RESTORATION OF AGROFORESTRY SYSTEMS

CASE STUDY OF MEDITERRANEAN OAK AGROFORESTRY SYSTEMS

Agroforestry and Forest Restoration Course

Restauro Florestal e Agroflorestal

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CONTENTS

1. Restoration of agroforestry systems

- Definition of agroforestry
- Classification of agroforestry systems and practices
- Types and examples of agroforestry systems
- Global distribution
- Ecological and socioeconomic principles and benefits
- Degradation factors
- Socioecological indicators to evaluate system conditions across scales
- Landscape fragmentation and connectivity
- Approaches and methods for restoration
- Examples of successful agroforestry restoration

CONTENTS

2. Restoration of Mediterranean oak agroforestry systems in Portugal

- Introduction
- Land management systems
- A socioecological mosaic landscape
- Degradation and disturbances
- Assessment of oak landscape dynamics (national and regional scales)
- Assessment of oak regeneration processes at the local scale
- Resilience, thresholds and critical transitions
- Approaches and techniques for the restoration of Mediterranean oak agroforestry systems
- Examples of restoration projects of cork oak landscapes in Portugal and the Mediterranean region

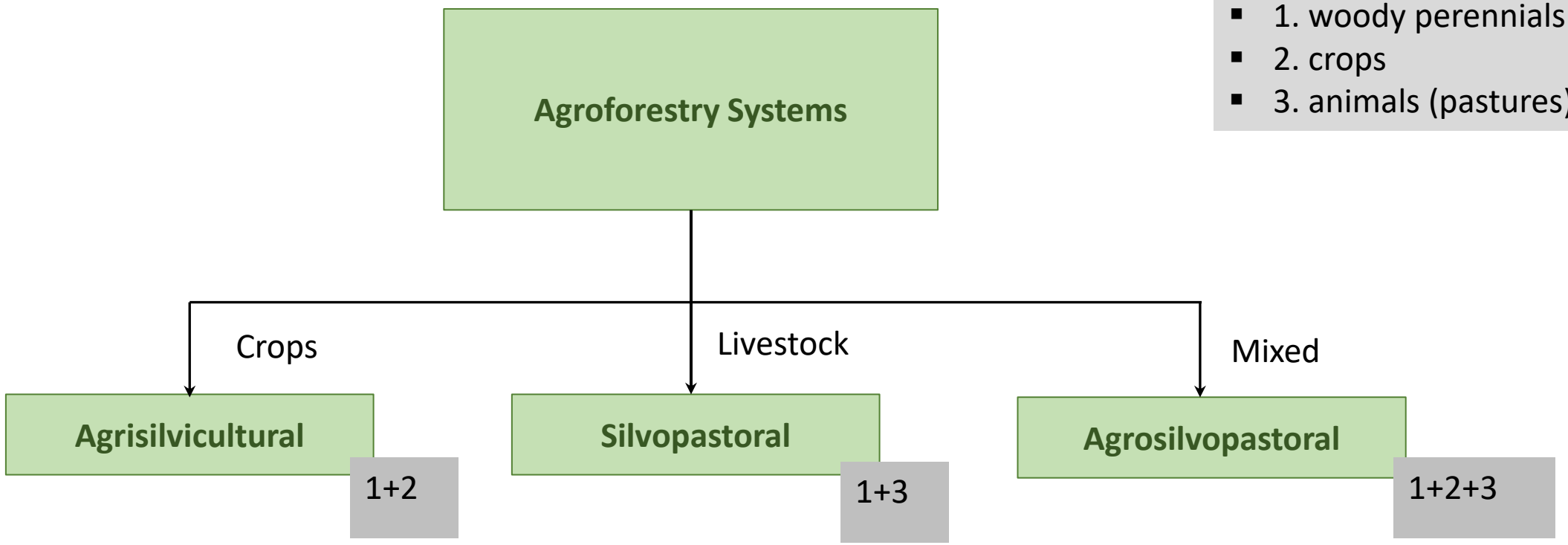
1. RESTORATION OF AGROFORESTRY SYSTEMS

Definition of Agroforestry

Agroforestry: land-use systems and technologies in which woody perennials (trees, shrubs, palms and bamboos) are used deliberately on the same land-management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence. *(ICRAF - International Council for Research in Agroforestry)*

three basic components:

- 1. woody perennials
- 2. crops
- 3. animals (pastures)



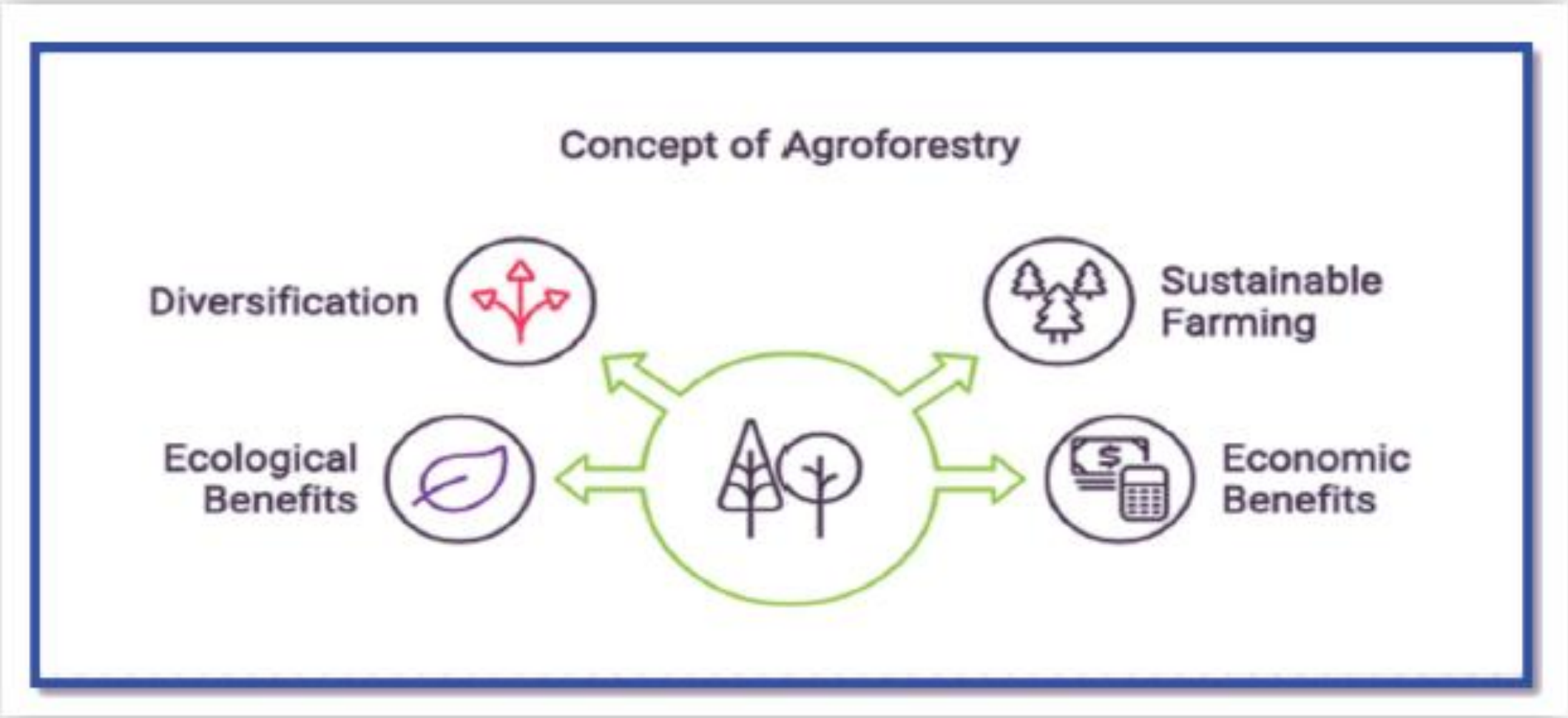
Definition of Agroforestry

The definition of Agroforestry implies that this type of land use system :

- involves two or more species of plants (or plants and animals), at least one of which is a woody perennial
- has a production cycle of more than one year with two or more outputs
- is more complex than a monocropping system, both ecologically (structurally and functionally) and economically

Definition of Agroforestry

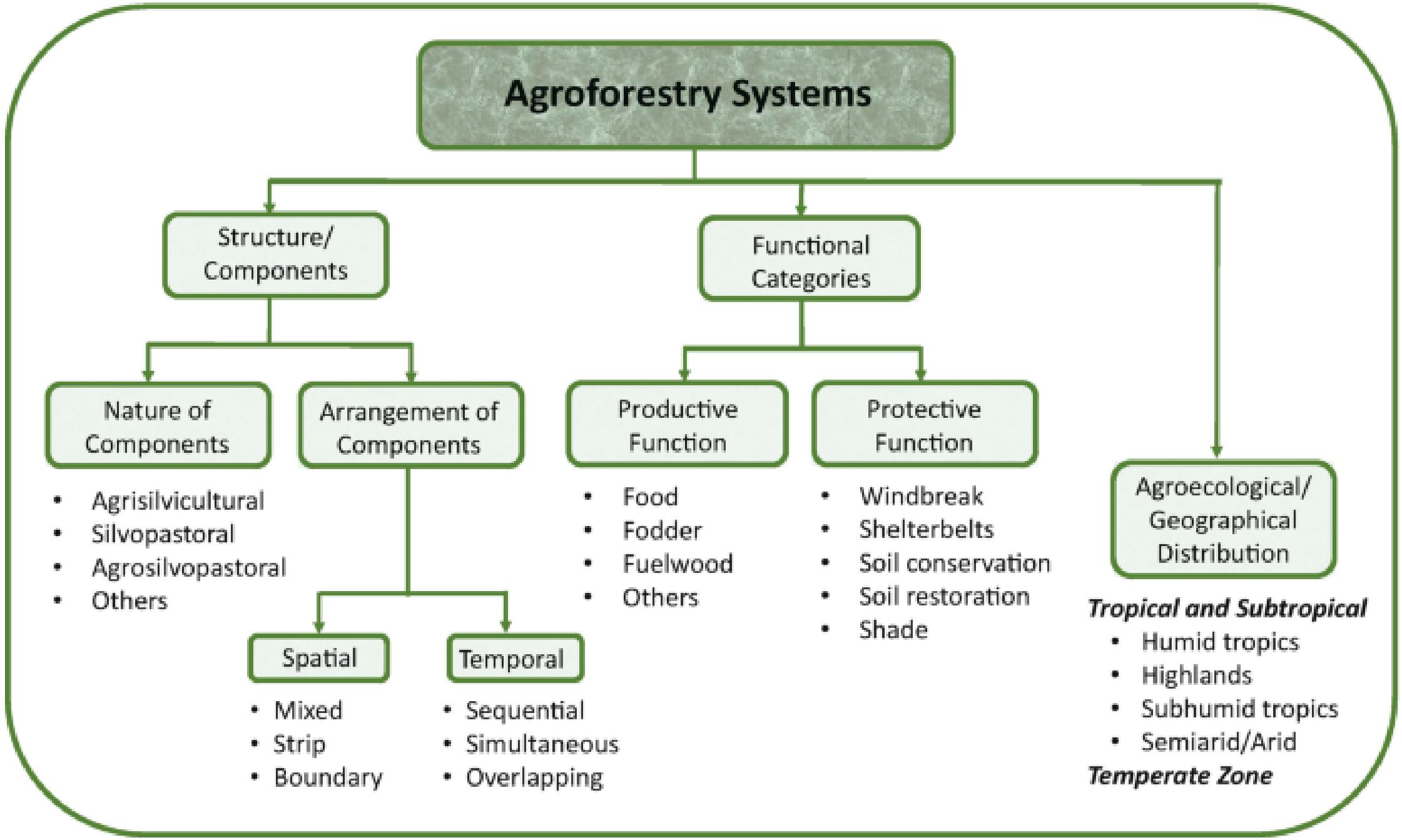
Agroforestry is based on the idea that trees and agricultural components work together to improve ecological resilience, agricultural productivity, and farmer livelihoods



Classification of agroforestry systems and practices

Agroforestry systems can be categorized according to:

- **STRUCTURE:** composition of the components, spatial arrangement of the woody component, vertical stratification and temporal arrangement of all components
- **FUNCTION:** major function or role of the woody components (protective or/and productive function, e.g., windbreak, soil conservation, wood production)
- **ECOLOGICAL CLASSIFICATION:** agroecological zones (arid and semiarid lands, tropical highlands, lowland humid tropics, etc.)
- **SOCIOECONOMIC CRITERIA:** level of technology input (low or high input), management intensity, scale of production, commercial goals (subsistence, commercial, intermediate)

