

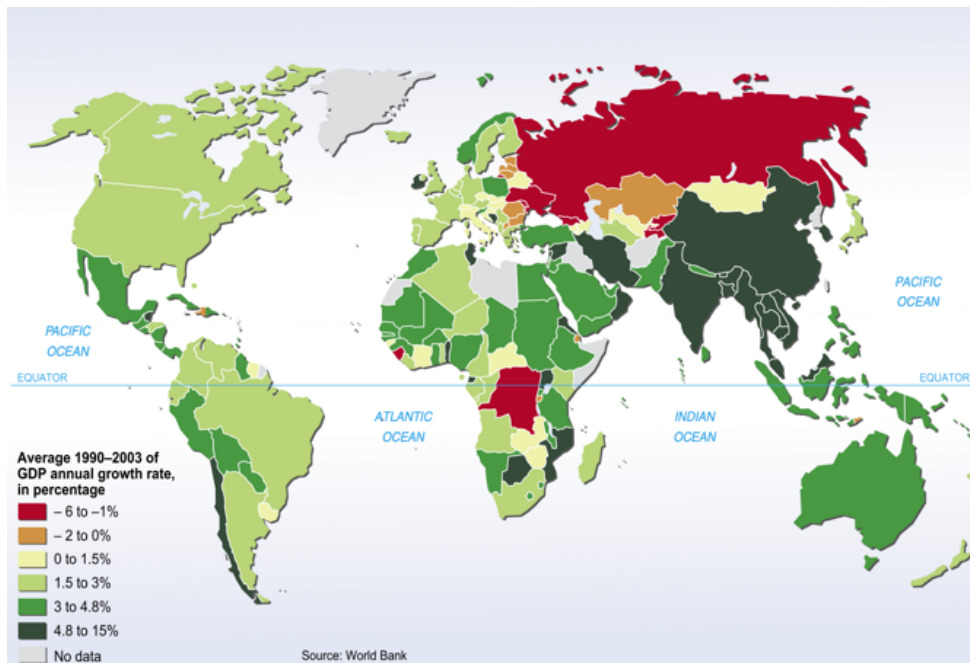
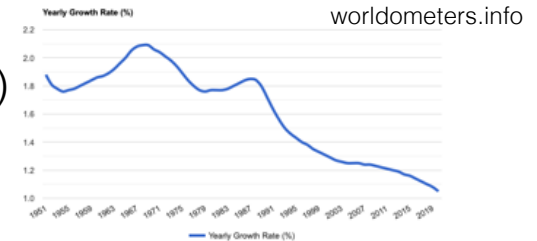
The great green wall of China

EPFL

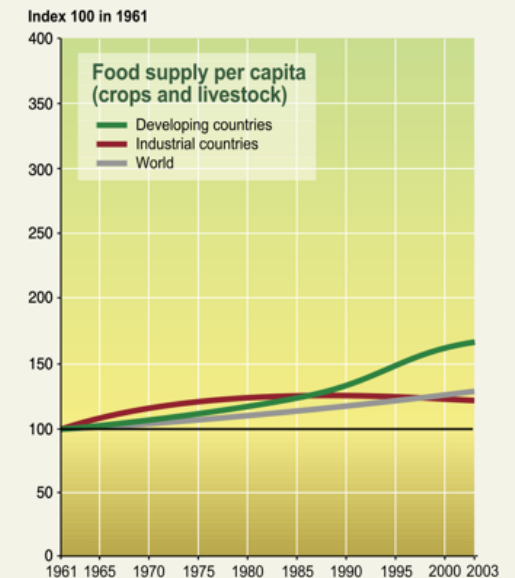
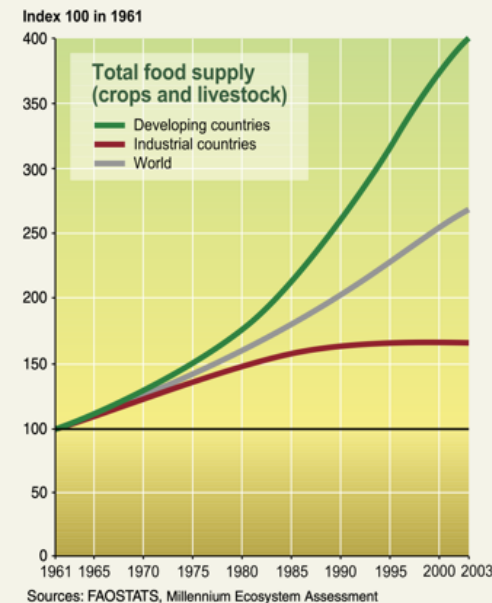


Everything is growing!

- world population doubled from 3 to 6 billion people from 1960–2000 (now 8)
- global economy increased more than sixfold in the same time



RELATIVE CHANGES IN FOOD SUPPLY (CROPS AND LIVESTOCK): INDUSTRIAL AND DEVELOPING COUNTRIES



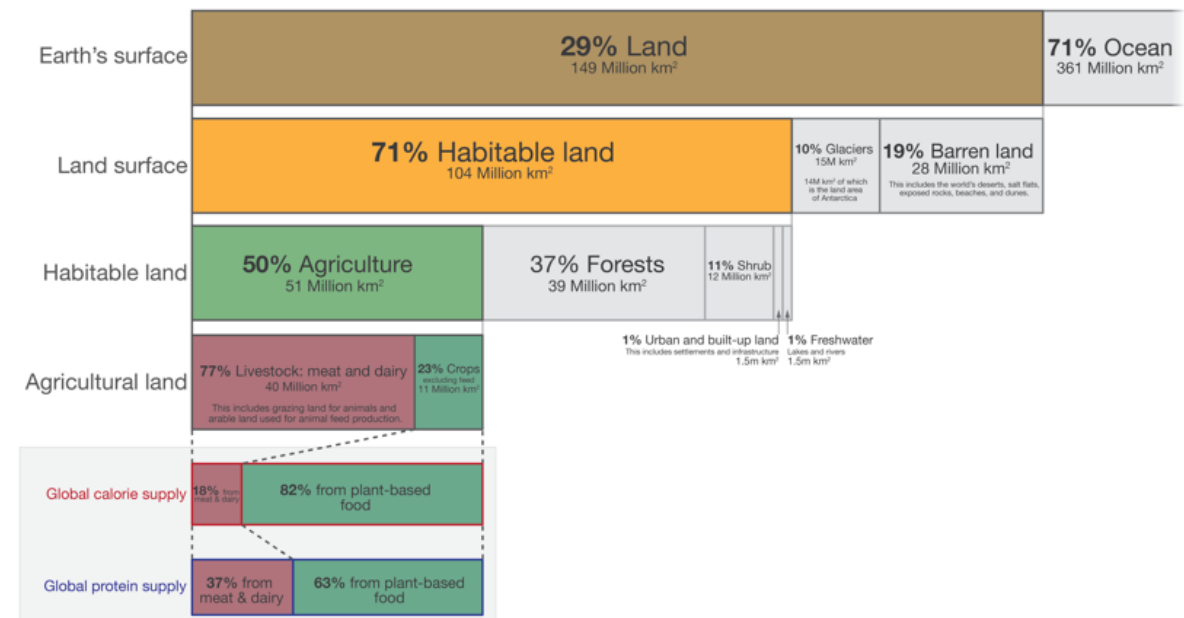
Average annual percentage of growth rate of GDP

To meet this demand

- food production increased 2 ½ times
- water use doubled
- wood harvests for pulp and paper production tripled
- timber production increased by more than half

Global land use for food production

Our World in Data

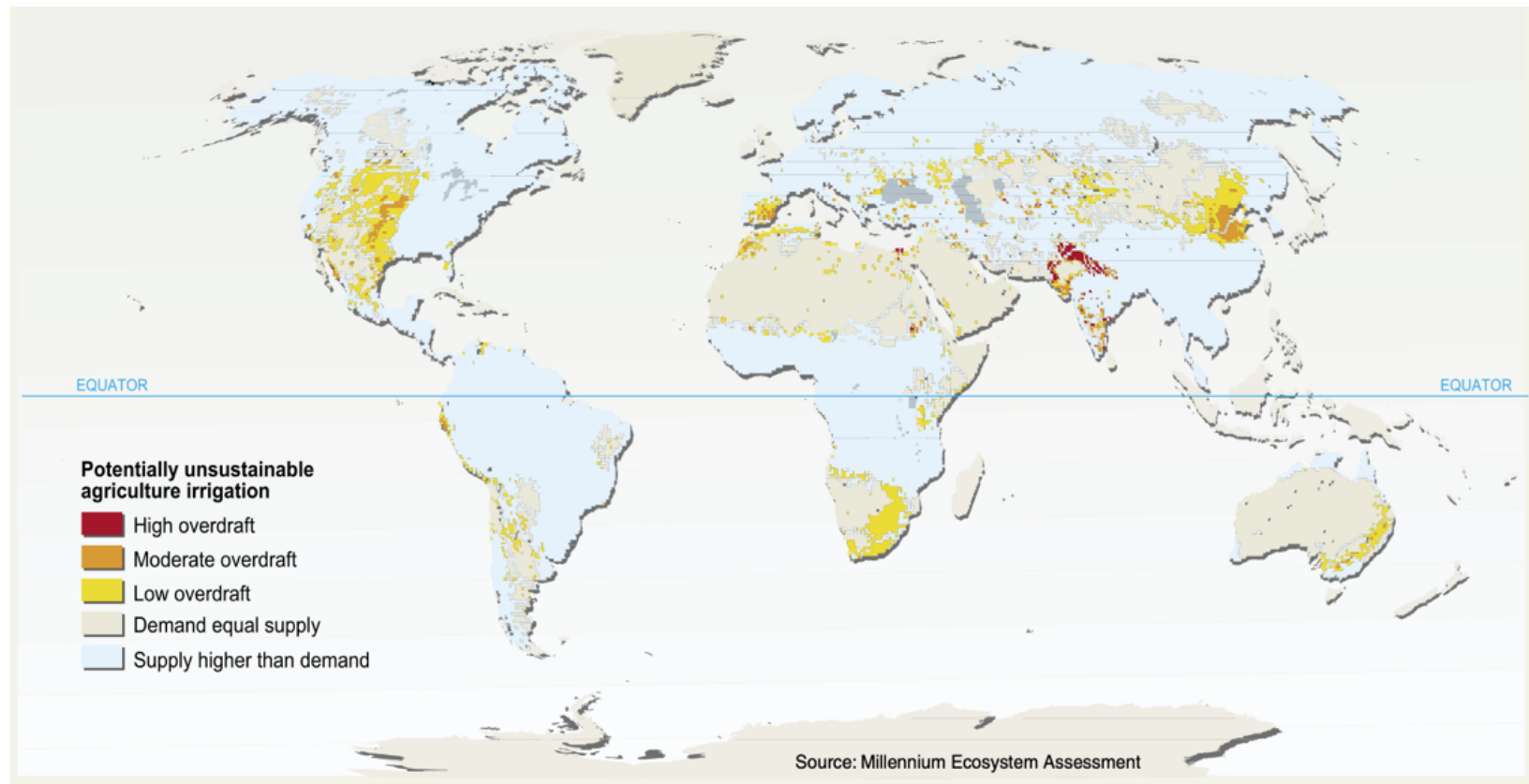


Data source: UN Food and Agriculture Organization (FAO)
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the authors Hannah Ritchie and Max Roser in 2019.

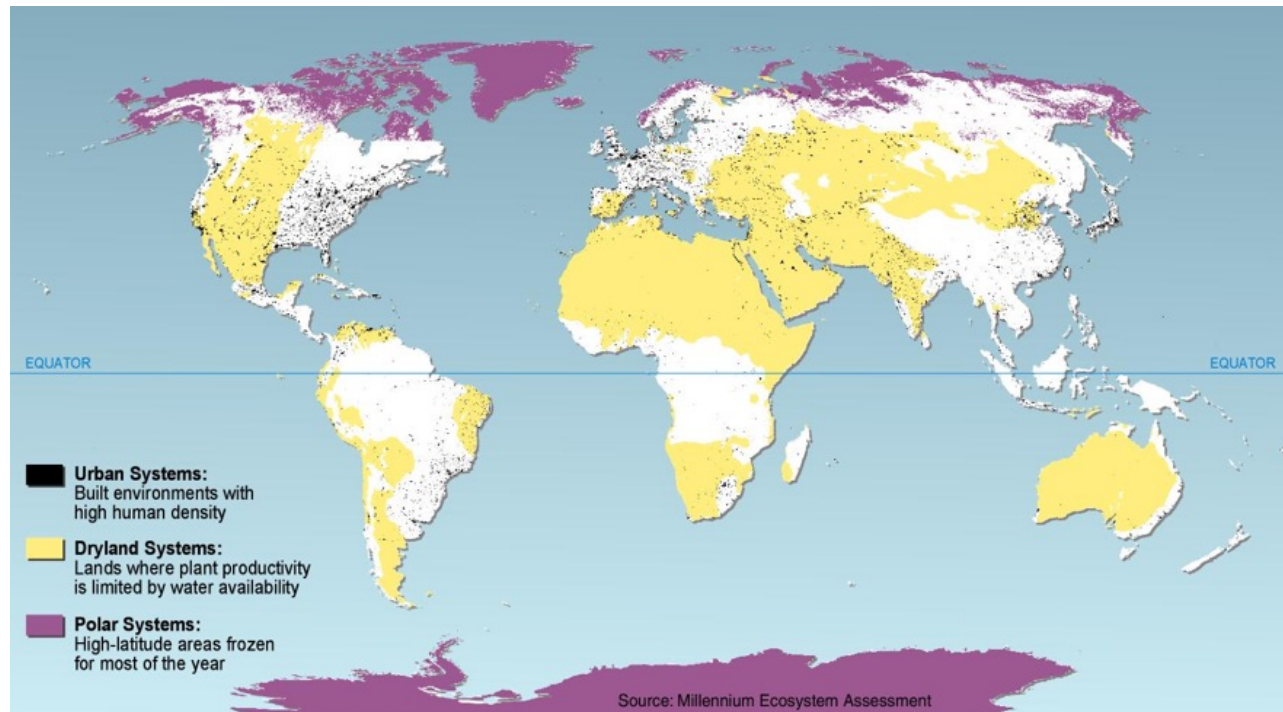
Land-use and degradation

Globally, roughly 15–35% of irrigation withdrawals are estimated to be unsustainable.



