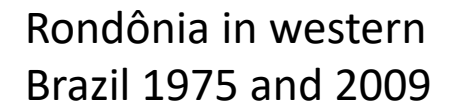
2015

# Changes in landscapes

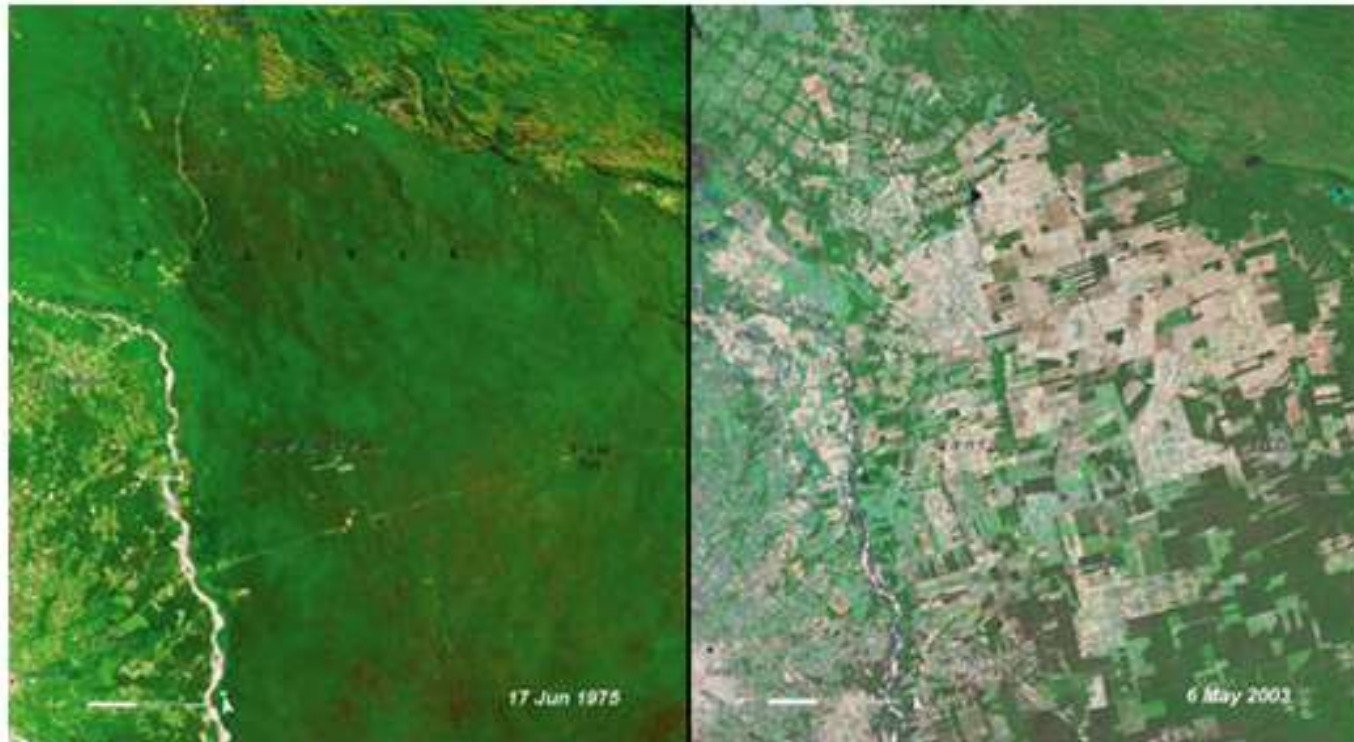


The Paraguay-Parana River before and after the construction of the Yacyreta Dam in 1985





# Changes in landscapes

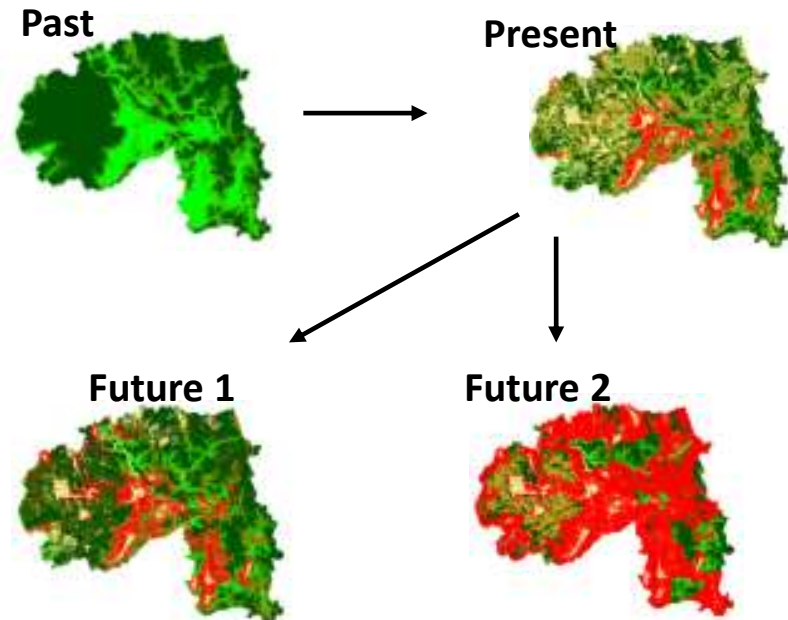


Deforestation in Bolivia  
1975 and 2003



# 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

# Measuring REDD+ performance

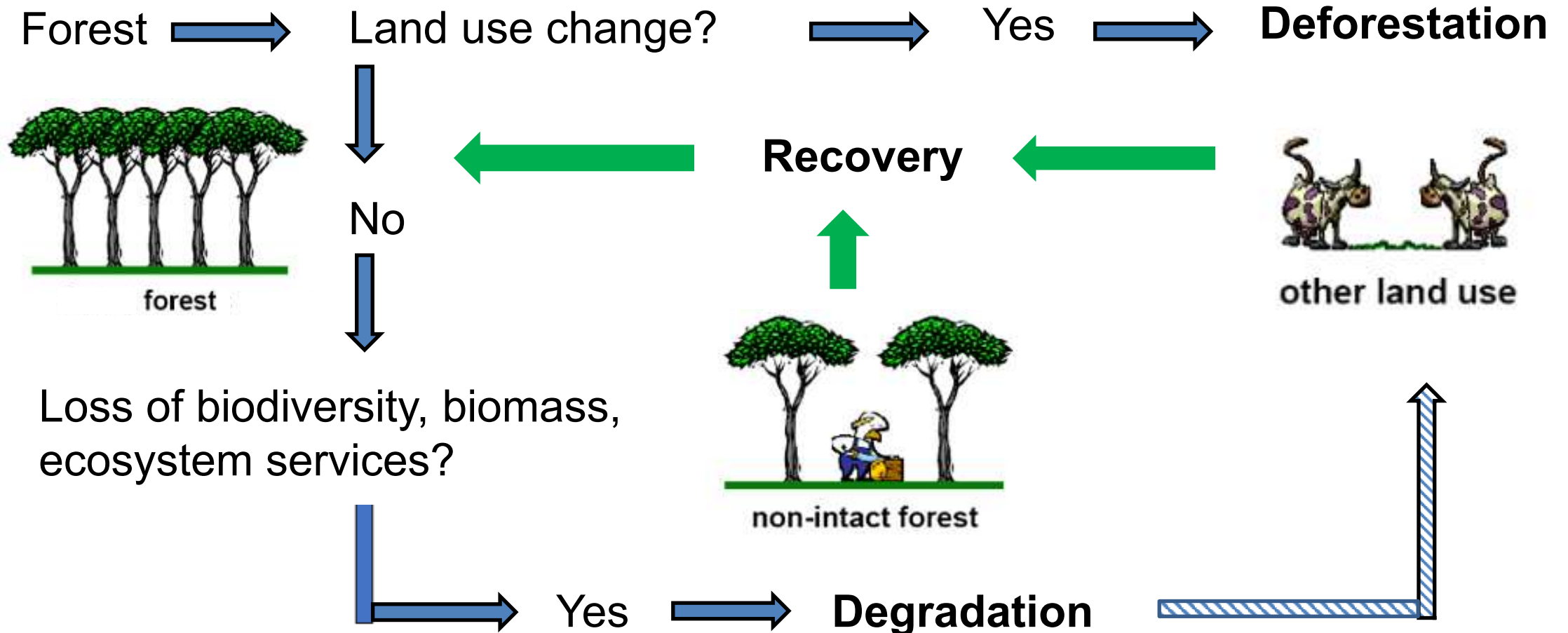
- What are we measuring?
  - Inputs, process, outputs, outcomes, impact
- Effectiveness (outcomes, impact)
  - The amount of emissions reduced or removals increased by REDD+ actions
- Approaches
  - An *ex post* evaluation of the effectiveness
    - Changes in forest carbon stocks (MRV) compared to a 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





# Deforestation, forest degradation, and recovery

(≈ forest transition)



# How can forests mitigate climate change?

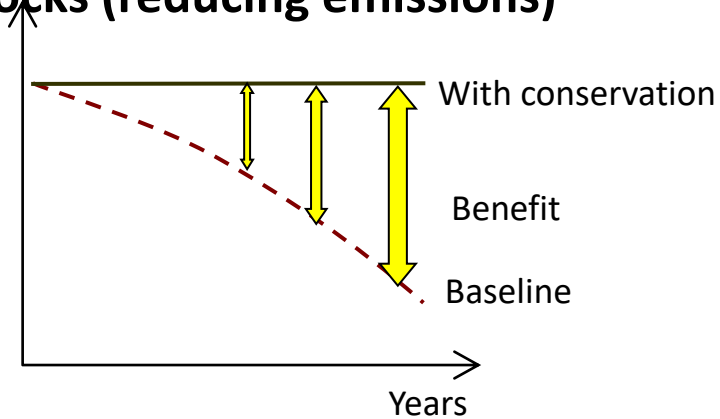
## 1) Avoiding losses of carbon stocks (reducing emissions)



Reducing  
deforestation and  
degradation



Applying other  
REDD+ activities



Forest

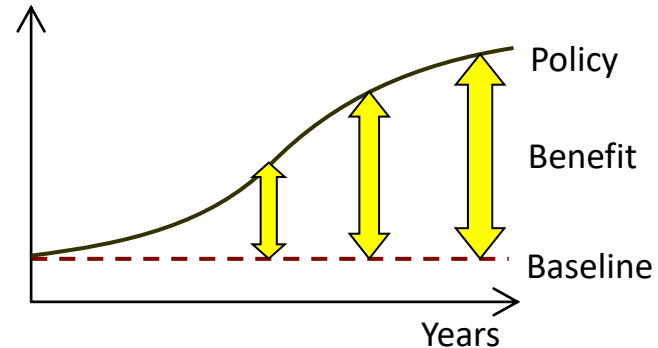
## 2) Increasing carbon stocks (carbon dioxide removal from atmosphere)



Creating  
plantations



Developing  
agroforestry



Energy

## 3) Producing biomaterials and bioenergy through substitution





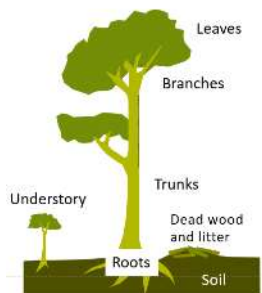
# How to quantify ecosystem carbon when land-uses are known?

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

Area (Hectares)



Carbon density per unit area  
(Mg C /ha)



Example 1		Example 2	
1 Ha		1 000 Ha	
1 x 100	➡	1 000 x 50	➡
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 ( $C_{tot}$ ):  
$$C_{tot} = D_c \times \text{Area}$$

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



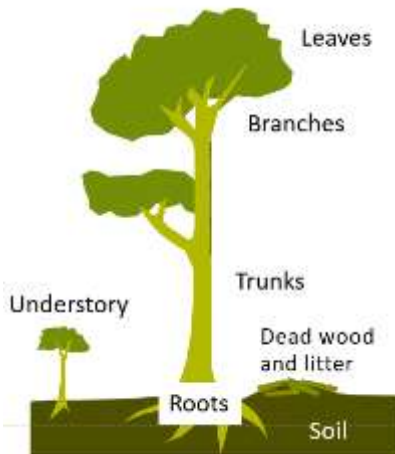
# CarboScen tool

## Carbon analysis at landscape scale

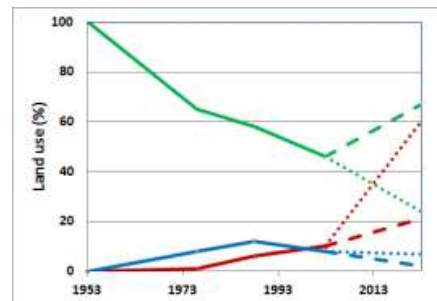
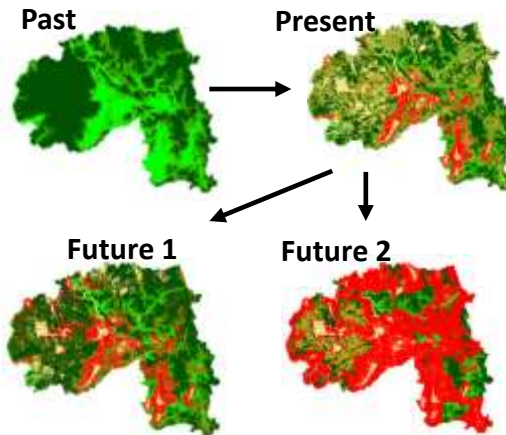
Carbon data for different land uses

IPCC Carbon pools, grouped as

- Above-ground
- Below-ground
- Soil



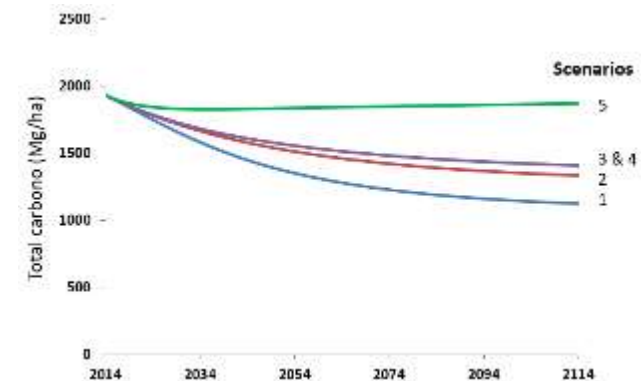
Scenarios of land use change



Carbon outcomes in different land use scenarios

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://www.cifor-icraf.org/gcs/knowledge/toolboxes/carboscen/>