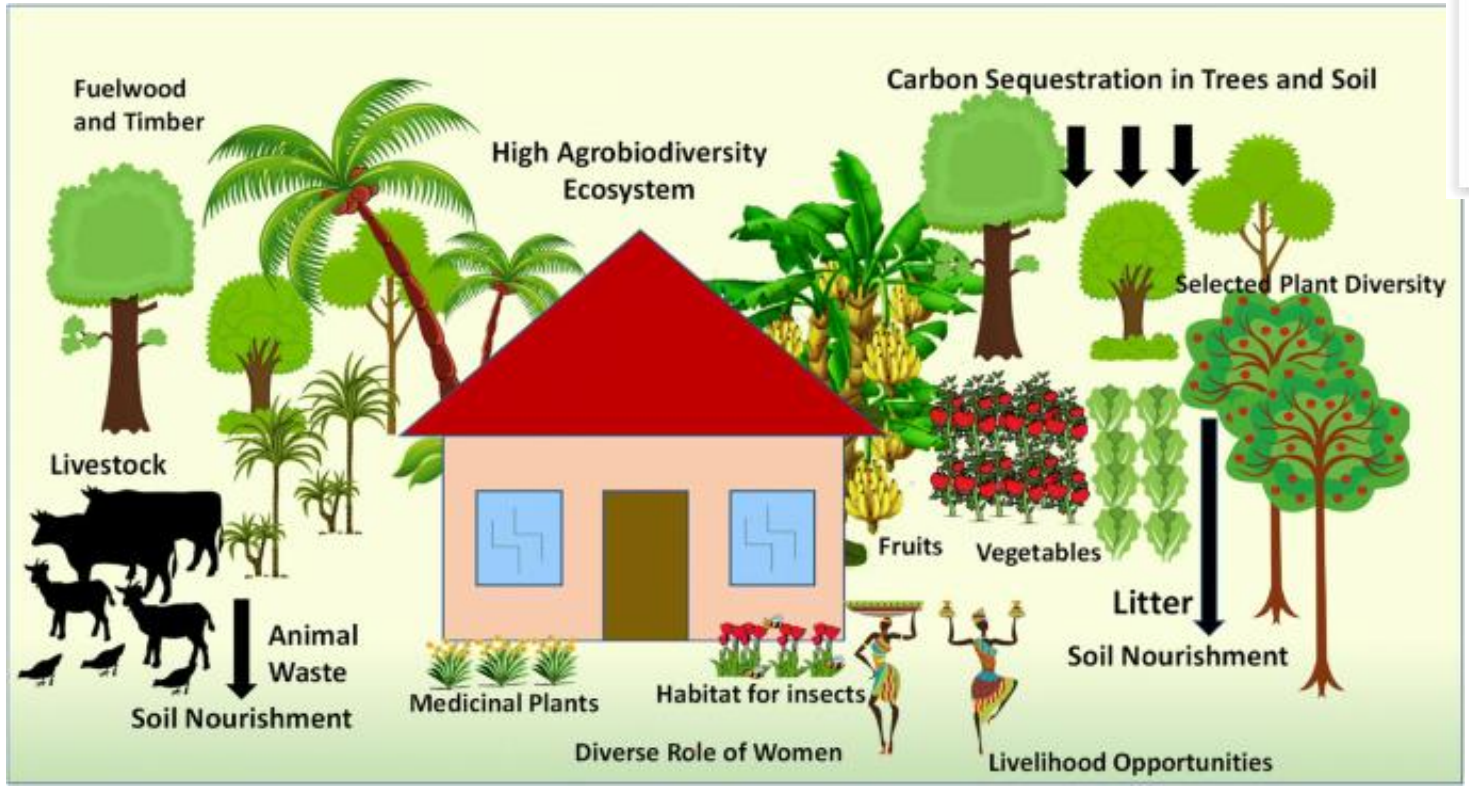


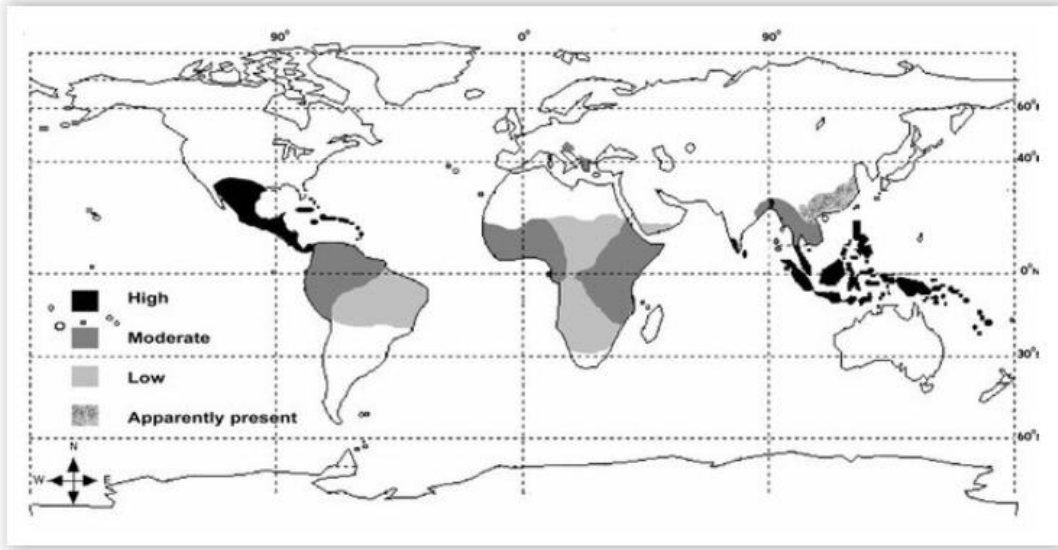
Source: Nair et al. (2021) Classification of Agroforestry Systems. In: An Introduction to Agroforestry. Springer. https://doi.org/10.1007/978-3-030-75358-0_3

Examples of agrisilvicultural systems: Homegardens (mainly in tropical regions)

A multistory "Kandyan" homegarden from central Sri Lanka.

Examples of agrisilvicultural systems: Homegardens





frequency of occurrence of homegardens

Kumar and Nair (2006) Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry

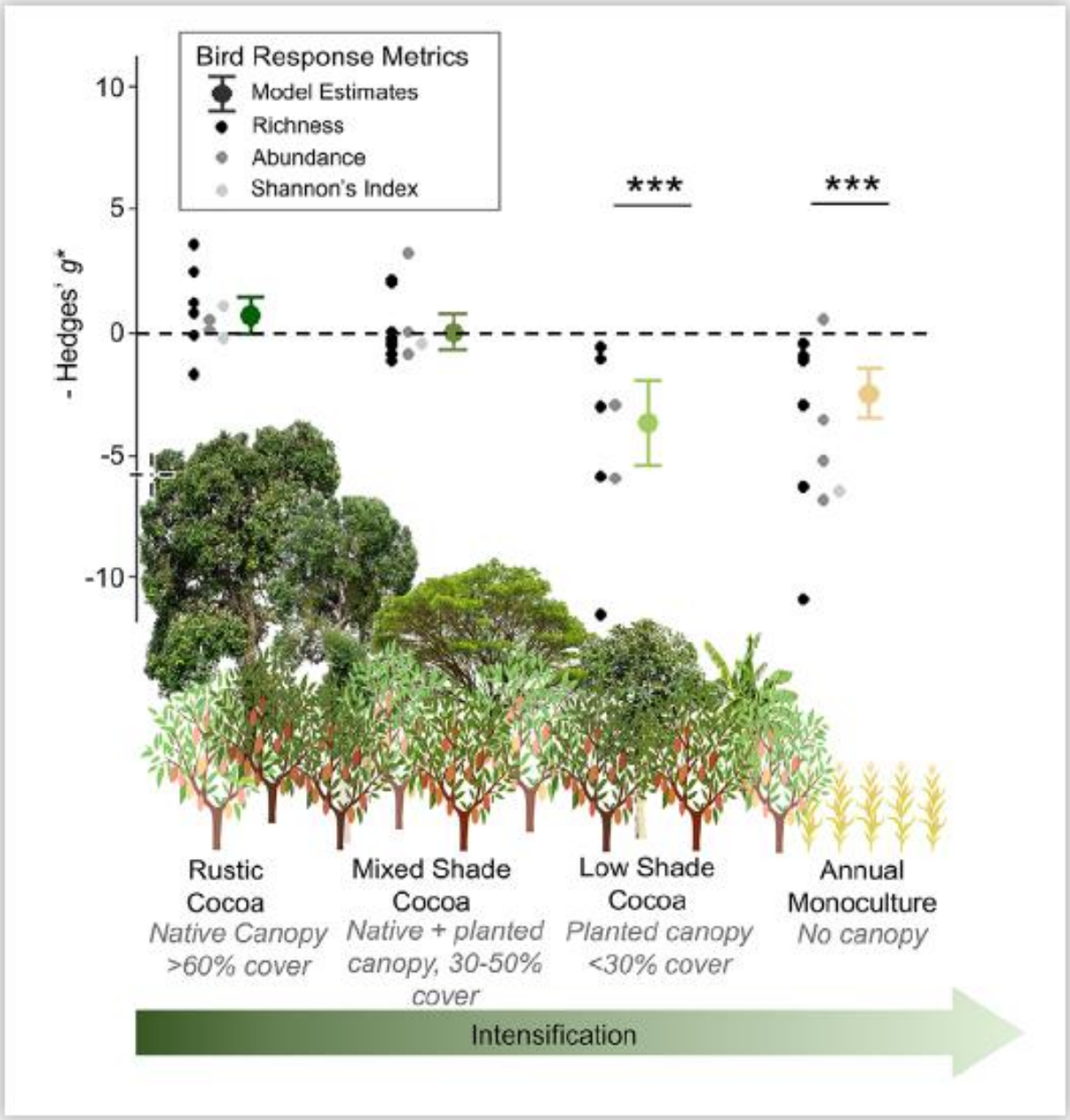
Homegardens are cultivated areas around a house where people grow a mixture of plants like vegetables, fruits, and herbs, sometimes with small animals, for household use or sale. They function as a traditional, sustainable practice with important ecological and socioeconomic benefits for families and communities.

Examples of agrisilvicultural systems: Forest farming – shaded cocoa (*Theobroma cacao*)

Cocoa agroforestry is a managed system of cultivation of cocoa with other trees and crops over time and space.

This type of system can optimize cocoa production, farmer income, carbon storage and other environmental benefits

Examples of agrisilvicultural systems: Forest farming – shaded cocoa (*Theobroma cacao*)



Bird diversity declined sharply in low shade cocoa. Cocoa with >30% canopy cover showed bird diversity similar to nearby primary or mature secondary forest but with a different bird community (Source: Bennett *et al*. 2021 *Impact of cocoa agricultural intensification on bird diversity and community composition*. Conservation Biology
DOI: 10.1111/cobi.13779)

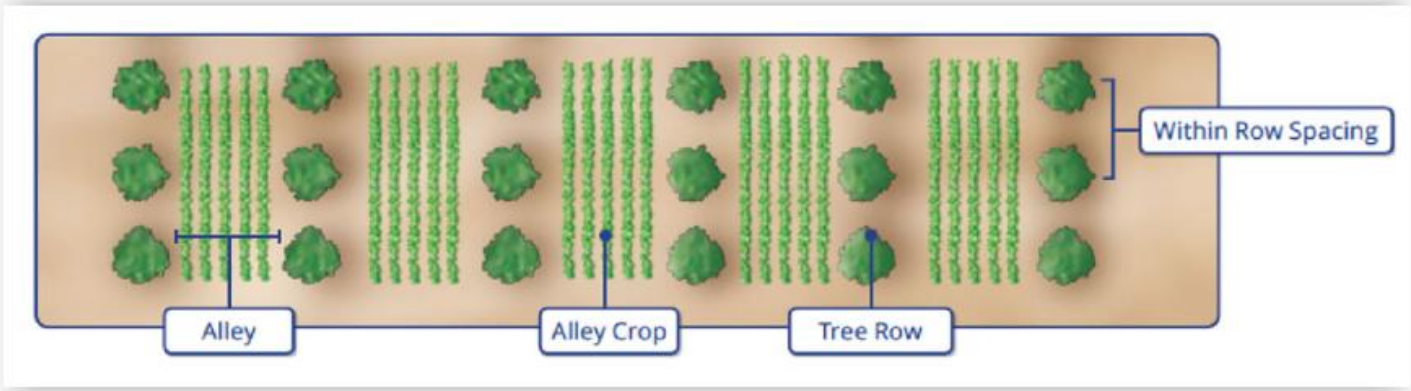
Bird Friendly certification for shade-grown coffee and cocoa agrisilvicultural systems

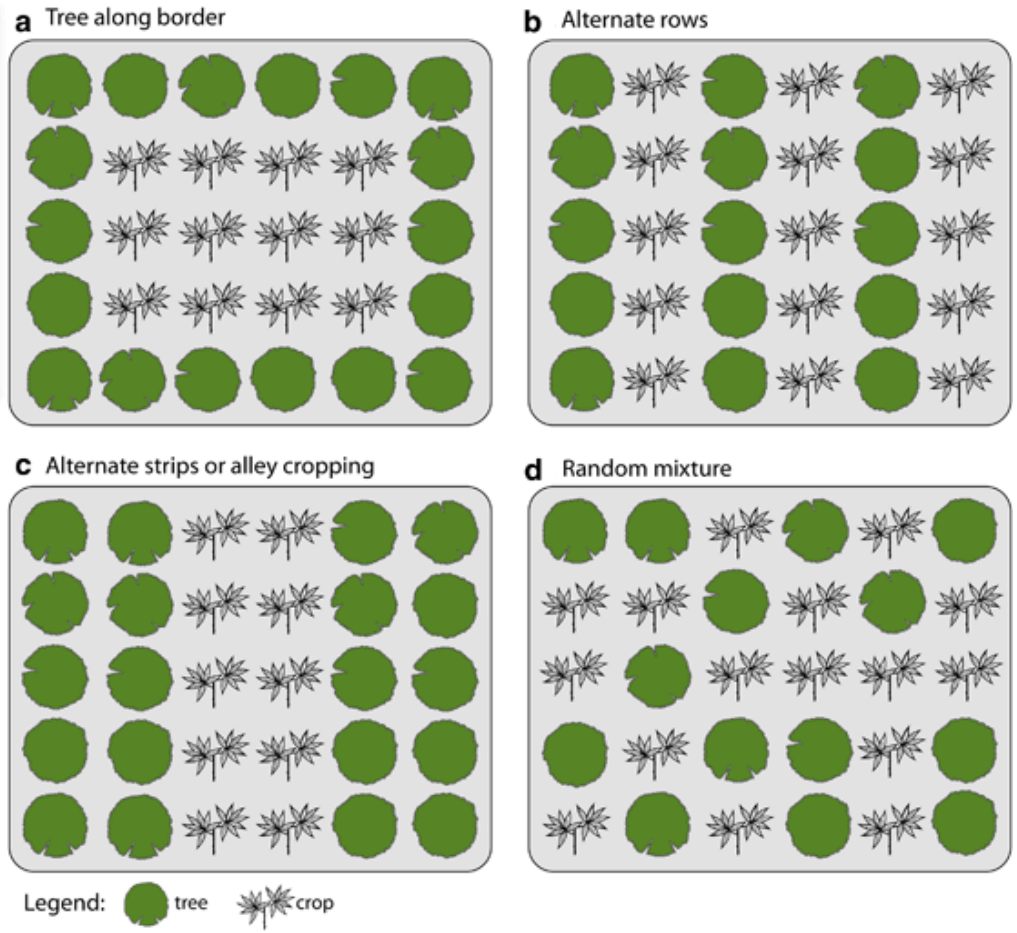
Examples of agrisilvicultural systems: Alley cropping

Alley cropping involves planting rows of trees or shrubs alongside agricultural crops, which can enhance productivity while potentially sequestering carbon and providing environmental benefits such as reducing wind erosion

Wheat is alley cropped with permanent walnut trees in Occitanie, Southern France. The walnut trees are managed for nut production

Examples of agrisilvicultural systems: Alley cropping

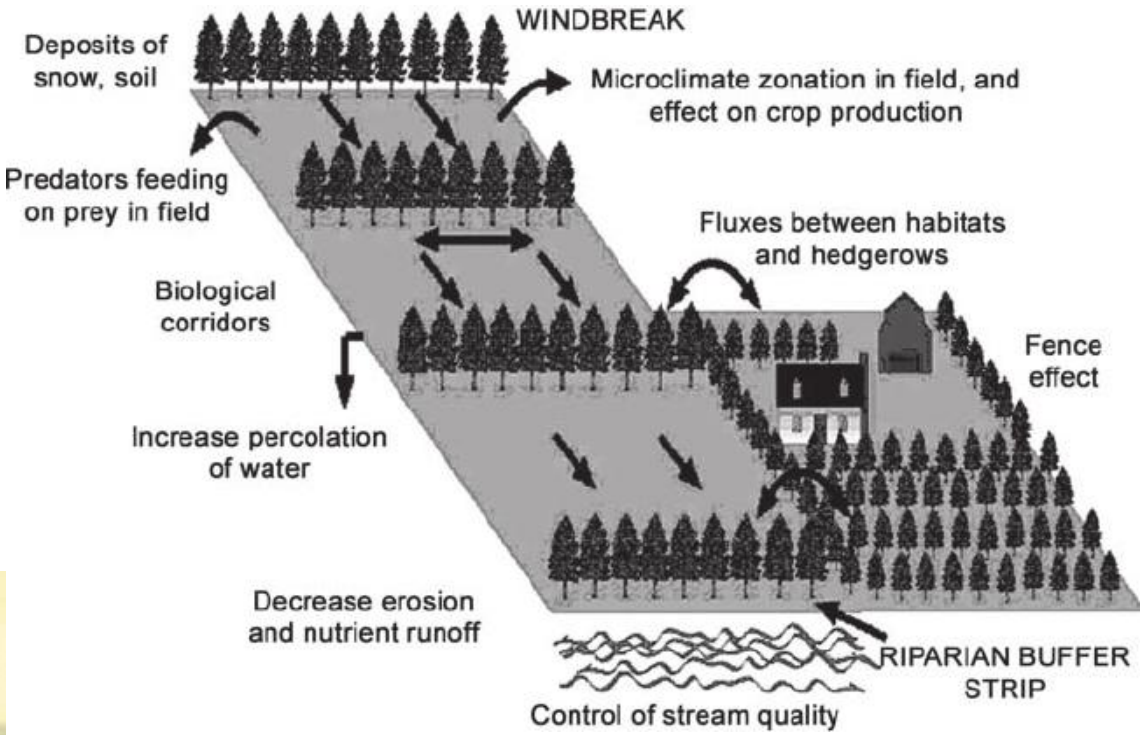


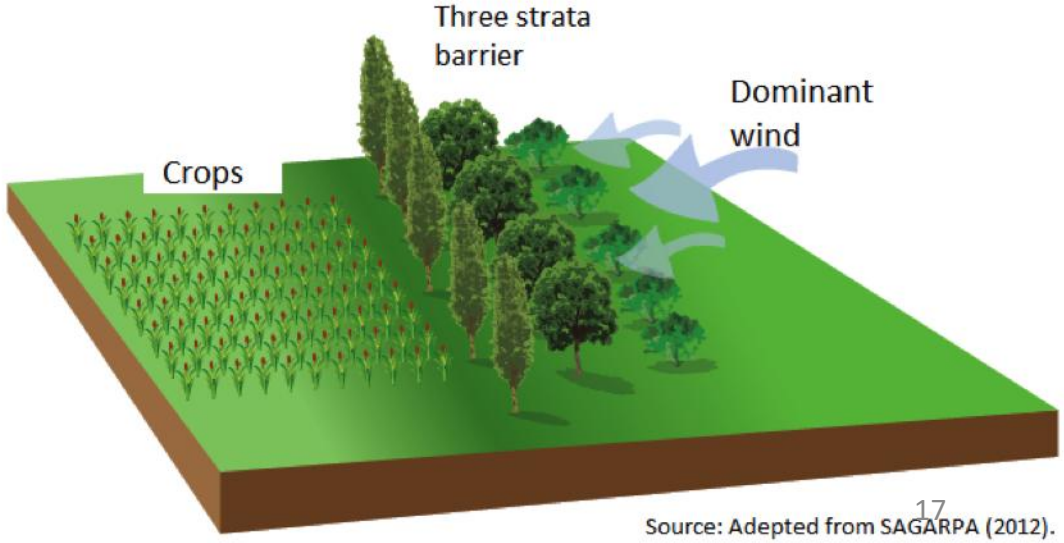


Different spatial arrangements

Examples of agrisilvicultural systems: Wind breaks or shelterbelts

Linear plantings of trees and shrubs that reduce wind speed to control erosion, protect crops, provide shade for livestock, and provide economic benefits such as timber and increased yields. They also provide other ecosystem services such as enhancement of biodiversity, wildlife habitat, carbon storage, pollinator habitat, and soil and water quality protection





Source: Adepted from SAGARPA (2012).

