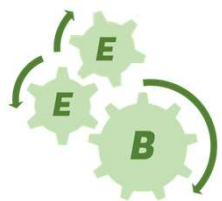


# UT7.1 Terrestrial forest ecosystems

## Forest C cycle



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# Contents

- C cycle in the terrestrial ecosystems
- How to measure forest productivity?
- Limiting factors for forest productivity
- Tree structural adaptations to stress
- Long-term assessment on forest growth

# Trivia (example) (1')

Which of the following statements is not true?

Photosynthesis captures C and releases O<sub>2</sub>

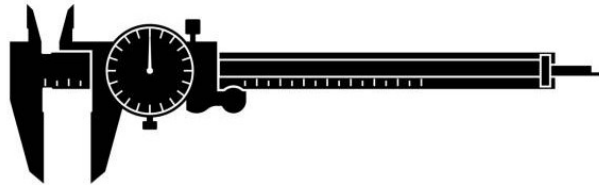
Forest productivity is dependent on regional climate

Forests worldwide net C emitters

Net primary production is the gross primary production minus the respiration

# The most important matter in Ecology...

## Is the grey matter!



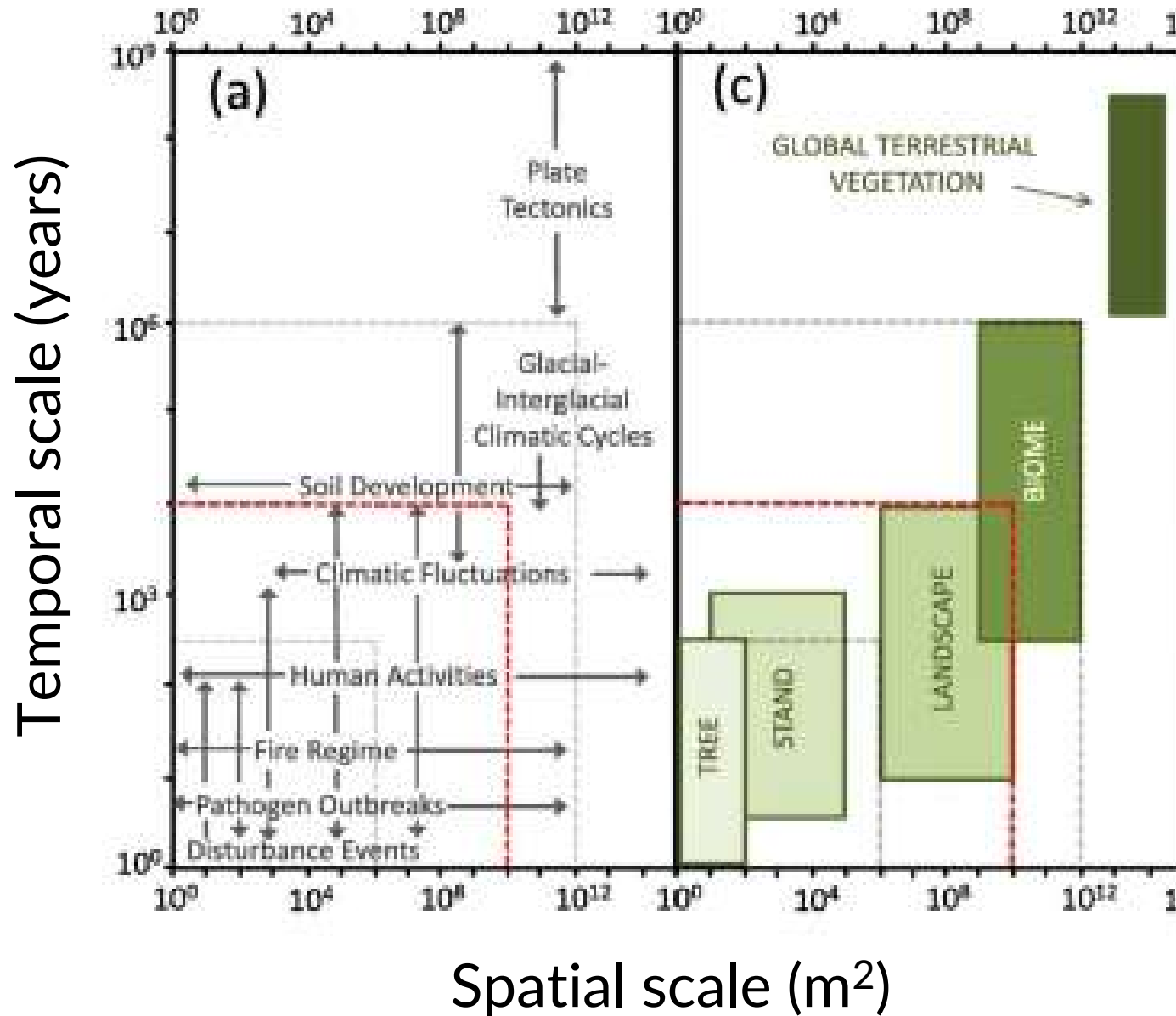
Forest C sequestration in Catalonia is able to fight climate change and produce biomass for energy



Catalan forests (1.25 M ha) uptake **1.3 tC year<sup>-1</sup>**.  
In Catalonia, 7.5 M people release each **5.1 tC year<sup>-1</sup>**.

**1.6 MtC Upt.** << **38.3 MtC Emi.**

# Ecology: a matter of scale



# Having a feel on the expected values



CO<sub>2</sub> uptake: 1 - 5 MgC ha<sup>-1</sup> year<sup>-1</sup>

Wood production: 1 - 8 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>

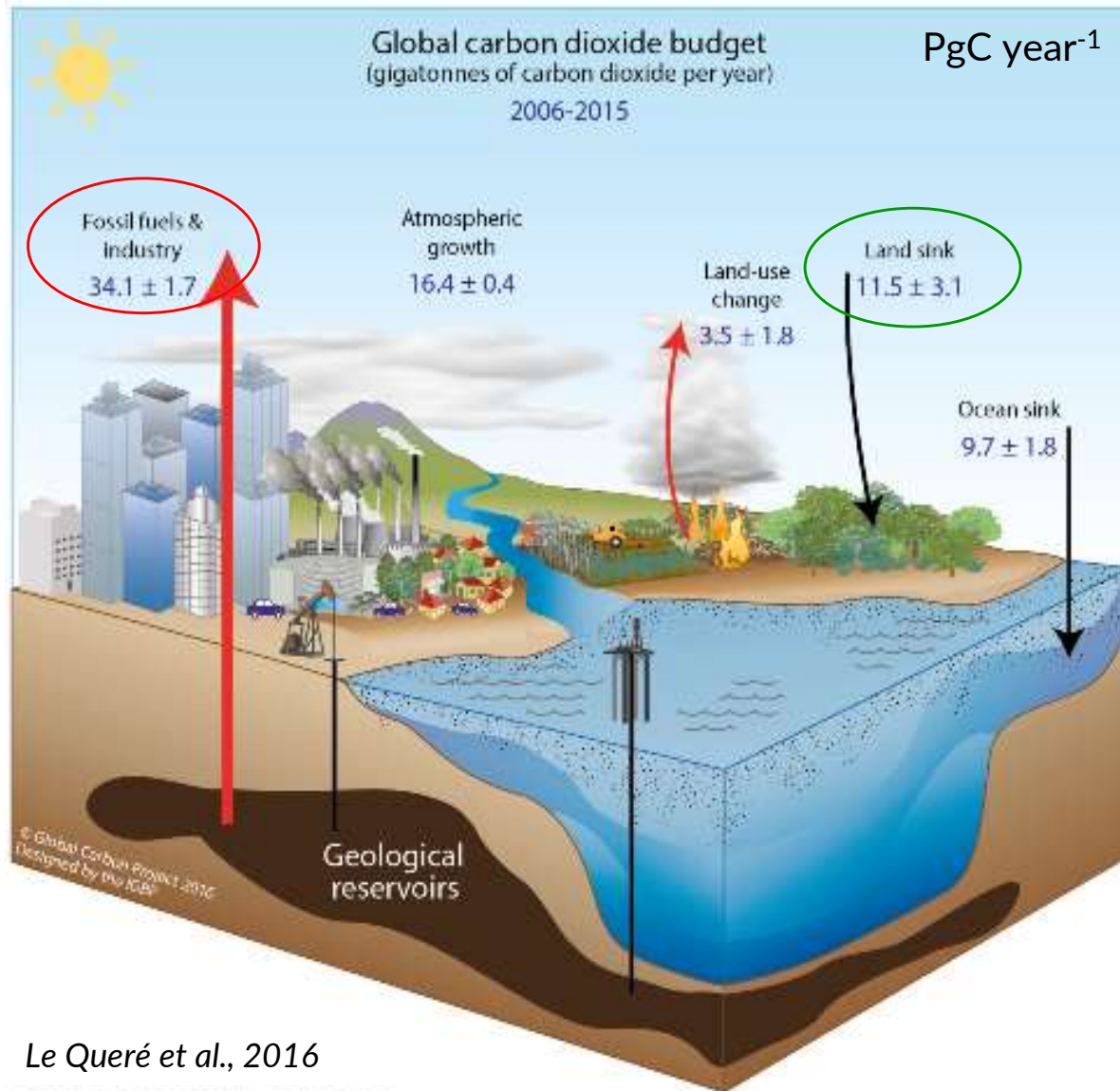
Transpiration: 150-500 mm year<sup>-1</sup>



+ Production

- Production

# Terrestrial C cycle globally



~ 34%  
Annual global anthropic CO<sub>2</sub>  
fossil fuel emissions captured  
by forests (biomass + soil)