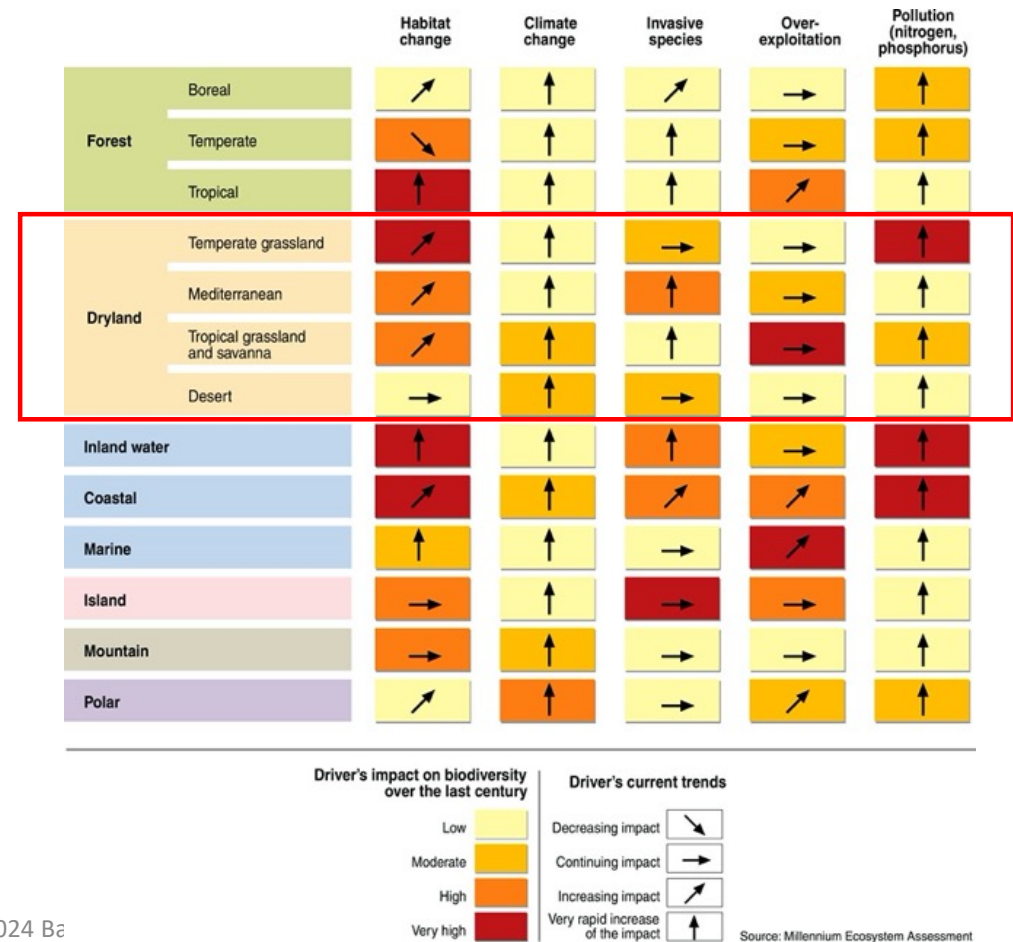
Degradation of drylands

- Drylands cover 41% of Earth's land surface and more than 2 billion people inhabit them, 90% of whom are in developing countries
- Approximately 10–20% of the world's drylands are degraded



Drivers of land degradation

- Most drivers of ecosystem degradation remain constant or are growing in intensity
- In deserts, climate change is one of the major concerns
- In other drylands habitat change, nutrient input and species invasion are the largest concern.



Land restoration

- Can be active (such as planting grasses, shrubs, and trees, or managing soils and wildlife)
- Or passive (such as allowing land to recover by itself after disturbance).

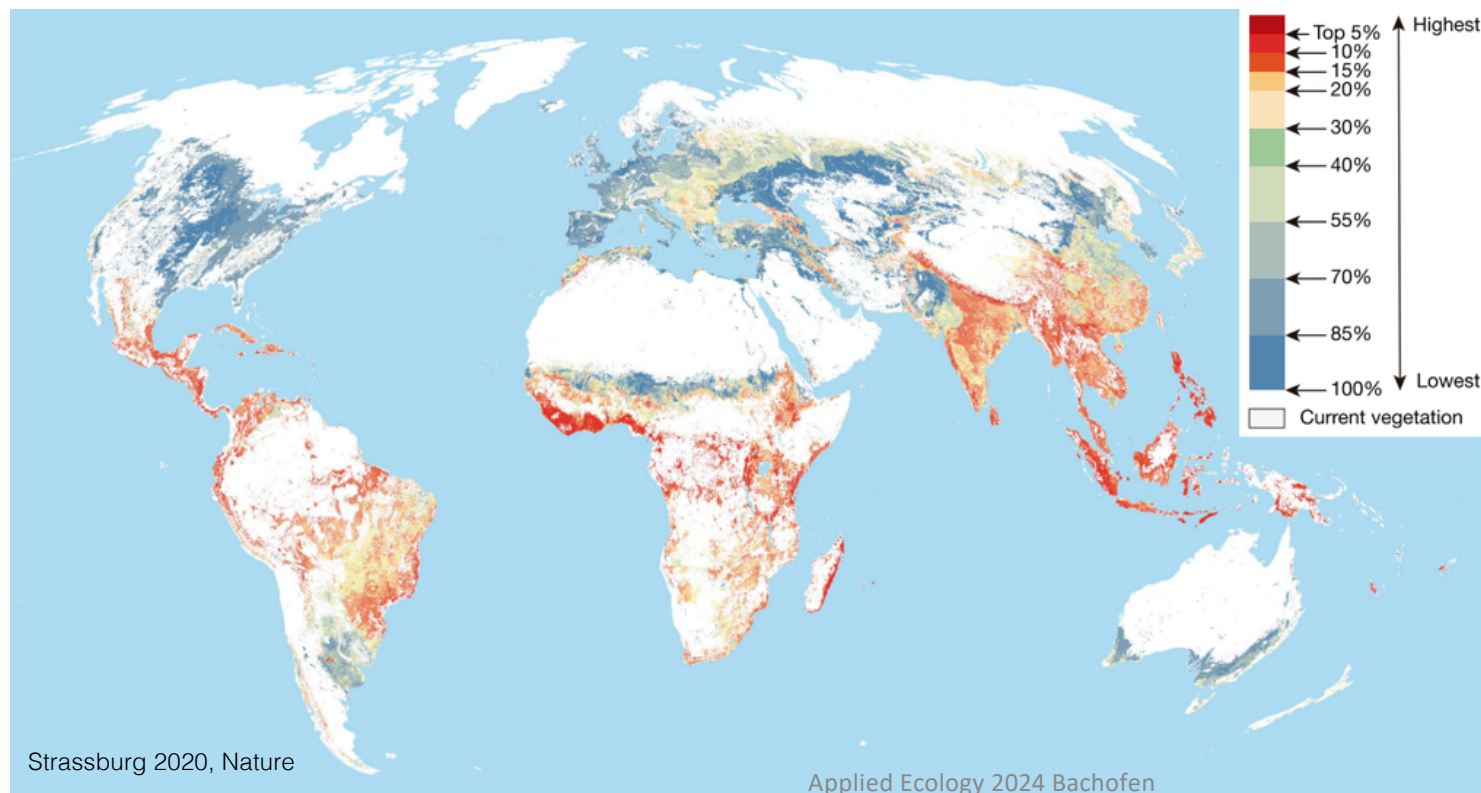
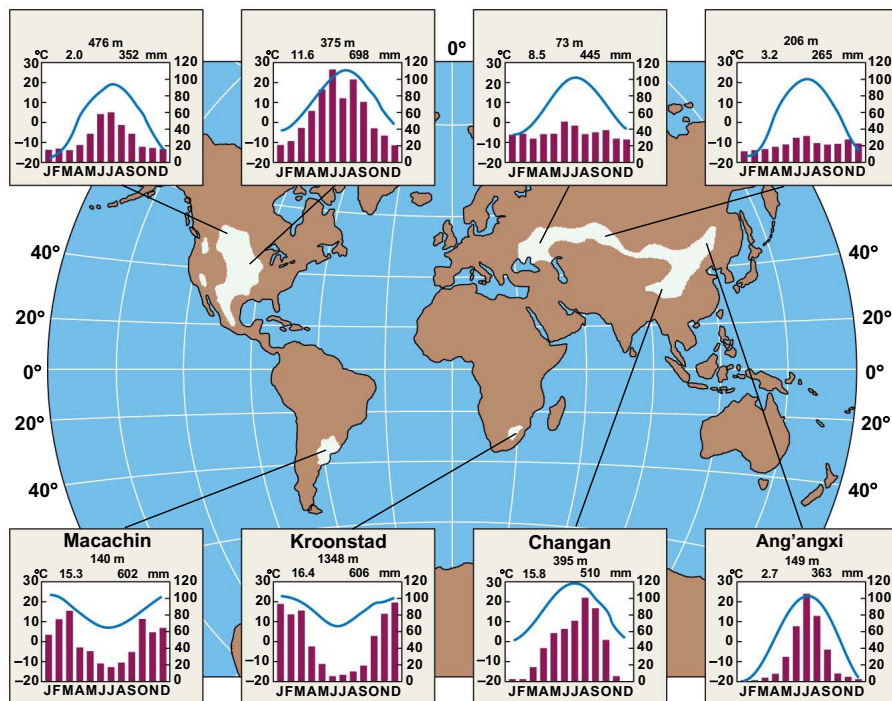


Fig. 1 | Global priorities for restoration according biodiversity, the mitigation of climate change, and minimizing costs

What is a dryland?

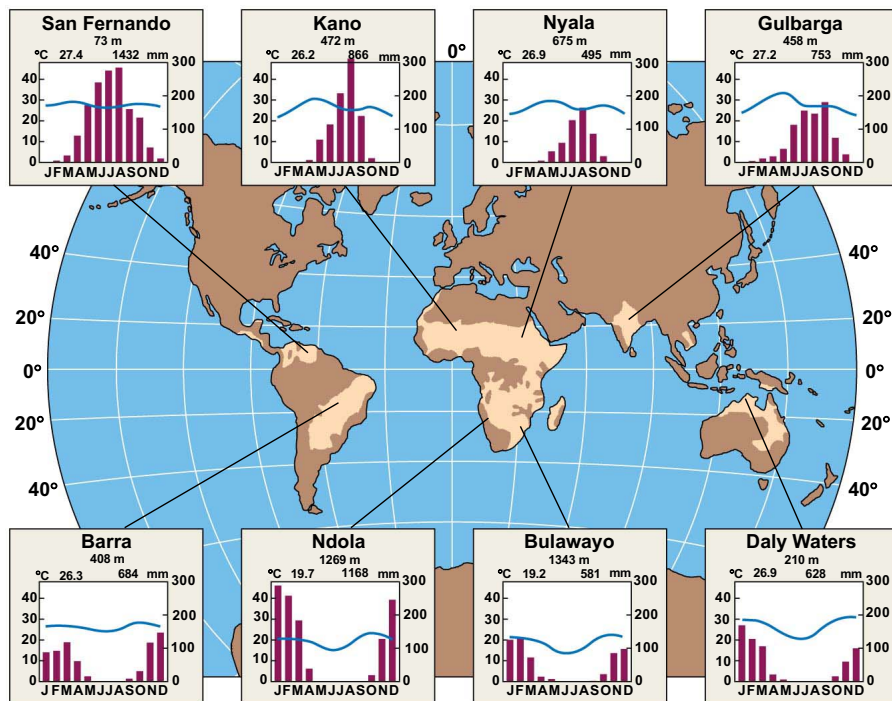
1. Grasslands



- Annual precipitation: 250–800 mm
- Fire, grazing, drought or freezing temperatures
- Typically midlatitudes, continental
- Tree growth naturally restricted

What is a dryland?