Examples of agrisilvicultural systems: riparian buffer

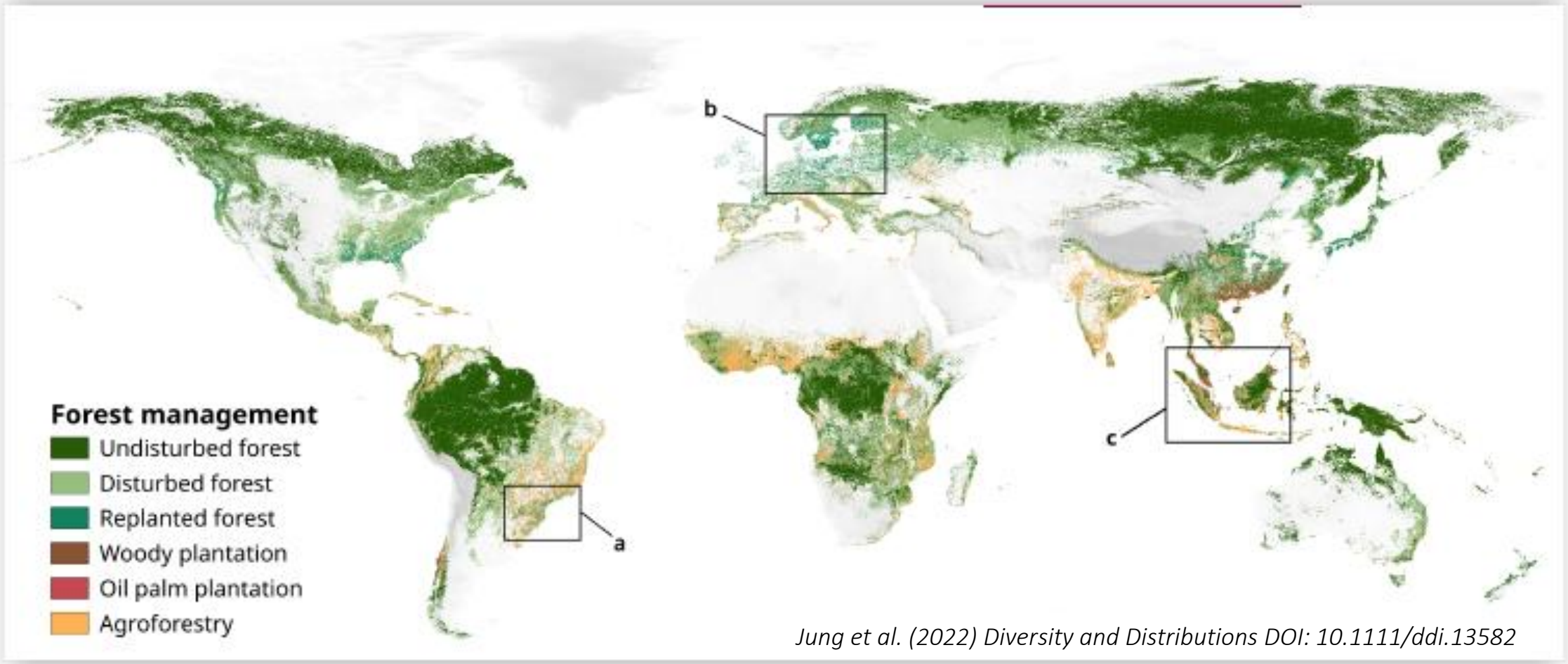
Permanent strips of vegetation like trees, shrubs, tall grasses (preferably native) that are used to prevent erosion and control the flow of water, protecting the crops. They also protect water quality and enhance biodiversity

Examples of silvopastoral systems: pasture systems with trees

Examples of different structures (temporal arrangement)

Examples of agroforestry systems classified according to management intensity and commercial goals

Global distribution: Agroforestry systems occupy about 43% of agricultural land (over 1 billion hectares), practiced by more than 1.2 billion people

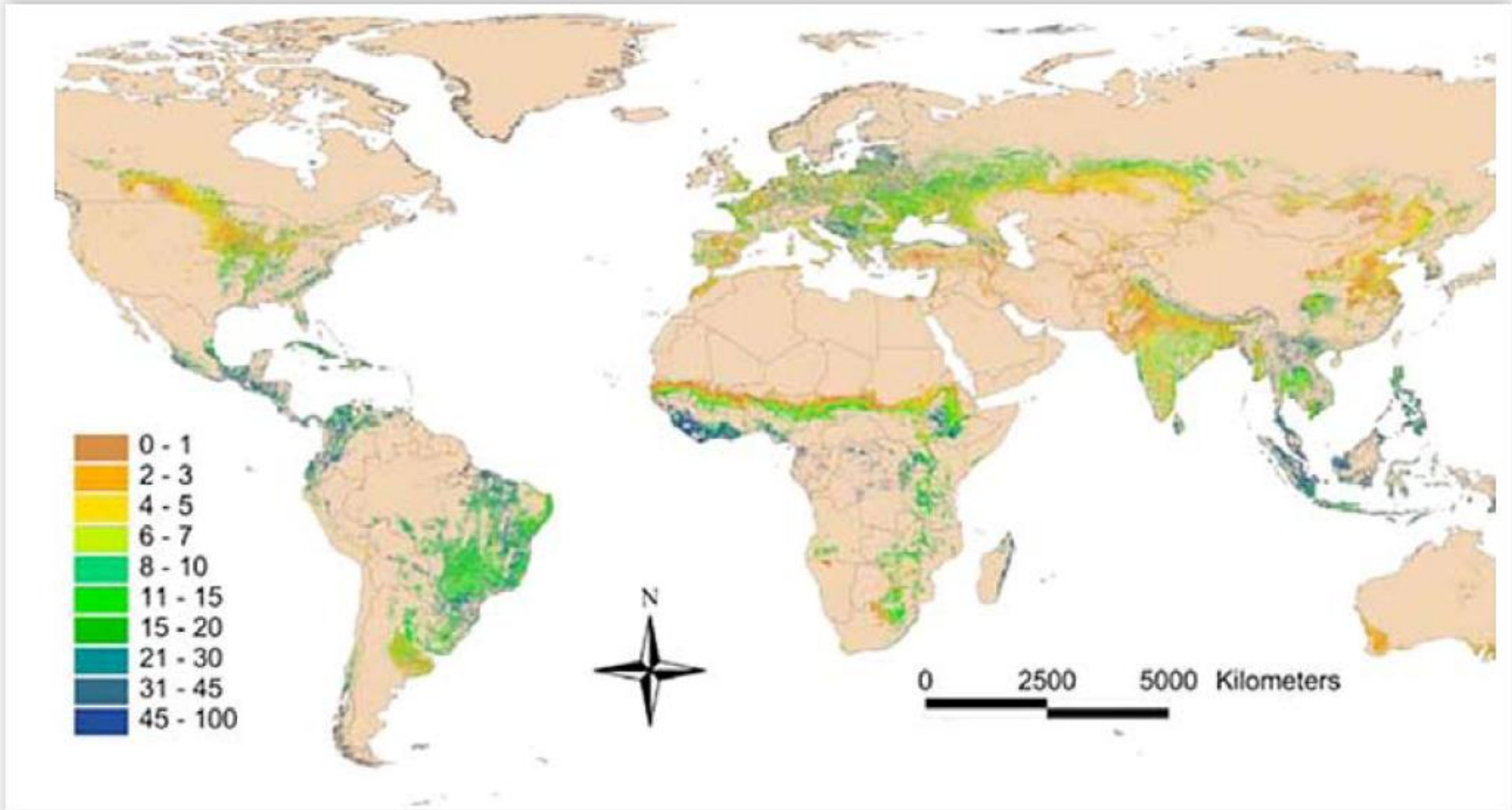


Jung et al. (2022) Diversity and Distributions DOI: 10.1111/ddi.13582

Tropical Humid Lowlands: shifting cultivation, tree shaded crops, homegardens

Semiarid Lowlands/Mediterranean climates: silvopastoral systems, windbreaks, multipurpose trees on farmlands

Tropical Highlands: silvopastoral combinations, tree-shaded crops



Tree canopy cover (%) on agricultural land

Source: Zomer et al. (2009) Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry. Working Paper no. 89, World Agroforestry Centre, Nairobi, Kenya

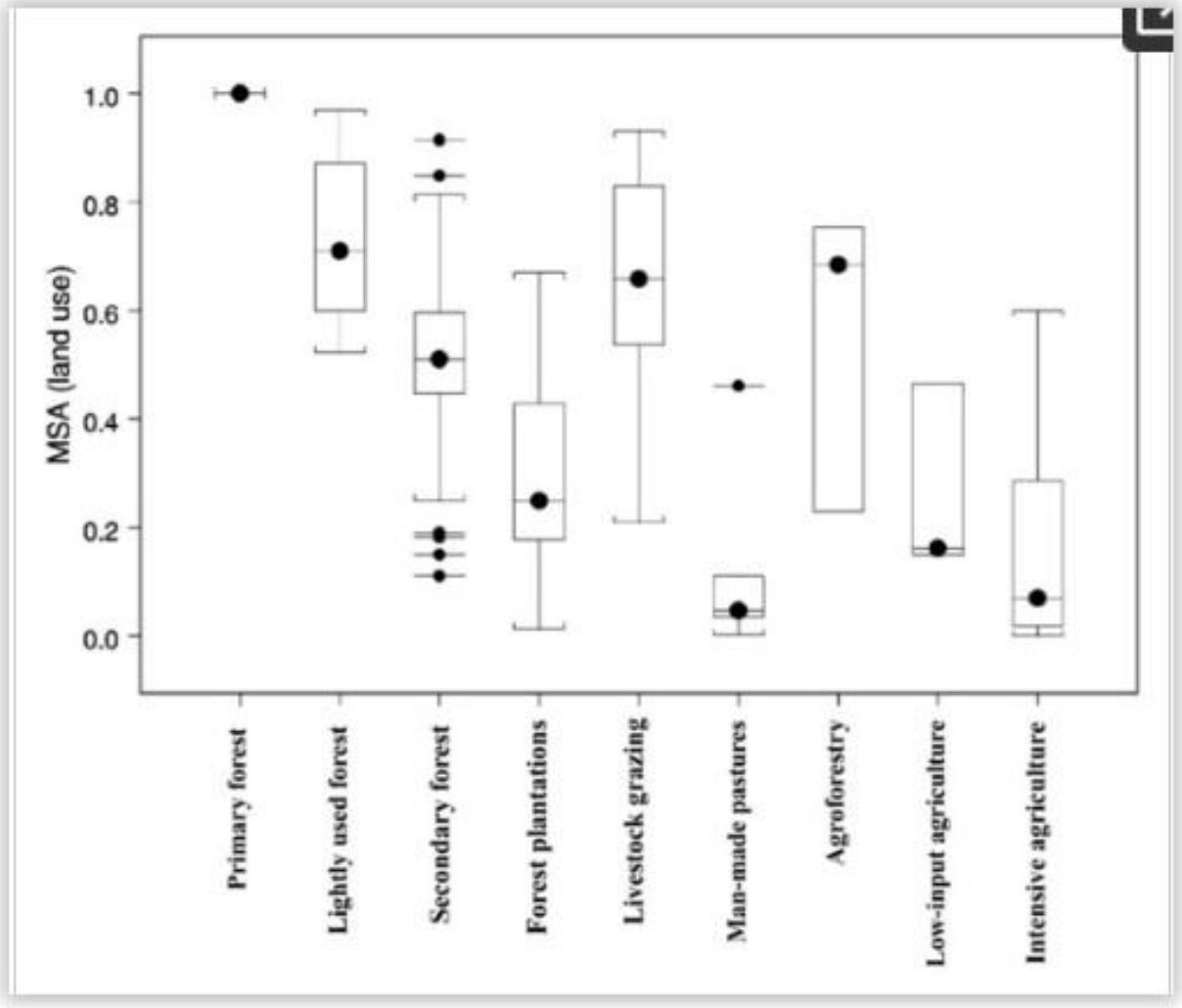
1. Biodiversity conservation

Provides a variety of habitats, enhancing resilience to pests and diseases and pollination

Higher soil biodiversity (soil fauna and microbes) contributes to soil health (e.g., nutrient cycling)

Helps preserve germplasm of sensitive species

Provides landscape connectivity by creating ecological corridors

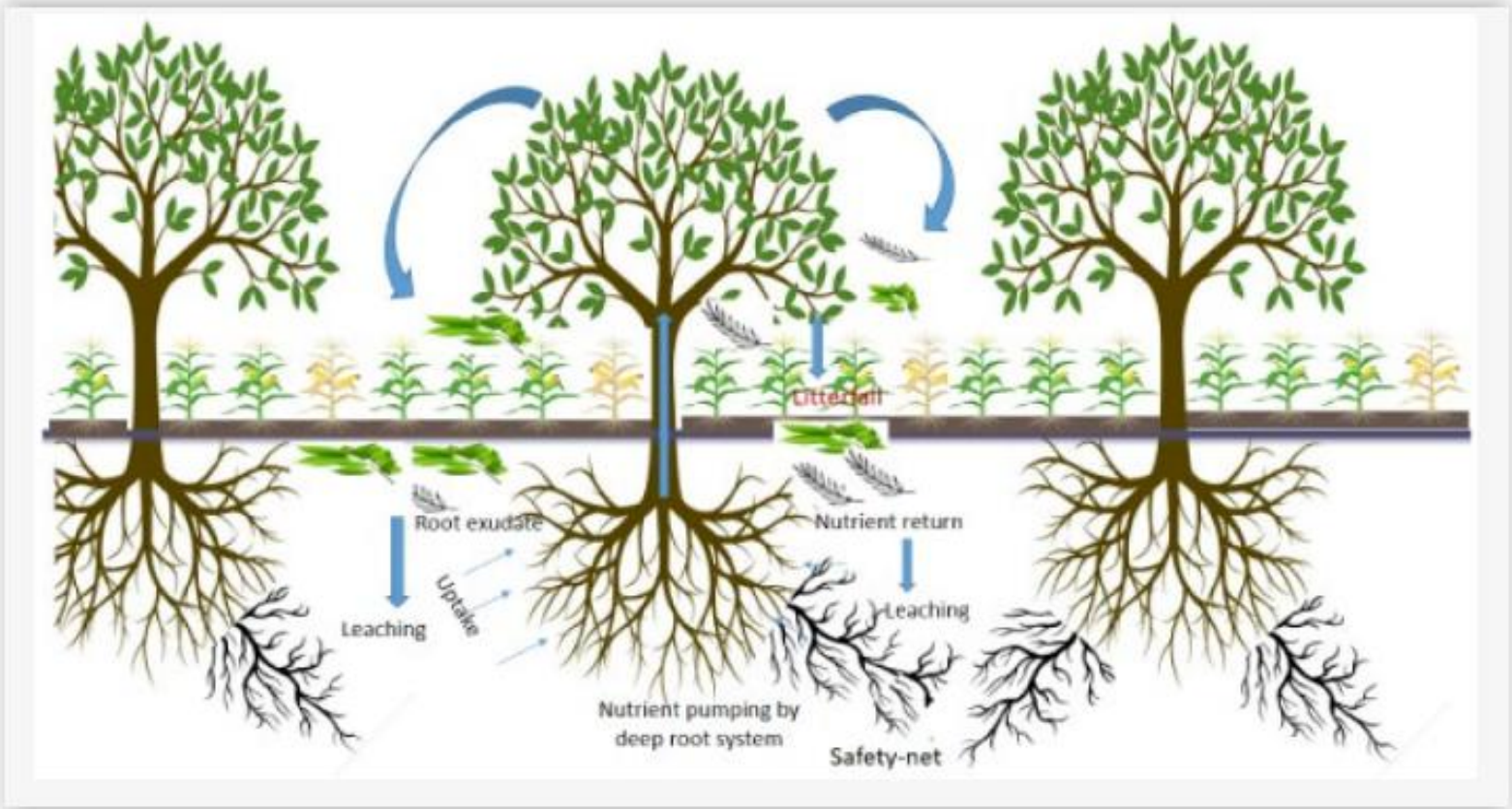


Mean species abundance (MSA) for different land management practices (Source: Alkemade *et al*. 2009. GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems *12:* 374–390 DOI: 10.1007/s10021-009-9229-5)

2. Soil health and fertility

- The presence of trees and shrubs improves physical soil properties (aggregation and porosity) and reduces runoff and soil erosion

- The addition of organic matter from leaf litter and root biomass improves soil health and enhances soil structure, increases water infiltration and retention, and improves nutrient cycling (reduced leaching).