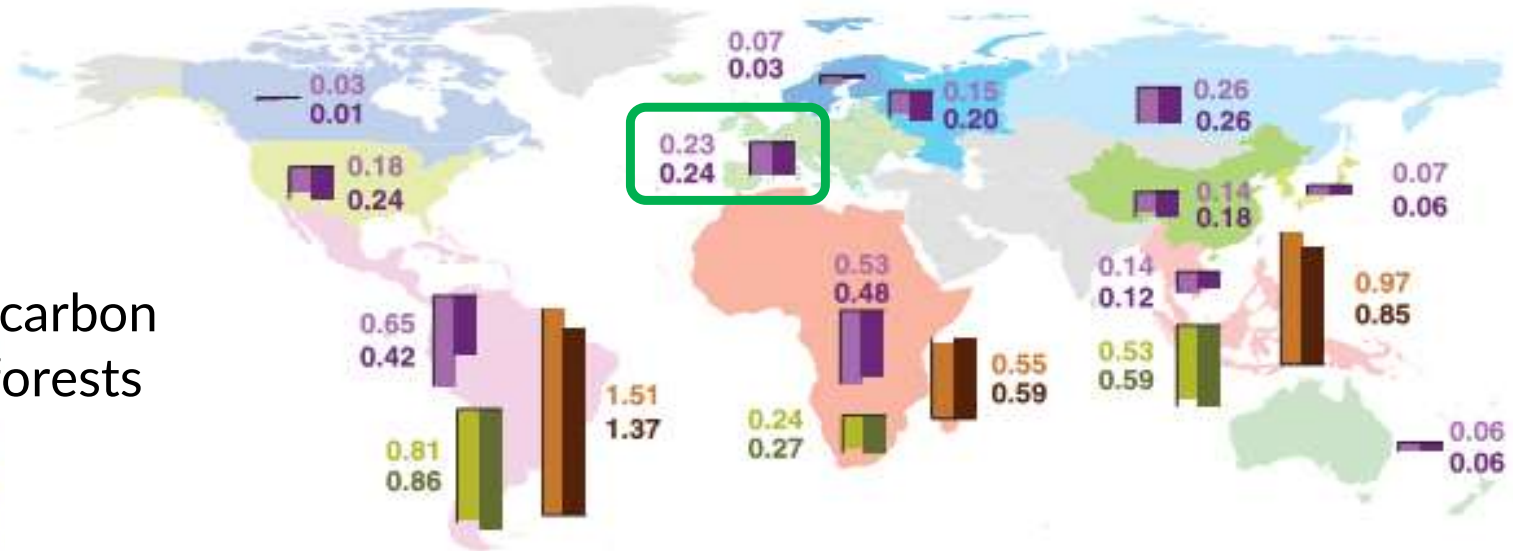


Le Queré et al., 2016

# And for Europe (and Catalonia)

Pan et al., 2011

Units in PgC year<sup>-1</sup> (period 1990-2007)

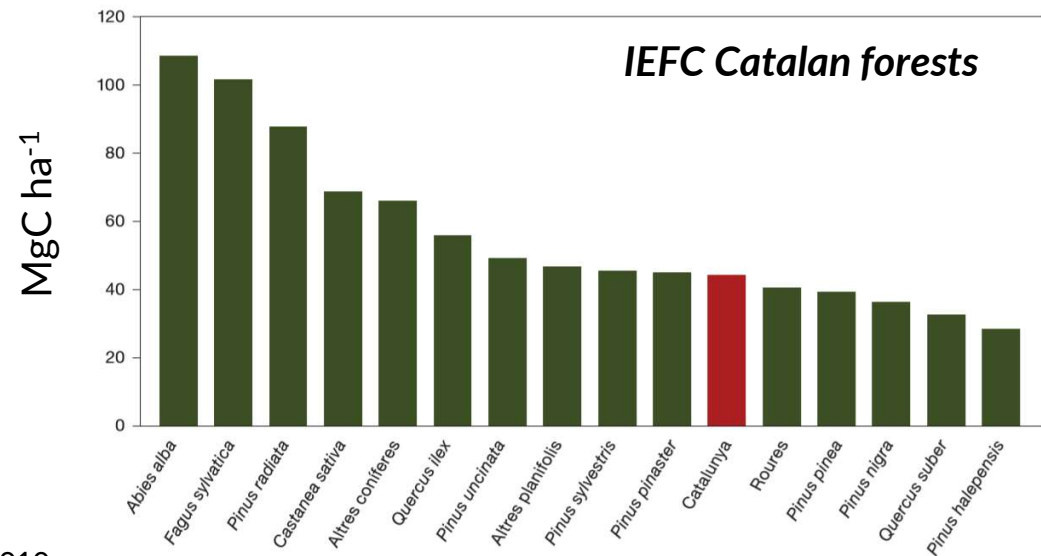


~ 10%

Worldwide forest carbon sink in European forests



More carbon stocked in alpine and sub-humid stands



Gracia et al., 2010

# Productivity and biomass at the different biomes

Biome	Extension	Mean T	Mean P	Biomass	NPP	Residence time
	10 <sup>6</sup> Km <sup>2</sup>	°C	m year <sup>-1</sup>	KgC m <sup>-2</sup>	KgC m <sup>-2</sup> year <sup>-1</sup>	years
Tropical rainforest	10.4	25-27	2 to 4	15	0.8	18.8
Tropical dryland	7.7	25-27	1.5 to 2	6.5	0.62	10.5
Temperate forests	9.2	10-15 (seasonality)	0.25 to 1	8	0.65	12.3
Taiga	15	< 5°C	0.3 to 1	9.5	0.43	22.1
Tundra	11	< 0°C	0.1 to 0.3	0.8	0.13	6.2
Sabana	24.6	20-26	0.5 to 1.5 (seasonality)	2	0.45	4.4
Steppe	15.1	Variable	Variable	3	0.32	9.4
Desert	18.2	variable	< 0.1	0.3	0.08	3.8

**From where it comes such production?  
How do we measure it?**

**Actually, what is  
considered to be a  
forest?**



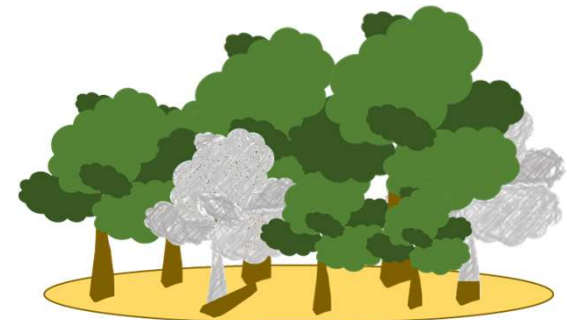
# Forest definition

**DIEC-2: “Place populated by trees”**

**Ministerio de Medio Ambiente y Medio Rural y Marino:** “Forest **surface** is considered the land **populated by forest tree species** and whose dominant **canopy cover (FCC) is more than 10%**. It consists of: (i) woodland - land with trees whose  $FCC > 20\%$ ; (ii) sparse woodland -  $10\% = <FCC < 20\%$ . It also includes land with scrub or grassland species dominant plant natural expression, but a FCC of between 10% and 20%.”

**FAO:** “Land **spanning more than 0.5 hectares** with **trees higher than 5 meters** and a **canopy cover of more than 10 percent**, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.”

**Forest = Trees + Cover + Surface**



# How to measure forest productivity?



Satellite observations  
(e.g. LANDSAT missions)

- Fine resolution
- Based on proxies

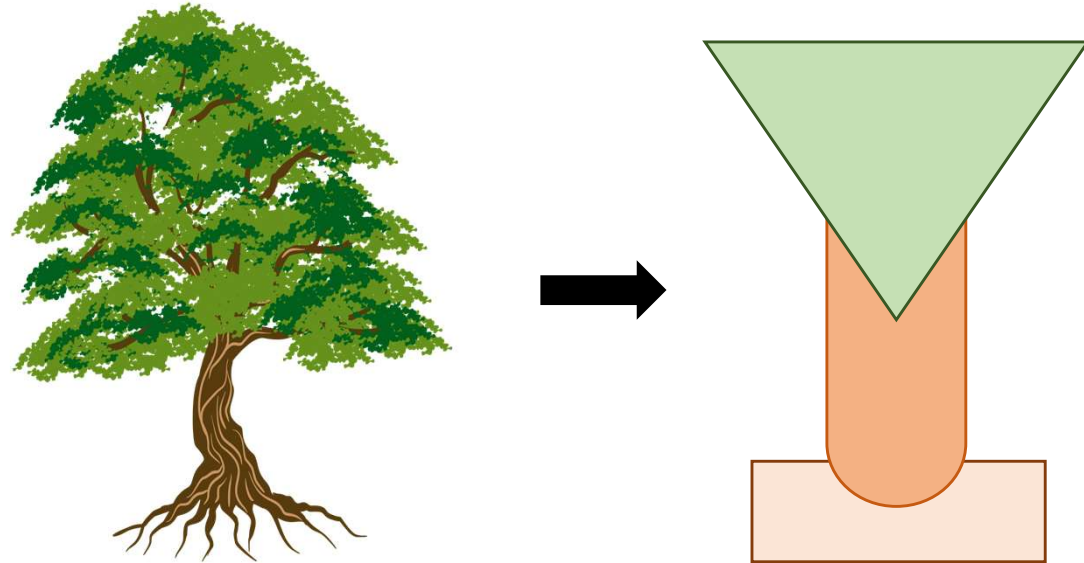
Forest inventories  
(e.g. NFI's)

- Coarser resolution
- Based on measurements

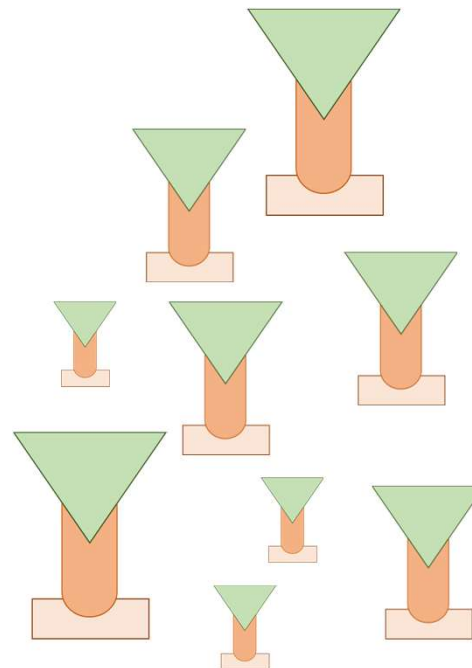


# Field measurements of biomass and productivity (I)

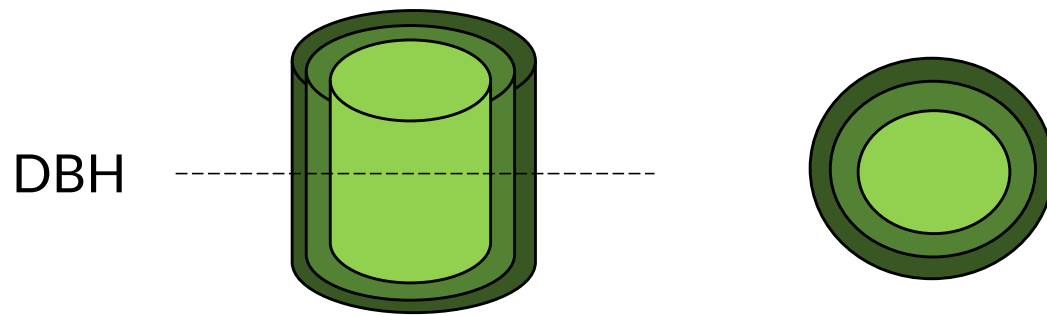
First, we need to simplify what a tree is