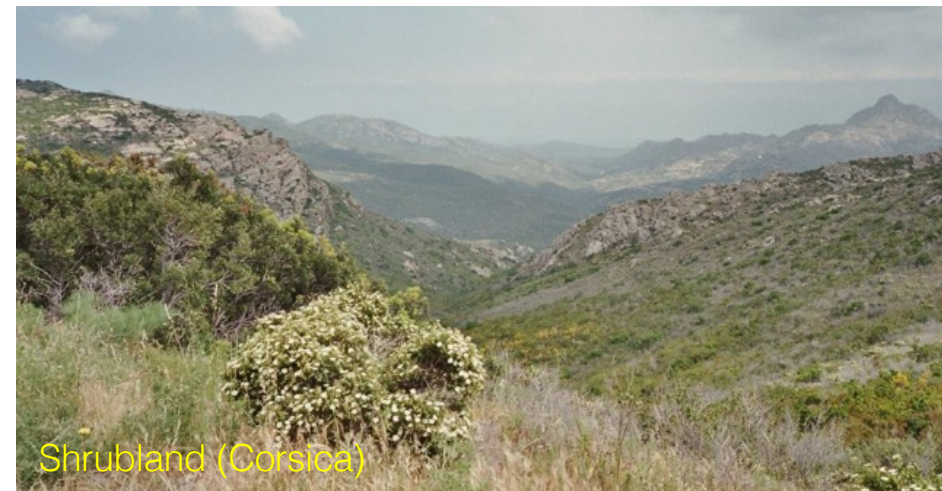
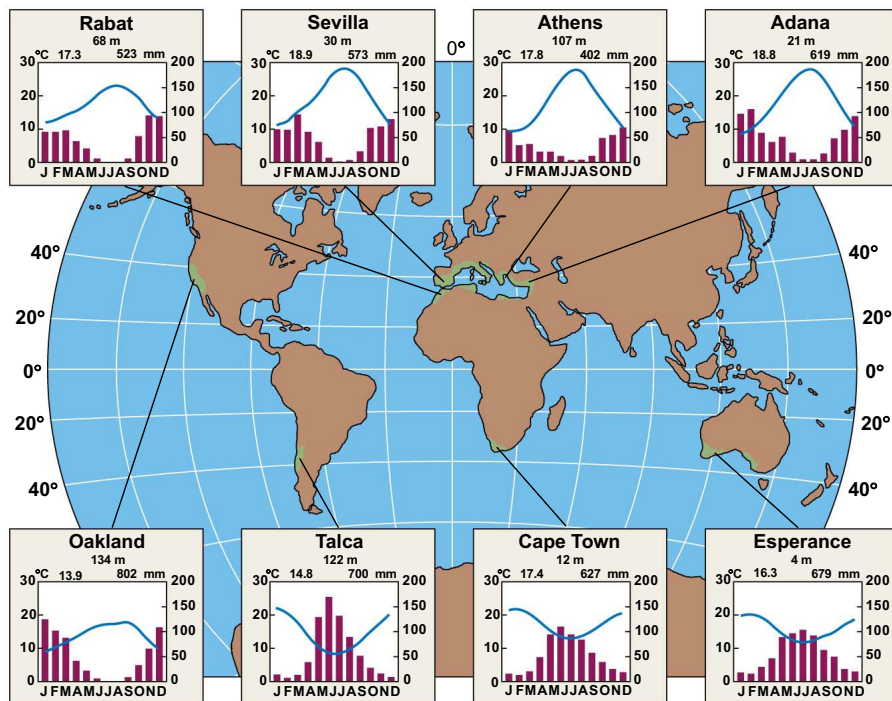
2. Savannah



- Mean monthly air temperature > 18°C
- Precipitation varying seasonally and annually
- Drier tropics and subtropics
- Megaherbivores restrict tree growth

What is a dryland?

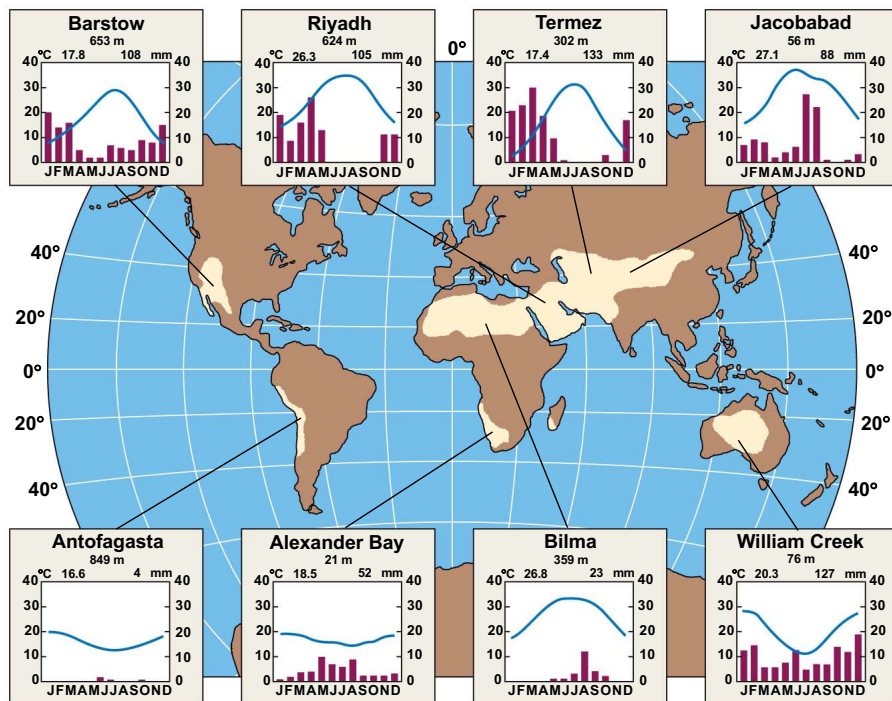
3. Shrubland



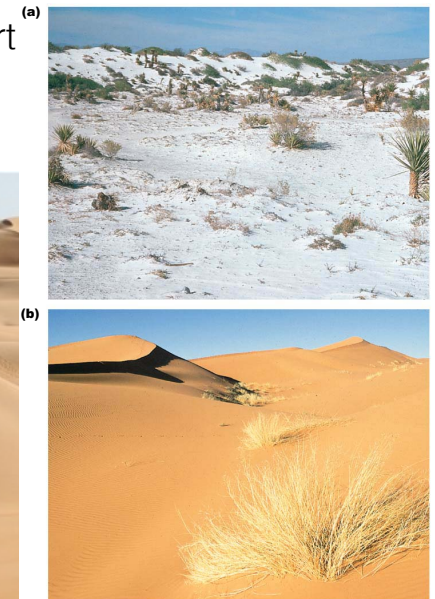
- Mediterranean climate
- Seasonal precipitation
- At western margins of continents 30°–40° latitude
- Evergreen shrubs and sclerophyllous trees

What is a dryland?

4. Desert



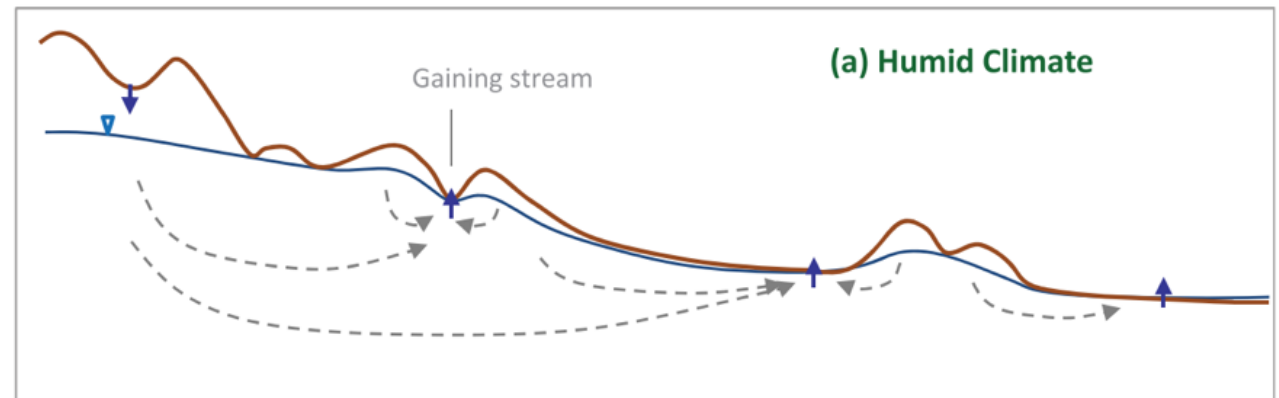
cold desert vs. hot desert



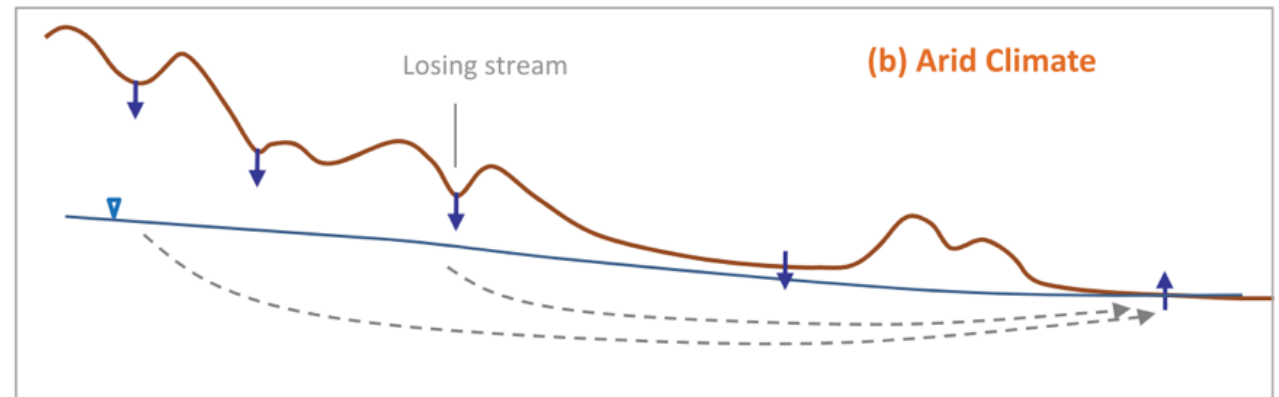
- 35% of the Earth's landmass
- Low precipitation, temperature hot or cold
- Cold ocean currents create arid climate
- Plants in low densities, mostly shrubs

Soil water in drylands

(a) In a humid climate, the water table is high and discharges into streams with both shallow/short and deep/long flow paths

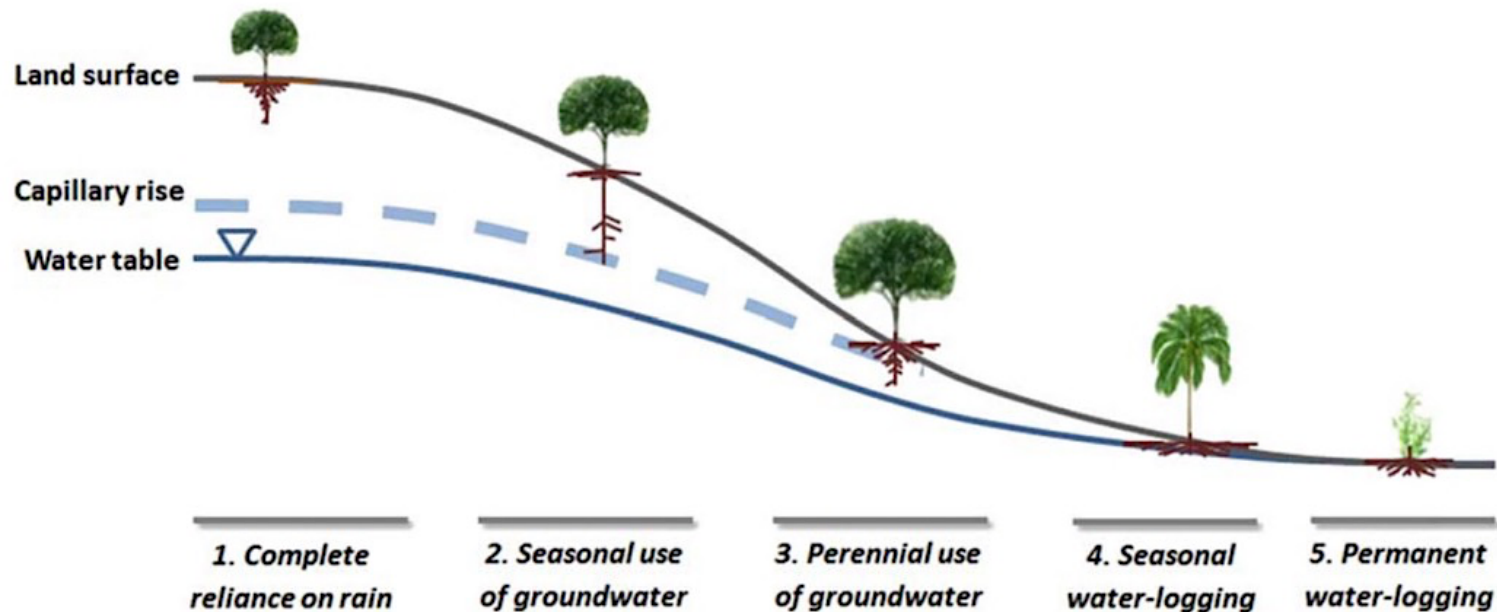


(b) In an arid climate, the water table is low and streams lose their water via seepage into the bed sediments with deeper and longer flow paths.