## Paper published in Ecography (open access)

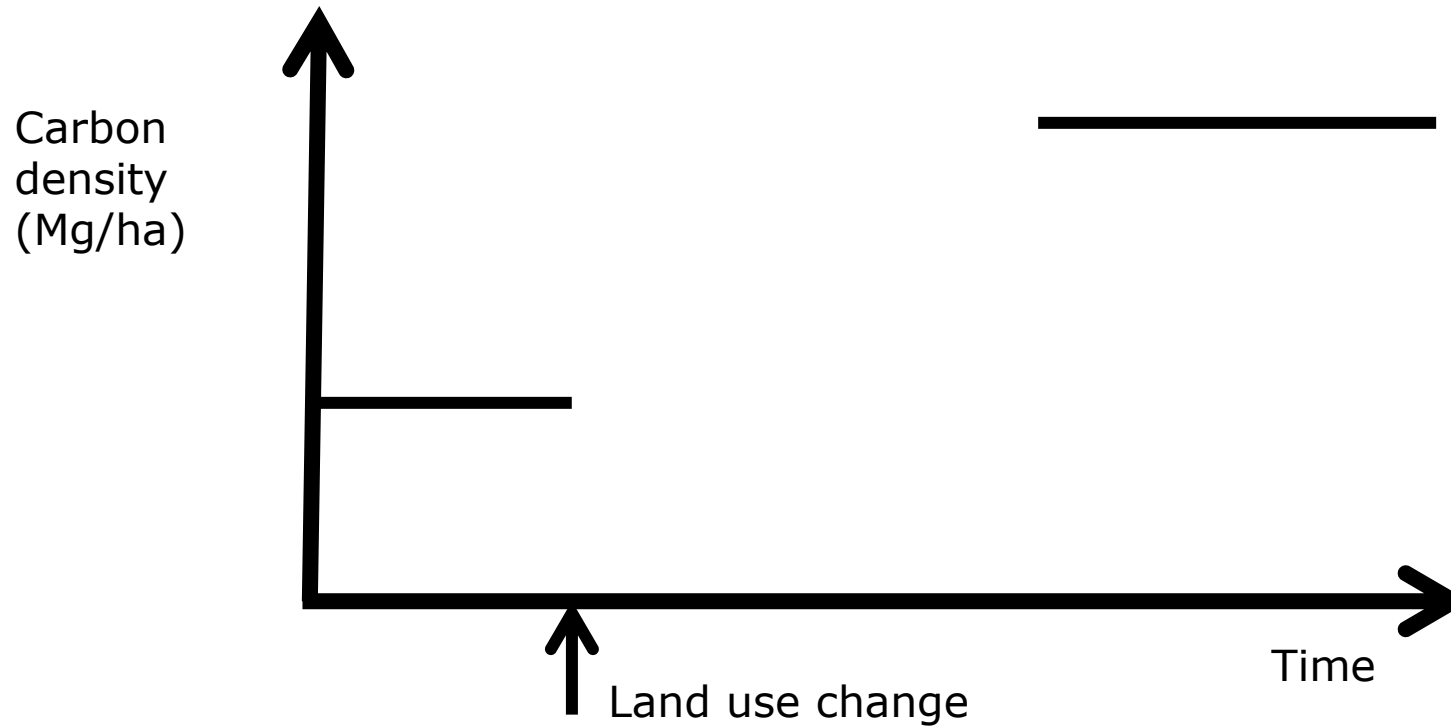
<http://dx.doi.org/10.1111/ecog.02576>

The screenshot shows the CIFOR website with a dark green header. The main navigation bar includes links for HOME, ABOUT US, RESEARCH, LIBRARY, EVENTS, NEWS, PARTNERS, and FORESTS NEWS. A search bar is located in the top right corner. Below the header, the page title is "Global Comparative Study on REDD+ Center for International Forestry Research (CIFOR)". The main content area features a large image of a person in a yellow hard hat and green shirt working in a forest. To the right of the image, the text reads: "A tool to compute ecosystem carbon **CarboScen** Adding or conserving ecosystem carbon can be an extremely cost-efficient way to mitigate climate change." Below this text is a "LEARN MORE" button. Further down, the text asks "How much ecosystem carbon is there when land uses are changing?" and provides a brief explanation of the tool's purpose. A list of bullet points follows: "Define land-use classes", "Predict future land-use changes", "Set carbon equilibrium densities (e.g. tons per hectare)", "Input transition speeds based on local or global data", and "Include uncertainty". Below the list, it says "Use CarboScen to compute future ecosystem carbon for a simulated land-use scenario". On the right side of the page, there is a screenshot of the CarboScen software interface, which shows a landscape image and the text "Welcome to CarboScen". At the bottom of the page, there are two sections: "DOWNLOADS" and "Download CarboScen". The "DOWNLOADS" section includes a link to "Download article" and a button to "Download CarboScen". The "Download CarboScen" section includes a button to "DOWNLOAD APP for Windows desktop".