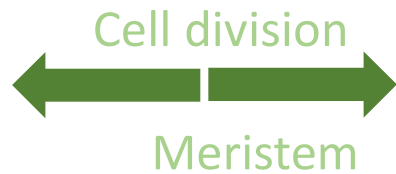
Then we measure the simplified units



# Field measurements of biomass and productivity (II)



Circular section of a tree stem (*P. sylvestris*, Prades, NE Spain, 2022)



Sapwood

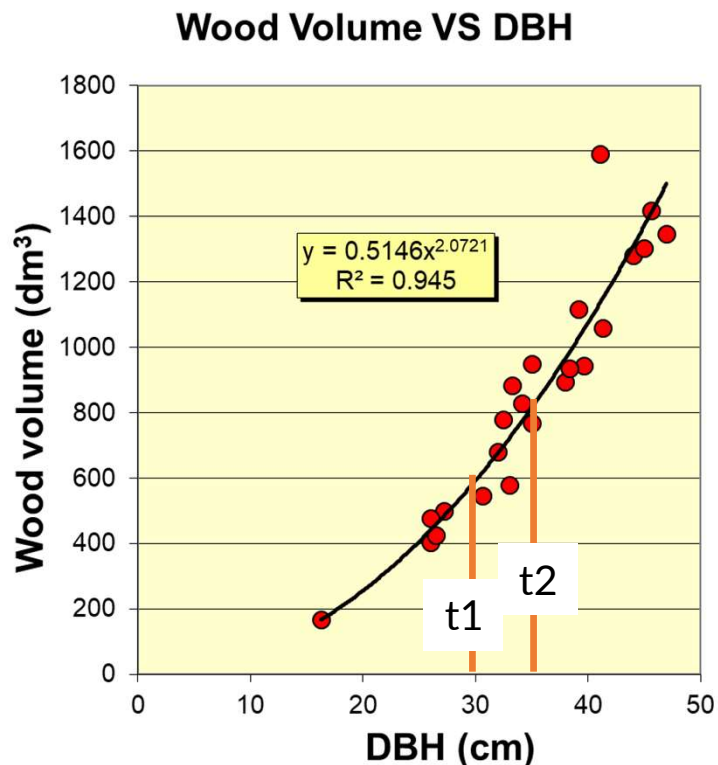


Bark Phloem

# Field measurements of biomass and productivity (III)

**Biomass or carbon stock:**  $\sum_i^n Density_n * Biomass_n$ , where “n” are the different diameter classes. To obtain the carbon, we multiply by  $0.48 \text{ gC gOM}^{-1}$ , a conservative estimate.

**Biomass production:** Obtained from diameter increases, it is calculated as  $\sum_i^n Density_n * Production_n$ , where “n” are the different diameter classes.



$$t2 - t1 = 10 \text{ years; } n = 400 \text{ trees ha}^{-1}$$

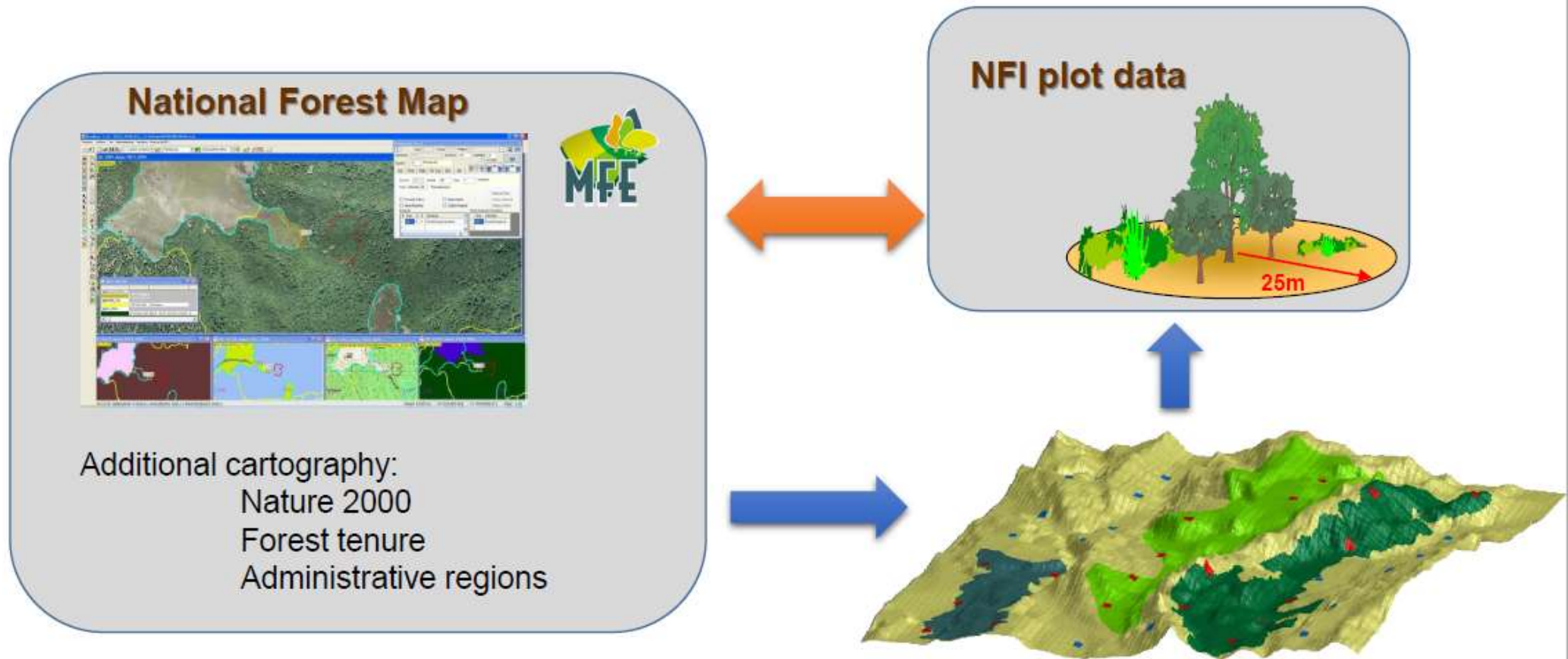
$$t1_{\text{Wood}} = 0.5146 * \underline{30}^{2.0721} = 510 \text{ dm}^3 \text{ tree}^{-1}$$

$$t2_{\text{Wood}} = 0.5146 * \underline{35}^{2.0721} = 700 \text{ dm}^3 \text{ tree}^{-1}$$

$$\Delta_{\text{Wood}} = (t2_{\text{Wood}} - t1_{\text{Wood}}) / (t2 - t1) = 19 \text{ dm}^3 \text{ tree}^{-1} \text{ year}^{-1}$$

$$\begin{aligned} \Delta_{\text{Wood,forest}} &= 19 \text{ dm}^3 \text{ tree}^{-1} \text{ year}^{-1} * 400 \text{ trees ha}^{-1} = \\ &= 7600 \text{ dm}^3 \text{ ha}^{-1} \text{ year}^{-1} = \mathbf{7.6 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}} \end{aligned}$$

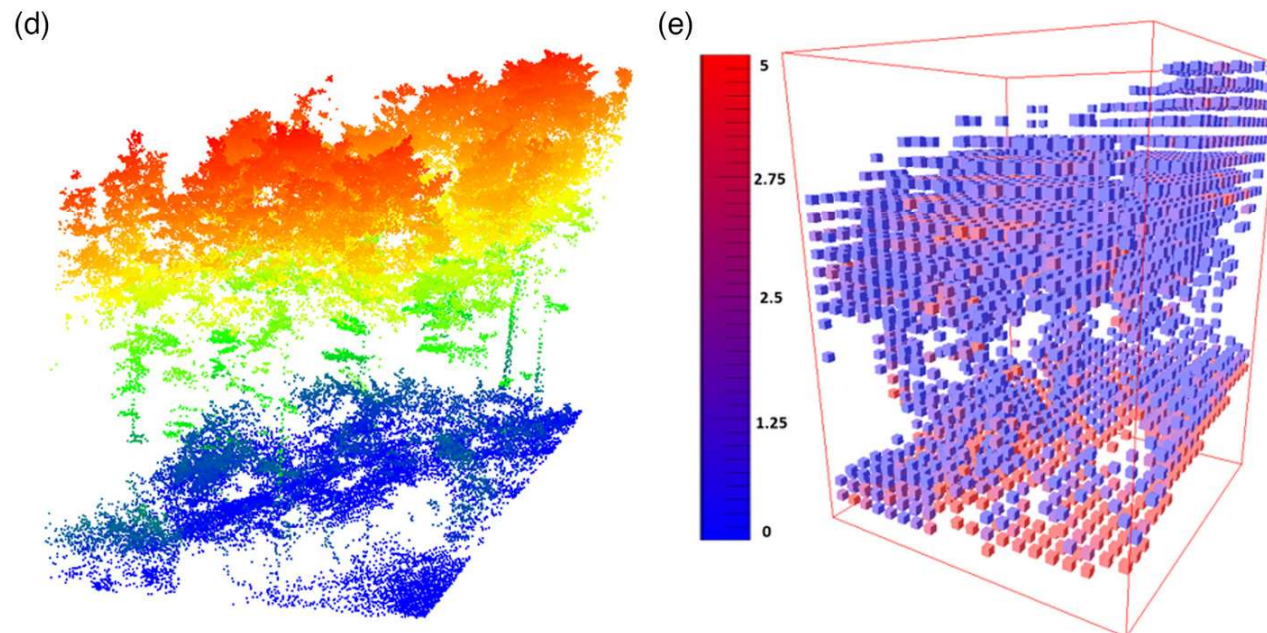
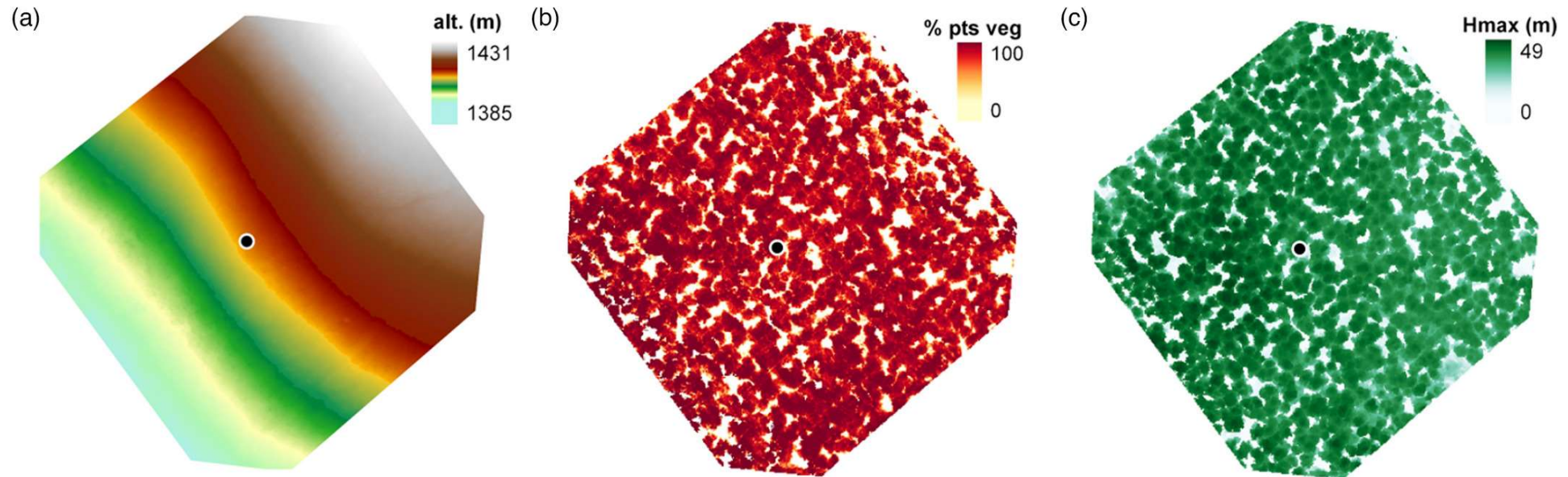
# Forest national inventories