Nutrient pumping and cycling in an agroforestry system via 'safety net' formation (Source: Fahad *et al*. 2022 Agroforestry Systems for Soil Health Improvement and Maintenance. Sustainability 14: 14877. https://doi.org/10.3390/su142214877)

2. Soil health and fertility: soil biota

Microbial abundance is higher in agroforestry systems due to the influence of the trees, the organic matter deposition, the root exudates, and the diverse litter

Increased soil microbial diversity enhances fertility, plant productivity and mycorrhizae

- **Carbon transformation and nutrient cycling**: nematodes, collembola, diplopoda, earthworms, fungi, insects
- **Maintaining the soil structure**: ants, termites, earthworms (soil engineers)
- **Biological control**: centipedes, ground beetles, predatory mites, collembola, carnivorous nematodes



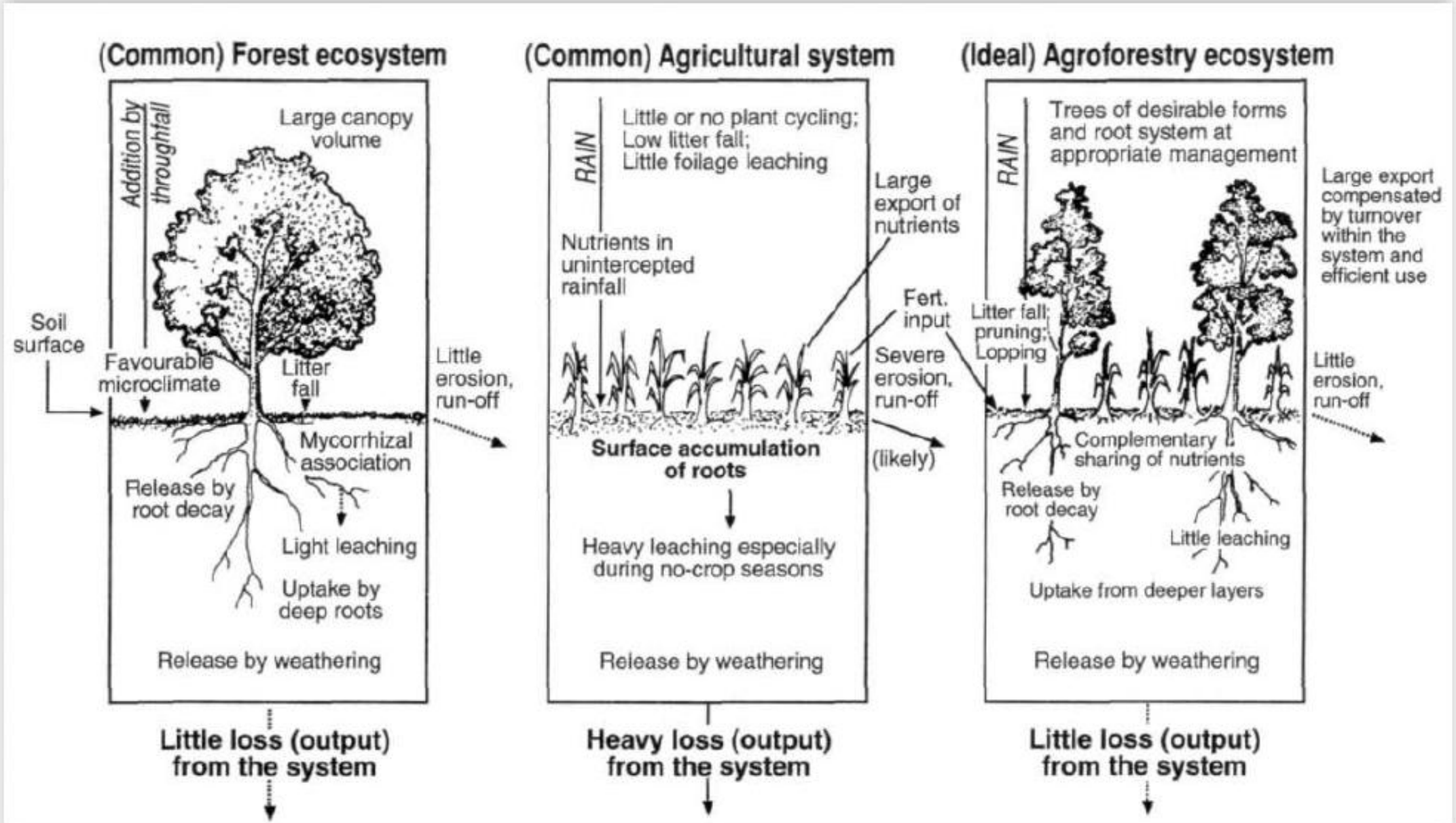


2. Soil health and fertility: soil biota

	Agroforestry	Monocrop
Soil macro fauna		
Earthworm	54.4	17.6
Beetles	20.9	9.6
Centipedes	2.7	0.5
Millipedes	8.1	1.3
Termites	90.7	81.0
Ants	23.2	8.6
Soil mesofauna		
Collembola	3890.1	2000.7
Mites	5100.7	1860.1
Soil microfauna		
Non-parasitic nematodes	2922	1288
Parasitic nematodes	203.7	

Comparison of mean densities of different soil biota under agroforestry systems and monoculture

Source: Barrios *et al.* (2012) Agroforestry and soil health: linking trees, soil biota and ecosystem services. In: Wall *et al*. (Eds.) Soil Ecology and Ecosystem Services. Oxford University Press



Nair (1984) Soil Productivity Aspects of Agroforestry

3. Water management

- The integration of trees into agricultural landscapes improves soil structure, which enhances water infiltration and reduces surface runoff
- This increased infiltration allows more water to be stored in the soil, making it available for crops and reducing the risk of soil erosion
- The shade provided by trees reduces evaporation from the soil surface, conserving soil moisture and improving the water use efficiency of crops

Alley cropping, significantly increases soil water retention and reduces runoff compared to conventional farming systems

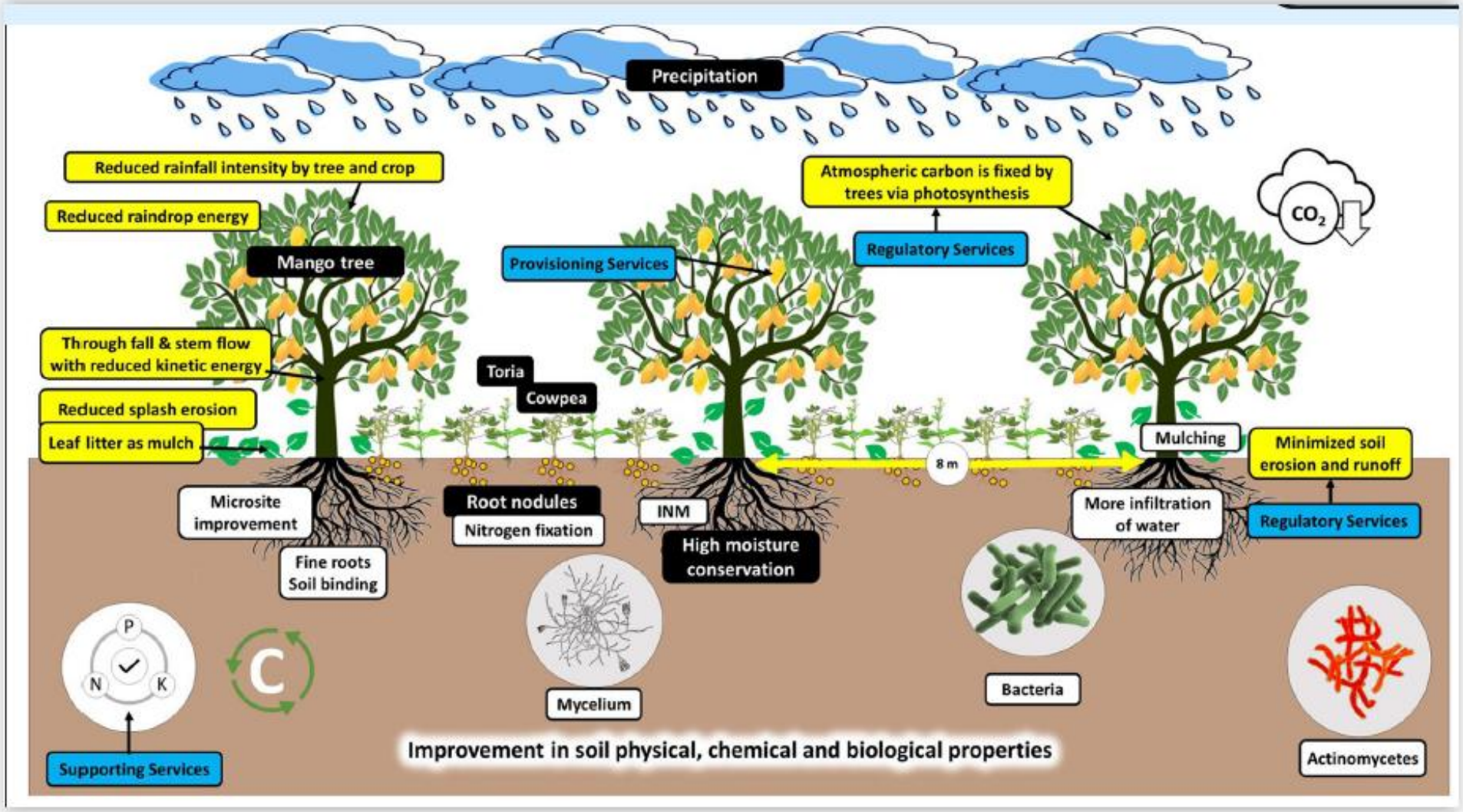
4. Resilience to climate change

Temperatures under tree canopies are usually 2–4°C lower compared to places exposed to direct sunlight

The increase in global temperatures negatively affects growth of crops, especially in the tropical arid and semi-arid regions of the world

Source: Dobhal *et al.* (2024) Global assessment of production benefits and risk reduction in agroforestry during extreme weather events under climate change scenarios. *Front. For. Glob. Change* 7:1379741. doi: 10.3389/ffgc.2024.1379741

4. Resilience to climate change



- Carbon sequestration

-Buffers the impacts of extreme events (droughts and floods)

- Provides shade

Source: Rathore *et al*. 2023 Impact of conservation practices on soil quality and ecosystem services under diverse horticulture land use system. *Front. For. Glob. Change* 6:1289325. doi: 10.3389/gc.2023.12893253.

4. Resilience to climate change

Risk	Adaptation	Agroforestry practice
Intense precipitation events	Slow water runoff to reduce flooding, soil erosion, and water pollution	Riparian forest buffers; alley cropping
Increased storm intensity (wind & precipitation)	Protect crops from wind damage	Windbreaks; alley cropping
Increased temperatures	Reduce heat stress on animals by providing shade	Silvopasture
Increased frequency and intensity of drought	Reduce evapotranspiration by reducing windspeed	Windbreaks
Changes in growing season due to temperature and precipitation	Protect crops by creating microclimates	Windbreaks; alley cropping; forest farming
Winter storms and cold temperature extremes	Reduce cold stress on animals by providing shelter	Silvopasture; windbreaks
Increased insect and disease problems	Control pests by providing habitat for beneficial insects	Windbreaks; riparian forest buffers; alley cropping
Increased possibility of crop failure due to other risks	Reduce total crop loss by increasing crop diversity	All agroforestry practices

Source: ENoP (2023) Reviving agroforestry landscapes in the era of climate change: for people, nature and local economy. European Network of Political Foundations (ENoP)

Socioeconomic Principles of Agroforestry

1. Food security

- Diverse sources of food throughout the year (e.g., fruits, nuts, fodder, fuelwood, timber)
- Higher agricultural productivity and crop yields due to improved soil fertility and protection against climatic extremes