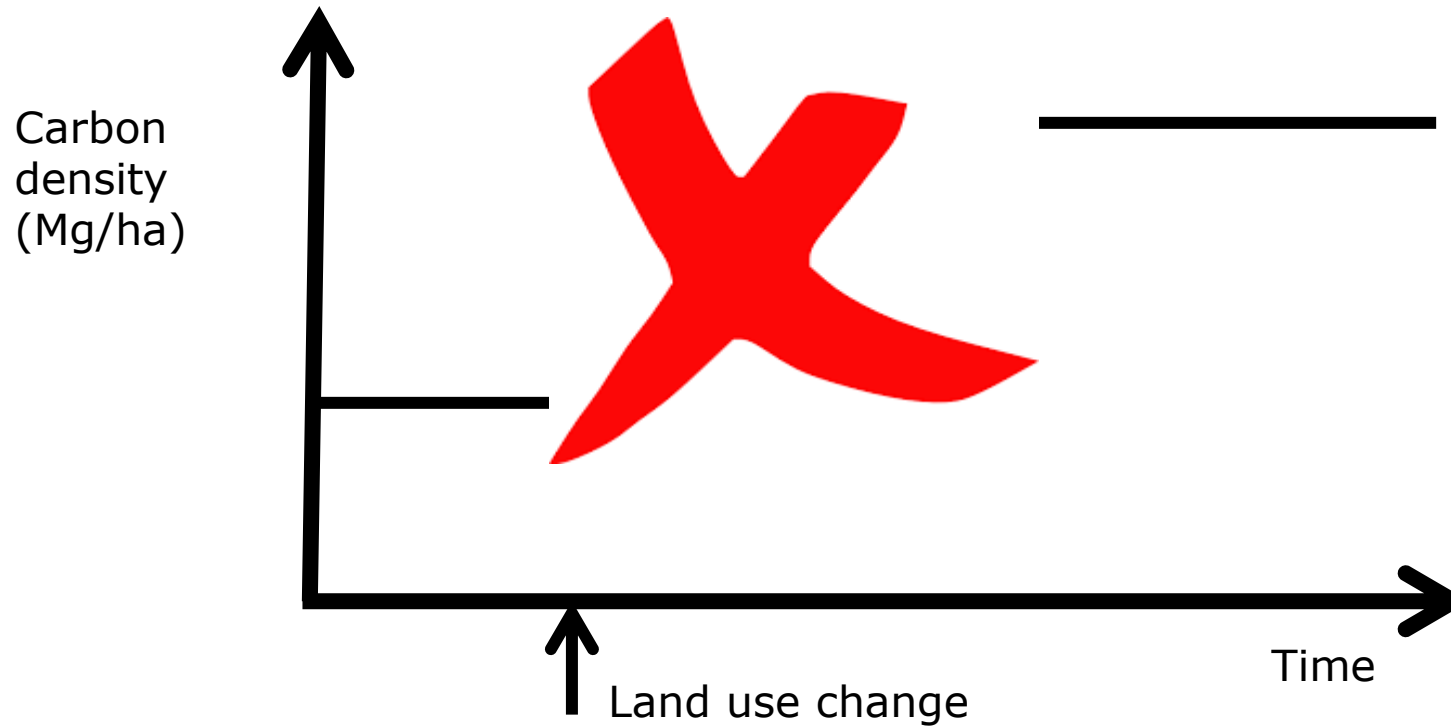


# How CarboScen works?



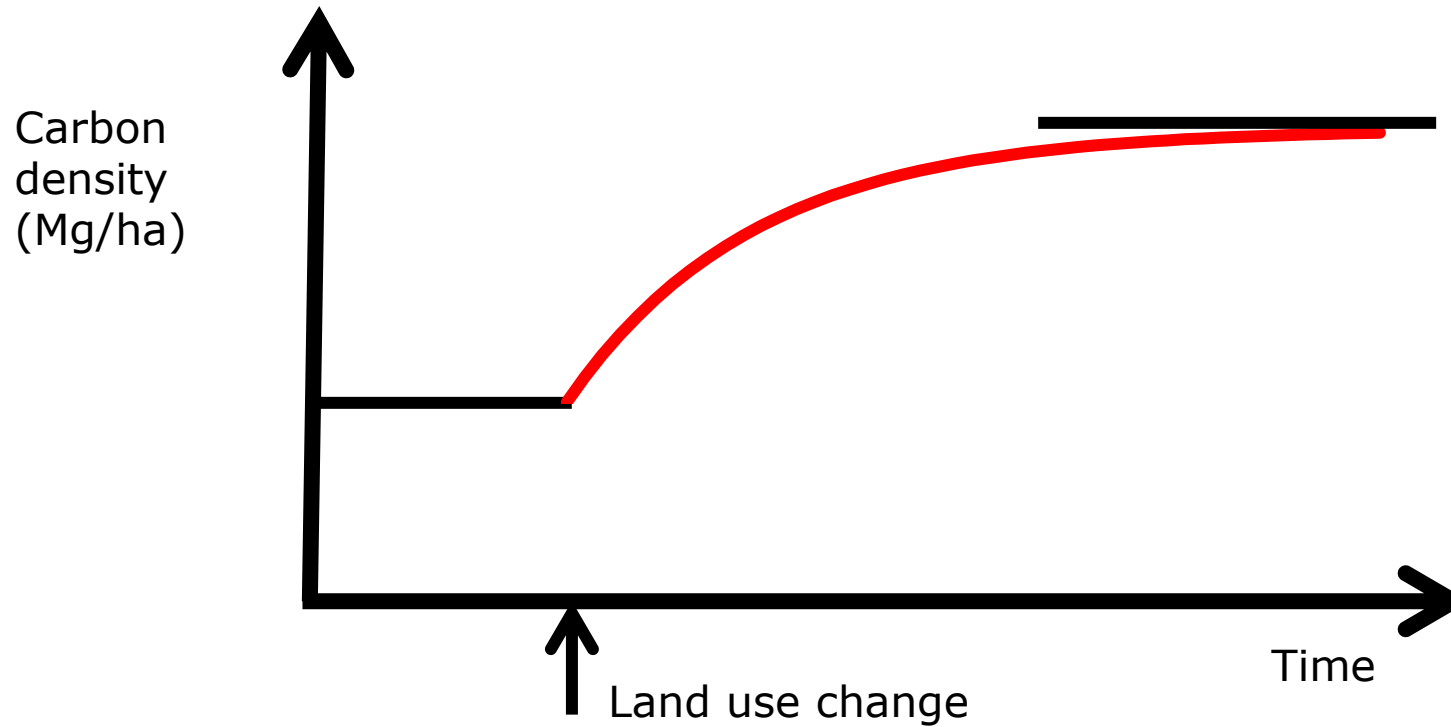


# How CarboScen works?



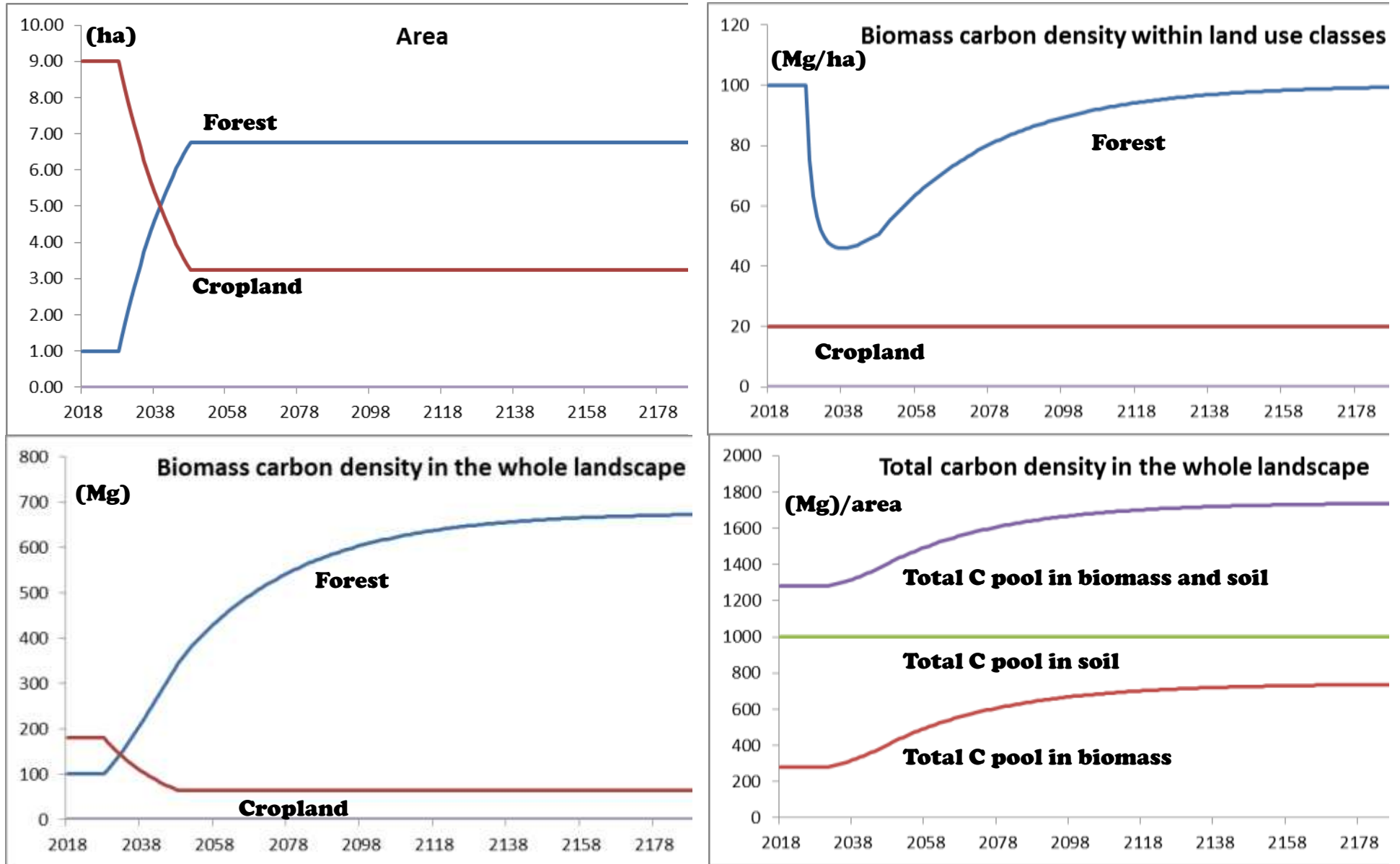


# How CarboScen works?



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

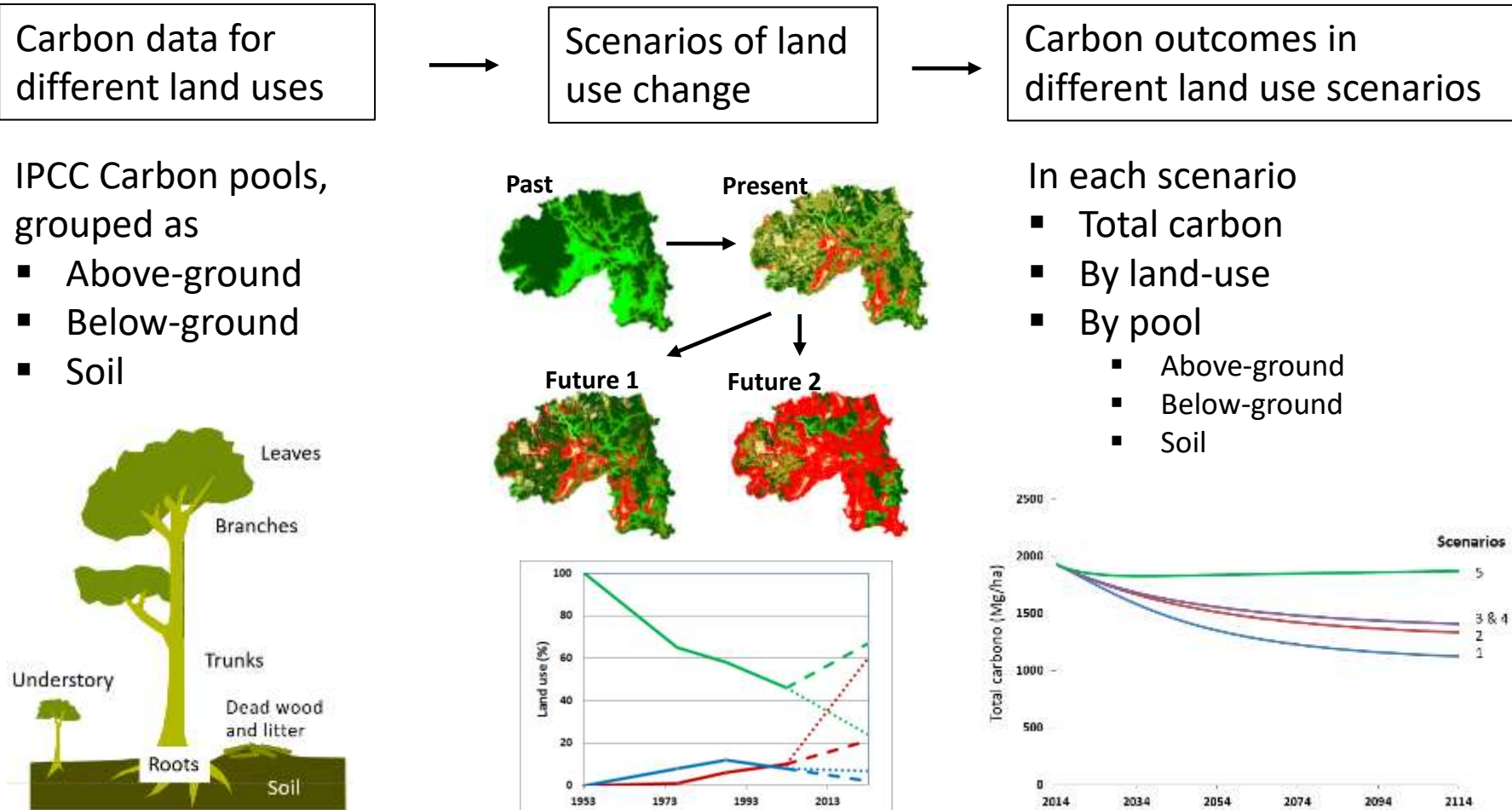
# Simplest case: two land-uses



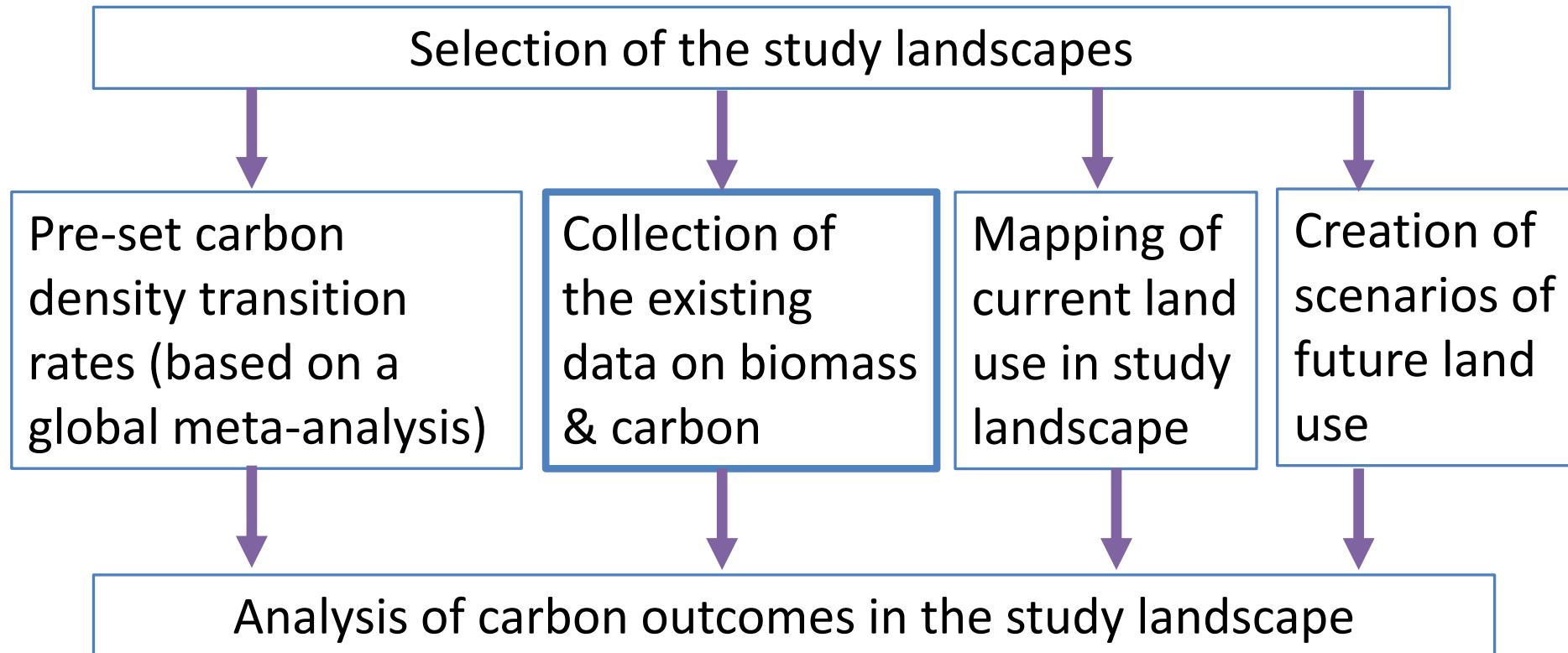


# CarboScen tool

## Carbon analysis at landscape scale



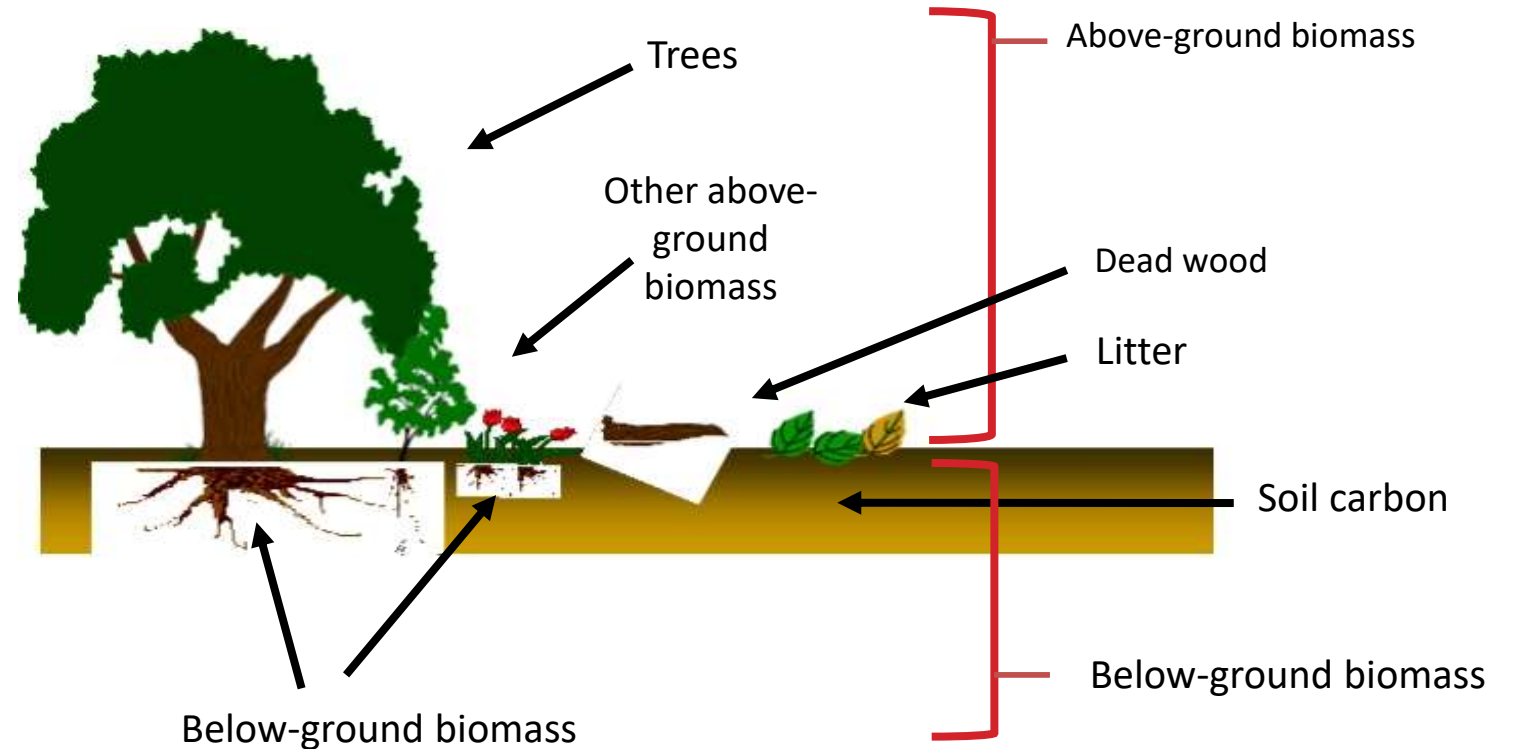
# CarboScen - steps



# Carbon pools (stocks, reservoirs)

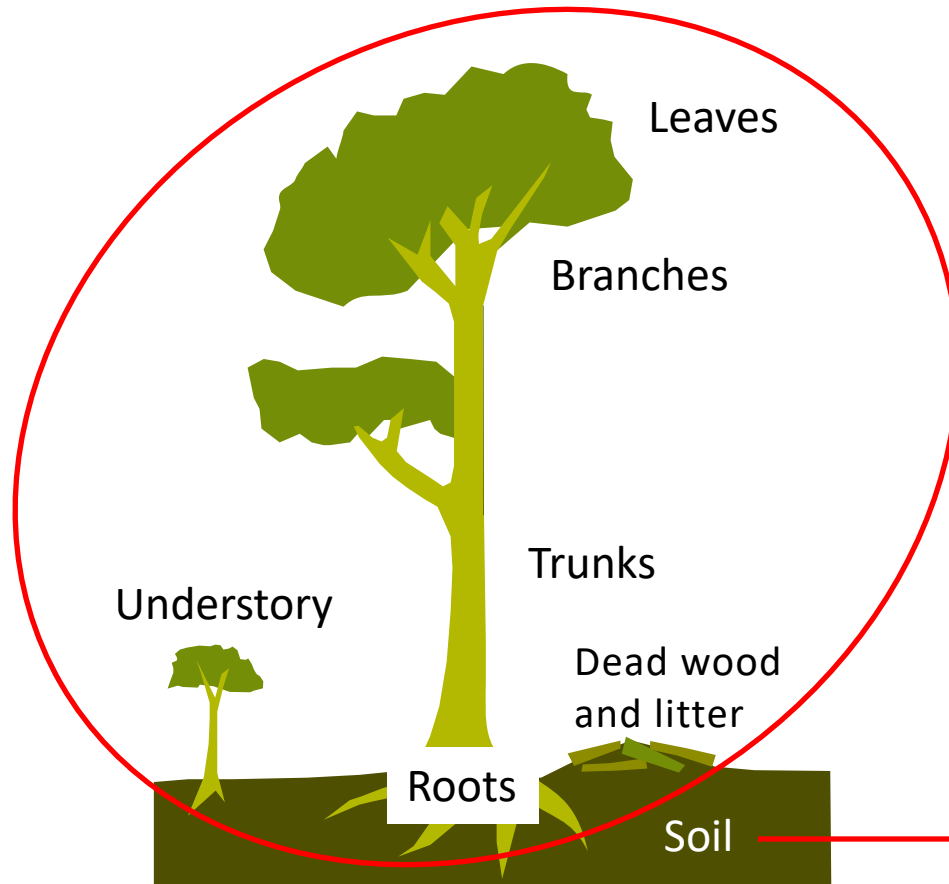
## The five IPCC carbon pools:

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



# 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



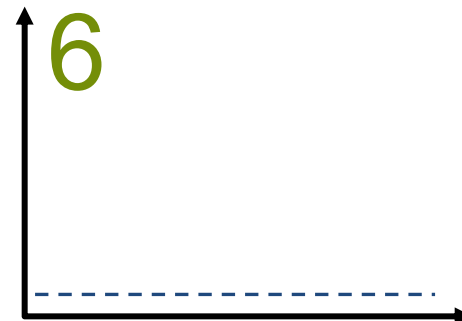
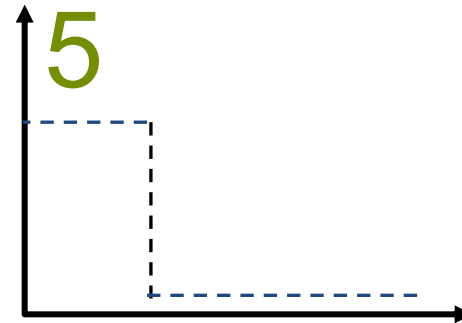
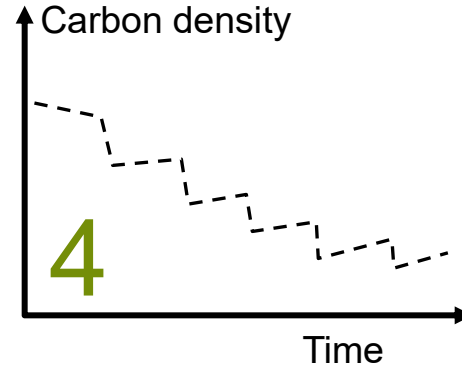
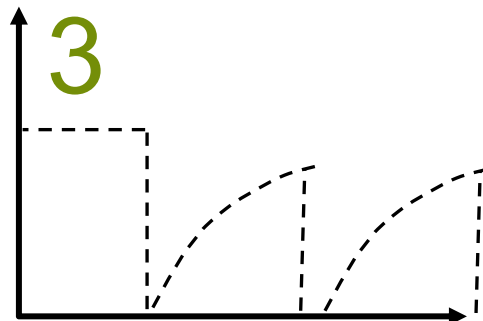
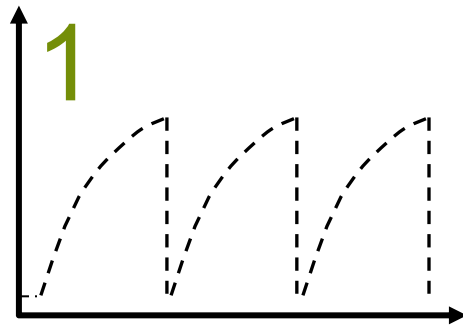
Soil carbon stock  
= Belowground C stock