Elena Robla, 2019 (MITECO)

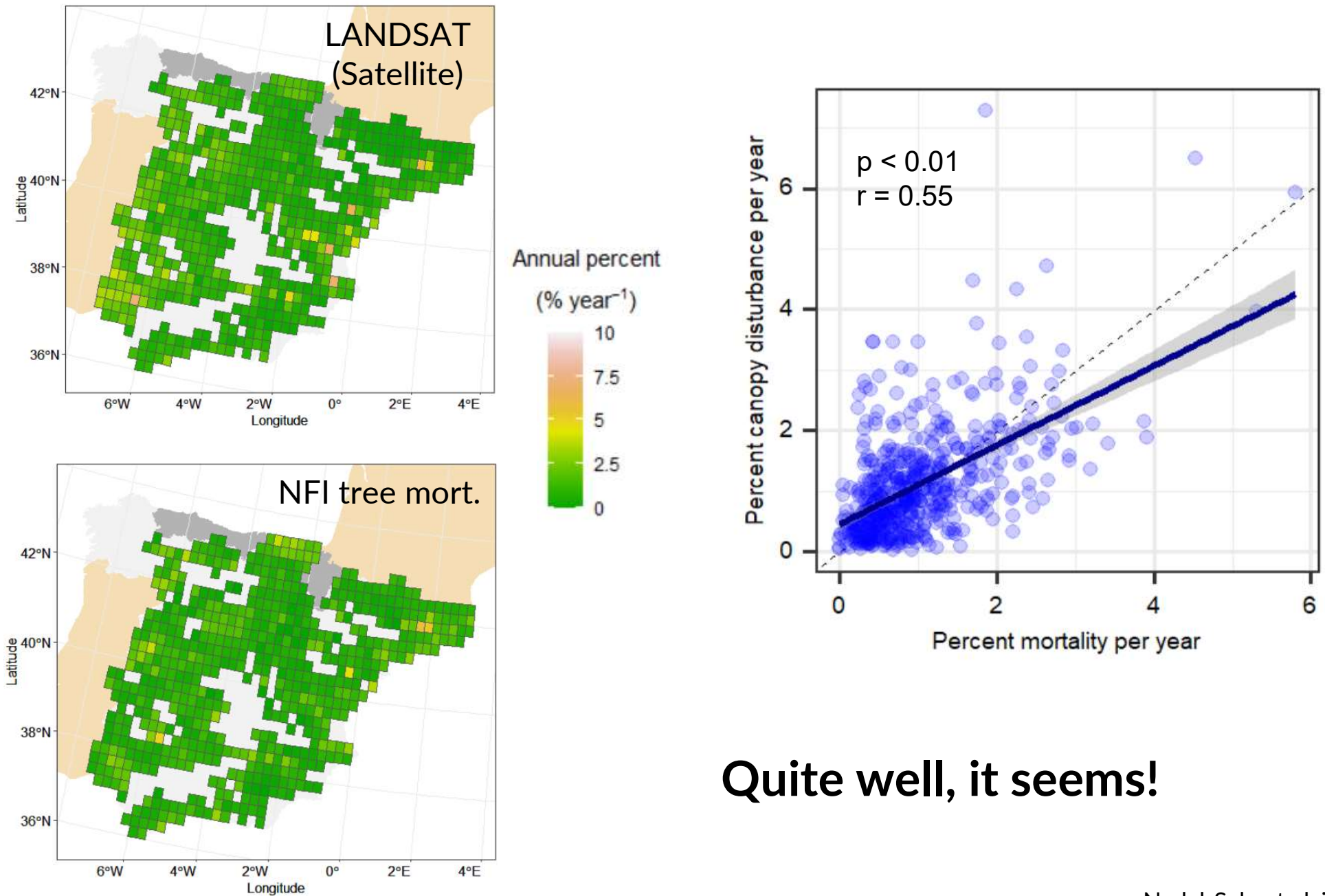
- Repeated forest inventories in time and at the same place
- Time- and effort-demanding
- Good overview of the national stocks

# LIDAR measurements of biomass and productivity



- Higher temporal and spatial resolution.
- Possibility to reach non-accessible regions.
- Use of proxies to estimate the indexes.

# Do the methods agree?



Quite well, it seems!

# Trivia (1')

Which of the following statements is not true?

Forest capture  
~34% of  
human GHG  
emissions  
annually

Forests in  
cold climates  
have the  
slowest C  
turnover  
rates

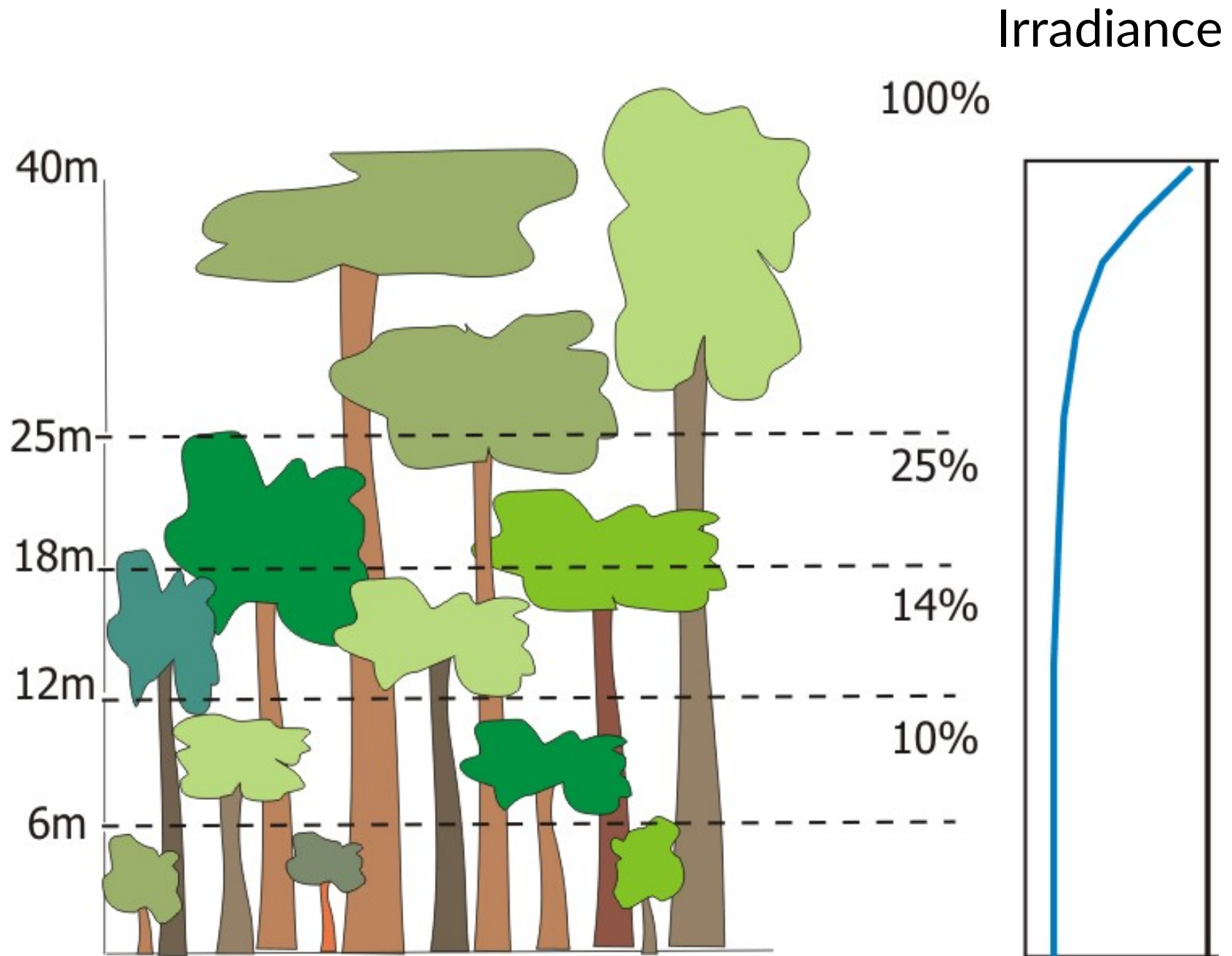
Average  
Catalan  
forests' C  
stock is ~  
40 tC ha<sup>-1</sup>