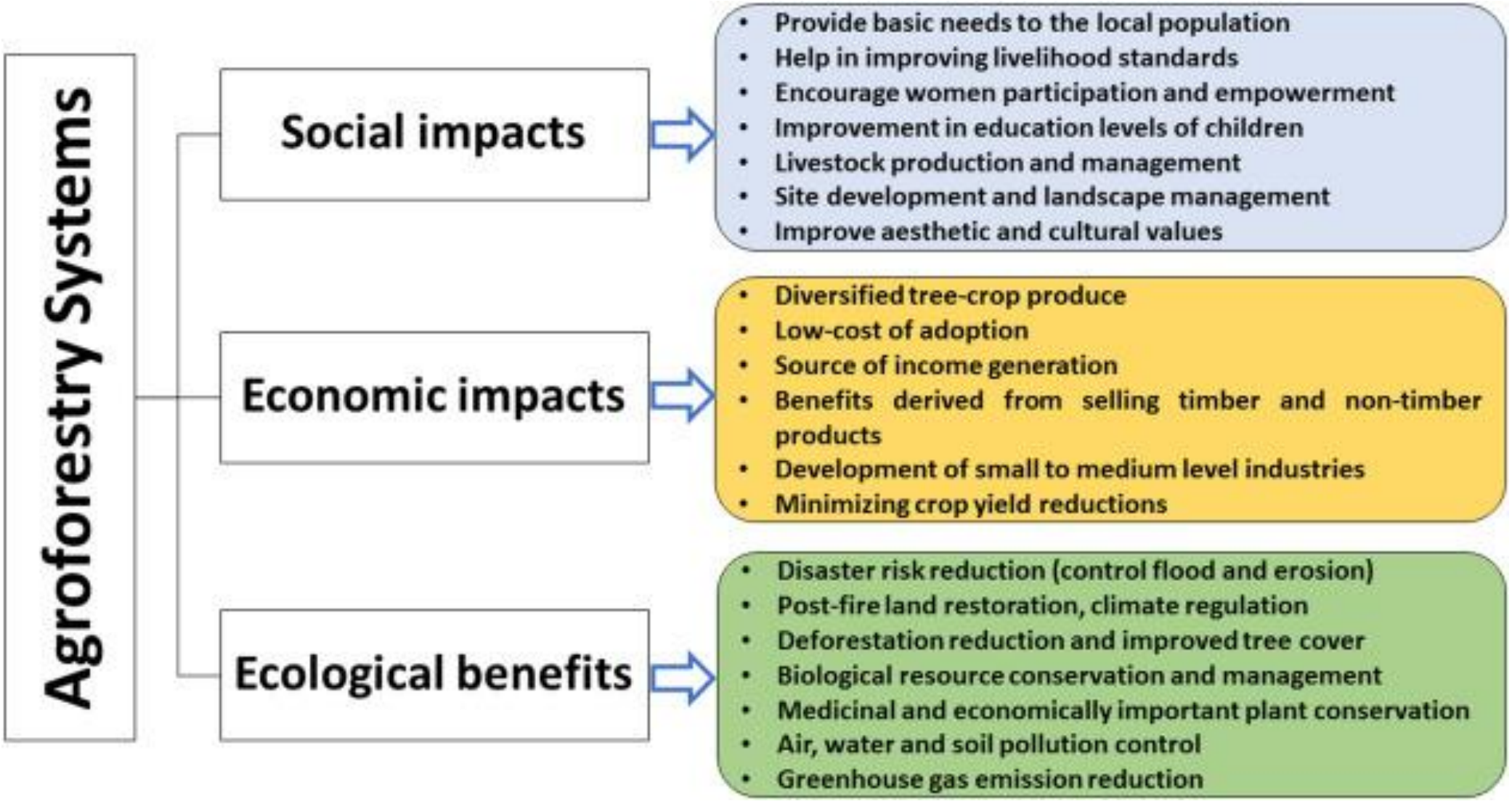
2. Economic Viability

- Increased efficiency in use of land, with production of several goods
- Greater efficiency in the use of production factors (water, light, nutrients)
- Fewer economic risks, due to lower sensitivity to negative price and climate fluctuations

3. Livelihood Improvement

- Diverse farm production can increase household income and alleviate poverty of rural communities
- Reduced risk of crop failure due to pests, diseases, or extreme weather events
- Enhanced ecosystem services, such as soil fertility and water retention, which indirectly supports agricultural productivity and sustainability

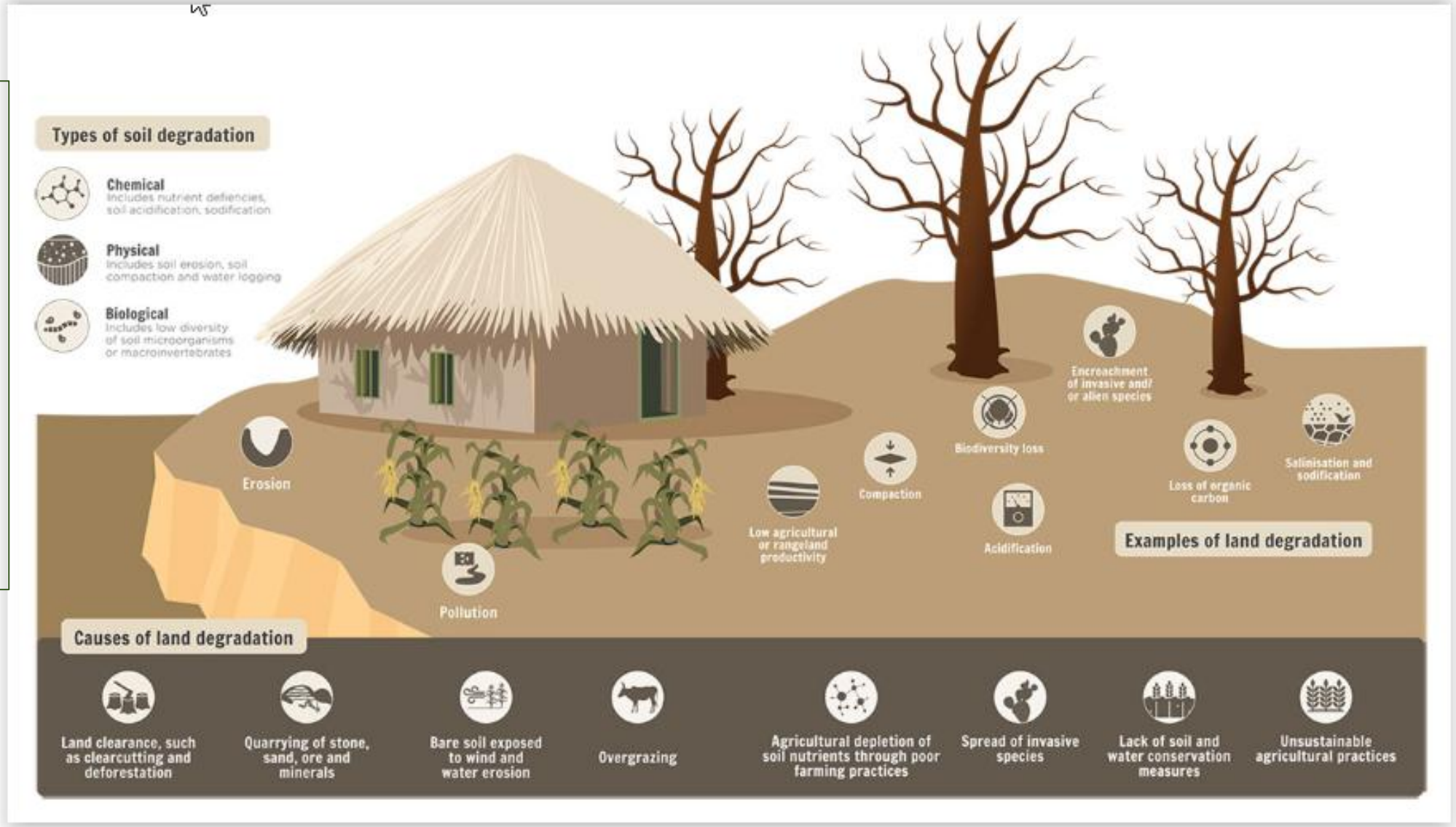
Environmental and socioeconomic benefits of agroforestry



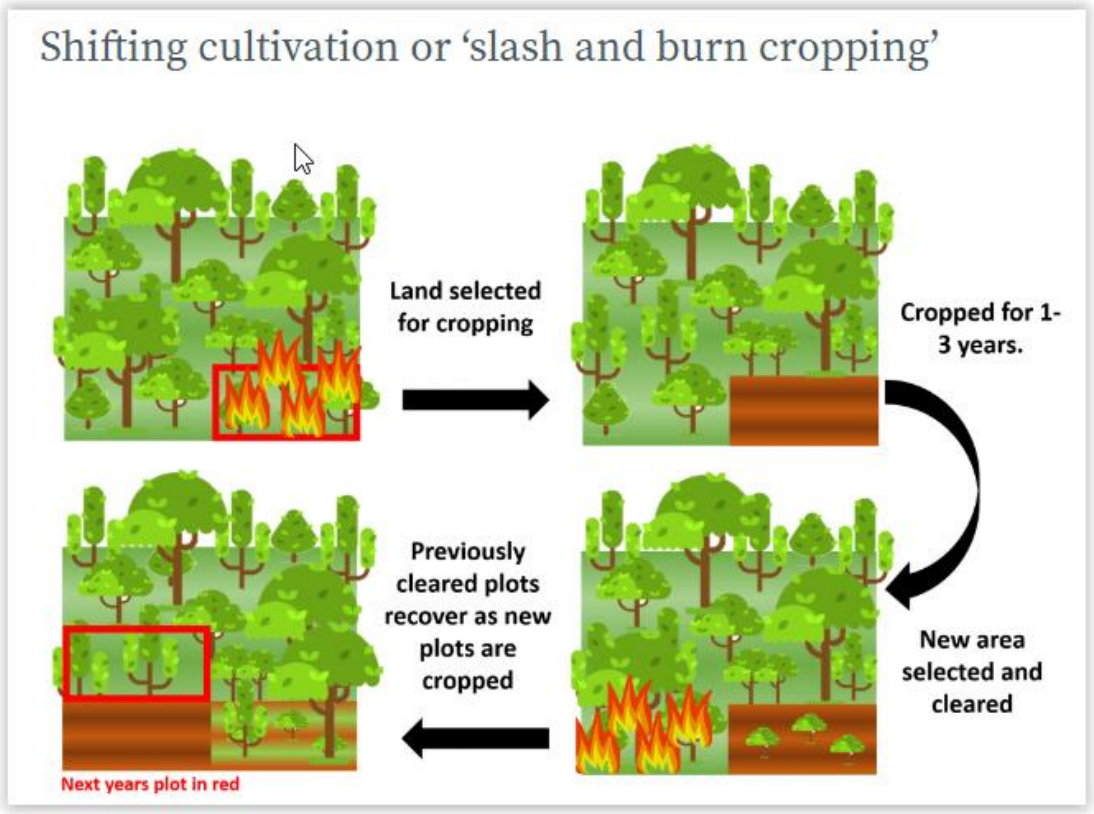
Degradation factors of agroforestry systems

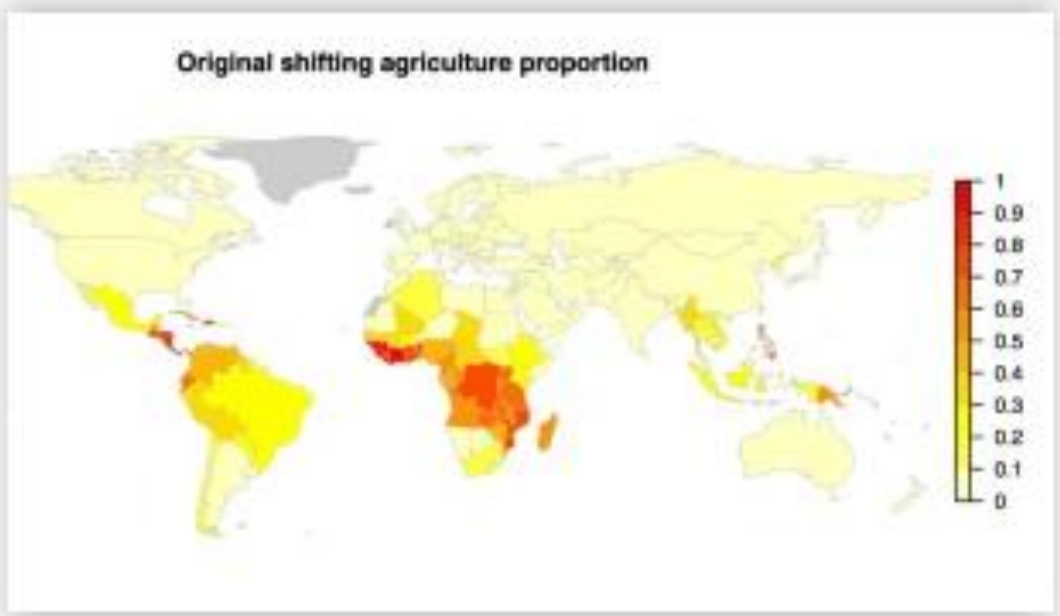
Main degradation factors

- Reduction in fallow periods (shifting cultivations) due to increasing demographic pressure
- Overgrazing (silvopastoral systems)
- Mechanization/ management intensification/high levels of technological inputs
- Climate change



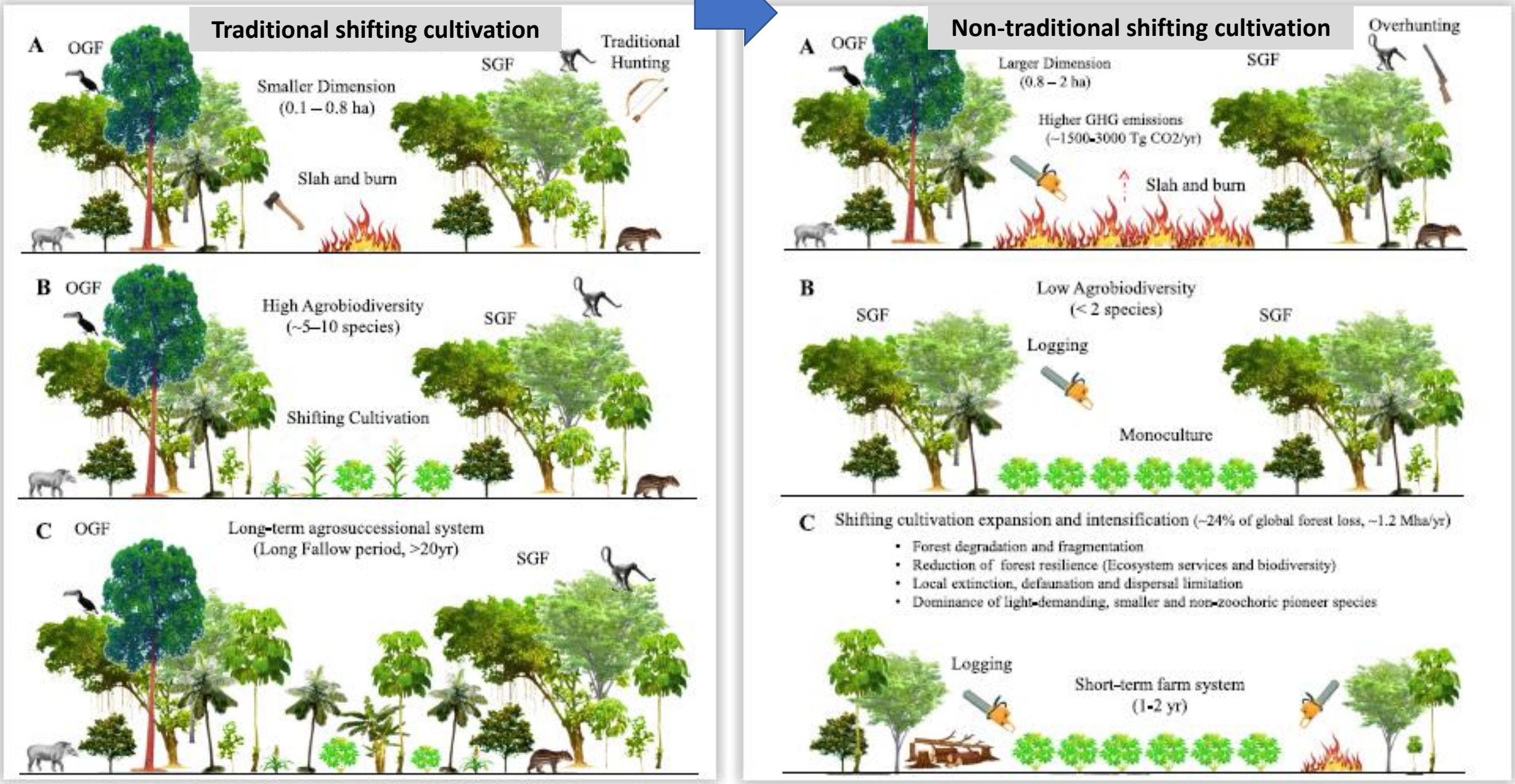
Degradation factors of agroforestry systems





Shifting cultivation is an extensive and traditional land use system still being practiced in some parts of the tropics and subtropics. It comprises of short cycles of agriculture (1–3 years) with high crop diversity followed by fallow periods of 2–7 years (long cycles have fallow periods of more than 15 years)