# 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

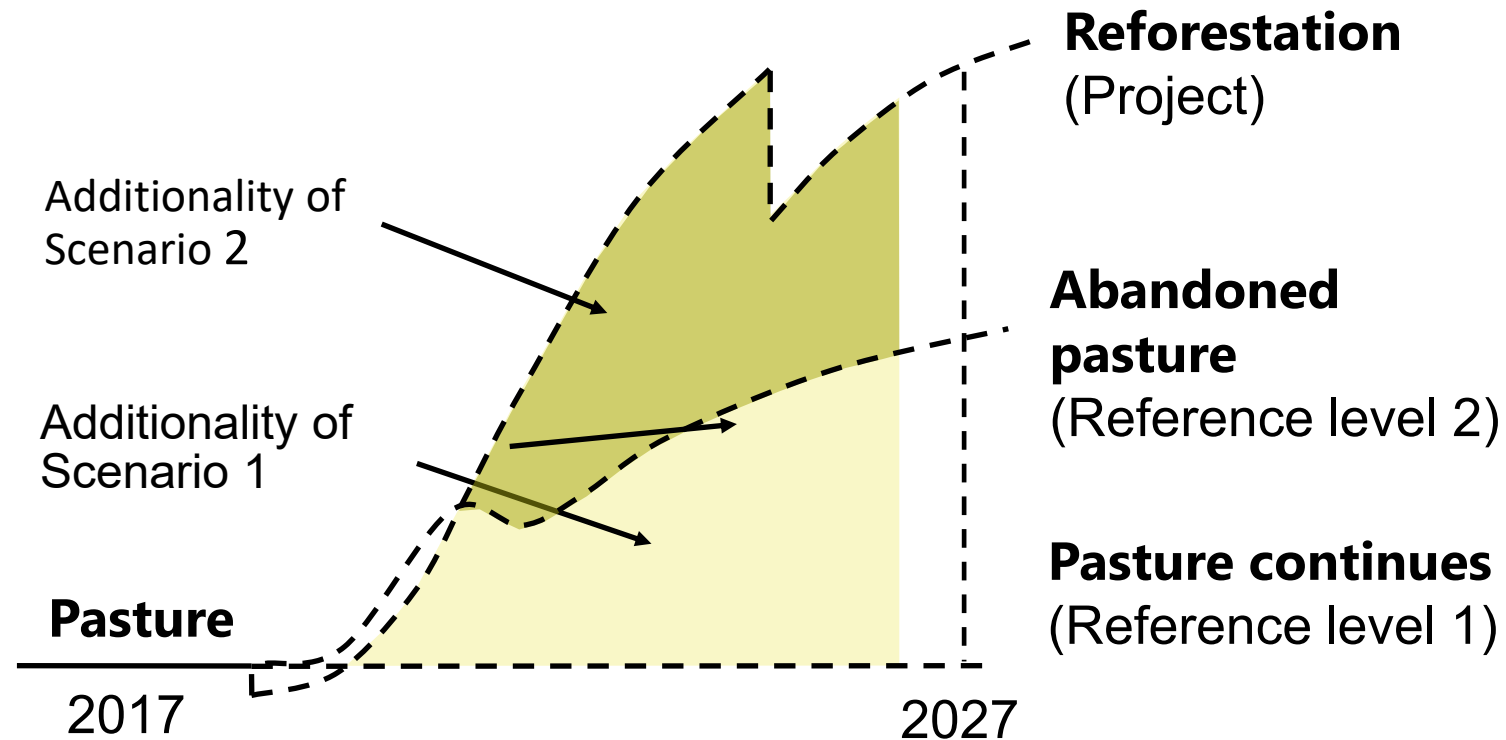
3

Forest converted to a plantation

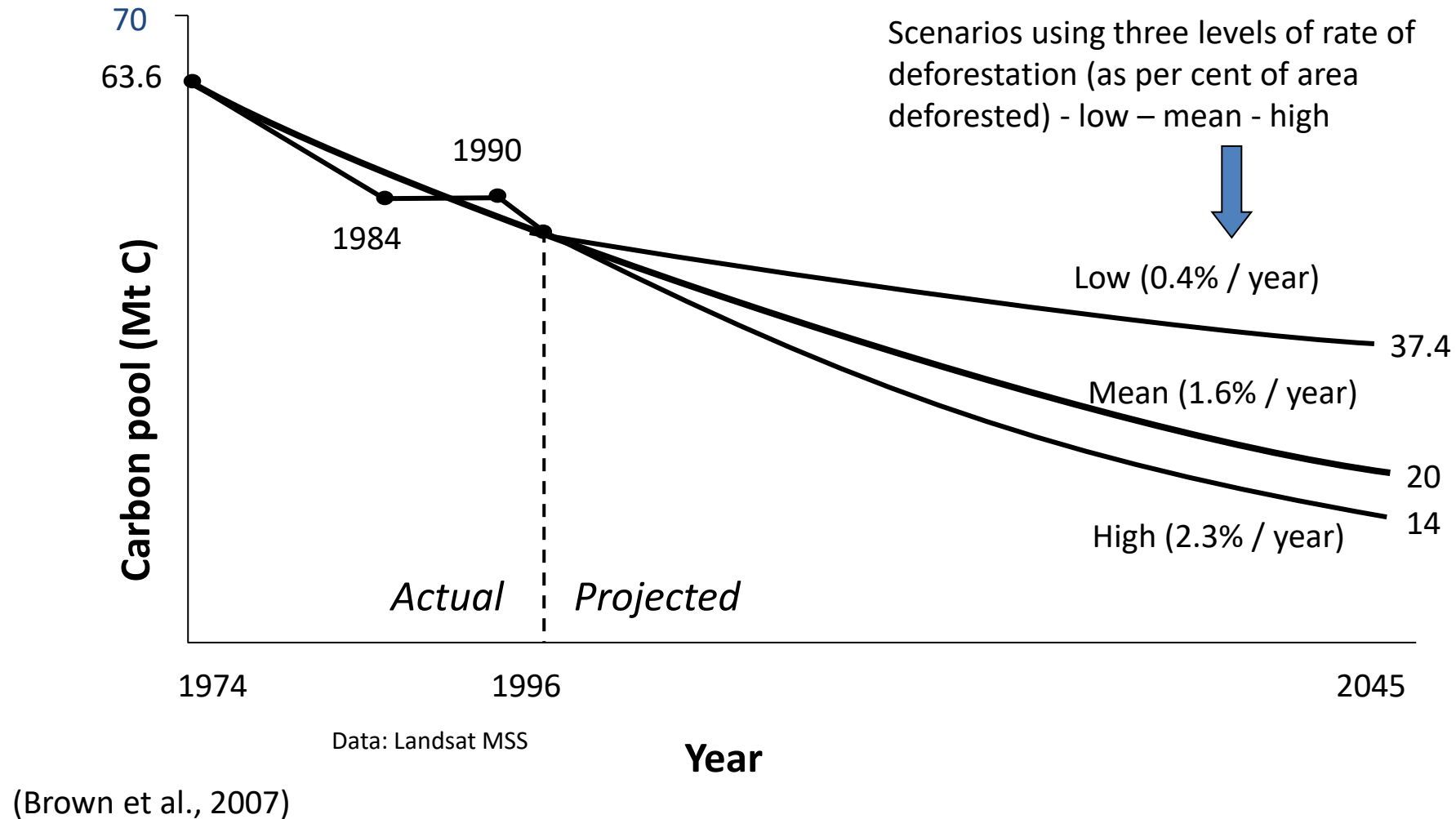
2

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





# 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
Land use class	C data on biomass	Notes on C density (Units and other relevant)	U	C	B	C	C	C	Li	C	D	C	Exact wording on land use class in	Reference (Harvard Style)	Credits and status of the Information	Soil C weight (not taken)	Biomass C weight (not taken)	Notes on Weight	Biomass C density (Mg/ha)	Biomass C weight
1	Agriculture and Pastures	335 Units: Mg/ha DBH>5 cm AGB, only. Woody debris and BGB not included.	2	ee	2	ee	2	ee	1	ee	3	ee	Complejos de chacras y purmas	Córdova, A. (2013) E-mail to Harold Gerdillo, 02 October.	Data available. Credits should be respected	-	1	Location is in the Region	172.6	1
2	Agriculture and Pastures	262 Units: Mg/ha DBH>5 cm	2	ee	2	ee	2	ee	1	ee	3	ee	Complejos de chacras	Córdova, A. (2013) E-mail to Harold	Data available.	-	1	Location is in the Region	135.8	1
321	Shrub and Bamboo Vegetation	11 Units: TnCha DBH>5cm C in AGB and BGB. C in woody debris not included.	1	11	2	11	1	31	1	11	5	16	piedemont a sudino Para	Recavarren, P., Delgado M., Angulo, M., León, A., Castro, A. (2011). Proyecto REDD en Áreas Naturales Protegidas de Madres de Dios. Informe para la elaboración de la línea base de carbono. Asociación para la Investigación y el	Data available. Credits should be respected	-	45	Almost identical area and conditions where the study was conducted	15.8	45
322																				

322

322



# 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 1.0.1

Start Settings Results

Analysis time span  -  ☐ Include uncertainties

☒ Carbon densities at start same as the equilibrium values  
☐ Carbon densities at start differ from the equilibrium values

Land use class code	Forest
Land use class code	FOR
Land area at the end of the first year	0.2
Biomass carbon density at equilibrium	100.0
Soil carbon density at equilibrium	50.0
Biomass transition speed	0.03
Soil carbon transition speed	0.05

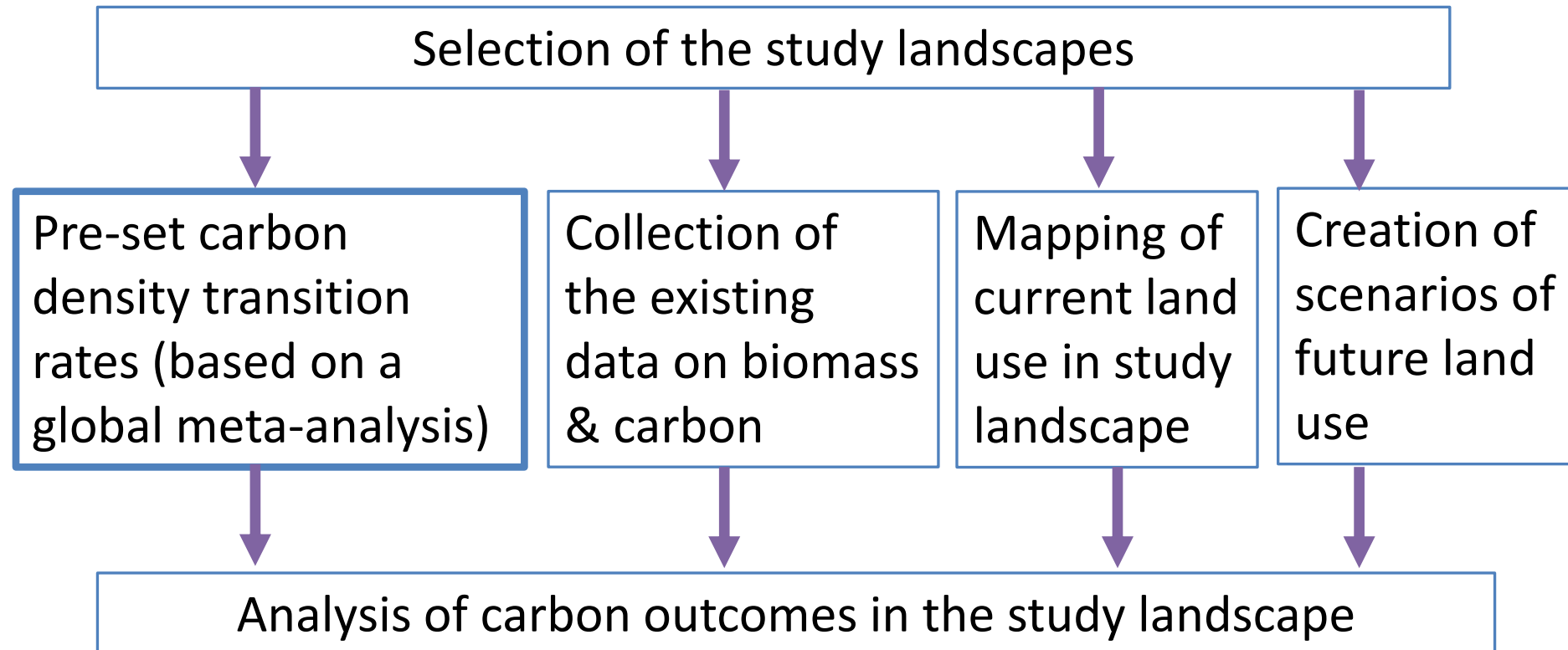
☒ Dynamic landuse transition rate  
☐ Linear landuse transition rate