Forest  
National  
Inventories  
occur once  
per year

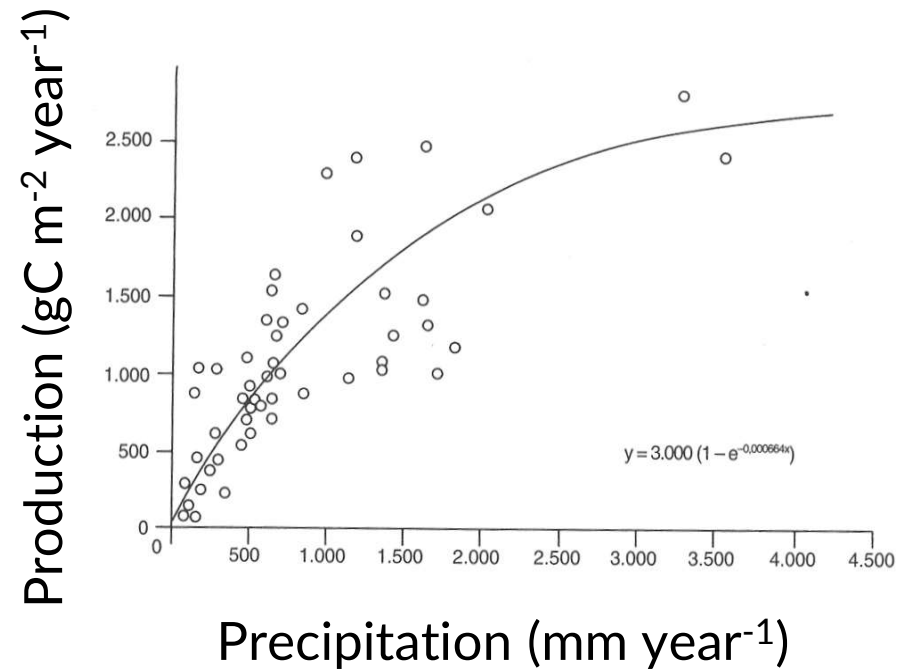
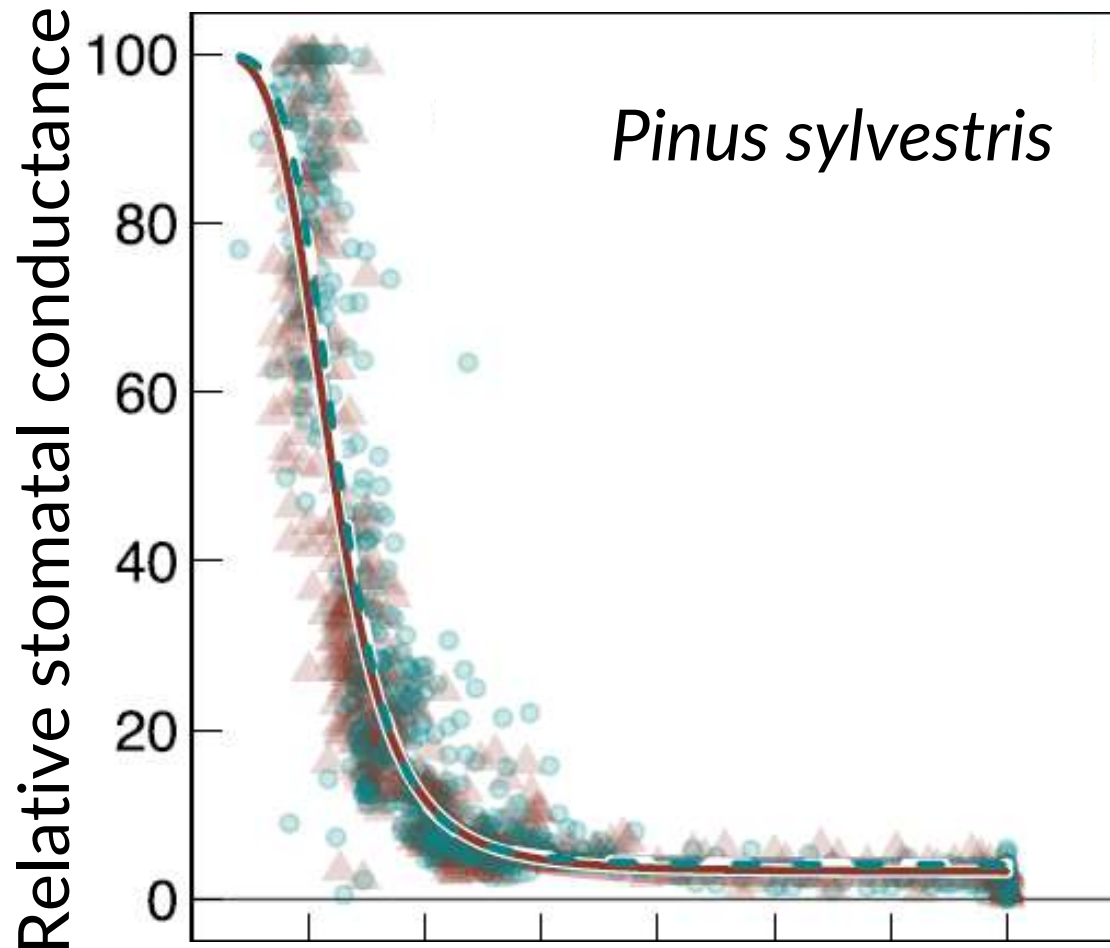
The image is a collage of three distinct environmental scenes. The top section features a close-up of clear water with numerous small, shimmering bubbles and ripples. The bottom-left section shows a vast, arid desert landscape with a large, dark rock in the foreground and jagged mountains in the distance under a clear sky. The bottom-right section depicts a bright, intense lightning bolt striking down from a dark, stormy sky. The text 'Environmental drivers of forest productivity' is centered over the water image.

# Environmental drivers of forest productivity

# Light availability constrains to productivity



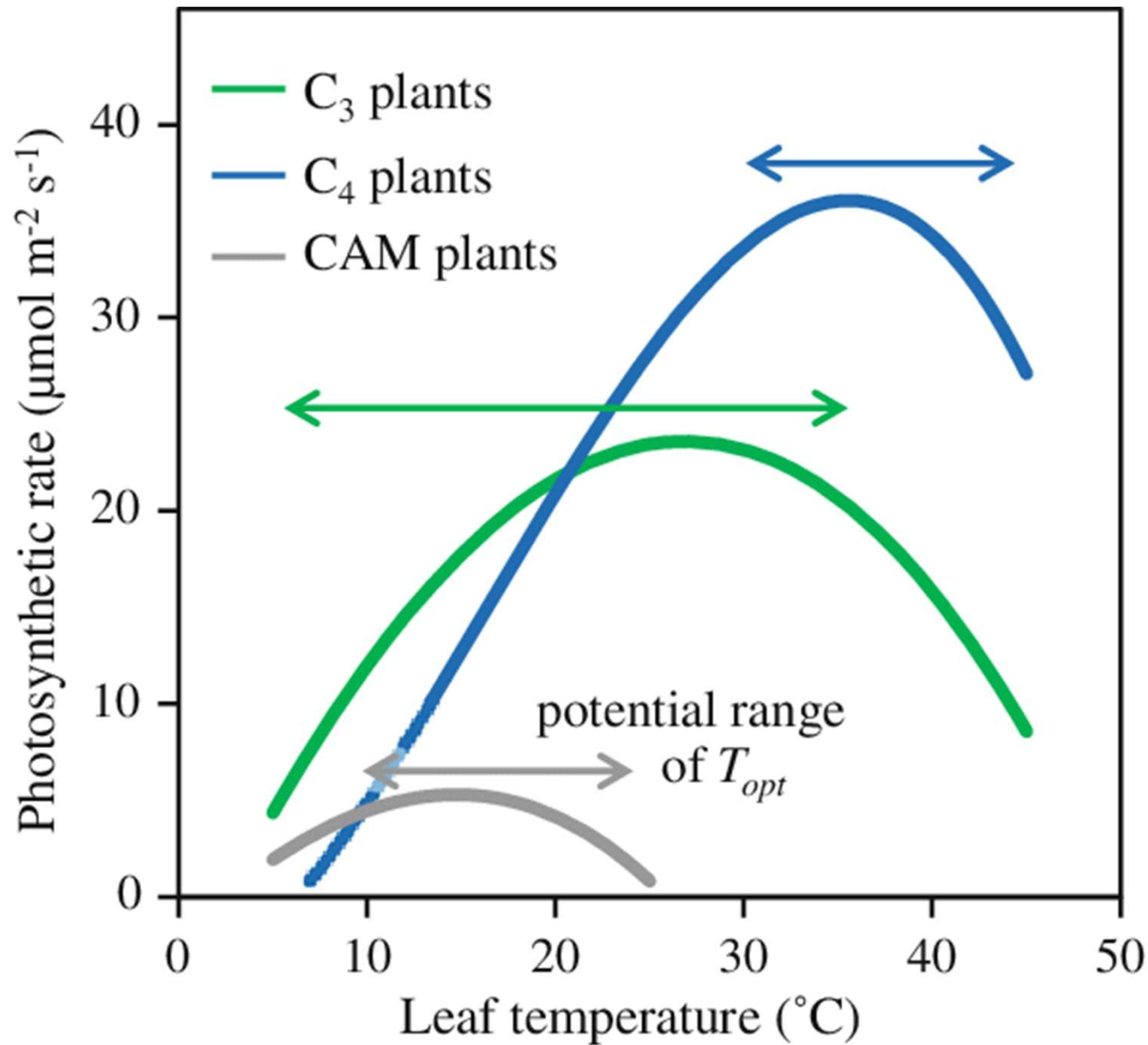
# Low water availability constrains productivity