Rooting depth is related to water table depth

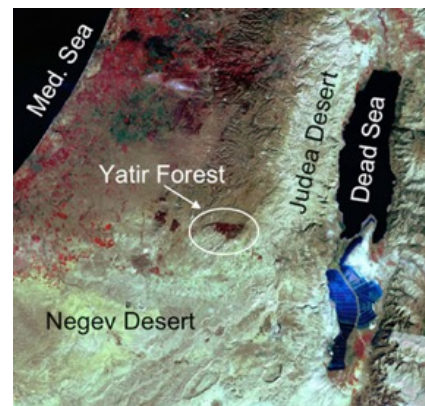
Maximum rooting depths follow the depth of the water table where/when the latter is accessible.



Fan 2015, Water Resources Research

Tree water uptake in drylands (Yatir forest):

- Extremely dry: 300–350 mm annual rainfall
- Mainly drought-tolerant Aleppo pine (*Pinus halepensis*), which has a relatively shallow root system with a few taproots penetrating into deeper soil-filled crevices in the bedrock



Tree water uptake in drylands (Yatir forest):

Higher surface rock cover and stoniness resulted in higher soil water concentration. This extended the time above wilting point by several months across the long dry season.

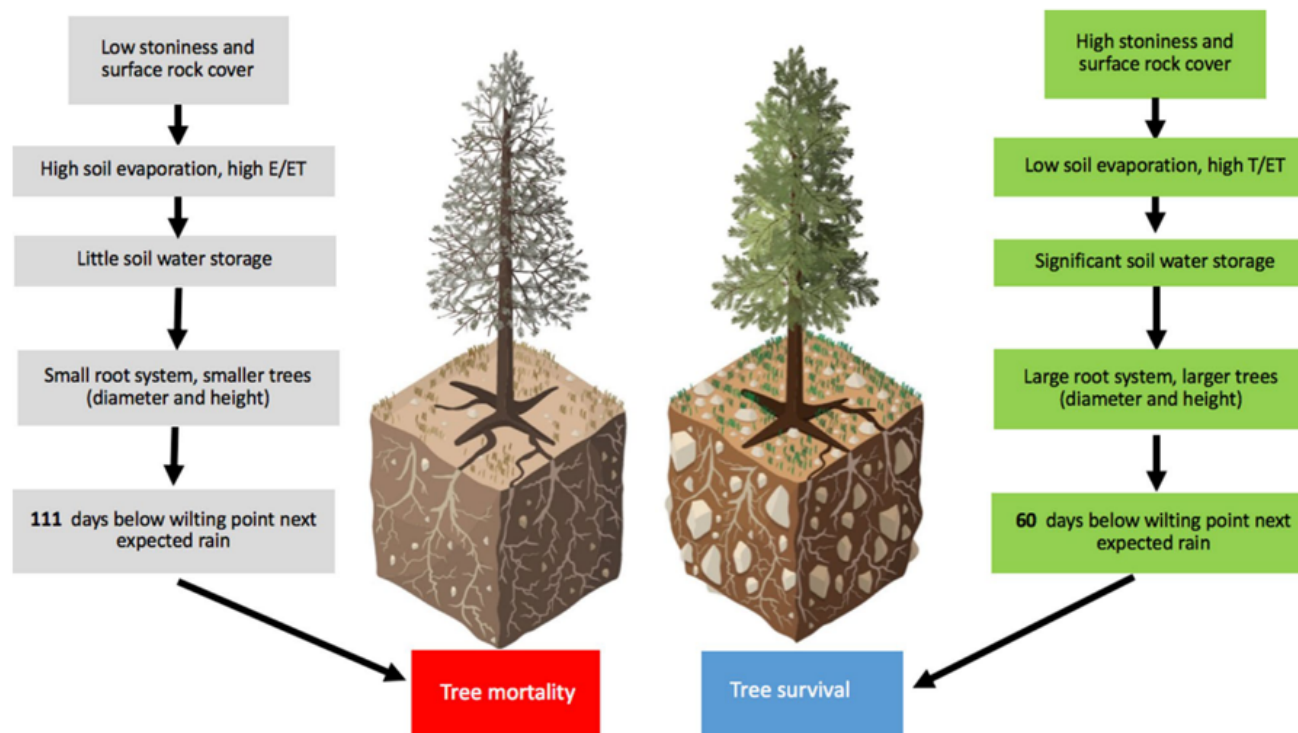
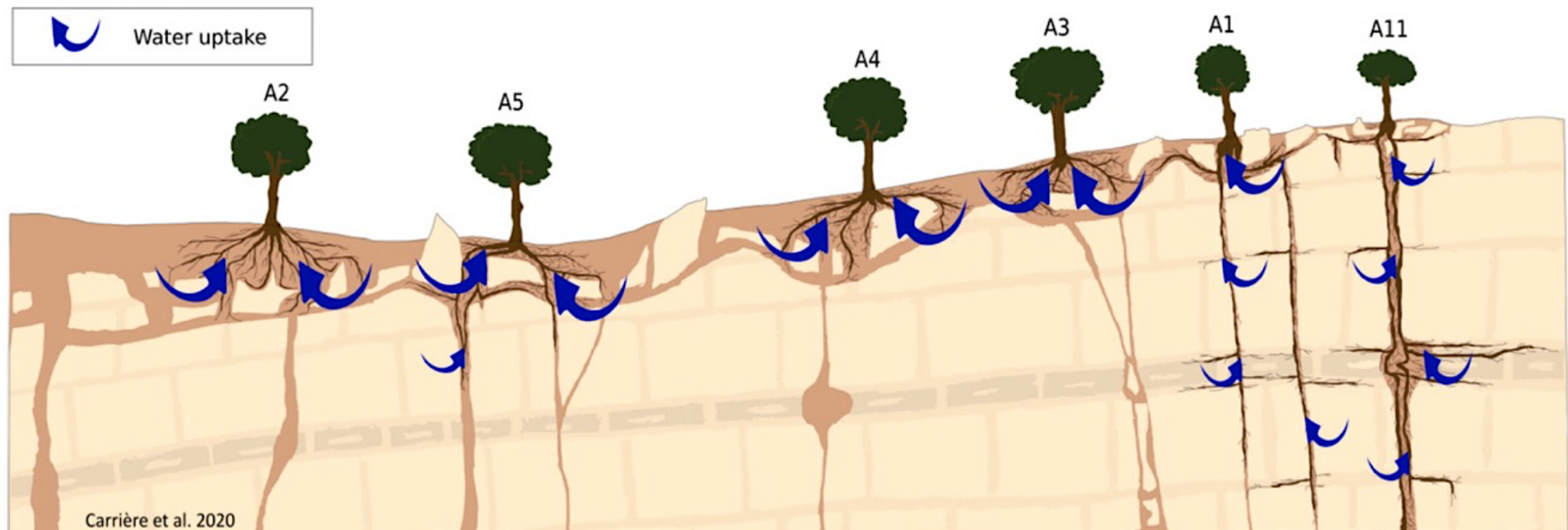


Fig. 6: A proposed conceptual sequence to mortality or survival associated with observed site variability in stoniness and rock cover, indicating the simulated shortening in of the period with no transpirable soil moisture content in the study site where seasonal drought can last well over 6 months.

Preisler 2019, Functional Ecology

Tree water uptake in drylands (Southern France):

Water uptake of oak (*Quercus ilex*) in a Mediterranean forest growing on karst soil. Trees with less favorable upper soil (0–2 m) conditions adapt their root systems to exploit deep water reserves more intensively to enhance their drought tolerance.



Root responses to drought: water uptake depth

The isotopic composition of xylem water ($\delta^{18}\text{O}$ and δD) can provide an estimate of tree water uptake depth

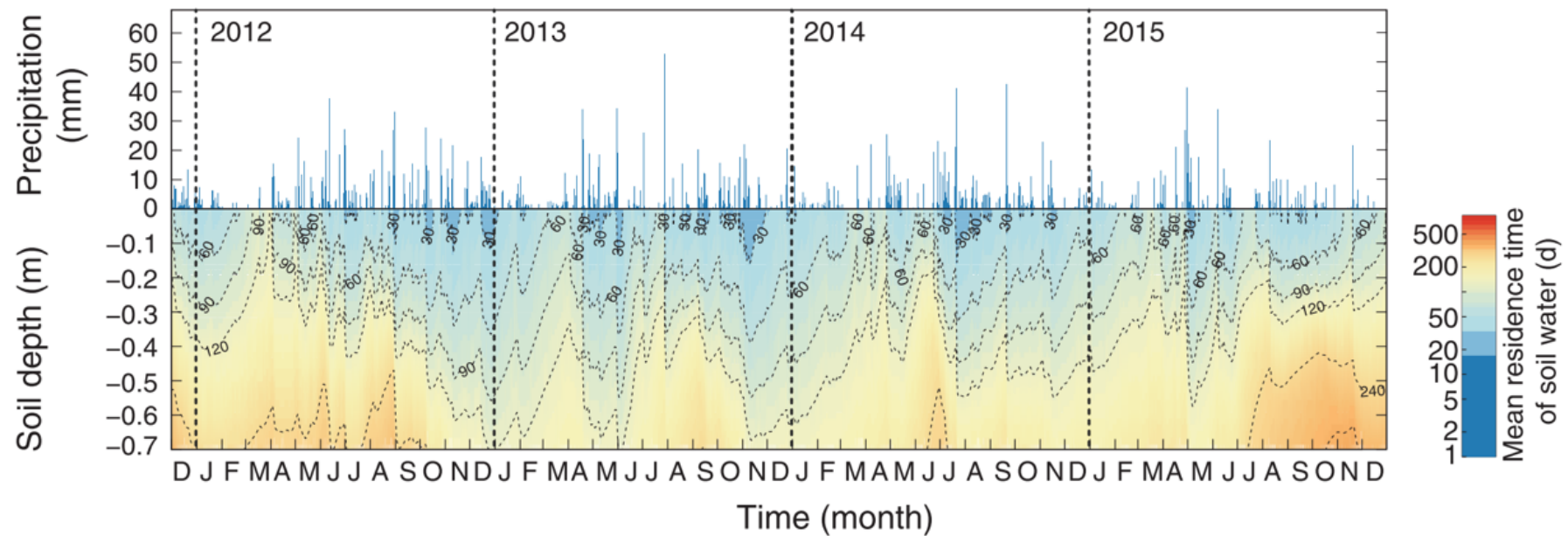
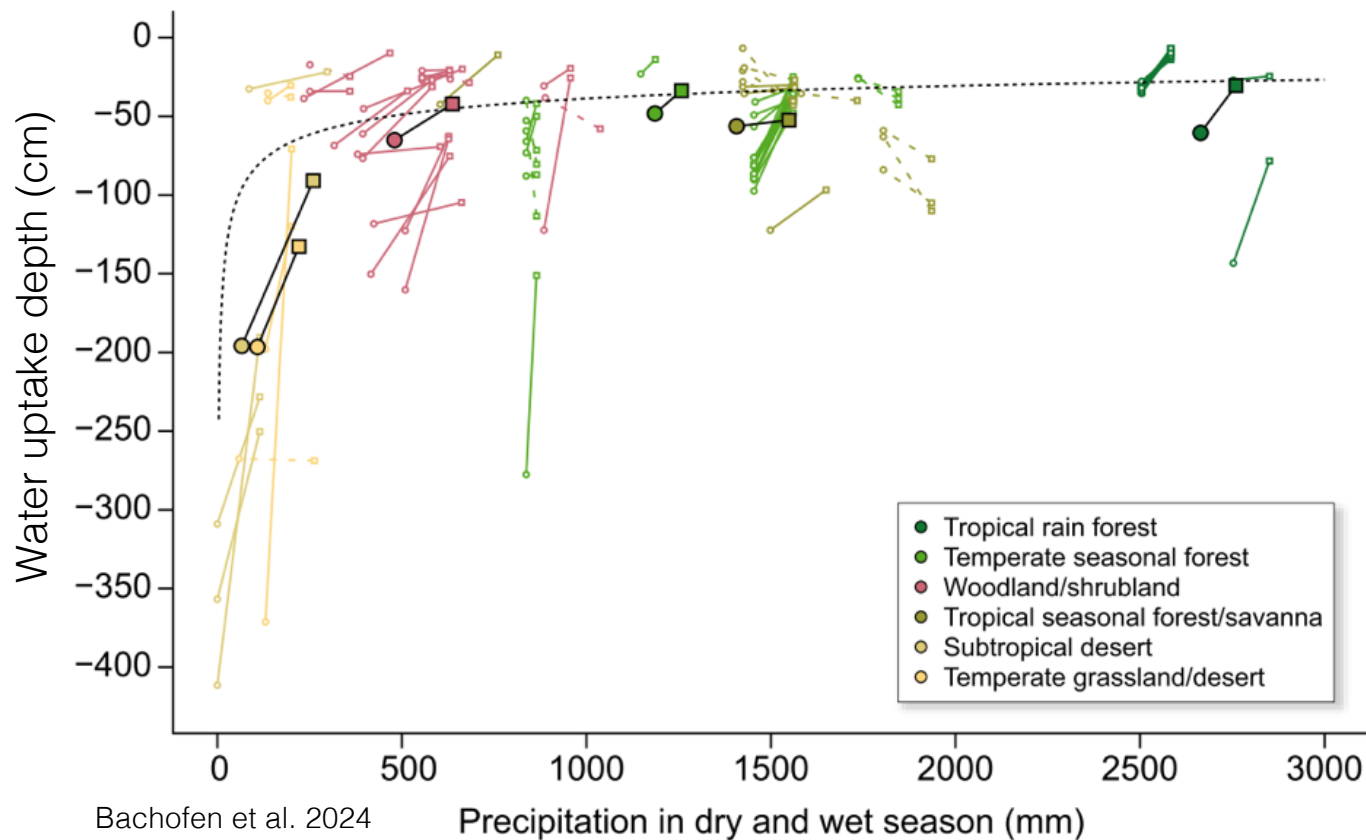


Fig. 4 Precipitation and mean residence time of soil water at 0.0–0.7 m soil depth for the four study years (2012–2015). The color gradient indicates the mean residence time of soil water (in d). Dashed lines indicate constant mean residence times of soil water of 30, 60, 120, 240 and 360 d.