	Cropland
	CROP
	0.8
	5.0
	30.0
	0.5
	0.1

Land use transition matrix 1. Time span  -

		From FOR		From CROP
To FOR	0.0		0.06	
To CROP	0.0		0.0	

# CarboScen - steps

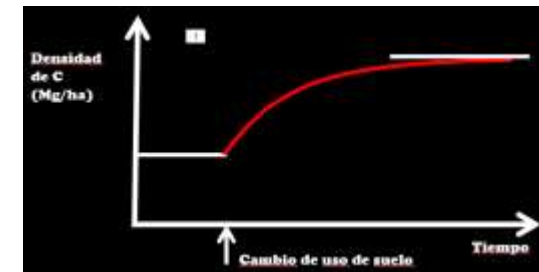






# Parameter for the transition rate (rate of change) of carbon density is more challenging to obtain

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 density

$p_e$  = equilibrium carbon density

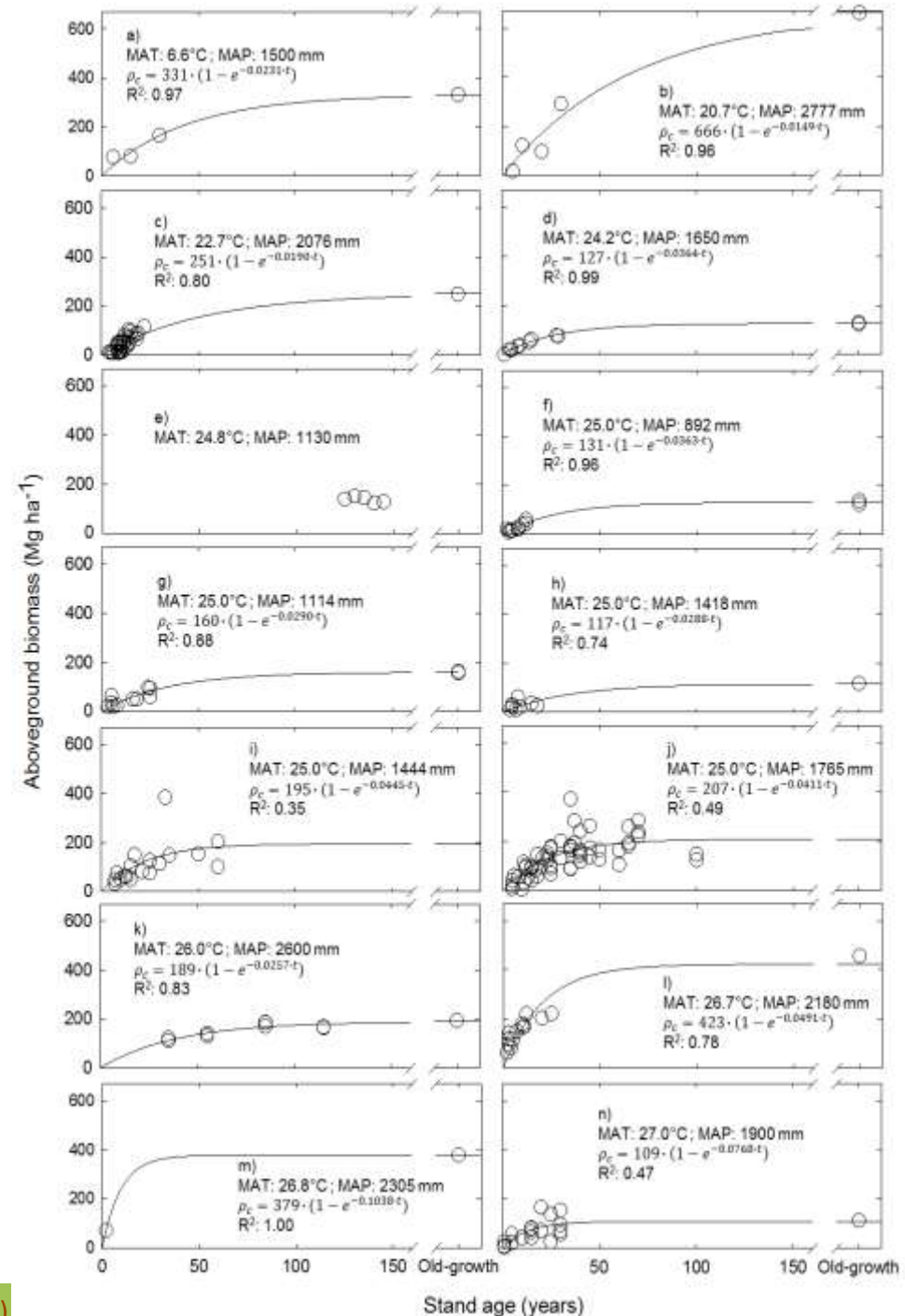
$e$  = Euler's number

$f$  = 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

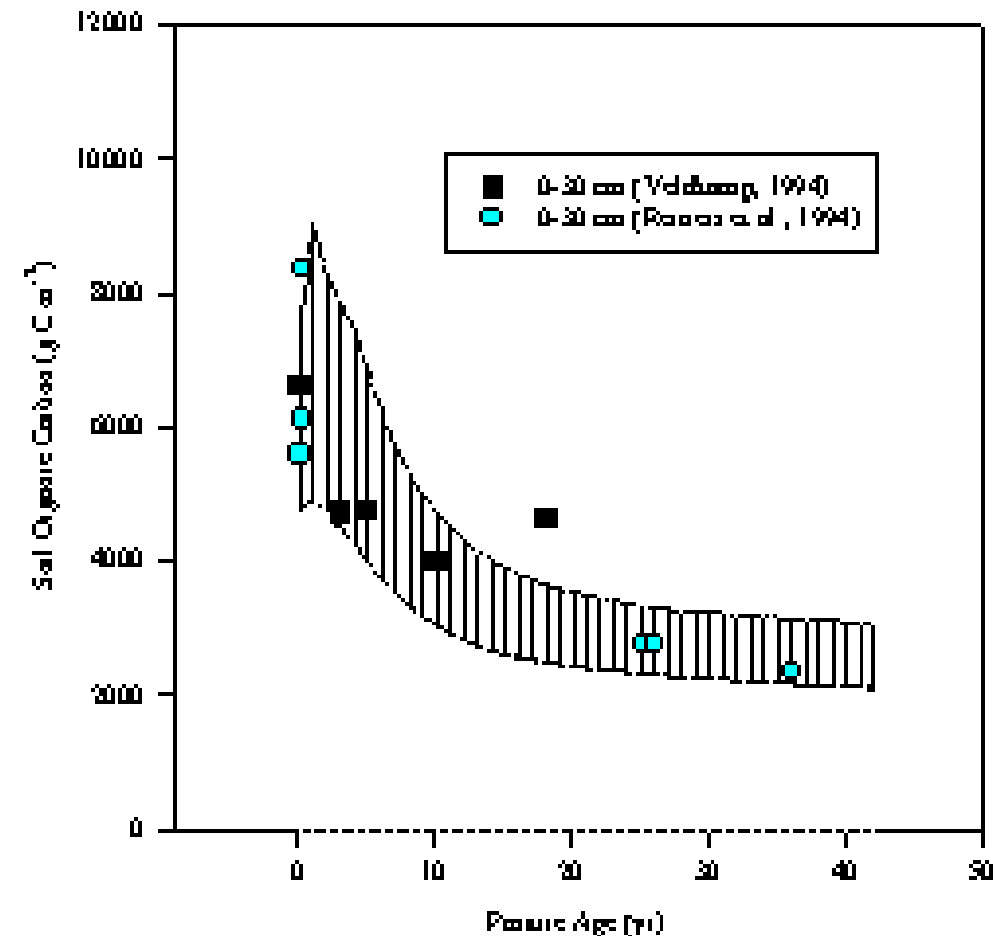


Conversion type	$f$	SD	CV	n
Cropland to forest	0.056	0.067	120	7
Forest to cropland	0.073	0.055	75	71
Cropland to grassland	0.073	0.061	84	3
Grassland to cropland	0.151	0.149	99	3
Average/total	0.074	0.061	82	84



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

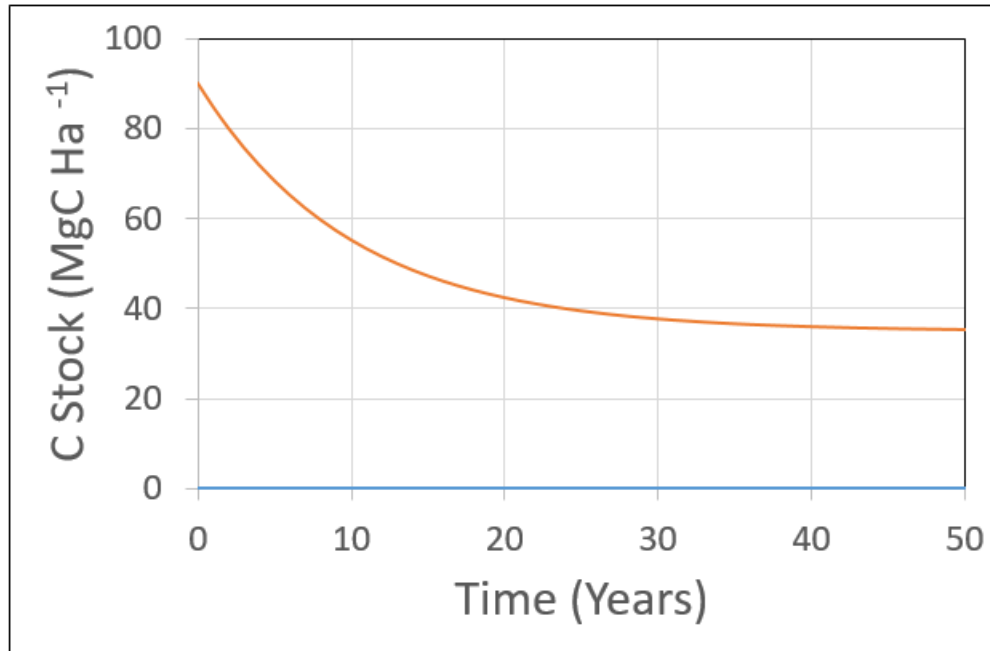
Soil organic carbon SOC ( $\text{Mg ha}^{-1}$ )  
after conversion



(Veldkamp, 1994)

# Soil carbon pool after conversion - CarboScen

## Rate of change of carbon density in biomass and in soil



### Parameters

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

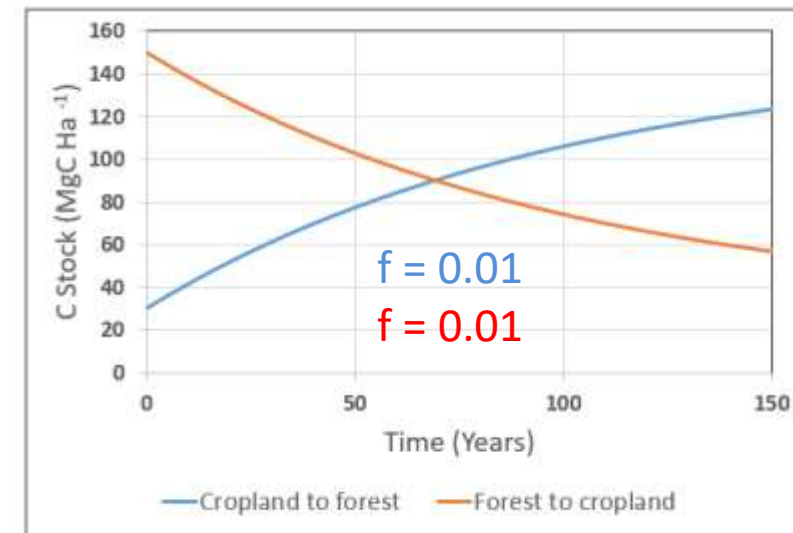
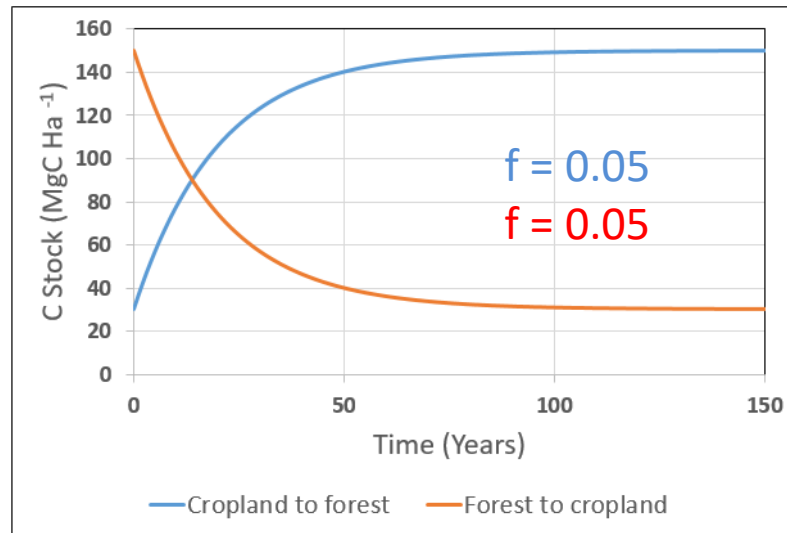
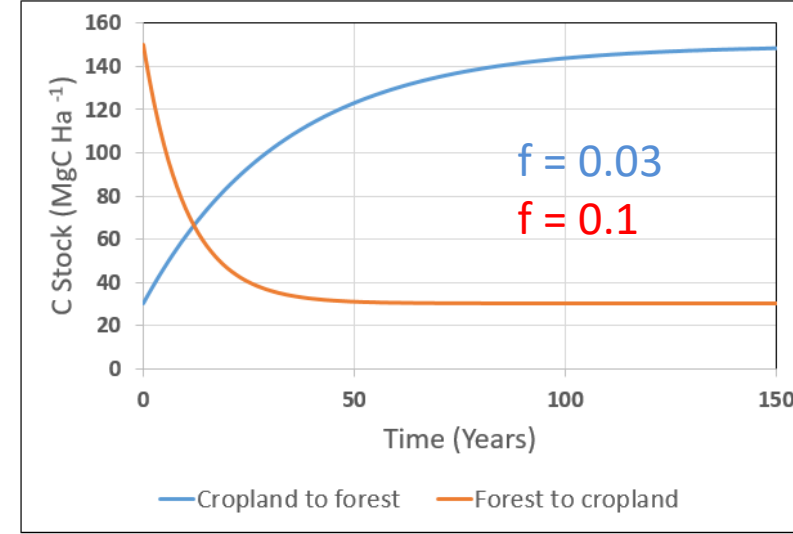
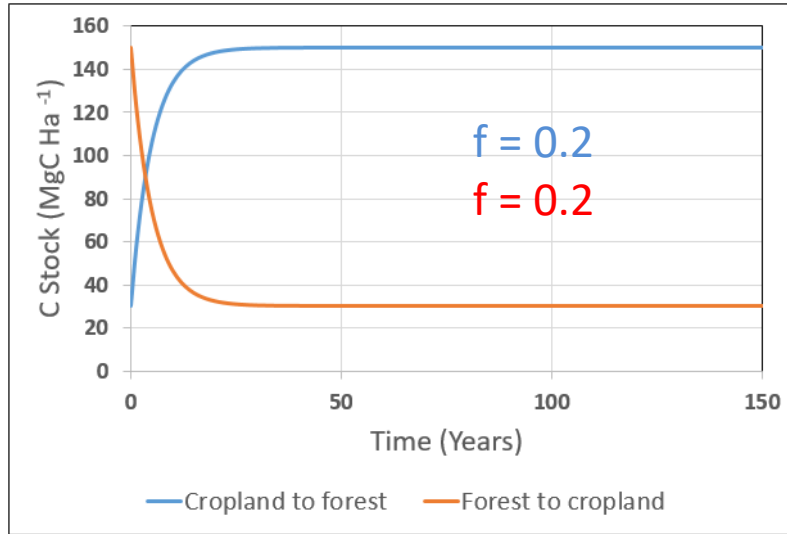
Ps	0
Pe	0
f	0.000
tau-Pe	0