Schlesinger, 2000

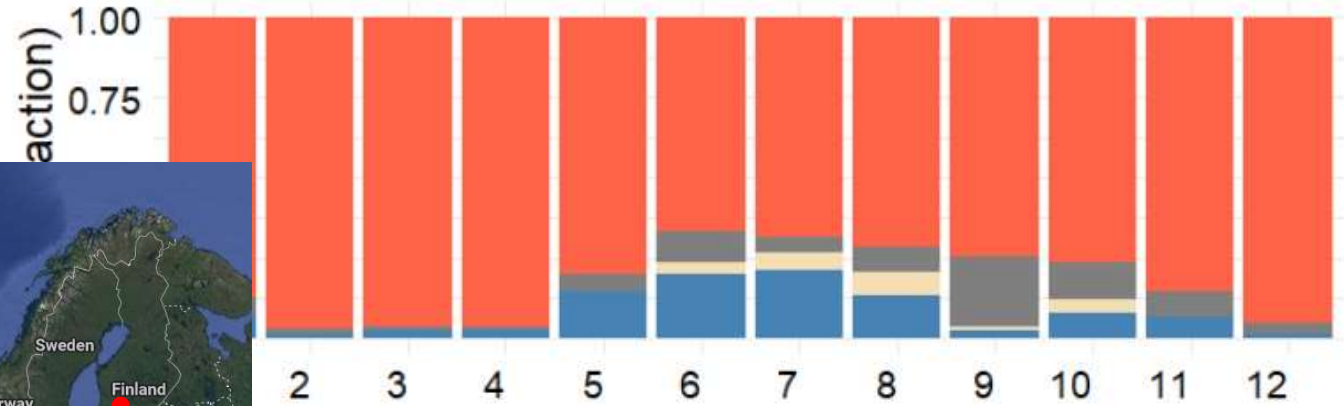
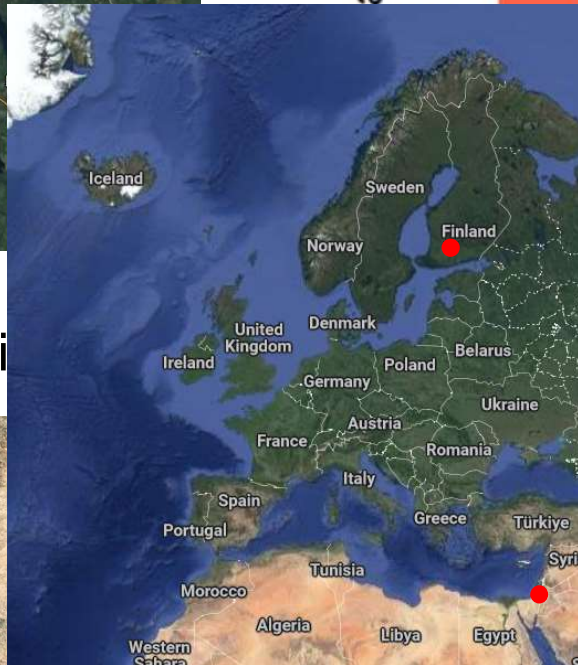
Drought stress

# Temperature constrains to productivity

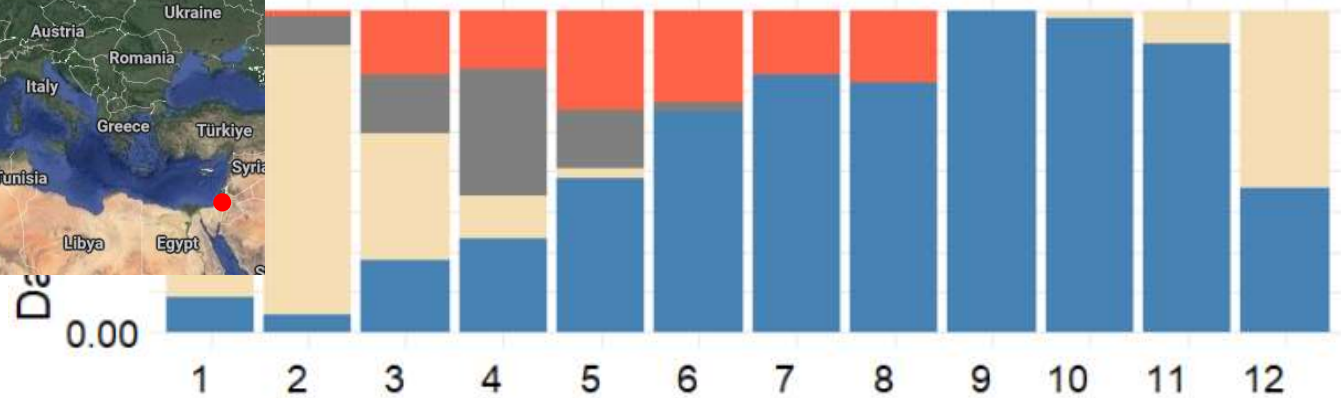


# Limiting factors over forest productivity

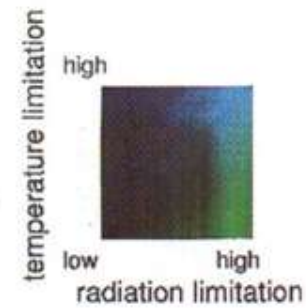
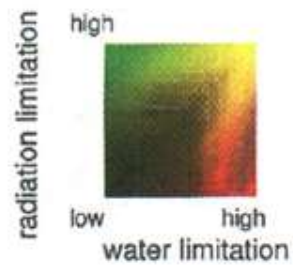
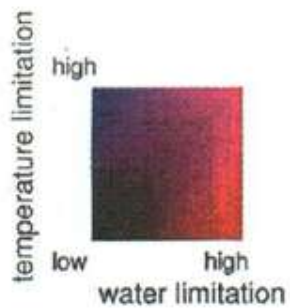
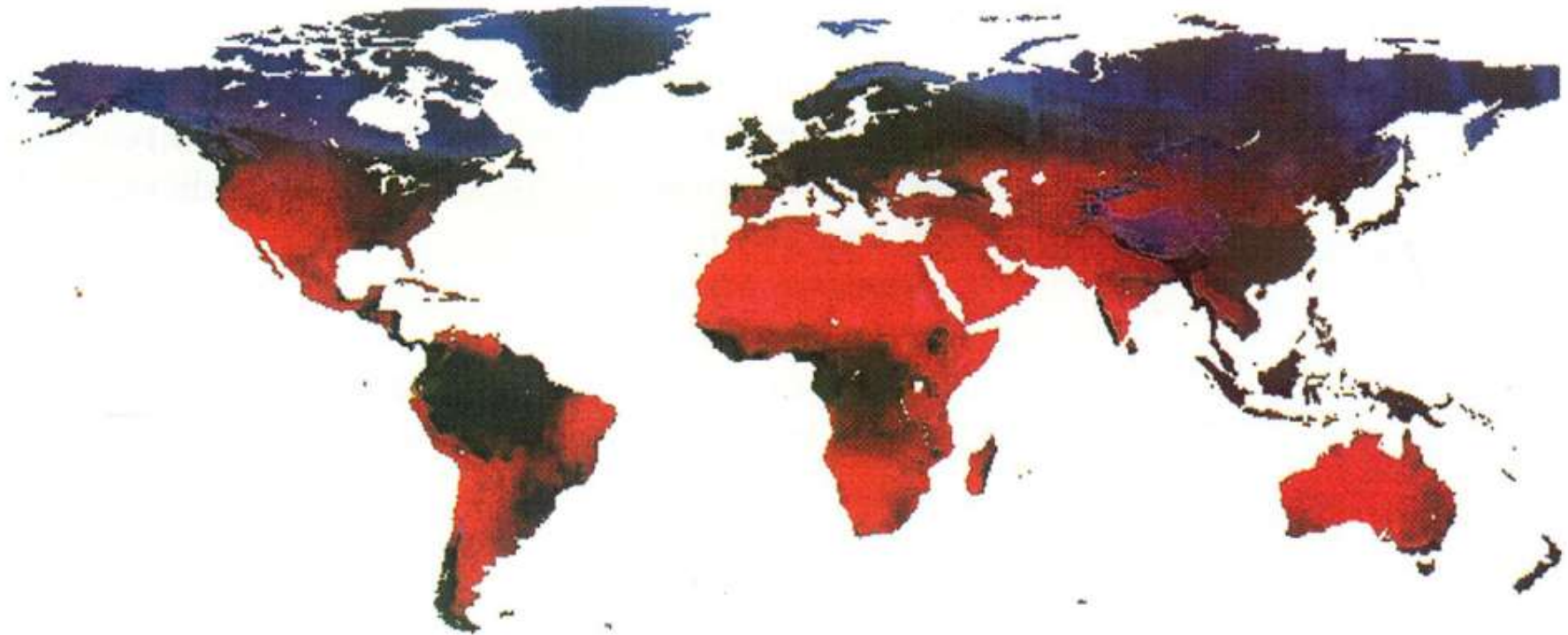
Hyytiala, boreal, Finland