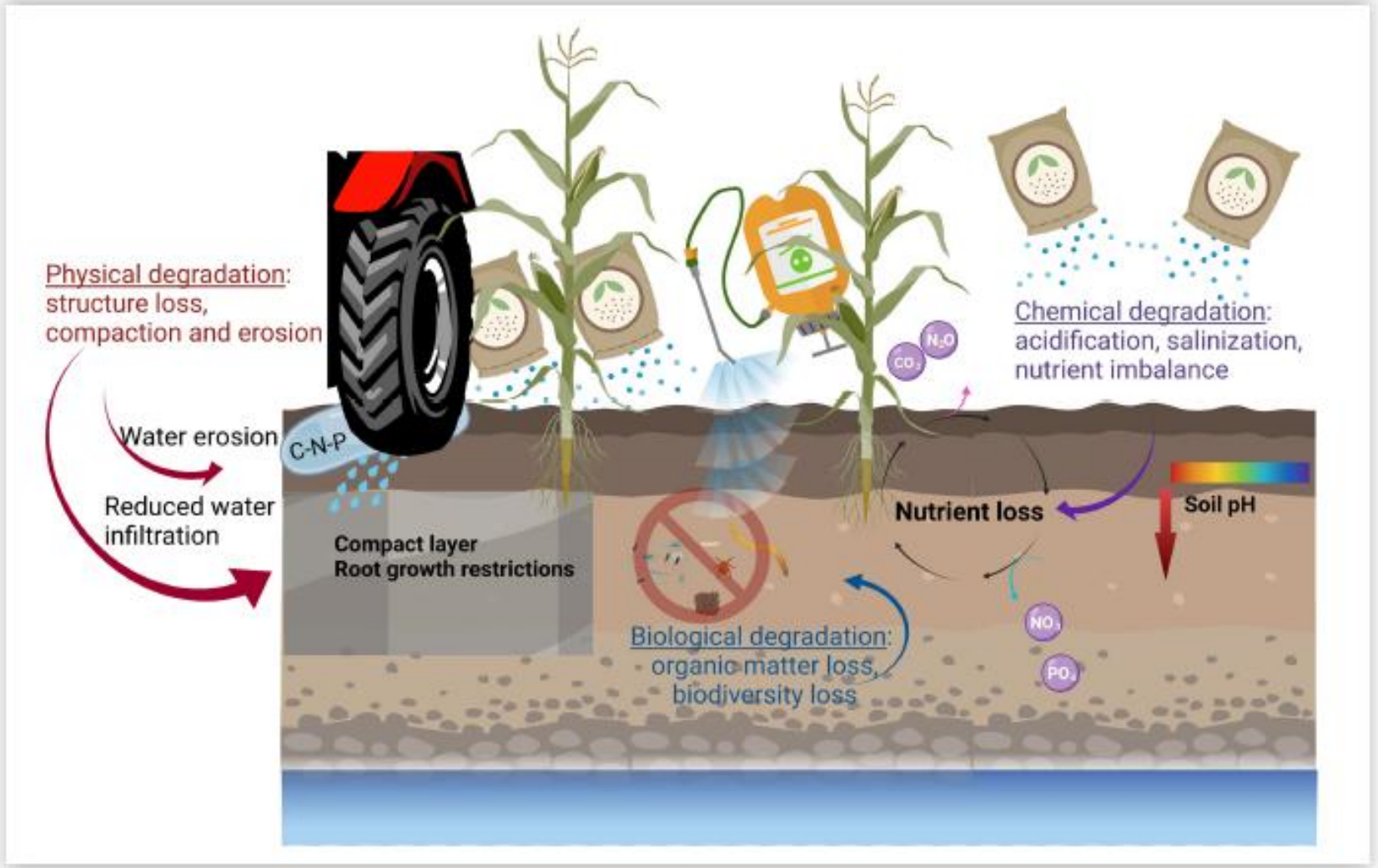
- The drastic reduction of the fallow period causes severe soil degradation and decline in productivity, and may lead to forest degradation, forest fragmentation and species loss



Source: Villa *et al*. 2021. Reducing intensification by shifting cultivation through sustainable climate-smart practices in tropical forests: A review in the context of UN Decade on Ecosystem Restoration. Current Research in Environmental Sustainability 3: 100058. https://doi.org/10.1016/j.crsust.2021.100058

Degradation factors of agroforestry systems

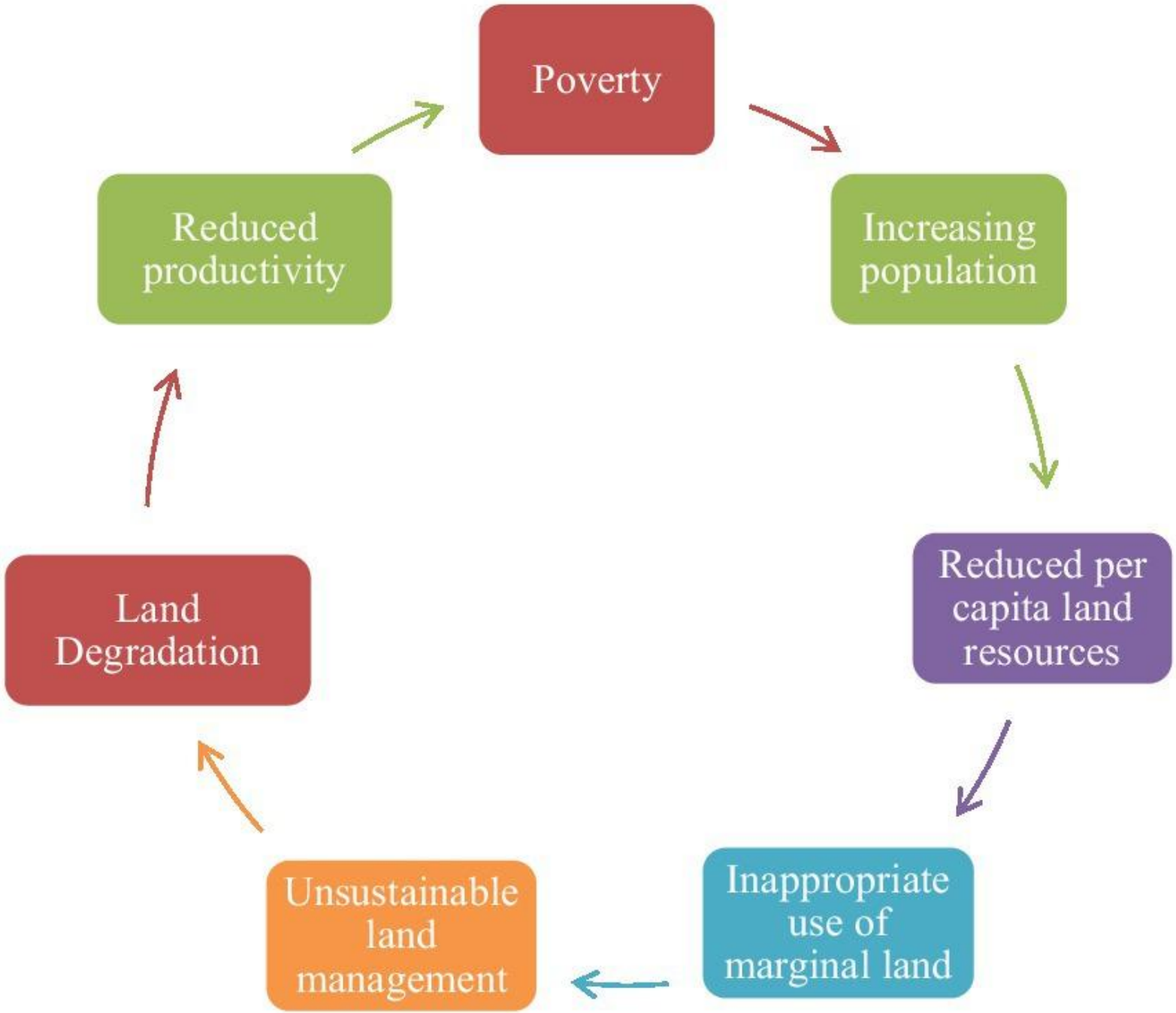
Soil degradation in an agroecosystem



Physical degradation drivers: soil compaction due to heavy machinery, overgrazing, monocropping, overuse of fertilizer

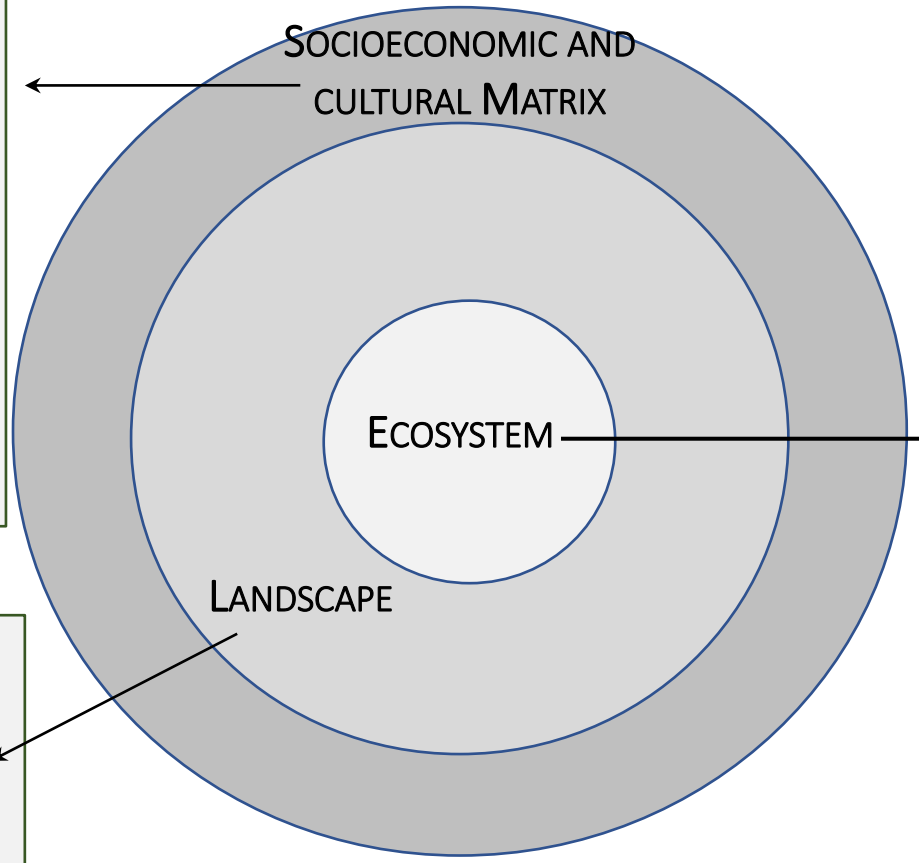
Biological degradation drivers: tillage intensity and frequency, poor crop rotation and soil coverage, heavy use of pesticides

Chemical degradation drivers: heavy use of fertilizer, poor irrigation water quality and intensity of cropping systems


Poverty
Increasing population
Reduced per capita land resources
Inappropriate use of marginal land
Unsustainable land management
Land Degradation
Reduced productivity

Socioecological indicators to evaluate the system condition across scales

- **Land governance: understand land tenure and engage stakeholders** (*Who owns the land? Who are the key stakeholders?)*
- **Understand how the forest is traditionally used**, which species provide products that are helpful to the local population (*What do people need?)*
- **Profitability and management costs**



Analyze landscape dynamics

- Changes in land use/land cover in space and time
- Underlying drivers of change/degradation factors
- Landscape fragmentation and connectivity

Ecosystem structural indicators

- Biodiversity (species richness and diversity/composition; indicator plants)
- Forest structure (tree natural regeneration, tree height, diameter, canopy cover, tree mortality)
- Soil health (soil organic matter and nutrient content, soil physical properties)

Analyze ecosystem functions

- Net primary productivity
- Carbon sequestration rates
- Seed dispersal
- Regenerative capacity and the stage of natural succession of the native plant cover (e.g., seeds, seedlings)
- Plant-plant interactions (competition/facilitation) between woody plants (trees/shrubs) and herbaceous crops
- Plant-animal interactions (herbivory on seeds and seedlings)

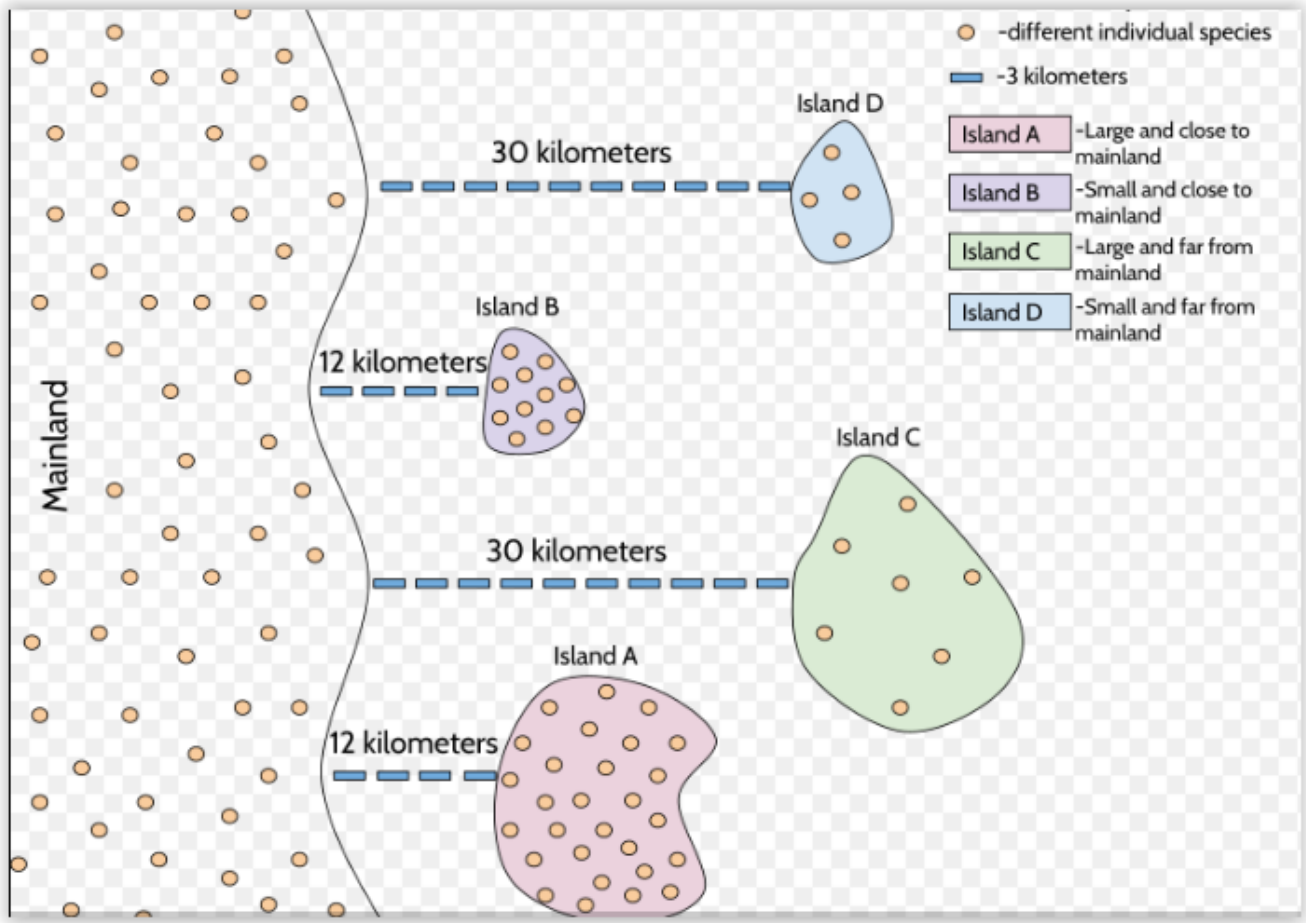
Landscape fragmentation and connectivity