Ps	90
Pe	35
f	0.100
tau-Pe	14

Veldkamp (1994) data parametrized in CarboScen

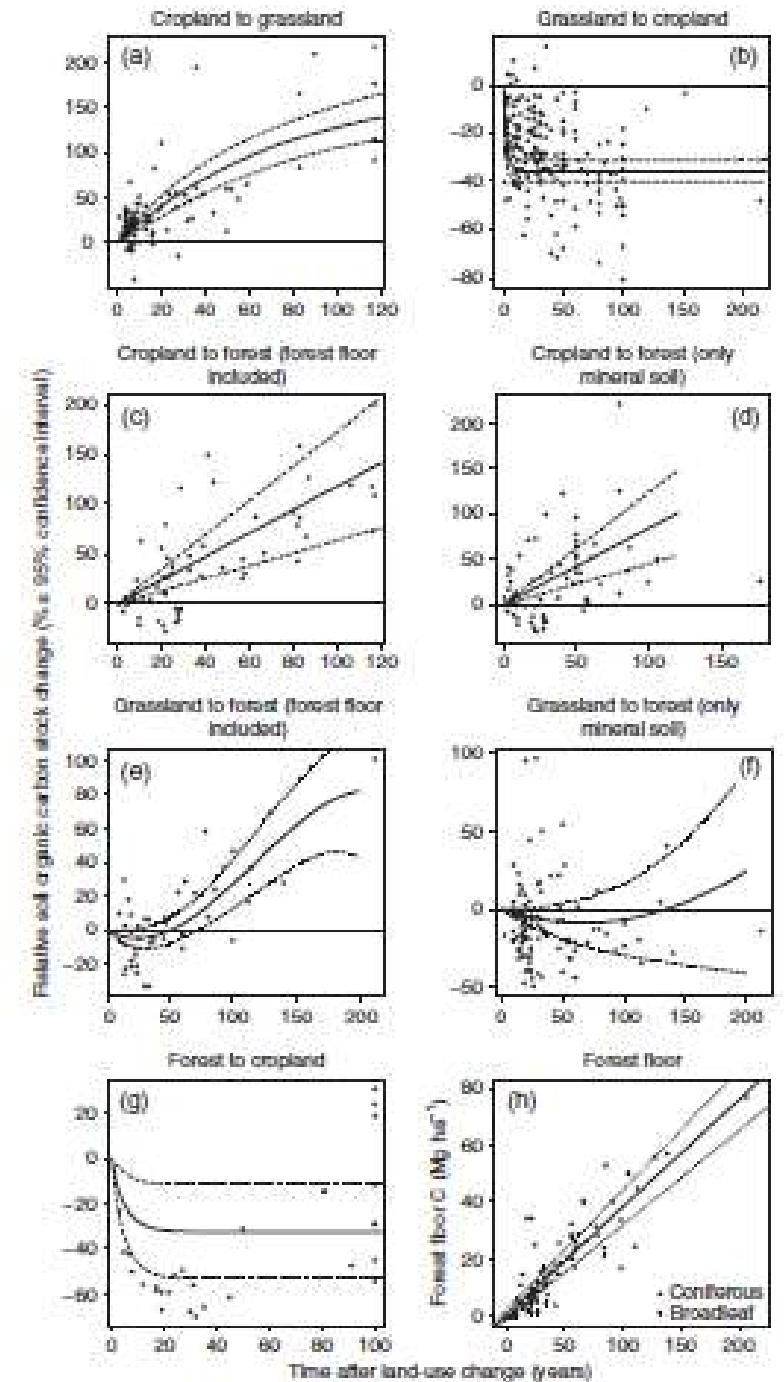


# Carbon pools after conversion - CarboScen



# Existing data on soil carbon density transition rate is messy

Few data and high uncertainty

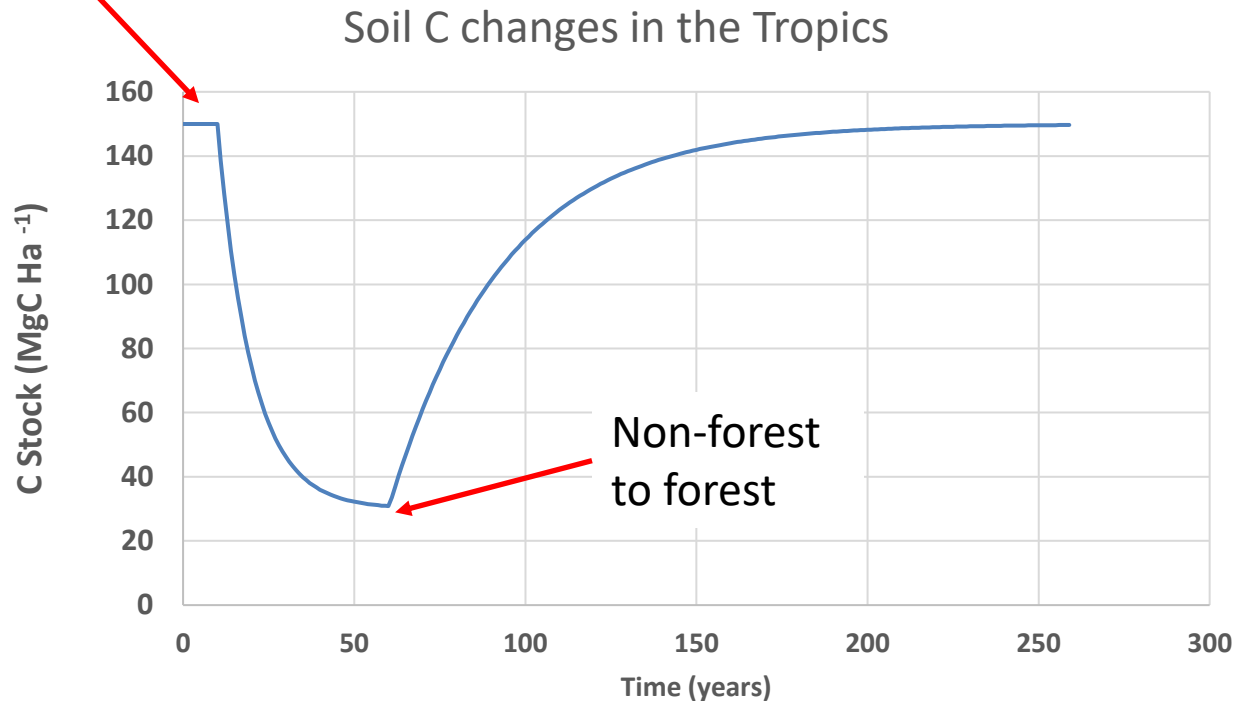


(Poeplau et al. 2011)

# 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

Forest to  
non-forest



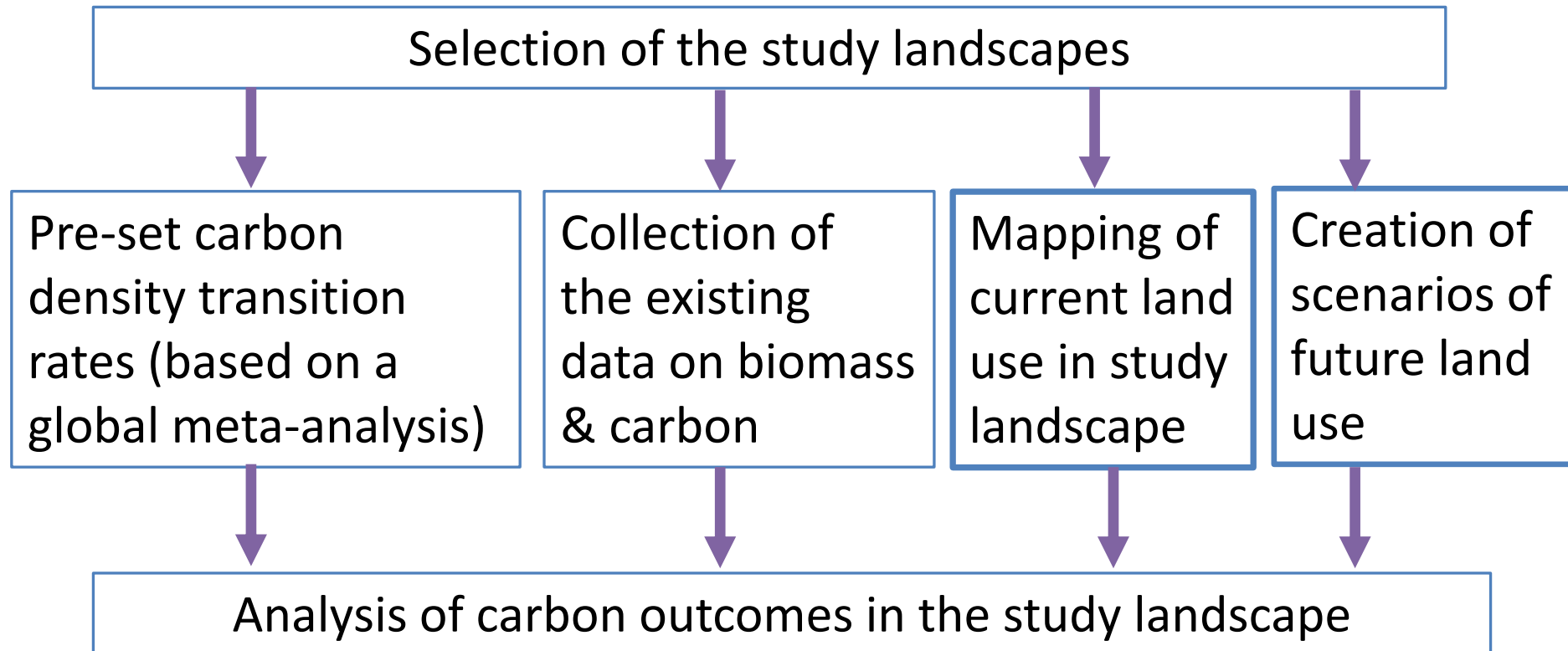
Example calculated with  
CarboScen tool  
Data: Poeplau et al. 2011

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

CarboScen 1.0.1

Start Settings Results

Analysis time span: 2020 - 2100 ☐ Include uncertainties

☒ Carbon densities at start same as the equilibrium values  
☐ Carbon densities at start differ from the equilibrium values

☒ Dynamic landuse transition rate  
☐ Linear landuse transition rate

Load... Save... Reset...

Land use class	Forest F00	Cropland C00
Land area at the end of the first year	0.2	0.8
Biomass carbon density at equilibrium	100.0	5.0
Soil carbon density at equilibrium	50.0	30.0
Biomass transition speed	0.03	0.5
Soil carbon transition speed	0.05	0.1

Land use transition matrix 1: Time span: 2020 - 2050

	From FOR	From CROP
To FOR	0.0	0.06
To CROP	0.0	0.0

Land use transition matrix 2: Time span: 2051 - 2100

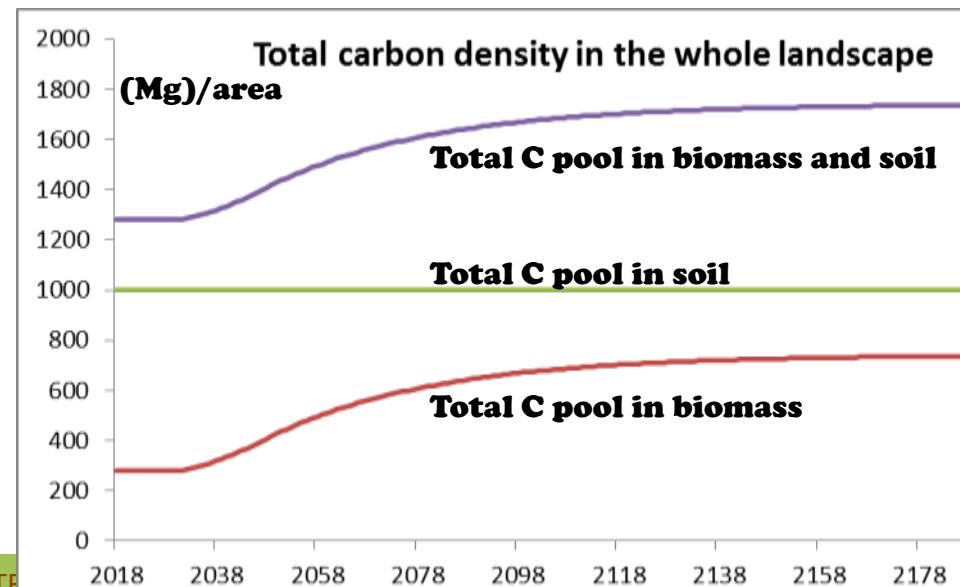
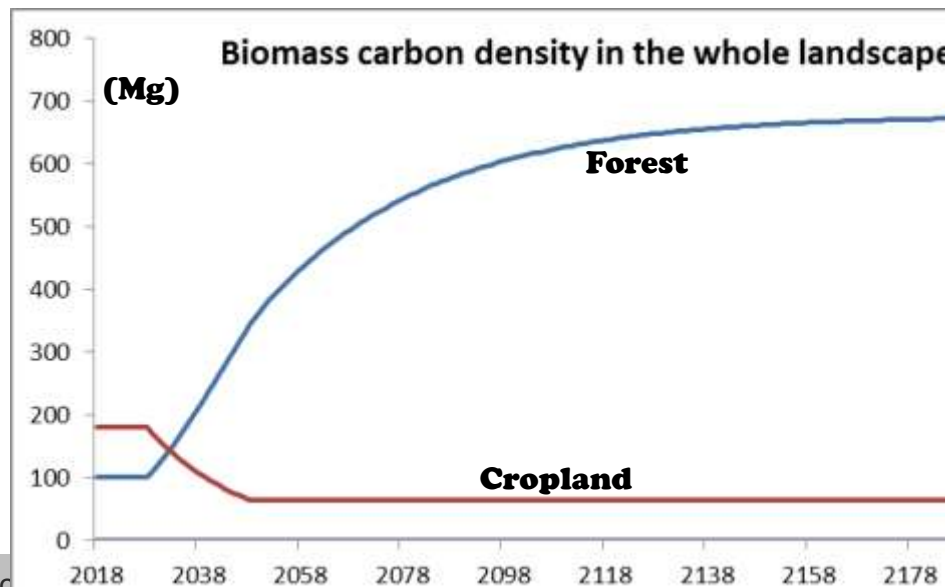
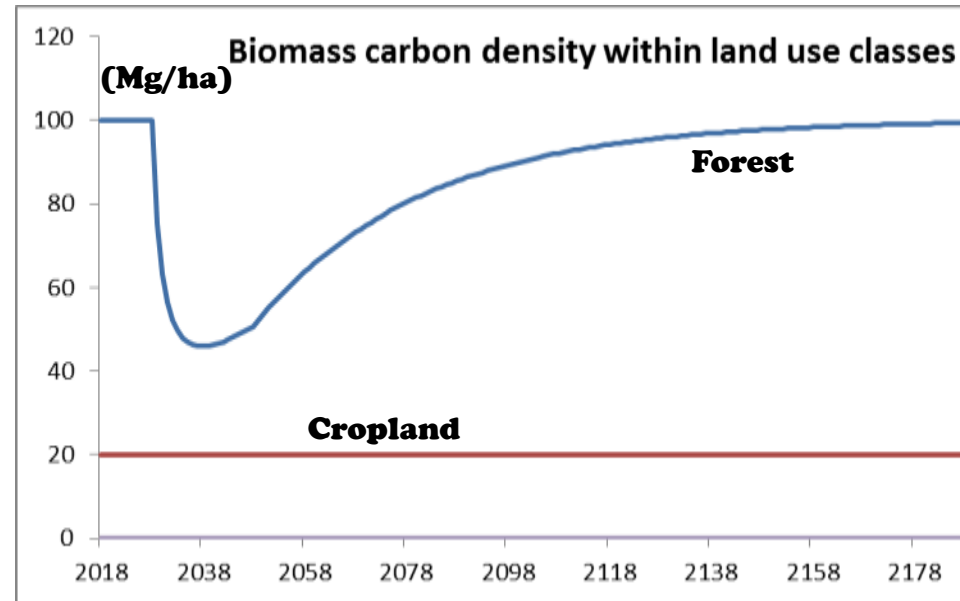
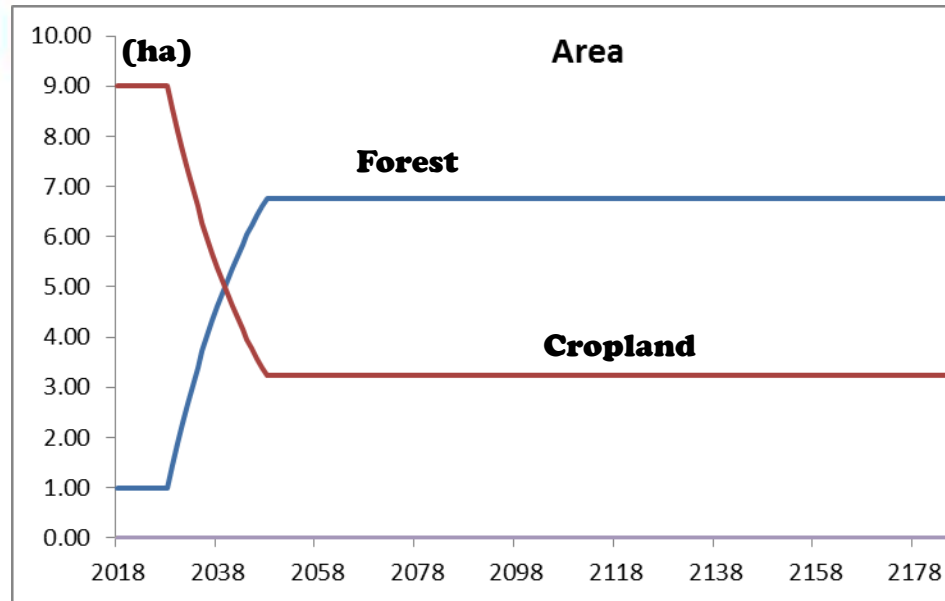
	From FOR	From CROP
To FOR	0.0	0.0
To CROP	0.0	0.0

Copy Remove





# 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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### LETTER

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*

*Natural  
phenomena  
and climate  
change*

*Government  
policies and  
programs, and  
alignment  
between levels  
of governance*

*Commodity  
prices*

*REDD+*

*Scenario 1*

*Scenario 2*

*Scenario 3*

*Scenario 4*



# Scenarios

<b>Factor of change</b>	<b>Scenario 1</b>	<b>Scenario 2</b>	<b>Scenario 3</b>	<b>Scenario 4</b>
<b><i>Natural phenomena and climate change</i></b>	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular
<b><i>Government policies and programs, and alignment between levels of governance</i></b>	Support for irrigated commercial agriculture	Integrated territorial (multi-sector) visión for land use	Support for adaptation measures and water management coordination among <i>ejidos</i>	Support for tourism and investment in industrial development in cities
<b><i>Commodity prices</i></b>	Commercial crop prices rise	Markets privilege organic and sustainably produced products	Commercial crop prices rise	All crop prices fall
<b><i>REDD+</i></b>	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

<i>Factor of change</i>	<b>Scenario 1</b>	<b>Scenario 2</b>	<b>Scenario 3</b>	<b>Scenario 4</b>
<i>Natural phenomena and climate change</i>	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular	Rain becomes more scarce and irregular
<i>Government policies and programs, and alignment between levels of governance</i>	Support for irrigated commercial agriculture	Integrated territorial (multi-sector) visión for land use	Support for adaptation measures and water management coordination among <i>ejidos</i>	Support for tourism and investment in industrial development in cities
<i>Commodity prices</i>	Commercial crop prices rise	Markets privilege organic and sustainably produced products	Commercial crop prices rise	All crop prices fall
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# Participatory scenarios

- What is going to happen in the future?