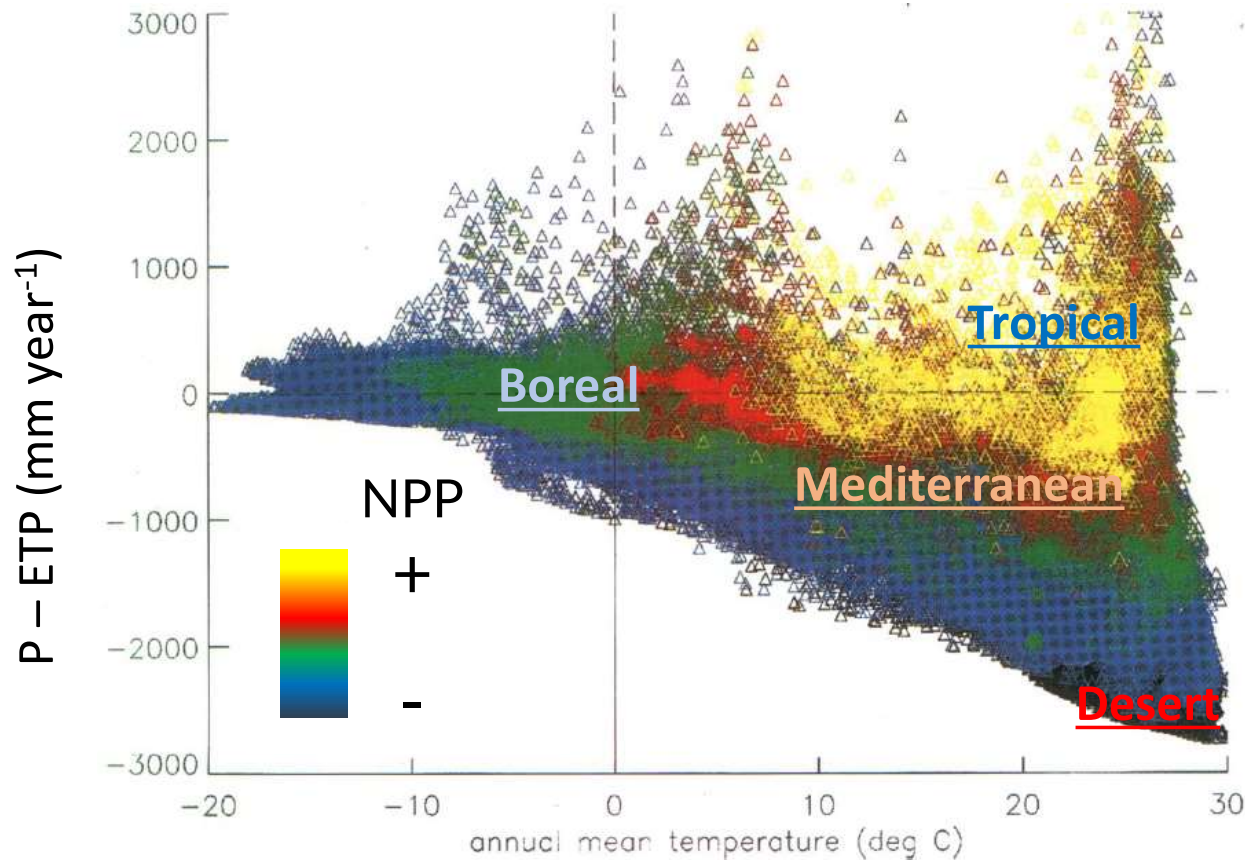
Yatir, semi-arid



# Limiting factors over productivity worldwide



# Limiting factors over productivity worldwide



Note the climate combinations that make productivity impossible



The image is a collage of several photographs. On the left, there are two close-up shots of green, serrated leaves, likely from a deciduous tree. On the right, there are three images of tall, mature trees with dense green foliage, possibly conifers or evergreens, set against a clear blue sky. The text 'Regional adaptations' is centered over the collage in a bold, black, sans-serif font.

# Regional adaptations

# Structural adaptations to environmental drivers



Leaf surface	Stratum	LAI	P	B	P/B
++	++	++	++	++	+

Water + Temperature + Radiation



+	+	+	+	+	++
---	---	---	---	---	----

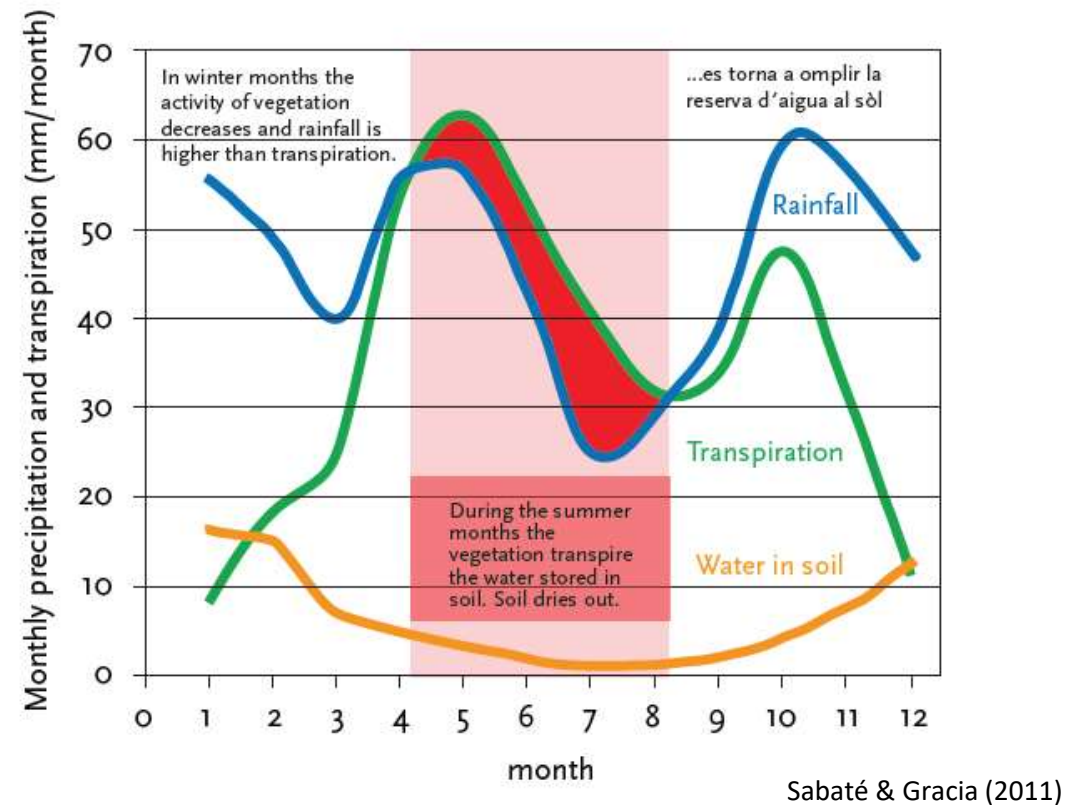
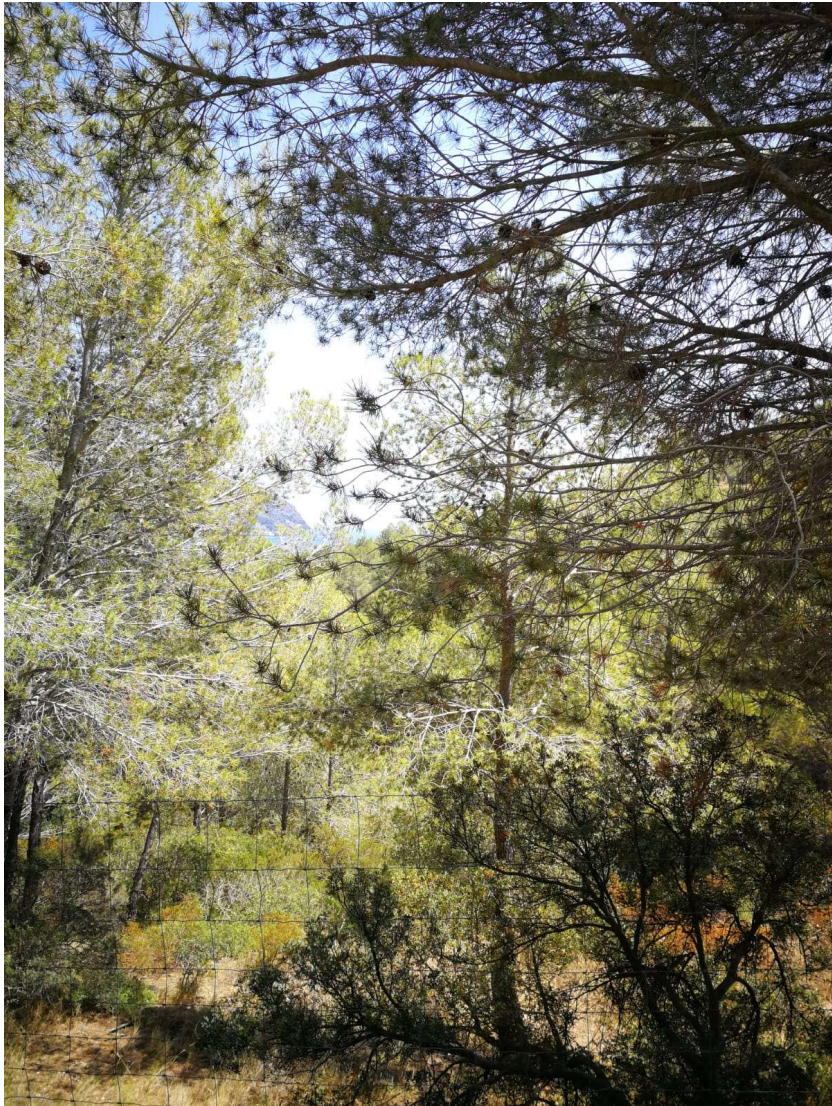
Moderate water + T seasonality + Q seasonality



-	-	-	-	○	-
---	---	---	---	---	---

Water + T limitation + Q limitation

# And in the Mediterranean



- Deciduousness
- Sclerophyll leaves
- Resistance forms (e.g. resprouters)
- Mid-to-low LAI
- Low productivity
- Mid-to-low biomass

# Trivia (1')

Which of the following statements is true?

Mediterranean forests are mostly limited by energy availability

Boreal forests have high productivity and high respiration

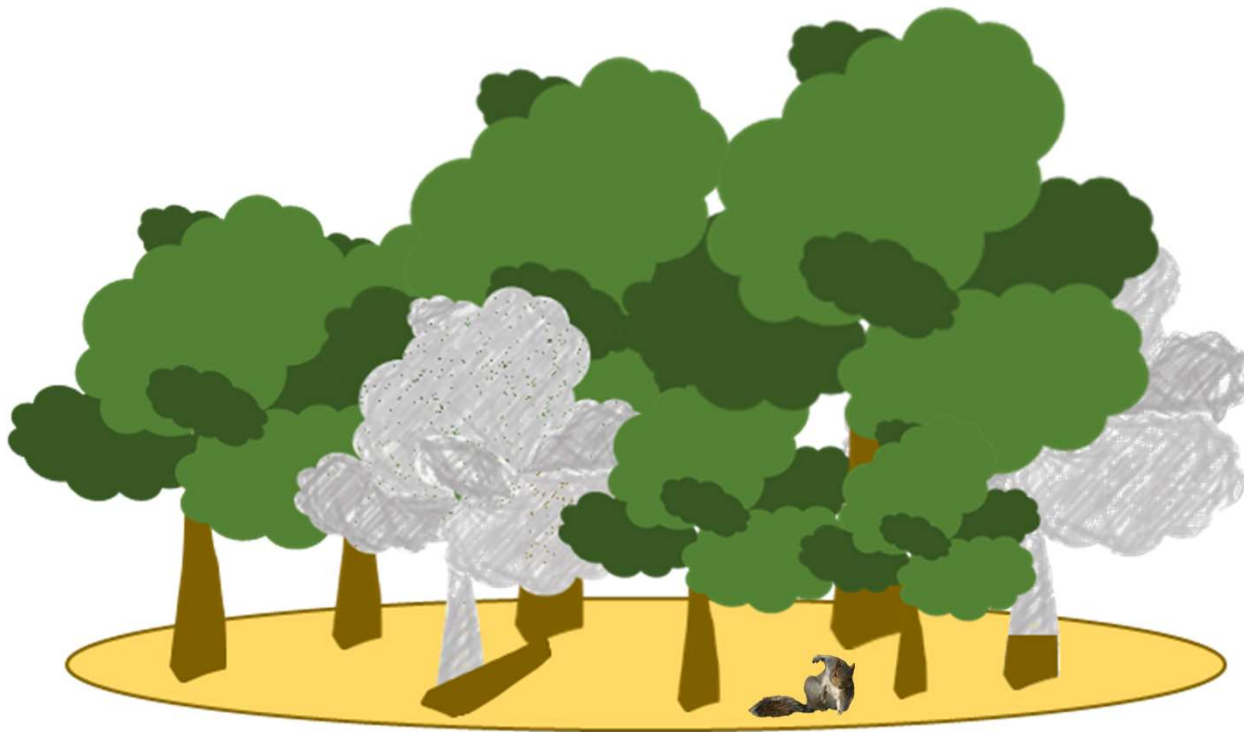
Low water availability limits forest productivity