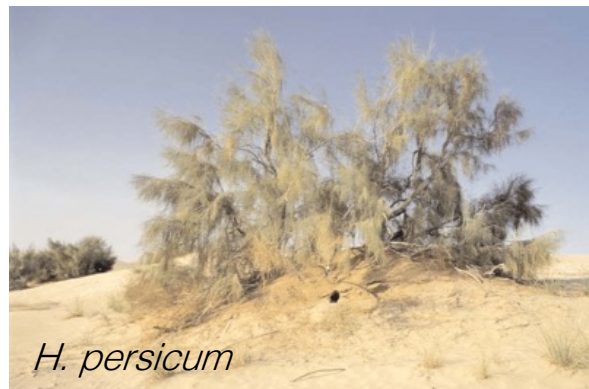
Root responses to drought: water uptake depth

Trees can switch between shallow and deep-water sources depending on soil water availability



Water uptake depth in desert plants

- *Haloxylon ammodendron* and *Haloxylon persicum* are the dominant species in the Gurbantünggüt Desert (10–150 mm annual rainfall) in Xinjiang (China)
- Important plant to fixate sand
- *H. ammodendron* grows at inter-dune lowland and *H. persicum* grows at the sand dune
- How can they survive there?



Gurbantünggüt Desert, Xinjiang



Water uptake depth in desert plants

- In spring, topsoil was humid
 - *H. ammodendron* mainly used shallow soil water
 - *H. persicum* mainly used middle soil water
- In summer, topsoil was dry
 - *H. ammodendron* mainly used groundwater
 - *H. persicum* mainly used deep soil water.
- The ability to exploit a deep, reliable water source makes it possible for *H. ammodendron* to survive long periods without rain

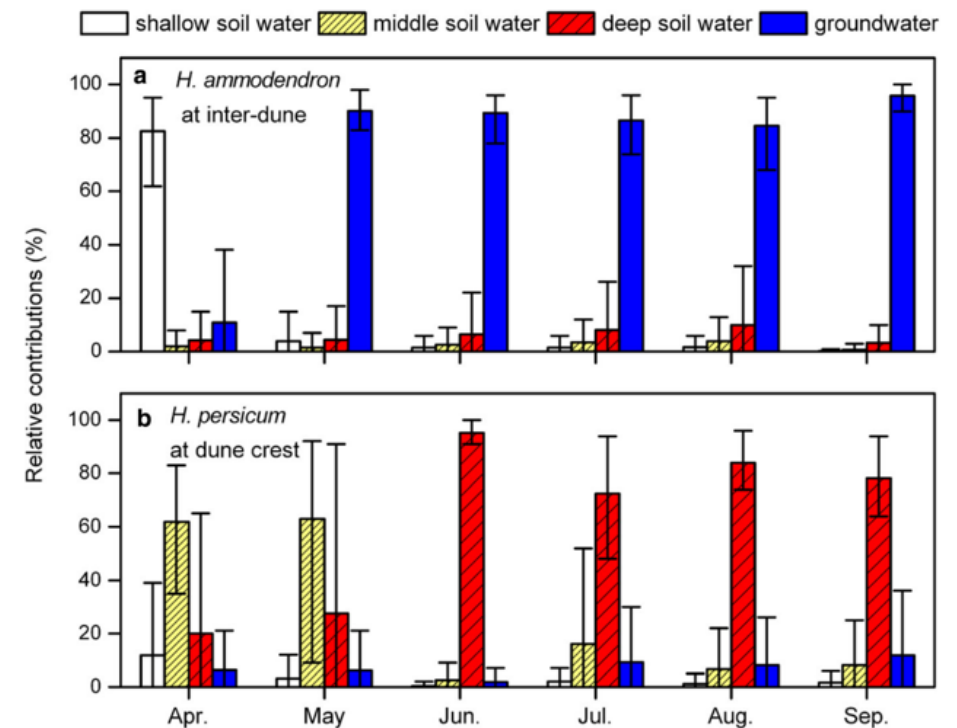


Fig. 4 Monthly changes in percentage contribution of potential water sources for *H. ammodendron* at inter-dune (a) and *H. persicum* at dune crest (b)

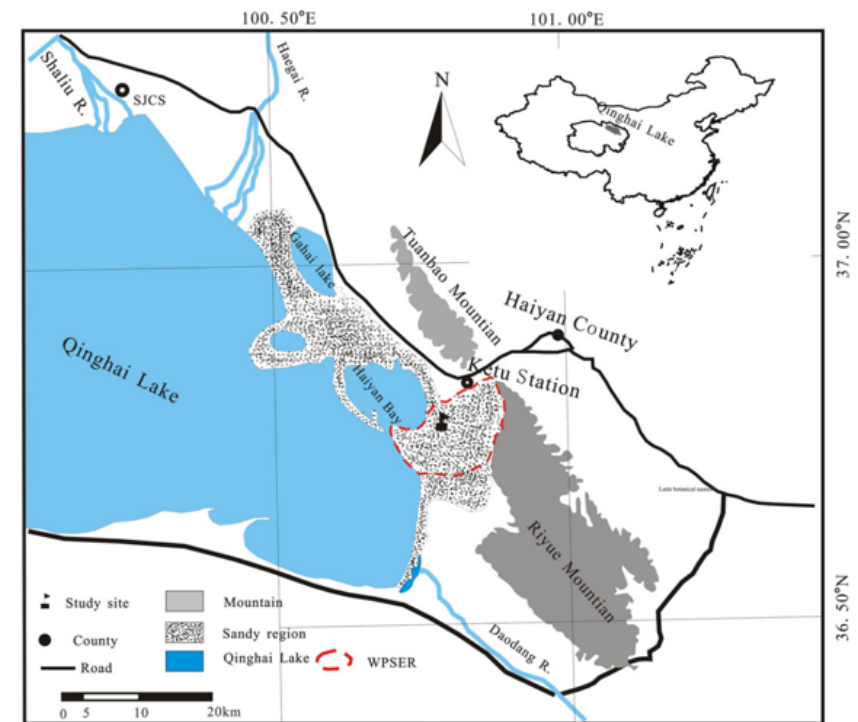
Dai 2015, Plant and Soil

Water uptake depth and non-native plants

- Screening introduced species (*Hippophae rhamnoides*) for sand fixation
- Large-scale afforestation may reduce the soil water availability of deep soil layers
- This increased the water stress for sand-fixation plants, the main cause of their dieback and mortality



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Wu 2016, Science of the Total Environment

Water uptake depth and non-native plants

- The introduced shrub (*H. rhamnoides*) was switching between water from shallow and deep soil layers depending on soil water availability
- The native plants mainly relied on water from the shallow layer (0–30 cm) throughout the growing season
- Different use of soil water of the two species might limit competition and allow for coexistence.

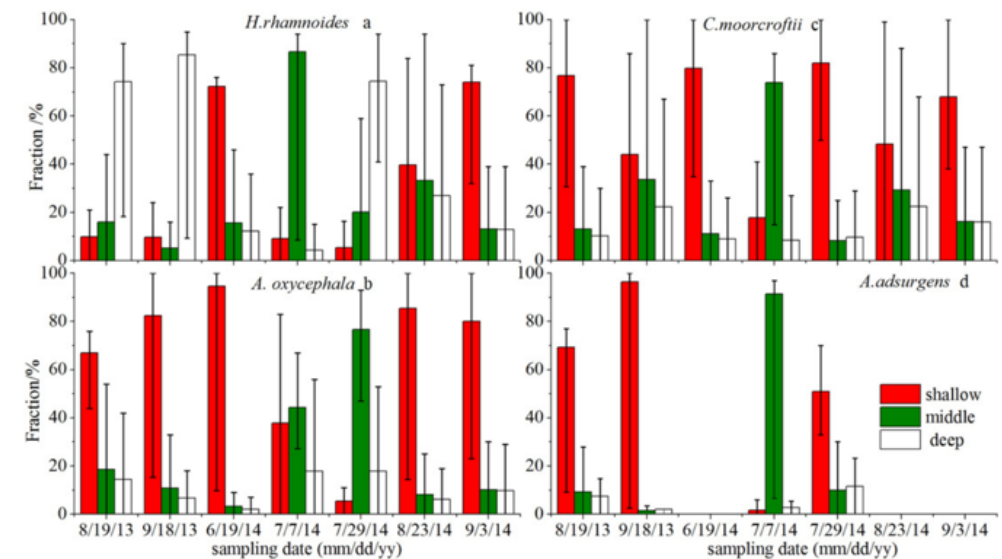
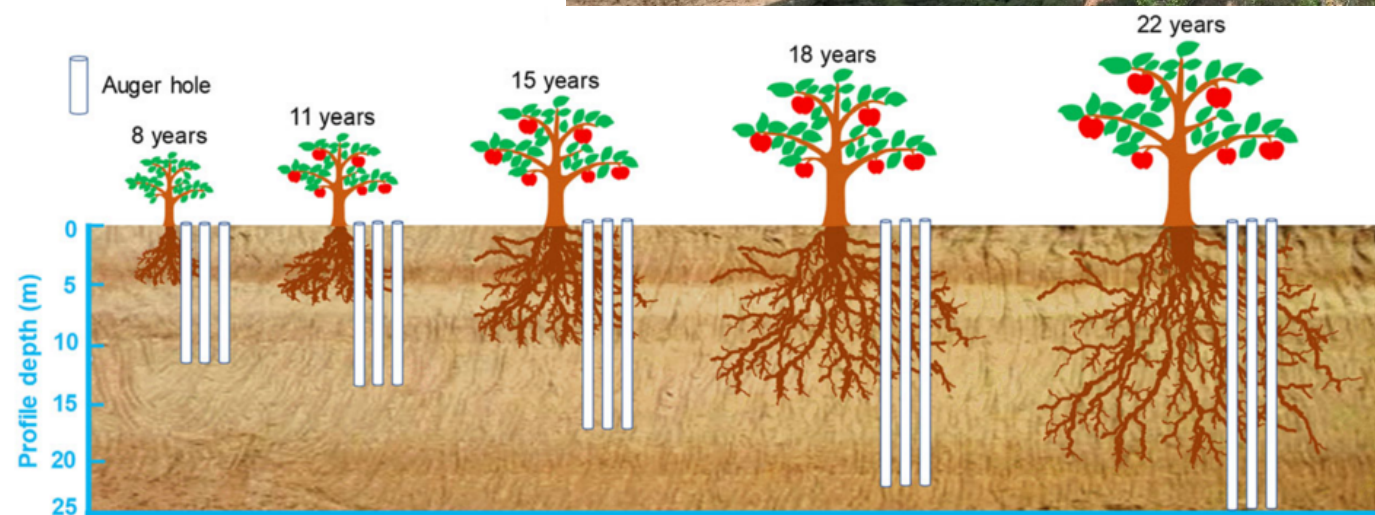


Fig. 6. Seasonal variations in fraction of uptake from three potential soil water source for introduced shrub (*H. rhamnoides*, a), natural shrub (*A. oxycephala*, b) and herbs (*C. moorcroftii*, c and *A. adsurgens*, d). Column height represents the mean value of fraction of uptake and vertical bar represents the range of maximum and minimum. Both are derived from the mixing isotope IsoSource.