The Theory of Island Biogeography

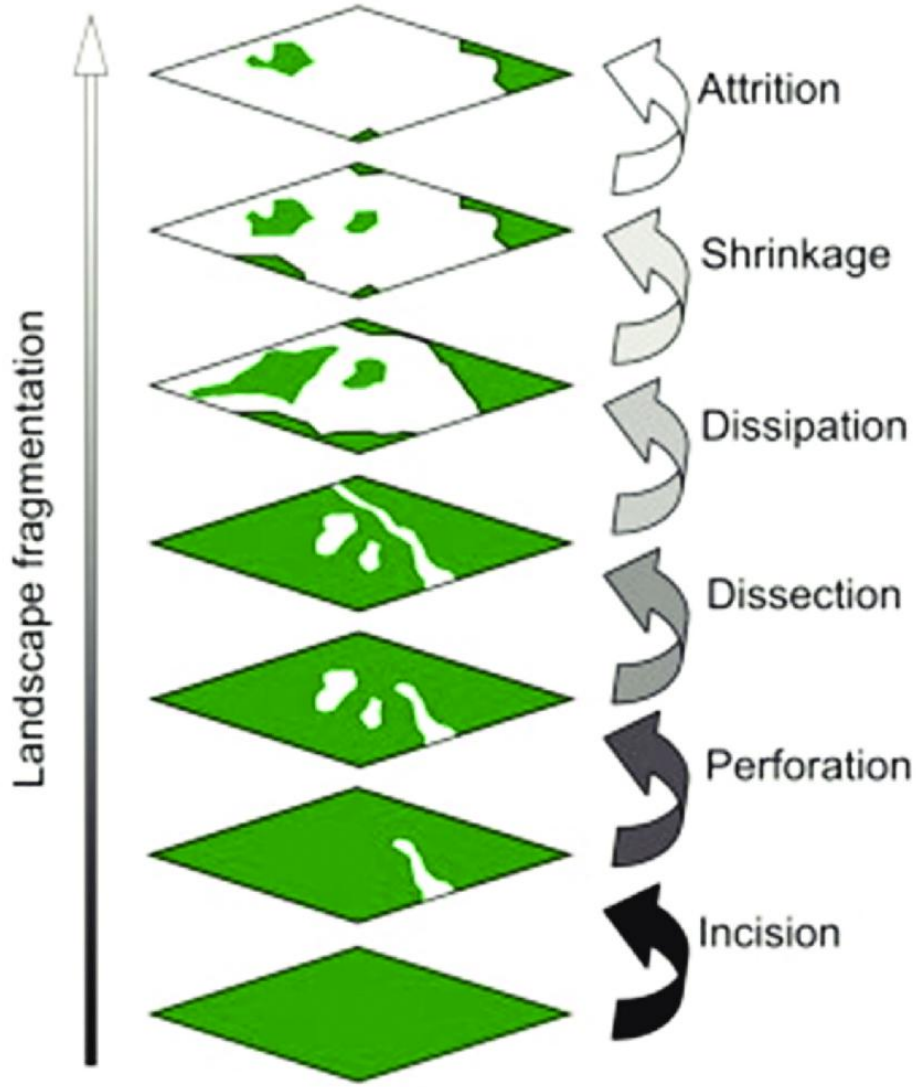
The distance of the island from the mainland (island isolation) and the size of the island affect equilibrium species richness.

Island isolation affects immigration rates and island size affects extinction rates.

Larger, less isolated islands have higher species counts, while smaller, more remote islands have lower counts.



Landscape fragmentation and connectivity



Landscape fragmentation is the process of breaking large areas of natural habitat into smaller, more isolated patches

Several phases showing significant changes in the pattern or function of the landscape (Forman 1995). In reality, these phases may take place simultaneously; however, a dominant phase can often be identified.

Under the theory of island biogeography, the remaining habitat fragments represent islands in an inhospitable sea.

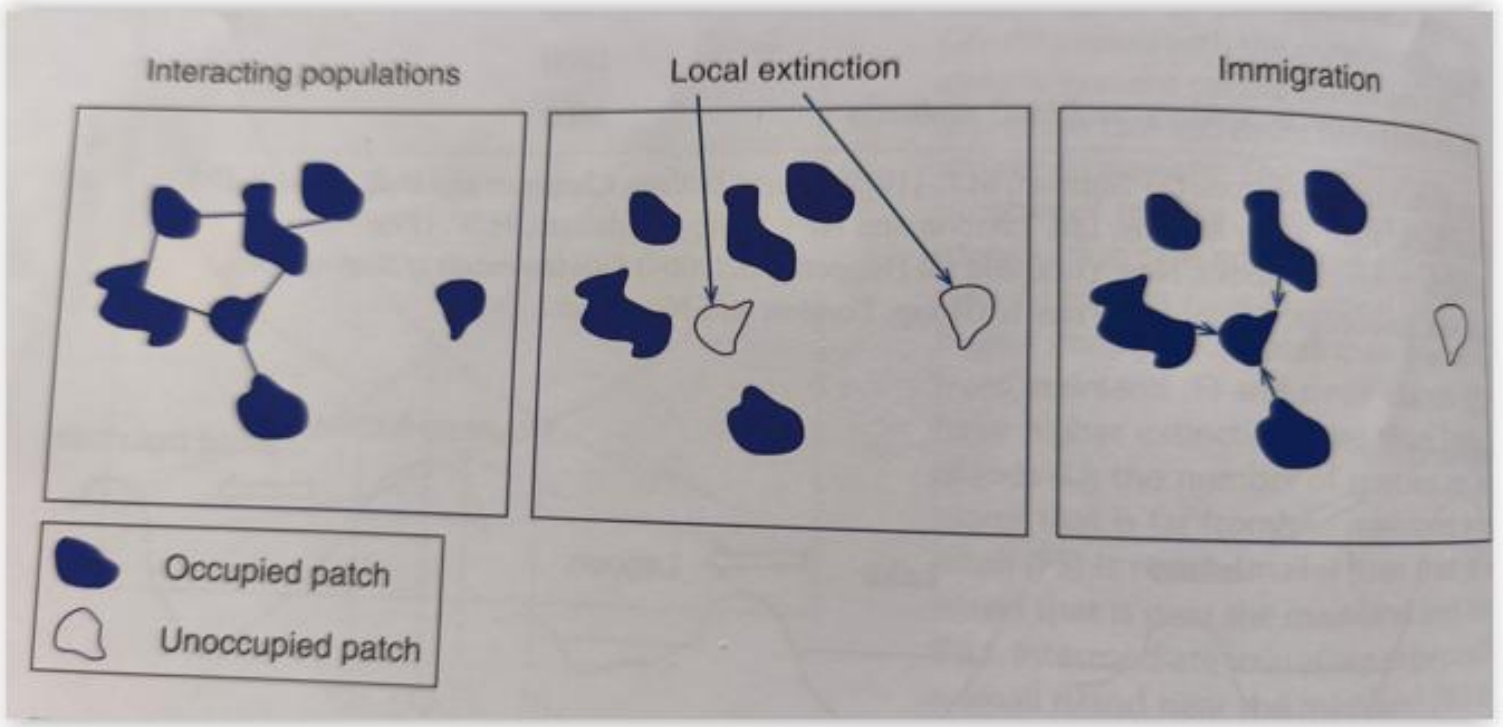
These fragments or islands can be seen as metapopulations.

Landscape fragmentation and connectivity

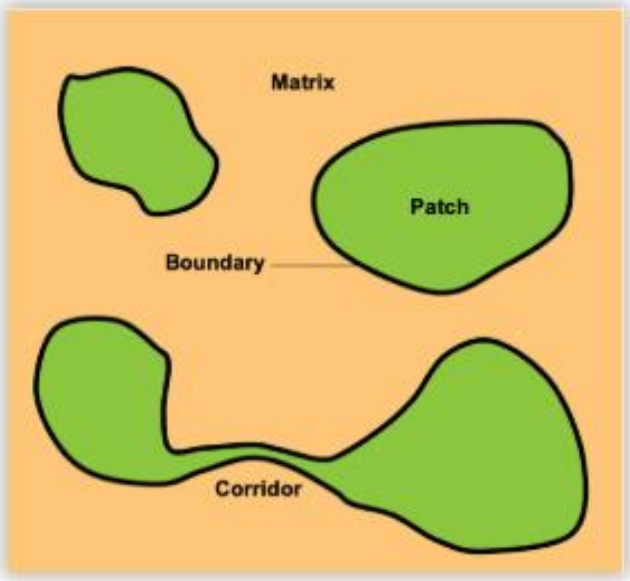
A **metapopulation** is a group of populations (often called subpopulations) that occupy spatially distinct habitat **patches** and where some movement of individuals among patches is possible.

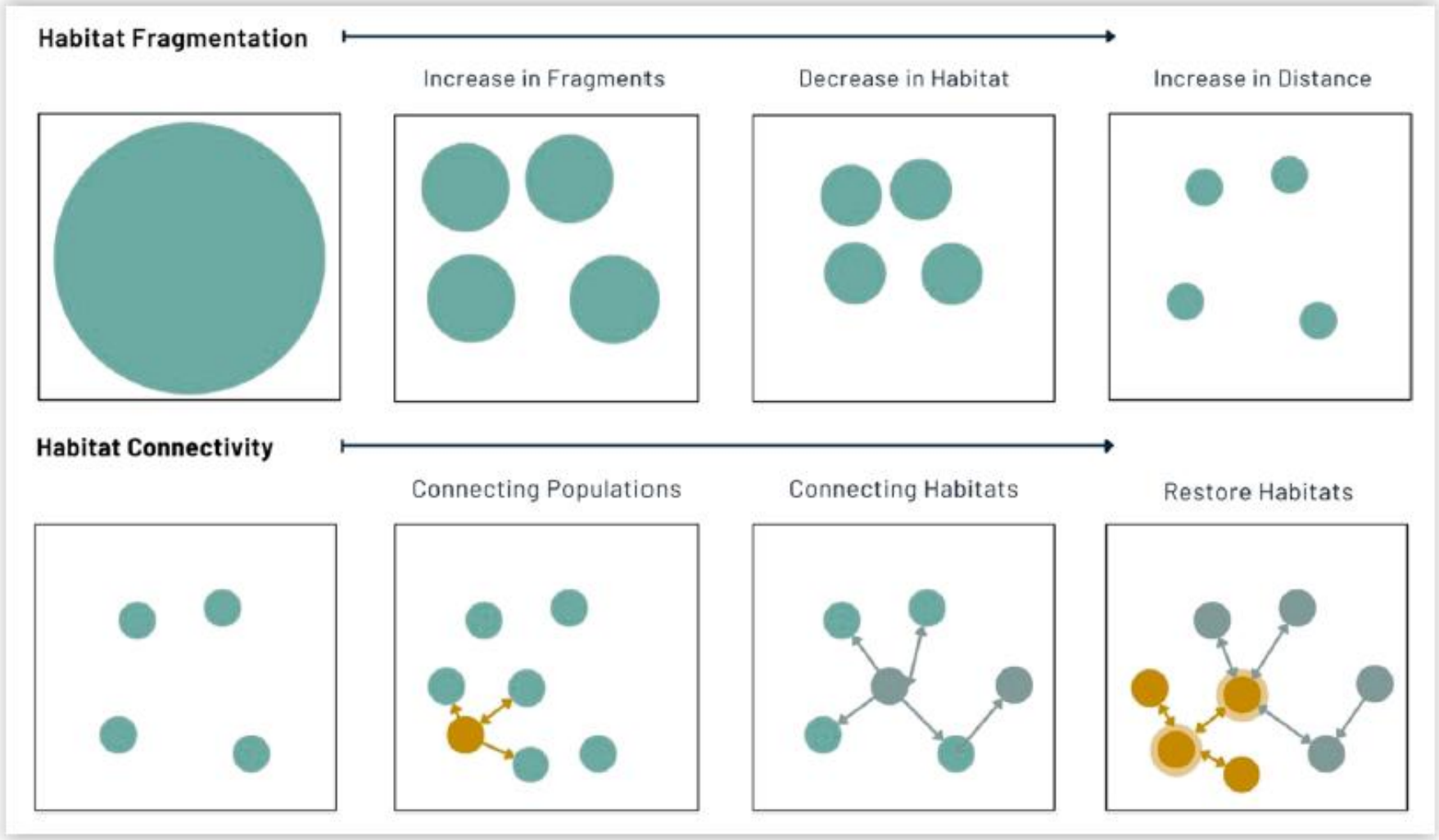
These local populations interact through the dispersal of individuals, or colonization and extinction.

Local populations (population on a single patch) have a probability of extinction, so the long-term persistence of the metapopulation depends on the process of (re)colonization



Landscape fragmentation and connectivity





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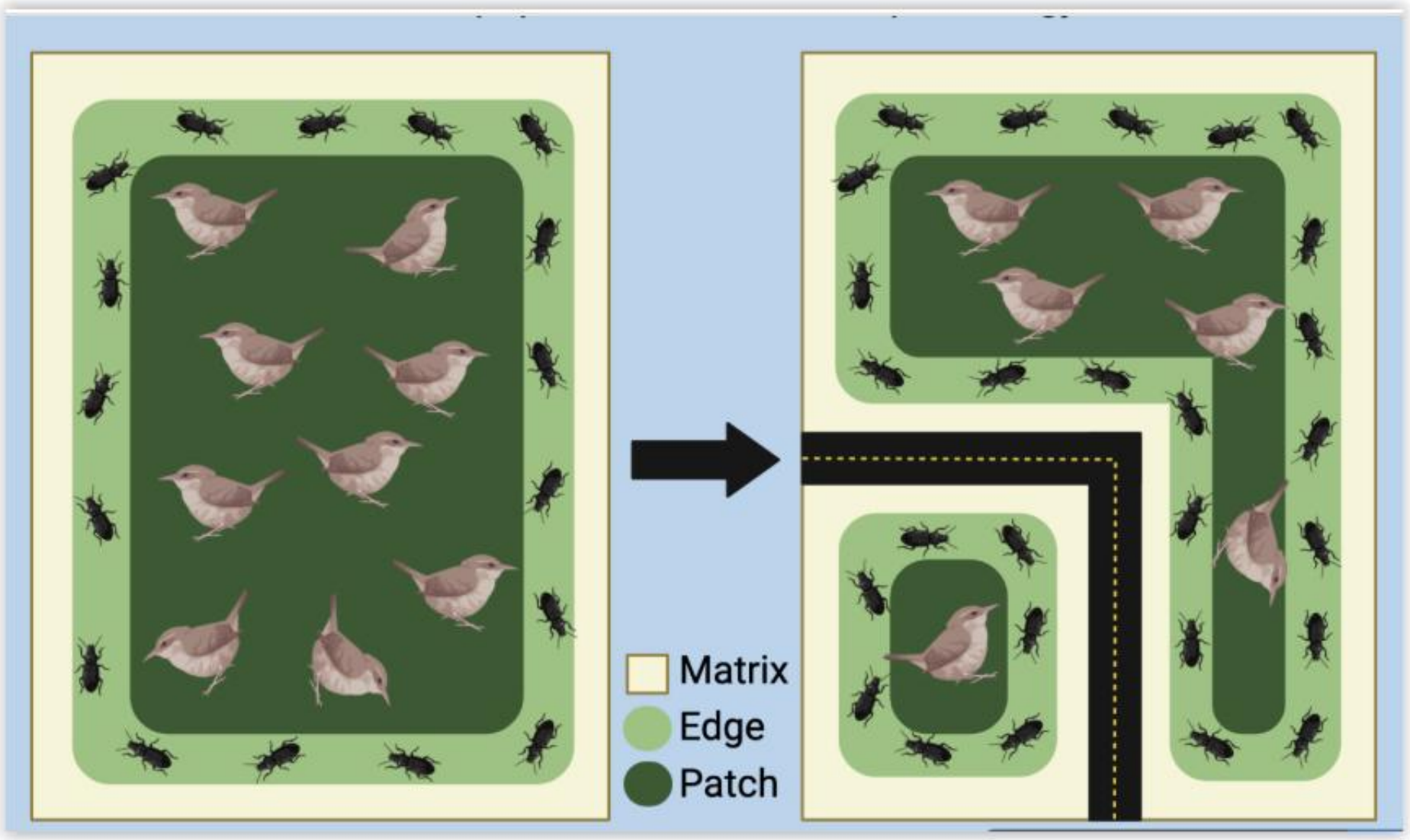
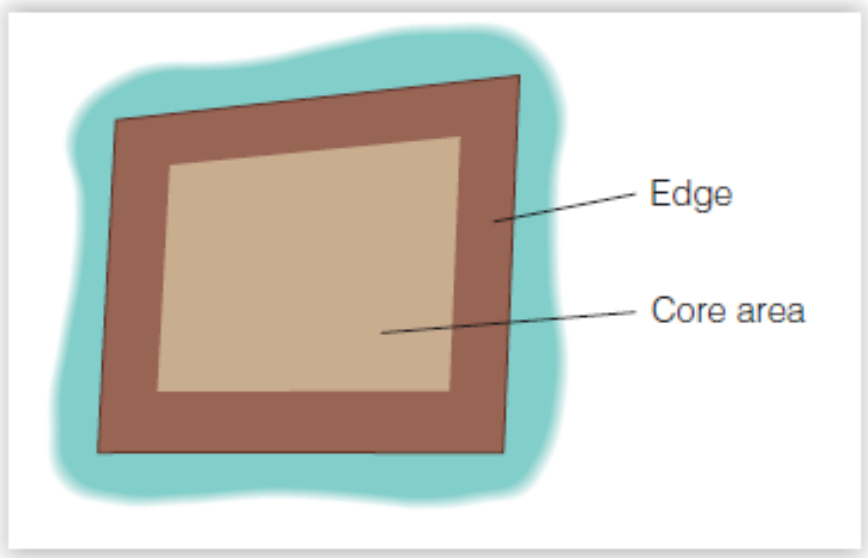
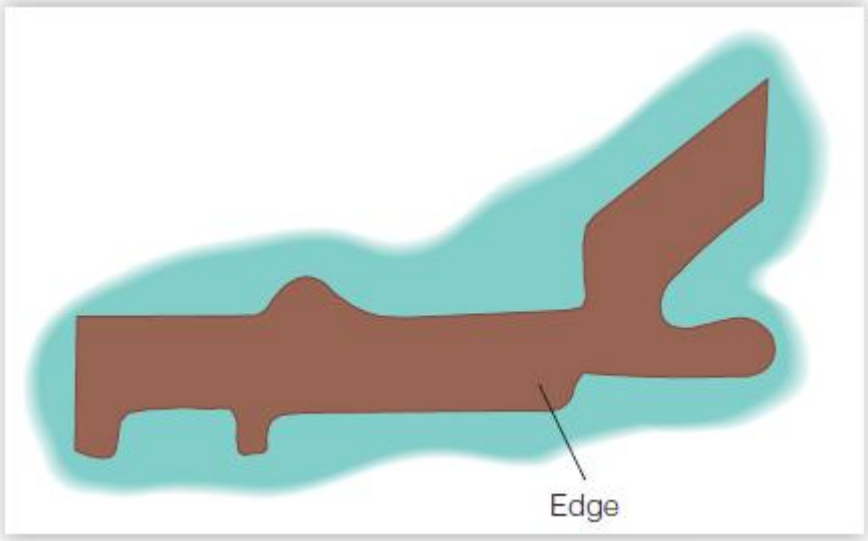