# San Martin, Peru



Lowlands – agriculture dominating



Coffee

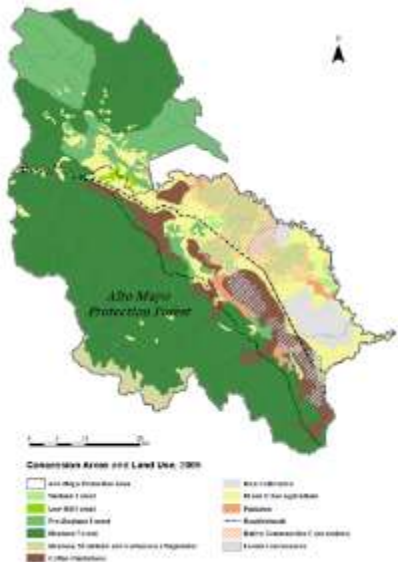


Highlands – natural forest and coffee expansion

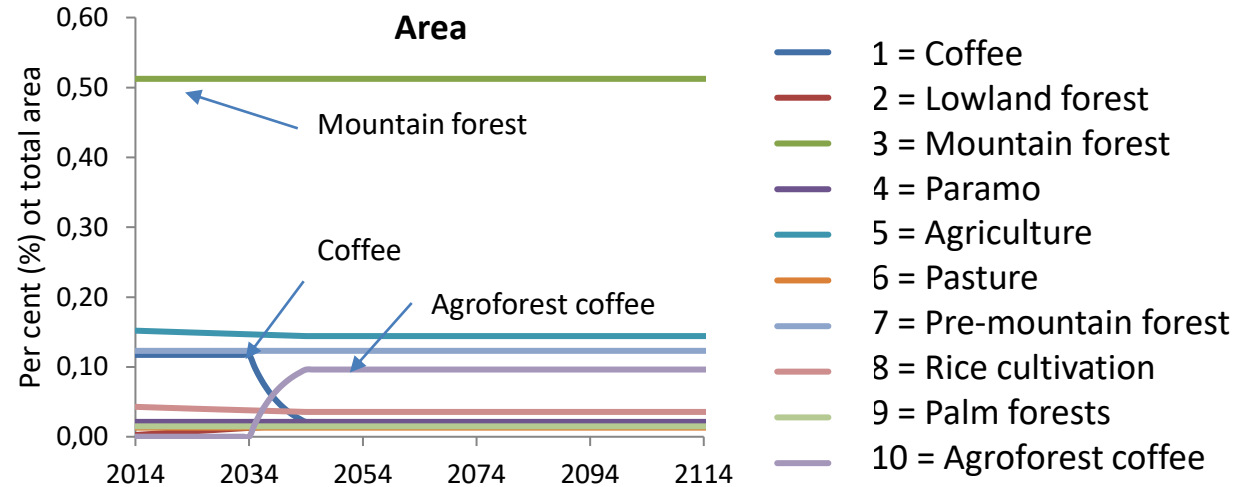


Shaded coffee - agroforestry

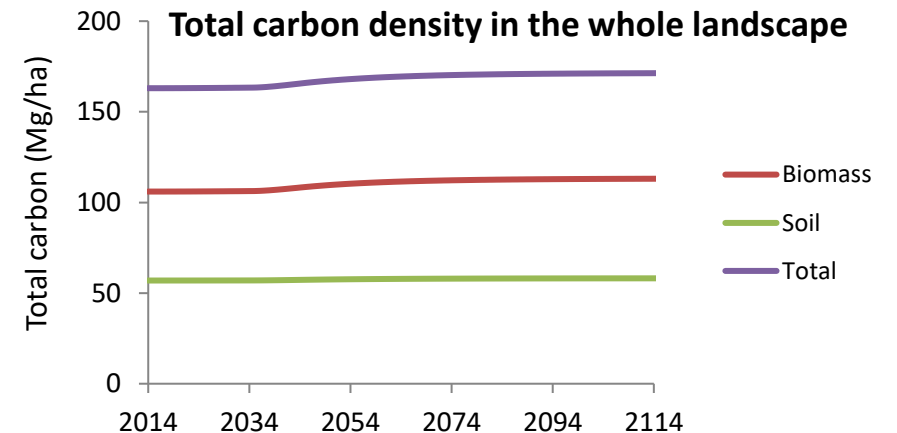
# One land use scenario in San Martin, Peru: “Forest conservation and agroforestry coffee”



Total area of the  
landscape:  
147 000 Has.



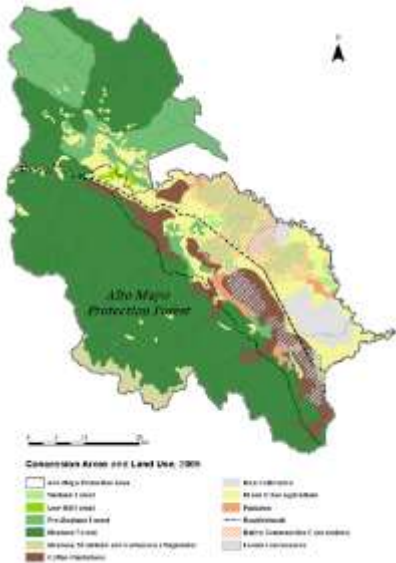
Scenario:  
Forest conservation and  
agroforestry coffee



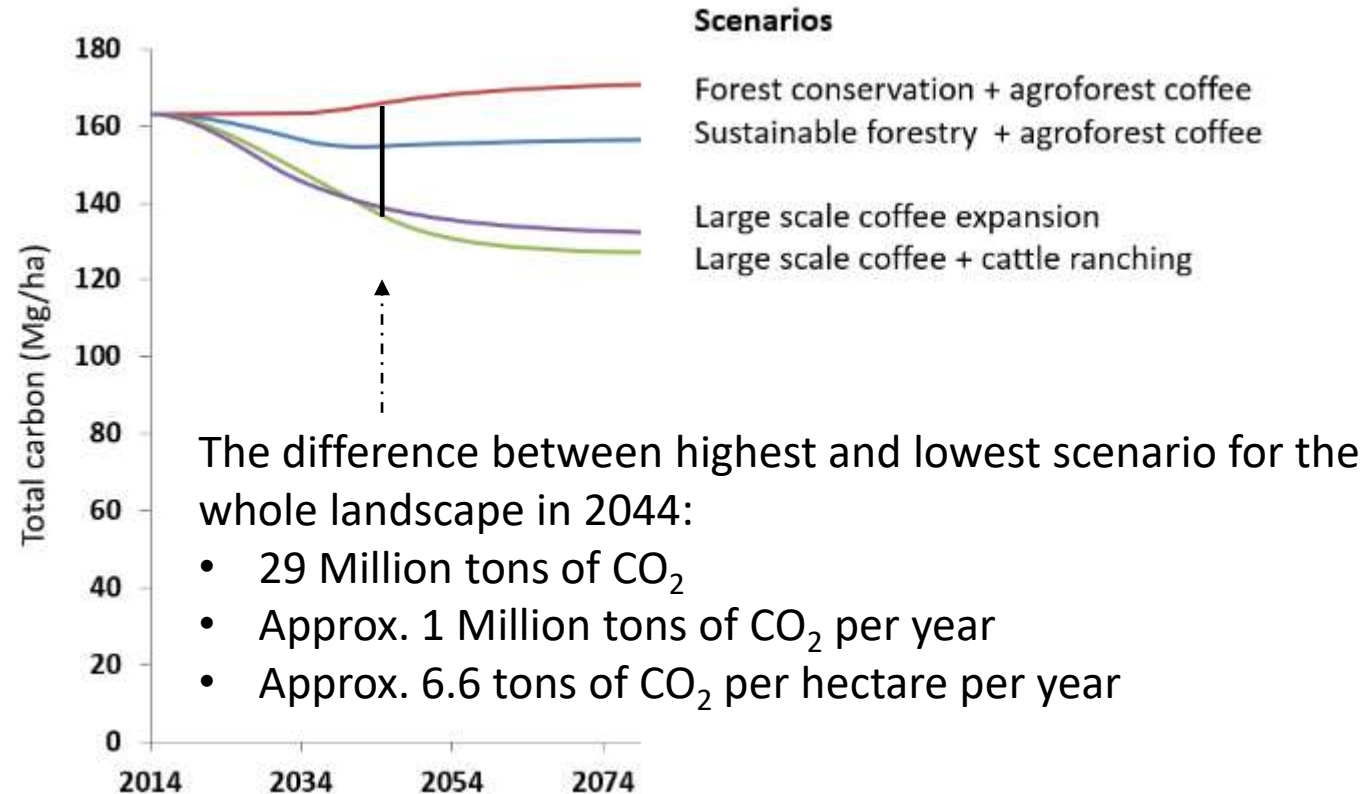




# Comparison of four scenarios in San Martin, Peru

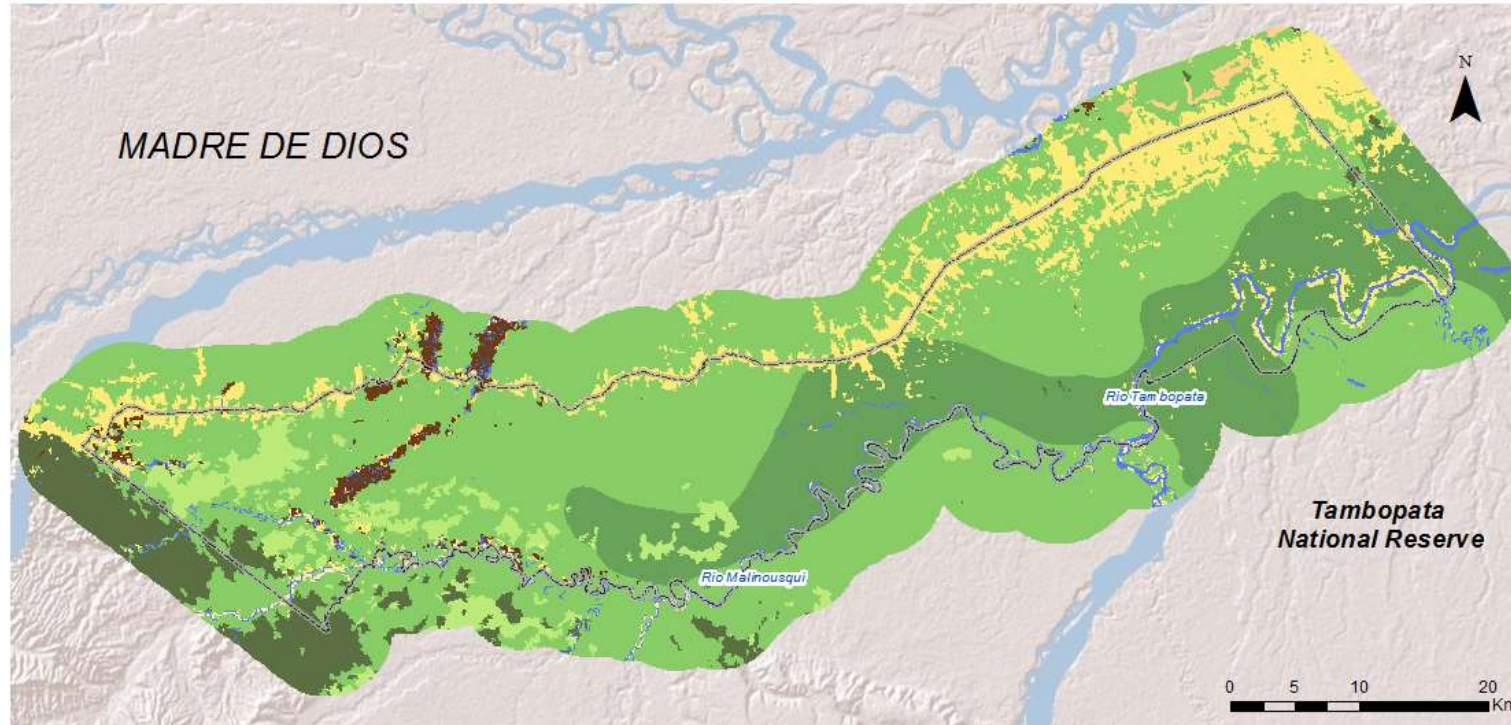


Total area of the  
landscape:  
147 000 Has.



# Madre de Dios, Peru

Total area of the  
landscape:  
146 000 Has.