Wu 2016, Science of the Total Environment

Water uptake of orchards vs. grasslands

- Apple orchards planted on farmland, replacing wheat and corn
- Trees are mining resident old water
- Water deficits are not replenished during the life-span of the orchard, thus one-way mining of the soil water



Chinese loess plateau
(up to 300 m loess)

Li et al. 2019, Hydrological
Processes

Hydraulic redistribution

- Soil water can be transported upward by deep roots from the moist region (deep soil) to the dry region (surface).
- Water can also be transported from the surface to deep soil layers – the reverse of 'hydraulic lift' (e.g. when the soil surface is rewetted).
- Potentially beneficial not only to the plant itself, but also to neighbours

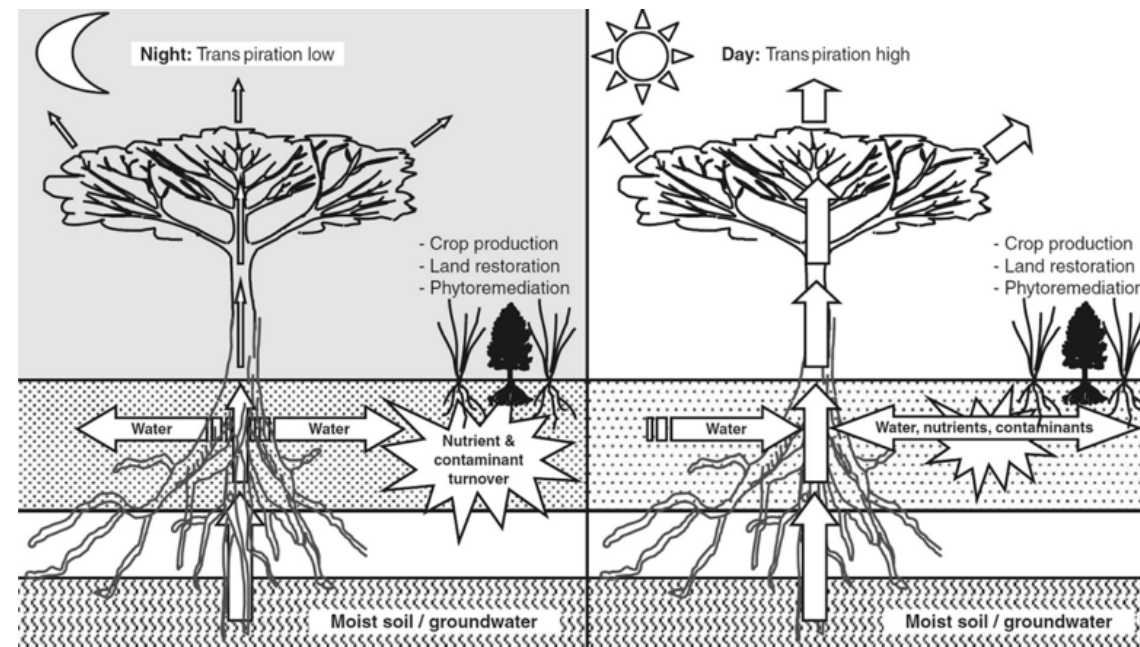


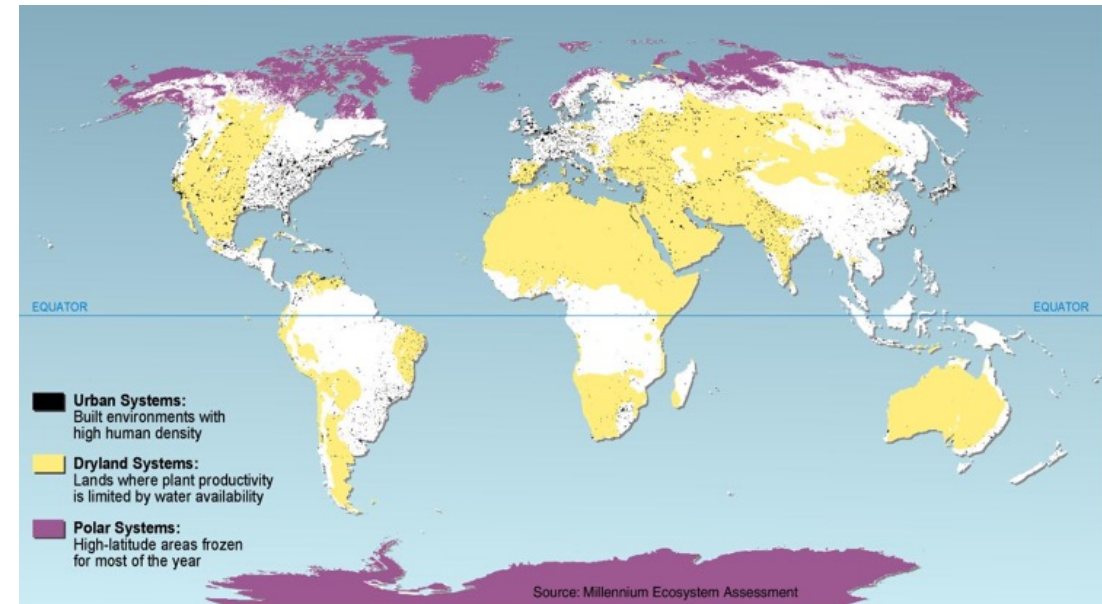
Fig. 1 Schematic showing the hydraulic lift (HL) process and some possible benefits for the water-lifting plant and neighboring plant.

Alagele 2021, Agroforestry Systems

Burgess 1998, Oecologia

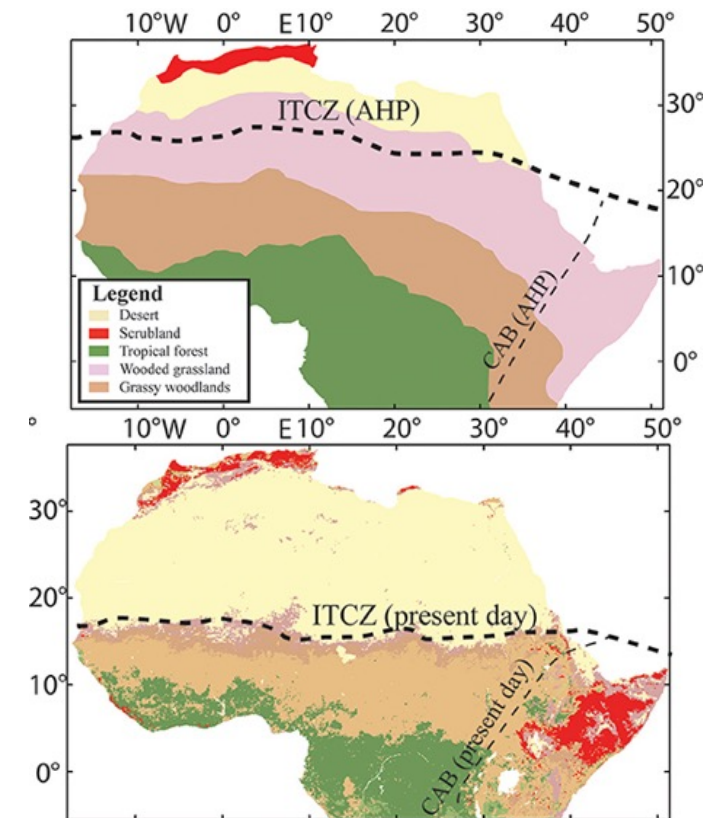
Desertification and aforestation

- Drylands cover about 41% of Earth's land surface
- Increased agricultural land-use affects soils
- Overgrazing and deforestation reduces plant cover
- Humus layer is eroded by precipitation or wind
- Increased water consumption by industry, agriculture and population lowers the water table of rivers and groundwater



Example: Sahel zone

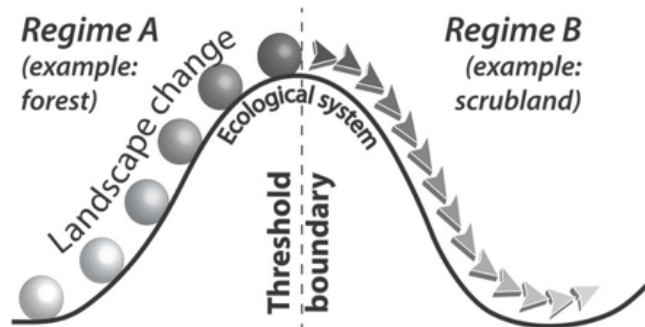
- Semi-arid transition zone between the Sahara desert and tropical Africa
- Annual rainfall 600–1000 mm, rainy season 3–4 months (savannah, grasslands, shrubland)
- Just over 5'500 years ago, the area was humid with lush vegetation
- Minor changes in precipitation due to changes in the Earth's orbit around the sun lead to the most sensitive species being lost



Reconstructed African Humid Period (AHP) biomes based on Larrasoana et al., 2013). Present-day biomes created from data downloaded from the Atlas of the Biosphere (<http://nelson.wisc.edu/>).

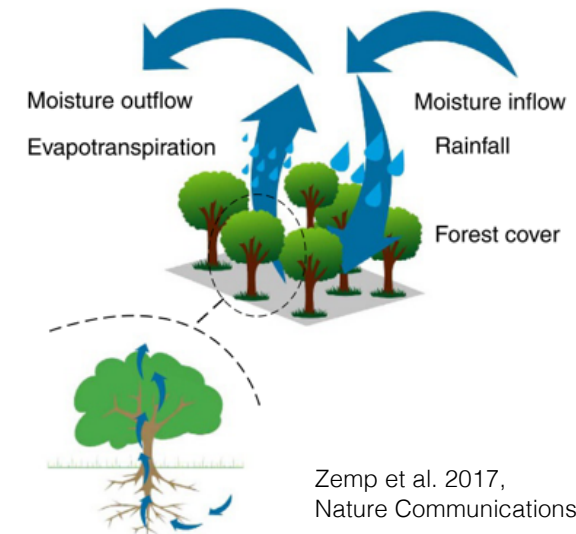
Example: Sahel zone

- Plants release moisture back to the atmosphere (transpiration)
- Reduced plant cover diminishes precipitation at regional scales.
- This resulted in a cascade event and the expansion of the Sahara desert



O'Connor, 2014, Sustainability
Dekker 2013, Nature Geoscience

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Zemp et al. 2017,
Nature Communications

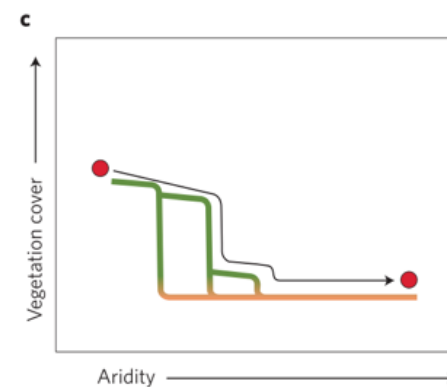
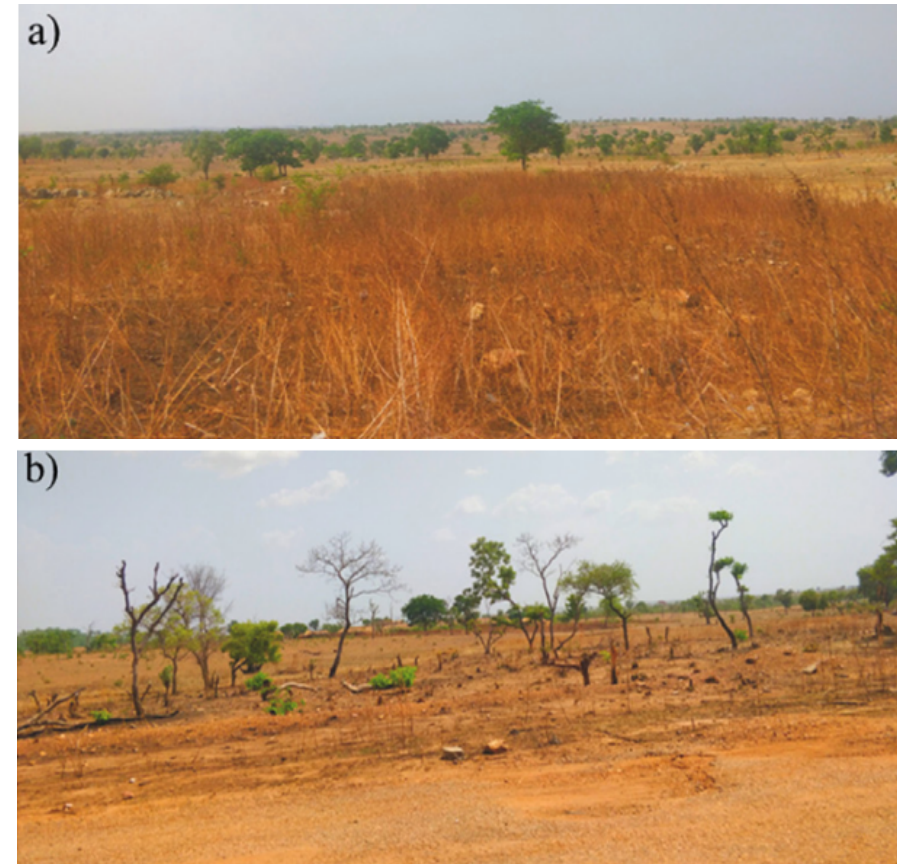


Figure 1 | Vegetation changes. During the desertification of the Sahara some 5,500 years ago, a small change in climate could have tipped the system from a vegetated state into a desert state, if vegetation–climate feedbacks were strong

Desertification in the Sahel zone

- High dependence of rain-fed agriculture
- Poor land management techniques, overgrazing, lack of water conservation strategies and human-initiated bushfires create desertification
- For instance, in Nigeria, livestock populations grew 11-fold between 1950 and 2006, with >66 million animals greatly exceeding the capacity of the grasslands
- In many regions, the primary source of cooking fuel is wood harvested from forests

Fig. 6. Degraded savannah in Niger state (a) cleared land in Lavun LGA (b) logged and burnt woodland patch in Agwara LG