Photosynthesis optimum in C3 plants occurs around 15 °C



# Assessing forest dynamics over time

# Forest dynamics span larger than a lifetime



So we need to accelerate the process... **MODELS!**

# And what simulation models actually are?



Music

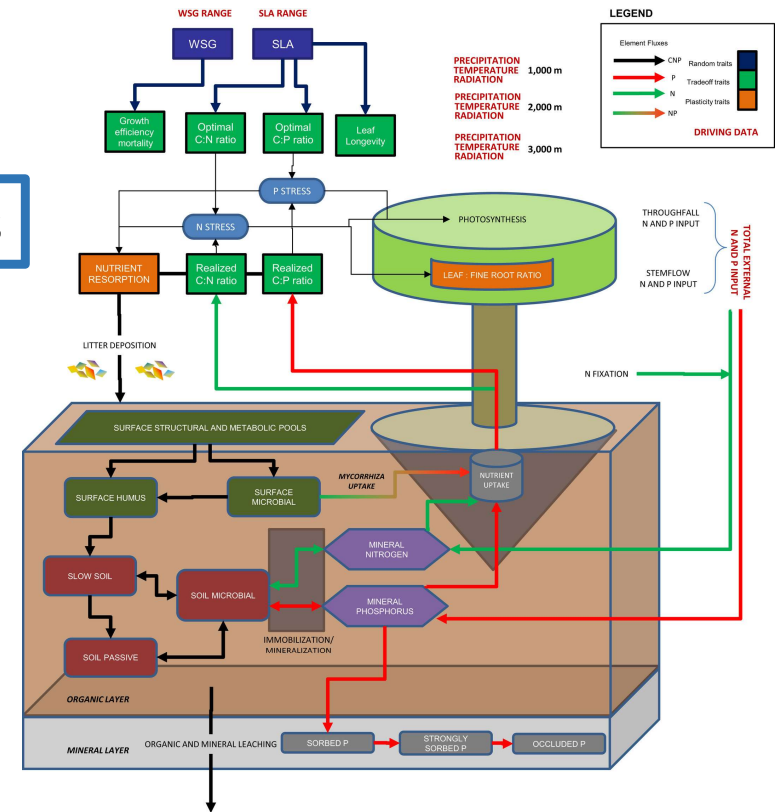


Crank

Engines

Equations

Input conditions



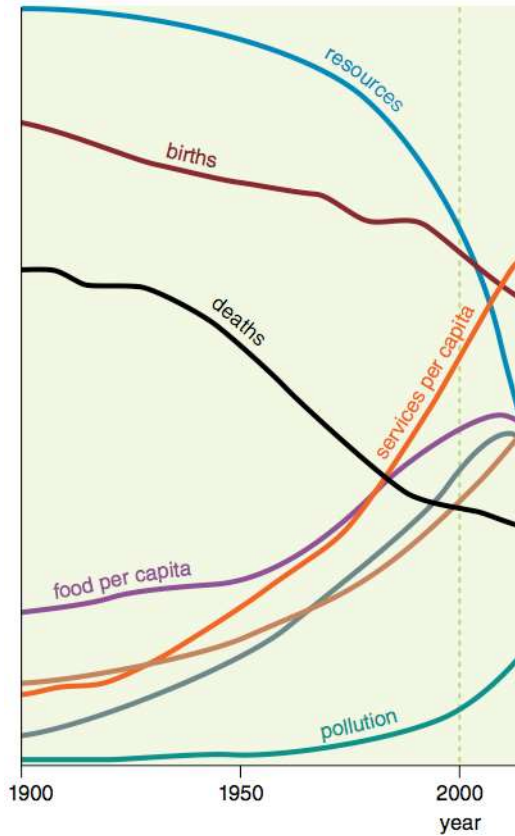
Projections

# Example: The Limits to Growth

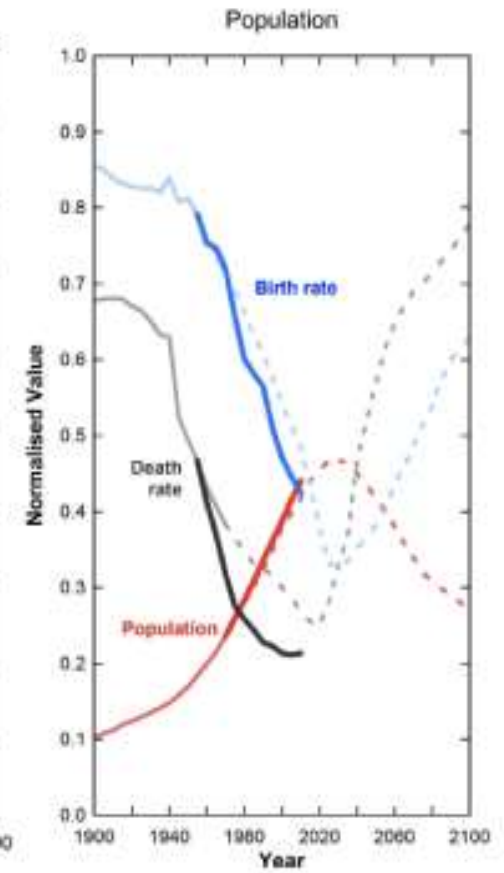
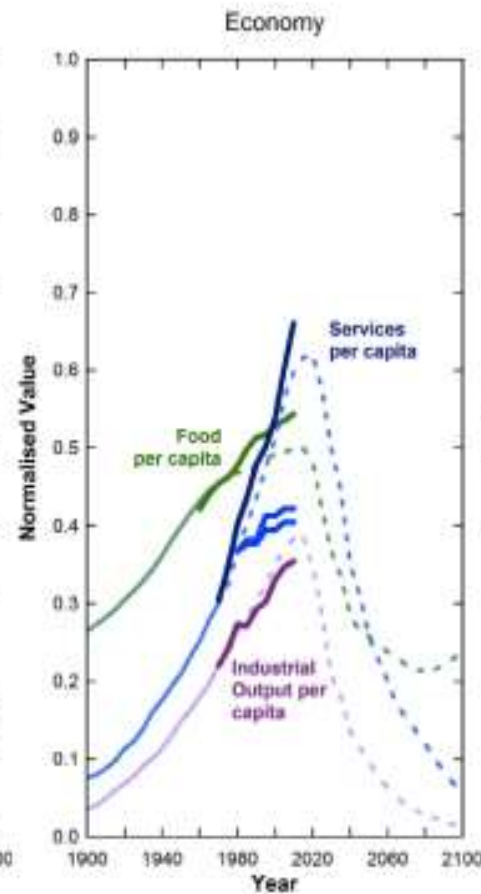
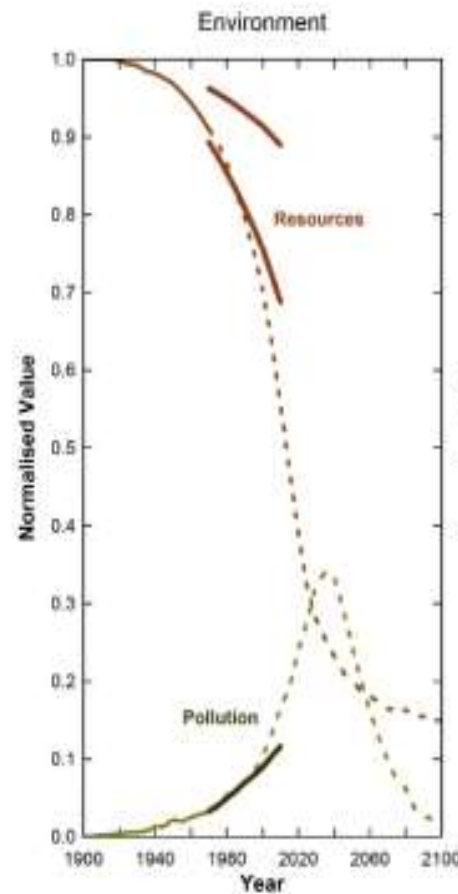


**Dr. Donella Meadows**

MIT. Lead author of "The limits to growth"



Meadows et al., 1972





'STEADY AS SHE GOES'

# Recommended lectures

Birot, Y., Gracia, C., & Palahi, M. (2011). Water for forests and people in the Mediterranean region: a challenging balance. European Forest Institute (EFI).

Churkina, G., & Running, S. W. (1998). Contrasting climatic controls on the estimated productivity of global terrestrial biomes. *Ecosystems*, 1, 206-215.

Gracia C, Sabaté S, Vayreda J, et al. (2010). Embornals a: Segon informe sobre el canvi climàtic a Catalunya. J. Llebot. Institut d'Estudis Catalans i Generalitat de Catalunya.

Le Quéré, C., Andrew, R. M., Canadell, J. G., et al. (2016). Global carbon budget 2016. *Earth System Science Data*, 8(2), 605-649.

Pan, Y., Birdsey, R. A., Fang, J., et al. (2011). A large and persistent carbon sink in the world's forests. *Science*, 333(6045), 988-993.

Terradas, J., Prat, N., Escarré, A., & Margalef, R. (1989). Història natural dels països catalans. Vol. 14. Sistemes naturals.