## Land use, 2011

### Class names

Moist Tropical Forest	Mires and Wetlands
Floodplain Tropical Forest	River Beaches, Unvegetated Areas
Montane Forest	Bodies of Water
Agriculture and Pastures	Other areas
Gold Mining Activities	Study area
Shrub and Bamboo Vegetation	







# Madre de Dios, Peru



Lowland natural tropical rain forest



Lowlands – conversion to agriculture



Lowlands – illegal gold mining



Lowlands – illegal gold mining



# Local carbon data, Madre de Dios

Land use class	Carbon density of above-ground biomass (Mg/ha)	Soil organic carbon density (Mg/ha)
Agriculture and cattle ranching	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

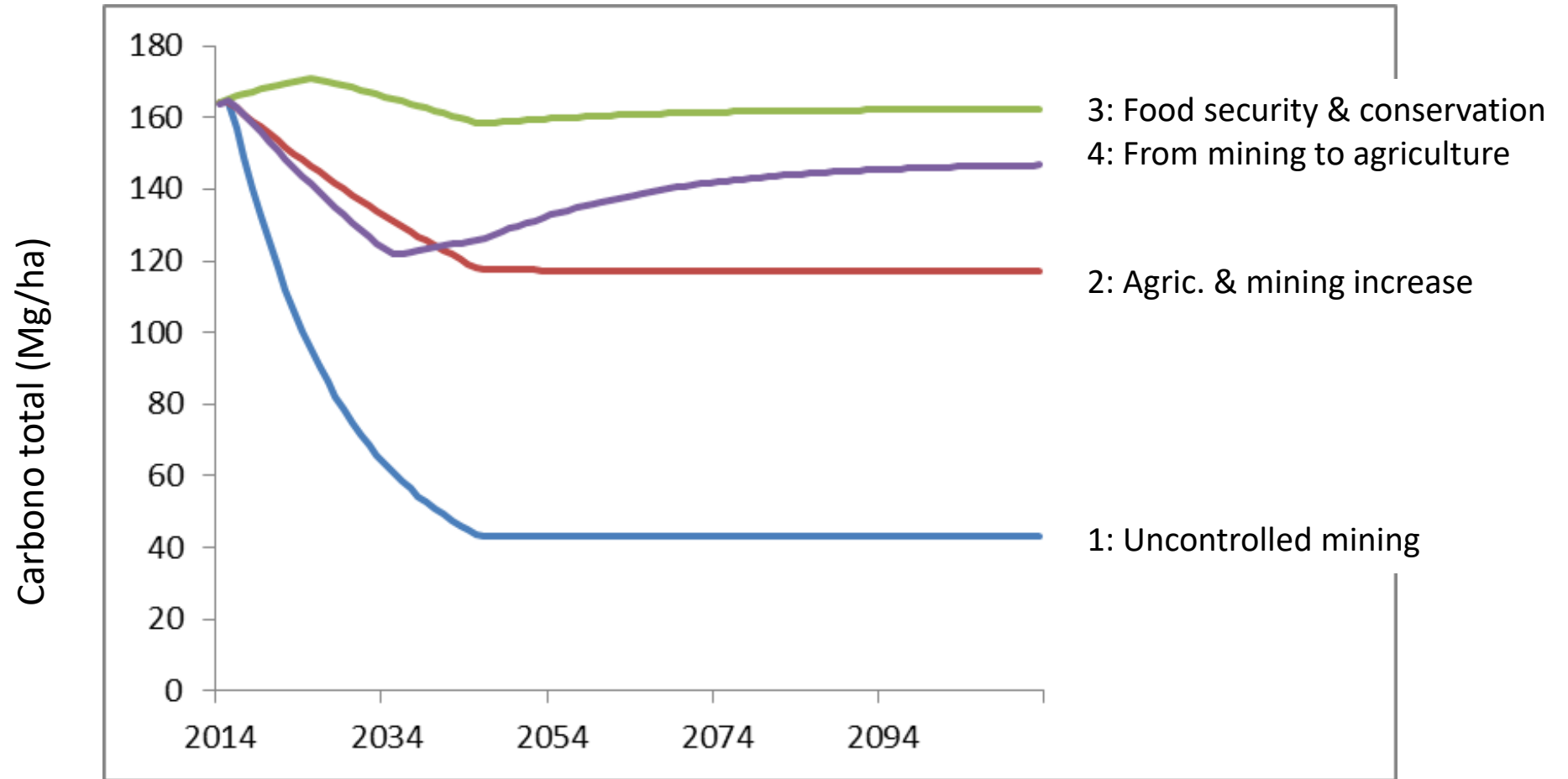




# Four scenarios in Madre de Dios



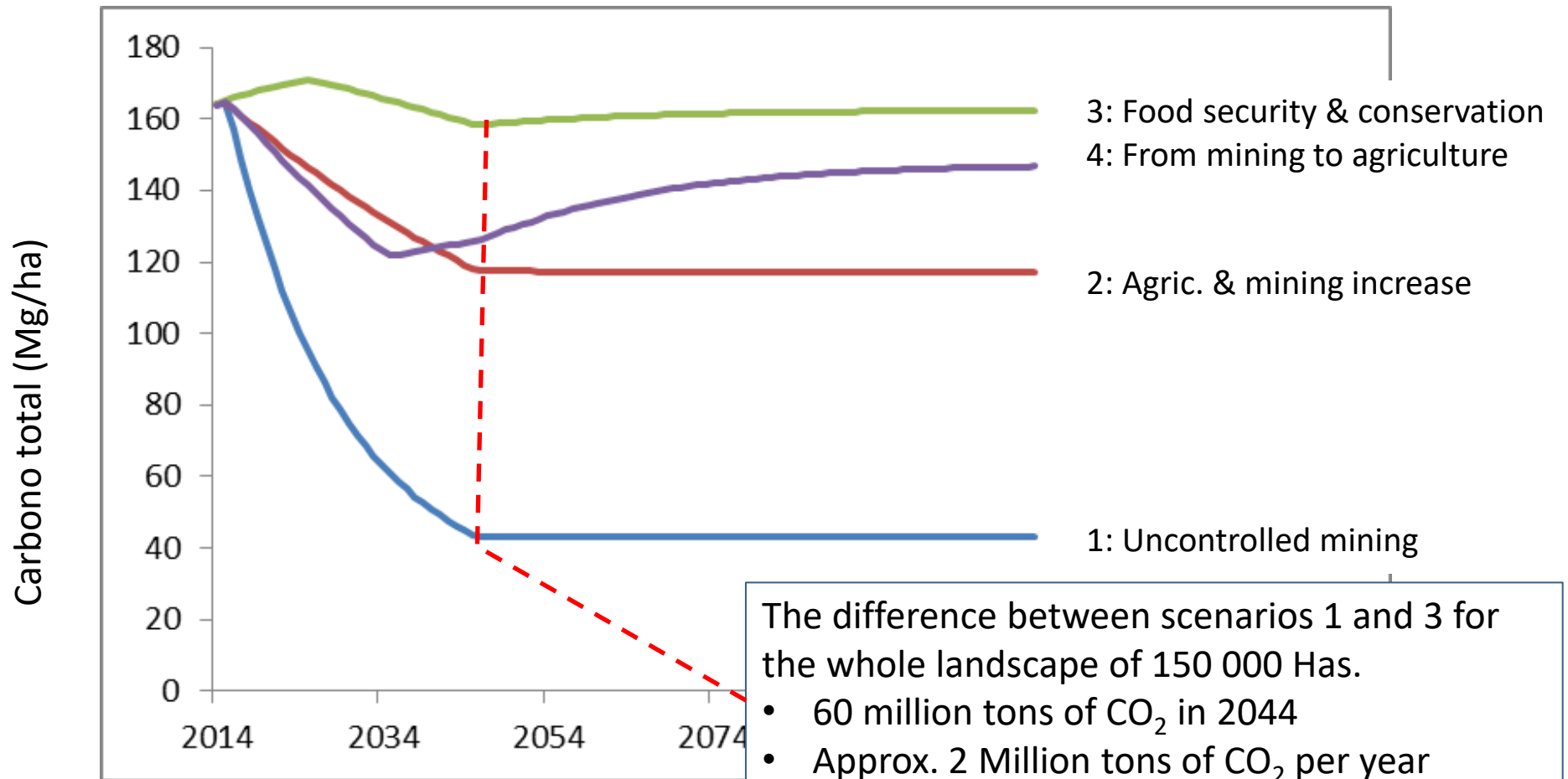
Total area of the landscape:  
146 000 Has.



# Four scenarios in Madre de Dios



Total area of the landscape:  
146 000 Has.





# Forest carbon data sets

Hett, C., Heinimann, A., Messerli, P. 2011. Spatial assessment of carbon stocks of living vegetation at the national level in Lao PDR. Danish Journal of Geography 111, 11-26.

<https://www.tandfonline.com/doi/abs/10.1080/00167223.2011.10669519>

IPCC. 2008. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K. (eds). IGES, Japan. 21 p.

[https://planning.lacity.org/eir/8150Sunset/References/4.E.%20Greenhouse%20Gas%20Emissions/GHG.27 IPCC%20National%20GHG%20Inventories.pdf](https://planning.lacity.org/eir/8150Sunset/References/4.E.%20Greenhouse%20Gas%20Emissions/GHG.27%20IPCC%20National%20GHG%20Inventories.pdf)

Rozendaal, D.M.A., Requena Suarez, D., De Sy, V., Avitabile, V., Carter, S., Adou Yao, C.Y., Alvarez-Davila, E., Anderson-Teixeira, K., Araujo-Murakami, A., Arroyo, L., Barca, B., Baker, T.R., Birigazzi, L., Bongers, F., Branthomme, A., Brien, R.J.W., Carreiras, J.M.B., Cazzolla Gatti, R., Cook-Patton, S.C., Decuyper, M., DeVries, B., Espejo, A.B., Feldpausch, T.R., Fox, J., G P Gamarra, J., Griscom, B.W., Harris, N., Hérault, B., Honorio Coronado, E.N., Jonckheere, I., Konan, E., Leavitt, S.M., Lewis, S.L., Lindsell, J.A., N'Dja, J.K., N'Guessan, A.E., Marimon, B., Mitchard, E.T.A., Monteagudo, A., Morel, A., Pekkarinen, A., Phillips, O.L., Poorter, L., Qie, L., Rutishauser, E., Ryan, C.M., Santoro, M., Silayo, D.S., Sist, P., Slik, J.W.F., Sonké, B., Sullivan, M.J.P., Vaglio Laurin, G., Vilanova, E., Wang, M.M.H., Zahabu, E., Herold, M. 2022. Aboveground forest biomass varies across continents, ecological zones and successional stages: refined IPCC default values for tropical and subtropical forests. Environmental Research Letters 17, 014047. <https://iopscience.iop.org/article/10.1088/1748-9326/ac45b3>

Sasaki, N., Asner, G.P., Pan, Y., Knorr, W., Durst, P.B., Ma, H.O., Abe, I., Lowe, A.J., Koh, L.P., Putz, F.E. 2016. Sustainable Management of Tropical Forests Can Reduce Carbon Emissions and Stabilize Timber Production. Frontiers in Environmental Science 4. <https://www.frontiersin.org/article/10.3389/fenvs.2016.00050>



# Forest carbon data set from Rozendaal et al. 2022

## Data for aboveground biomass carbon

Ecological zone	Continent	Successional stage	Mean AGB (Mg ha <sup>-1</sup> )	SD (Mg ha <sup>-1</sup> )	Median AGB (Mg ha <sup>-1</sup> )	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	52.0	35.6	56.3	Grid cell	83	9	[9–11, 14, 15, 17]
	America	OGF	307.1	104.9	—	Weighted	407	—	[3, 4, 9, 10, 18–21]
		OSF	206.4	80.4	200.3	Grid cell	320	26	[9, 10, 22–28]
		YSF	75.7	34.5	67.1	Grid cell	513	23	[9, 10, 14, 22, 23, 28, 33]
Tropical moist forest	Asia	OGF	413.1	120.5	—	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	80	7	[9, 10, 37–39]
	Africa	OGF	236.8	104.7	—	Weighted	25	—	[1, 2, 18]
		SF	72.8	36.4	64.2	Grid cell	7530	52	[9, 10, 16, 40–47]
		YSF	107.3	94.0	—	Weighted	106	—	[3, 4, 9, 10, 18–21]
	America	OGF	131.0	54.2	112.4	Grid cell	105	17	[9, 10, 22–26]
		YSF	55.7	20.7	44.7	Grid cell	353	17	[9, 10, 22, 23, 25, 26]
		All	67.7 <sup>a</sup>	93.4	31.9	Grid cell	322	36	[9, 10, 35, 40–50]
		All	69.6	47.5	59.7	Grid cell	9410	47	[1, 2, 43, 44, 51–53]
Tropical dry forest	Africa	OGF	127.5	72.6	—	Weighted	12	—	[18–21]
		OSF	110.9	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	104.6 <sup>b</sup>	144.5	161.6	Grid cell	36	3	[9, 10, 35, 40–50]
		All	40.4	45.0	37.2	Grid cell	2626	17	[44, 57, 58]
		All	71.5	46.4	62.5	AGB map	—	216	[59]
Tropical shrubland	America	All	30.3	33.0	27.1	AGB map	—	1450	[59]
		All	190.0	131.2	210.9	Grid cell	2057	46	[1–4, 9, 10, 42–44, 47, 53, 60–63]
		OGF	195.0	95.6	—	Weighted	83	—	[3, 4, 9, 10, 18–21]
	Africa	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]
		All	433.5 <sup>c</sup>	147.5	—	Weighted	23	—	[3, 4, 9, 10, 33, 35]
Tropical montane forest	Asia	OSF	66.4	61.0	40.5	Grid cell	329	19	[9, 10, 50, 71–73]
		All	54.1	20.6	52.4	AGB map	—	203	[59]
		All	84.5	42.9	91.5	AGB map	—	3906	[59]
	Africa	OGF	323.0	157.7	201.3	Grid cell	29	11	[9, 10]
		SF	286.4	126.1	245.7	Grid cell	34	14	[9, 10]
		All	65.2	27.1	60.2	AGB map	—	650	[59]
Subtropical humid forest	America	All	115.9	46.2	110.0	AGB map	—	330	[59]
		All	70.9	26.2	75.6	AGB map	—	223	[59]
		All	50.5	23.9	47.0	AGB map	—	147	[59]
	Africa	All	44.0	26.0	39.0	AGB map	—	2797	[59]
		All	41.6	24.7	39.9	AGB map	—	400	[59]
		All	35.1	22.2	26.0	AGB map	—	601	[59]
Subtropical dry forests	America	All	74.6	40.1	64.6	AGB map	—	1035	[59]
		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]
	Africa	All	65.2	27.1	60.2	AGB map	—	650	[59]
		All	115.9	46.2	110.0	AGB map	—	330	[59]
		All	70.9	26.2	75.6	AGB map	—	223	[59]
Subtropical steppe	America	All	50.5	23.9	47.0	AGB map	—	147	[59]
		All	44.0	26.0	39.0	AGB map	—	2797	[59]
		All	41.6	24.7	39.9	AGB map	—	400	[59]
	Africa	All	35.1	22.2	26.0	AGB map	—	601	[59]
		All	74.6	40.1	64.6	AGB map	—	1035	[59]
		OGF	250.2	59.4	247.5	Grid cell	115	17	[9, 10]
Subtropical montane forest	Asia	SF	155.2	41.7	166.5	Grid cell	32	14	[9, 10]
		All	65.2	27.1	60.2	AGB map	—	650	[59]
		All	115.9	46.2	110.0	AGB map	—	330	[59]
	Africa	All	70.9	26.2	75.6	AGB map	—	223	[59]
		All	50.5	23.9	47.0	AGB map	—	147	[59]
		All	44.0	26.0	39.0	AGB map	—	2797	[59]

The IPCC refers to montane forests as 'mountain systems'; old-growth forests are included as 'primary' forests (IPCC 2019). YSF: young secondary forest ( $\leq 20$  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 et 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
Eucalyptus 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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# References

## CarboScen papers

- 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.
- Larjavaara, M., Kanninen, M., Gordillo, H., Koskinen, J., Kukkonen, M., Käyhkö, N., Larson, A.M., Wunder, S. 2018. Global variation in the cost of increasing ecosystem carbon. *Nature Climate Change* 8, 38-42.
- Ravikumar, A., Larjavaara, M., Larson, A., Kanninen, M. 2017. Can conservation funding be left to carbon finance? Evidence from participatory future land use scenarios in Peru, Indonesia, Tanzania, and Mexico. *Environmental Research Letters* 12(1).