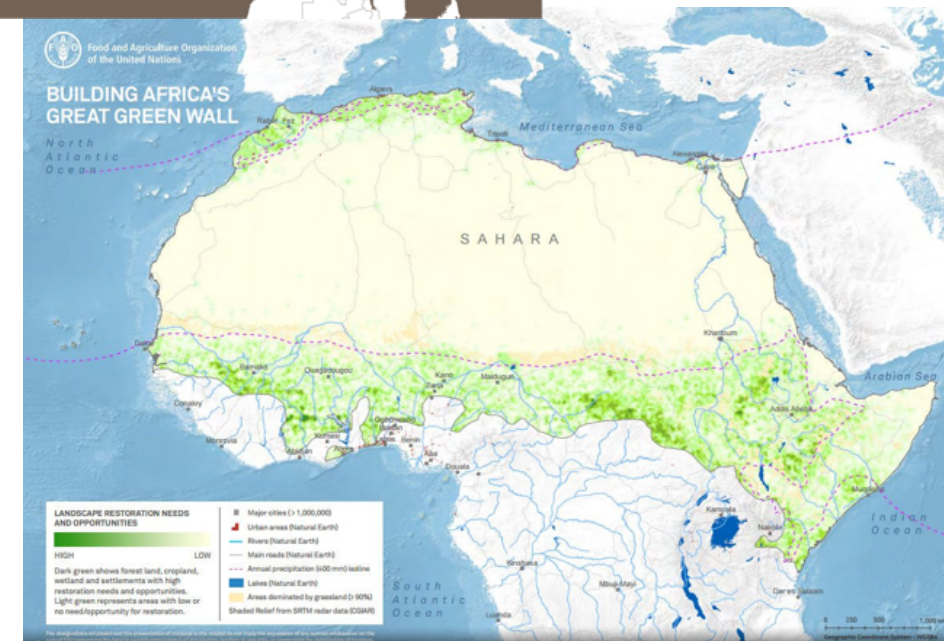
Adenle 2022, Environmental Challenges

Aforestation of the Sahel zone

- Aforestation of Sahel is planned since 2005, with restoration areas over 7500 km from coast to coast across Africa
- Aim: planting of a broad continuous band of trees from Senegal to Djibouti
- Trees should reduce desertification by
 - moderate temperature
 - reduce wind speed
 - reduce soil erosion
 - ameliorate local microclimate and humidity for agriculture
- Initially proposed in the 1980s
- Only two out of 11 countries are implementing measures



EPFL



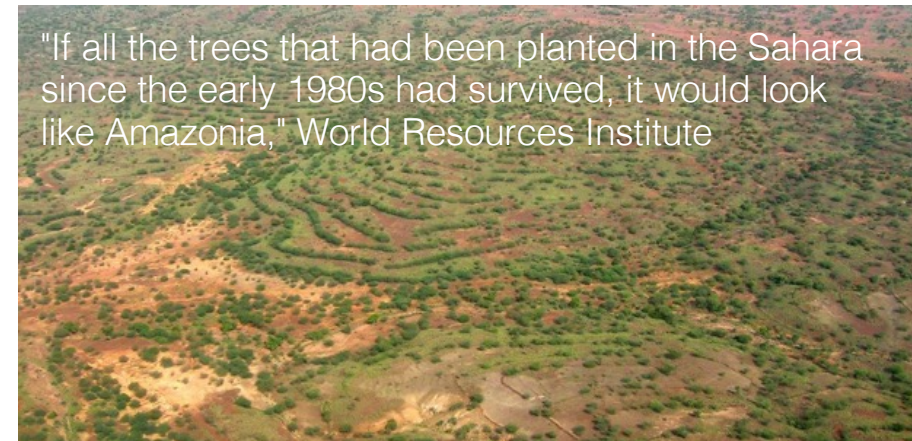
www.un.org/sustainabledevelopment

O'Connor, 2014, Sustainability

Huebner 2022, J of Geoscience and Environmental Protection

Key lessons from Sahel aforestation

- Land restoration and food production must be linked
- Innovation by local people, using indigenous knowledge
- A single technique or practice alone is rarely enough
- Technical options must be flexible, adaptable, and testable by farmers under local conditions
- Innovations need to provide swift benefits – in the first or second year – to win support



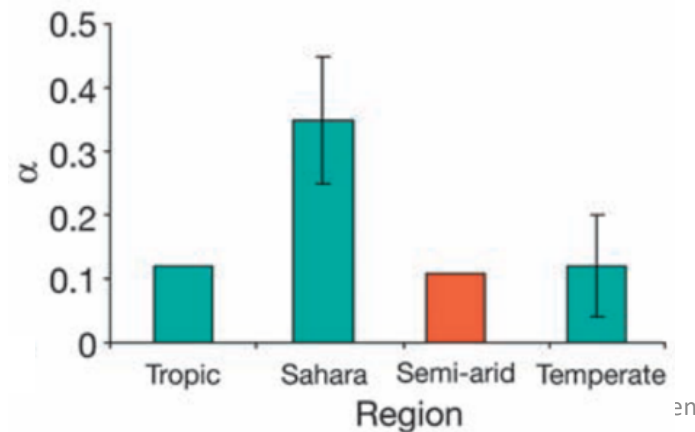
Aerial view of agroforestry management practices in Niger in 2004. www.smithsonianmag.com



Promotion of Farmer Managed Natural Regeneration (FMNR) in Ghana (fmnrhub.com.au)

Side effects of aforestation

- Forests are dark and absorb incoming solar radiation (low albedo) that is converted into heat, causing local warming
- The atmosphere above deserts is overall cooler than above forests
- Desertification has thus likely contributed local cooling and partly offset the global warming from the carbon release



Albedo of different ecosystems. The semi-arid ecosystem is represented by Yatir forest.

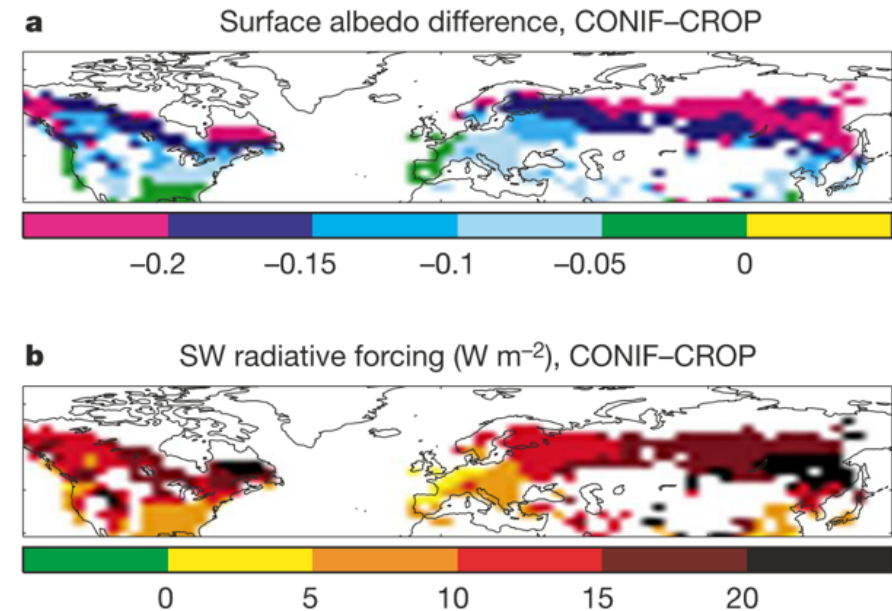


Figure 1: Effects of aforestation on the solar radiation budget
a) Simulated difference in annual-mean surface albedo
b) Simulated local shortwave (SW) radiative forcing at the tropopause due to surface albedo change

Betts 2000, Nature
 Rottenberg 2010, Nature
 Schimel 2010, Science

Should we do large-scale afforestation?

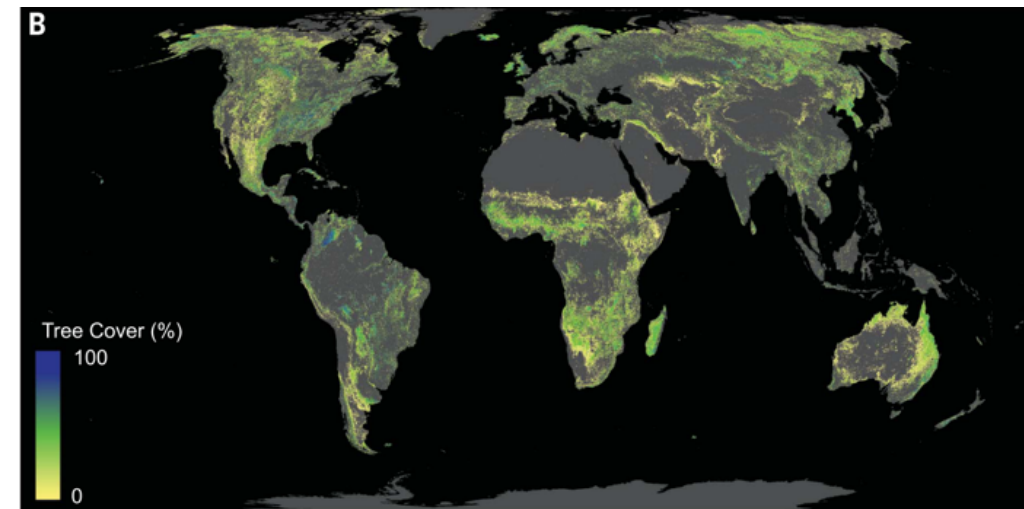


Fig. 2. The current global tree restoration potential. (B and C) The global potential tree cover available for restoration.

Trillion trees initiative:
<https://www.1t.org>

Should we do large-scale afforestation?

RESEARCH

RESTORATION ECOLOGY

The global tree restoration potential

Jean-Francois Bastin^{1*}, Yelena Finegold², Claude Garcia^{3,4}, Danilo Mollicone⁵, Marcelo Rezende⁶, Devin Routh⁷, Constantin M. Zohner¹, Thomas W. Crowther¹

The restoration of trees remains among the most effective strategies for climate change mitigation. We mapped the global potential tree coverage to show that 4.4 billion hectares of canopy cover could exist under the current climate. Excluding existing trees and agricultural and urban areas, we found that there is room for an extra 0.9 billion hectares of support woodlands and forests. This highlights global tree restoration as one of the most effective carbon drawdown solutions to date. However, climate change will reduce the potential canopy cover by 1.5 billion hectares by 2050. Our results suggest that tree restoration is a viable mitigation strategy.

mental conditions, with minimal human activity (Fig. 2A). This work is directly underpinned by our systematic dataset of direct tree cover measurements (entirely independent of climate and modeled remote sensing estimates) (27) across the globe (Fig. S1) (28).

Across the world's protected areas (Fig. S2), tree cover ranged between peaks of 0% in dry desert and 100% in dense equatorial forest, with fewer values falling between these two extremes (Figs. S2 and S3). We paired these tree cover measurements with 10 global layers of soil and climate data (Table S1) (27). Our results suggest that tree restoration is a viable mitigation strategy.

● This article is more than 3 years old

Tree planting 'has mind-blowing potential' to tackle climate crisis

Research shows a trillion trees could be planted to capture huge amount of carbon dioxide

● Editor's pick: best of 2019. We're bringing back some of our favorite stories of the past year. **Support the Guardian's journalism in 2020**



¹Crowther Lab, Department of Environmental Systems Science, Institute of Integrative Biology, ETH Zurich, 2 Switzerland. ²Food and Agriculture Organization of the United Nations, Rome, Italy. ³...

Science

TECHNICAL COMMENTS

Cite as: P. Friedlingstein *et al.*, *Science* 10.1126/science.aay8060 (2019).

Comment on "The global tree restoration potential"

Pierre Friedlingstein^{1*}, Myles Allen², Josep G. Canadell³, Glen P. Peters⁴, Sonia I. Seneviratne⁵

¹College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter EX4 4QE, UK. ²Department of Physics, University of Oxford, Oxford OX1 3PJ, UK. ³Global Carbon Project, CSIRO Oceans and Atmosphere, Canberra, ACT 2601, Australia. ⁴CICERO Center for International Climate Research, Oslo 0349, Norway. ⁵Institute for Atmospheric and Climate Science, ETH Zurich, 8092 Zurich, Switzerland.

*Corresponding author. Email: p.friedlingstein@exeter.ac.uk

Bastin *et al.* (Reports, 5 July 2019, p. 76) claim that global tree restoration is the most effective climate change solution to date, with a reported carbon storage potential of 205 gigatonnes of carbon. However, this estimate and its implications for climate mitigation are inconsistent with the dynamics of the global carbon cycle and anthropogenic carbon dioxide emissions.

Interview

'I've never said we should plant a trillion trees': what ecopreneur Thomas Crowther did next

Patrick Greenfield

The ecologist admits 'messaging up' in the past, but says his Restoration project will be 'a Google Maps of biodiversity', showing the impact of restoration - from a forest to your own back garden

Listen to our podcast: **Can we really solve the climate crisis by planting trees? - part one**



storage multiplied by the airborne fraction, at 45% the reported impact of this forest on the atmospheric CO₂ growth rate. Al- potential carbon removal from forest resto- be directly compared to cumulative emissions to date (about 600 GtC), but not mining in the atmosphere.

205 GtC figure is obtained from the poten- spatial distribution (as shown in their fig- and the carbon densities across the major world (table S2, with distribution shown in table S2, it appears that the authors simply potential canopy cover (in Mha) by the car- in tC/ha) of the biome currently in these re- potential carbon storage. By doing so, they ignore the carbon that is currently stored in the right approach is to estimate the carbon al as the difference between carbon poten- a forest and the carbon currently stored by ecosystem—for example, forest versus tundra a forest could be sustained in the Arctic clin- dra biome). From the carbon densities given each biome, it is clear that the potential car- would be substantially lower than reported. can only store about 15% more carbon than erate (tropical) forests are given the same car- as temperate (tropical) grasslands, implying no gain from forest restoration.

forests affect climate through biophysical such as changes in albedo or evapotranspiration an counteract the cooling effect from CO₂ up- well established, for instance, that...

Should we do large-scale afforestation?

We should consider intact grasslands as important for climate change mitigation



<https://www.youtube.com/watch?v=GAoVZoZpqro>

<https://www.theatlantic.com/science/archive/2022/07/climate-change-tree-planting-preserve-grass-grasslands/670583/>

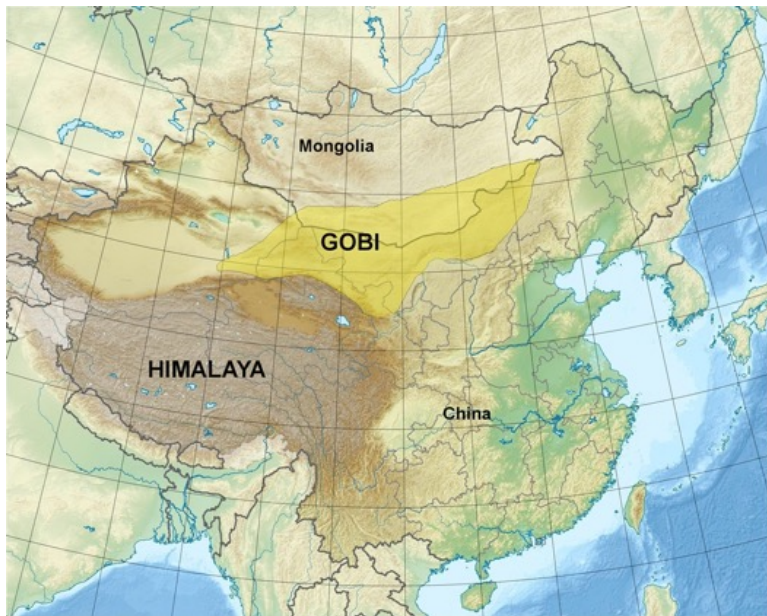
TREES ARE OVERRATED

Preserving the world's great expanses of grass could be essential to combatting climate change.

By Julia Rosen

The great green wall of China

- 28 % of China are deserts
- Annual loss of 2'500 km² to desert
- Threatening 100 Mio. People
- Increases temperature of nearby Beijing



wikipedia

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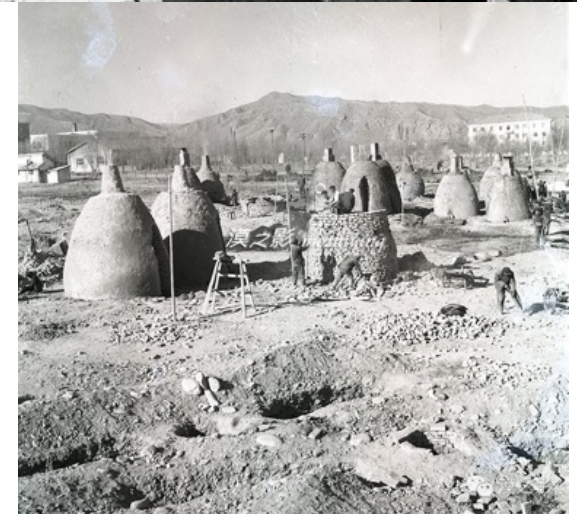
The great green wall of China

Deforestation in China:

- Land reform 1950–1955 to restructure ownership and wealth: forests were confiscated and collectivised
- "Great Leap Forward" (1957–1964): mass deforestation, sharp decline of forest cover, plus ca. 55 million people killed
- "Cultural Revolution" (1966–1976): food production was prioritised, 24% of China's total forest area was lost



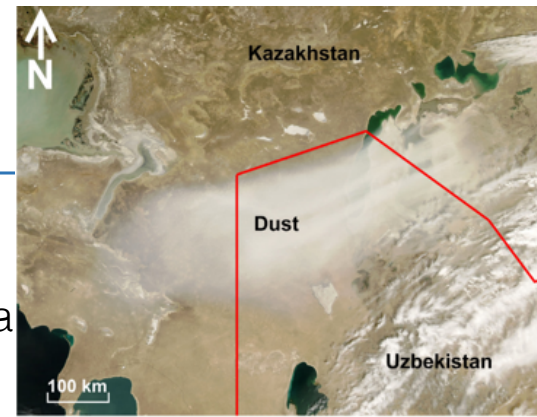
Backyard steel furnaces during the "Great Leap Forward"



Richardson 1990, Forest and forestry in China
<https://blogs.ubc.ca/umbreenbutt/forestry-under-agricultural-policy-1949-to-1976/>

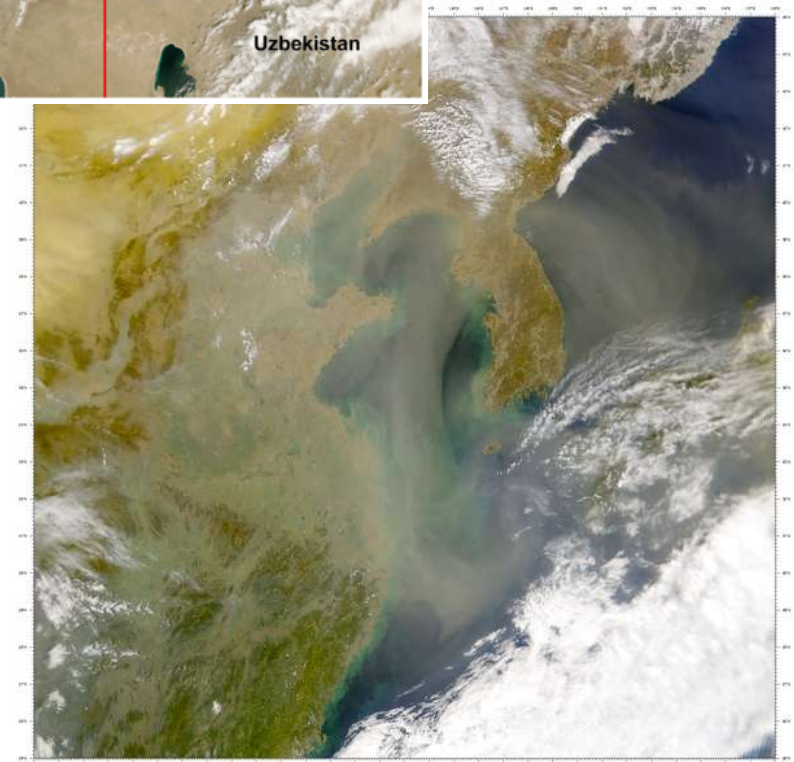
Yellow Dragon

- Affects large parts of north-east asia in spring.
- From the Gobi desert and the plains of northern China and Kazakhstan, transported by winds to the east
- The phenomenon is not new, and has been reported since 1150 B.C.
- The problem increased due to the aridification of the Aral region (overexploitation of water for cotton plantations) and other areas in Central Asia
- Due to the rapid industrialisation of China, the winds contain a number of industrial pollutants that are harmful to humans, but also to the agricultural soils (sulfur)



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Groll 2013, Aeolian Research



Yellow dragon over NE China, wikipedia

The great green wall of China

Basic information:

- Worldwide largest afforestation project
- Start of the Project: 1978 (until 2050)
- Plantation of an area ~ size of Germany
- Protect from sandstorms coming from the north: "Yellow dragon" (e.g. towards Beijing, Korea, Japan)
- Protects from desertification

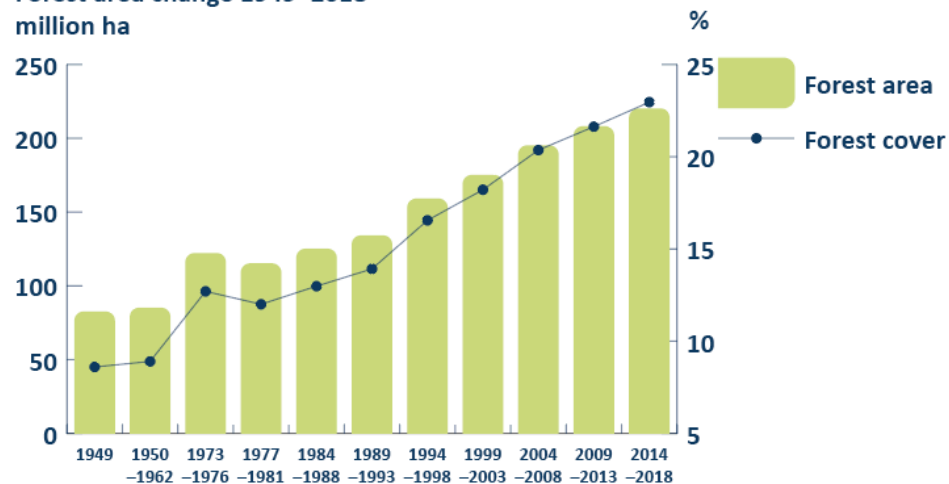


The Economist

A wall of trees

- Forest plantation reduces wind speeds and soil erosion
- Plantation of trees, bushes and grassland over a length of 4'800 km with a width of several 100 km
- Doubling of forested area in China since 1990

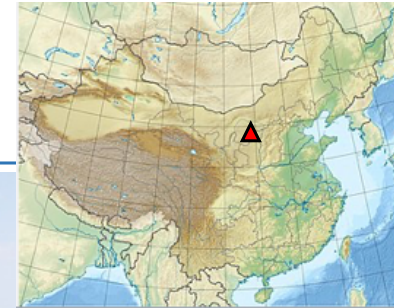
Forest area change 1949–2018
million ha



IUCN World Conservation Congress 2021

Huebner 2022, J of Geoscience and Environmental Protection

Applied Ecology 2024 Bachofen



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Aforestation efforts in the Mu Us Desert. (Baijitan Nature Reserve)

A wall of trees

Problems:

- Non-native tree species could lower the water table through their water consumption
- Sometimes poor survival rates
- The Asian long-horned beetle destroys 5'000 km² of the aforested monocultures annually
- ... and more to discover by you!





Student's roles

Presenting group: Scientists learning from past mistakes, adapting the strategy, keeping a holistic perspective

Other groups:

- Local farmer / contractor for afforestation project (financial involvement, trade-off agricultural land and afforestation)
- Concerned residents of Beijing (sand storm problem)
- Environmental activists (concerned with biodiversity, water use, non-native species)

Teachers: Officials of the government (large scale planning, financing, efficiency)

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Additional Information

Further reading:

- Li 2012, "An overview of the "Three-North" Shelterbelt project in China"
- For the Chinese GGW numerous "lessons learned" were published: Sun et al., 2006; Liu et al., 2008; Cao et al., 2011; Huebner, 2020.
- A positive effect of the restoration measures on soil, agronomy and climate was reported: Tan, 2016; Zhuang et al., 2017
- Wang 2017, Scientific reports: "Key driving forces of desertification in the Mu Us Desert, China"

Additional Information



Lingwu City (Ningxia) developed a project – Six-in- One Desertification Control System at the Baijitan Forest Farm – that employs multiple forms of defense to create a barrier to prevent the Mu Us Desert from advancing. On the frontline are two vegetative shelter belts comprised of drought- tolerant shrubs to prevent the encroachment of the desert. A second line of defense consists of forest shelter belts with sustainable harvesting opportunities. There are also two circular industries where afforestation is linked to crops, livestock, and poultry. In addition, an emerging ecotourism industry promotes eco-awareness. Thousands of hectares of desertified land were rehabilitated, forming a 62-kilometer-long barrier that is 20-30 kilometers wide. It prevents the Mu Us Desert from moving both southwards and westwards.

**Global Land Outlook 2022, UN
Convention to Combat
Desertification**

Yuyang District of Yulin (Shaanxi) followed the same approach used in Lingwu. Eight major forestry and grassland projects were launched with demonstration zones for the wider region. Grassland zones were established to prevent sandstorms, and regenerative forest management practices helped to establish a new industry base, including for ecotourism. Five bases have been established for orchards, health resorts, floral nurseries, forage-grass, and mulberry silk industries. A comprehensive, rule-based ecological conservation system has been established, encompassing protection at source, procedural oversight, individual accountability, and mechanisms for diversified investment and compensation. As a result, the landscape has been transformed with 50% forest coverage, urban greenery at 34%, and over 55% of eroded land successfully treated. Taken together, these measures have improved both the local economy and ecology

In the Axla Desert (Inner Mongolia), Chinese entrepreneurs established the Society of Entrepreneurs and Ecology to combat regional desertification and address national environmental challenges. The region is one of the largest sources of sand and dust storms. The Axla project was designed to appeal to those outside the region, with nearly 500 million people participating, including farmers and herdsman promoting the project through online and offline communications. The objective is to plant 100 million saxaul shrubs between 2014-2023 to halt desertification, reduce land degradation in source areas of sandstorms, and raise the living standards of local herders. The goal is to maintain vegetative areas to prevent three deserts from converging: the first phase of the project involved setting up nine afforestation demonstration sites with village communities. In the second phase, afforestation will be done along provincial roads and the ‘sand transport channels’ of the three deserts that will be linked to the demonstration sites by corridors.