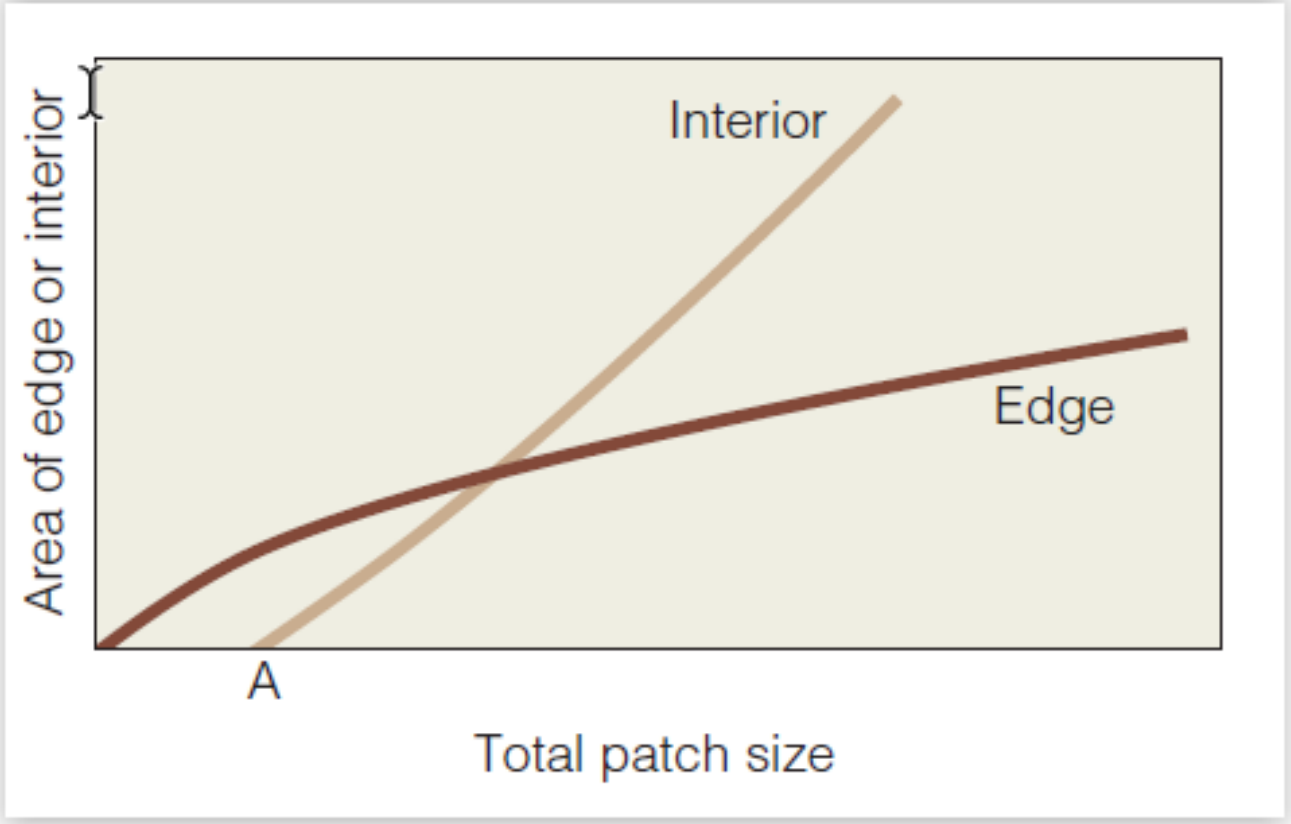
Fragmentation in a landscape:

- Core habitat and interior populations decrease
- Edge habitat and populations in edges increase

Landscape fragmentation and connectivity







Relationship between habitat patch size and area of edge and interior

Source: Smith and Smith (2015) Elements of Ecology. Pearson Education Limited

Landscape fragmentation and connectivity

Landscape connectivity is the degree to which the landscape facilitates or impedes the movement of organisms among patches. Connectivity is closely related to fragmentation.

Connectivity is species-specific

Landscapes with high connectivity (for a given species) are those that facilitate movement of organisms due to:

1. patches that are relatively close together (configuration) or
2. areas of non-habitat being relatively 'permeable' (because they are easy to move through).

Landscape connectivity

- **Structural connectivity** relates to the physical arrangement of habitat patches in the landscape (structure or configuration of the landscape, independent of species´ behavior)
- **Functional connectivity** describes the degree to which the landscape facilitates the movement of organisms. It is a function of both the physical structure of the landscape and the behavioral responses of organisms to the structure (species-specific).

Landscape fragmentation and connectivity

Grassland patches in an agricultural matrix

Structural connectivity:

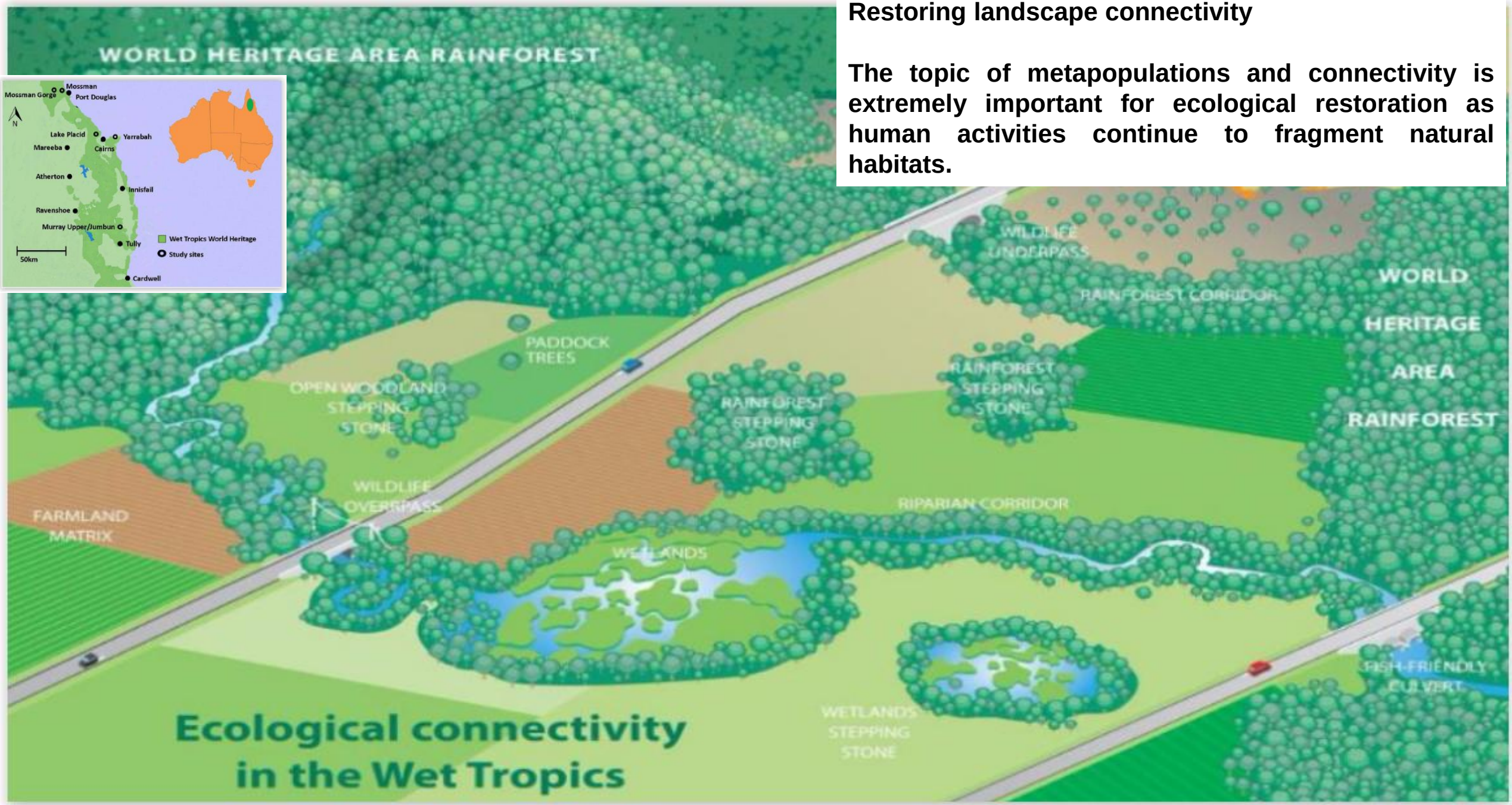
Low because grassland patches are isolated within the agricultural matrix

Functional connectivity:

- High for butterflies with strong dispersal ability that might fly from patch to patch
- Low for a ground beetle with poor dispersal

Restoring landscape connectivity

The topic of metapopulations and connectivity is extremely important for ecological restoration as human activities continue to fragment natural habitats.



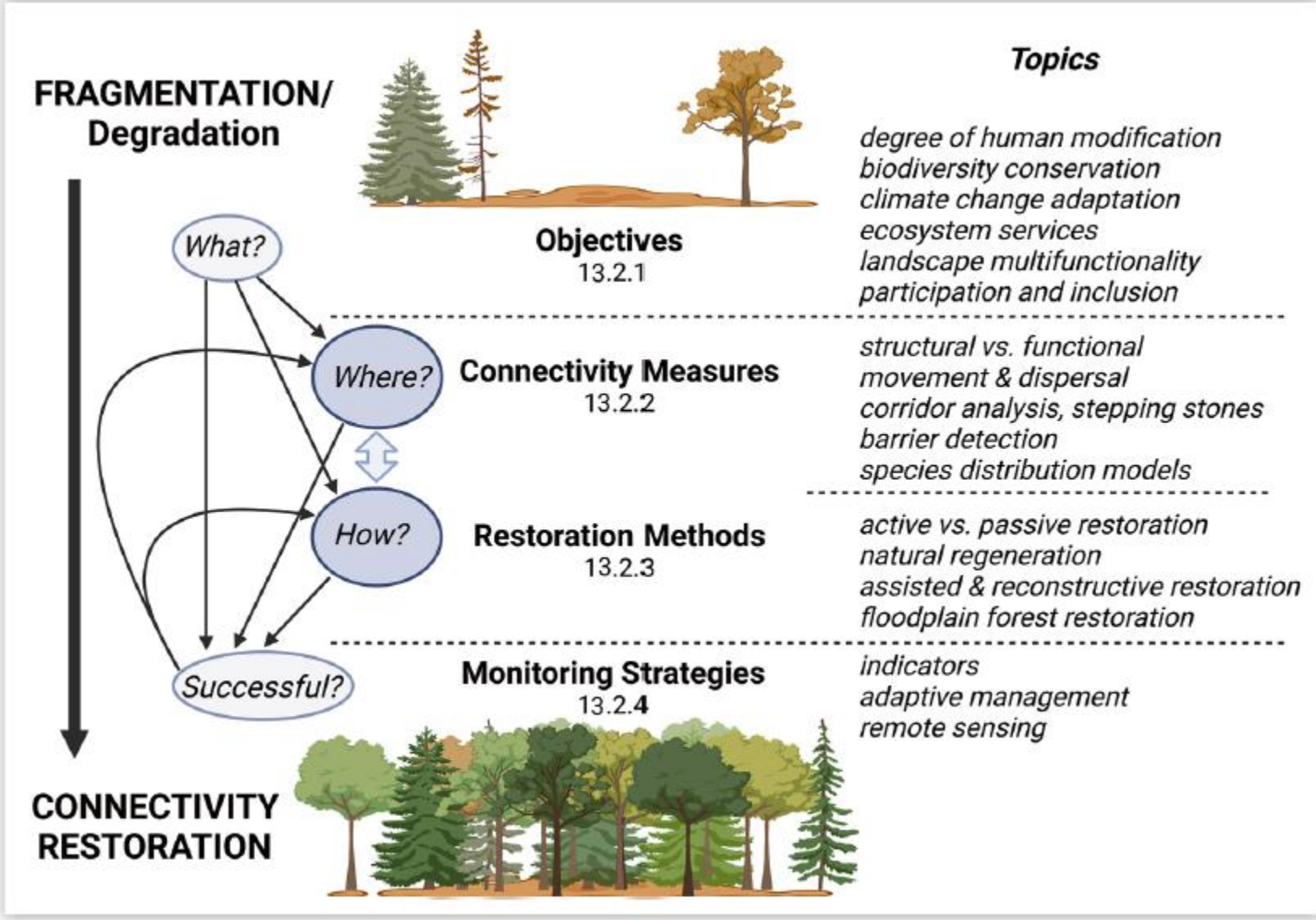
Approaches and methods for restoration: general overview

(1) **What is to be restored?** (identify causes of degradation/disturbances and restoration objectives)

(2) **Where should the restoration activities be focused?** (determining spatial and connectivity measures)

(3) **How can the restoration best be implemented?** (restoration methods)

(4) **How successful is the restoration?** (determining monitoring measures)



Source: Lapin *et al.* (2025) Ecological connectivity of forest ecosystems. Springer https://doi.org/10.1007/978-3-031-82206-3

The choice of restoration methods depends strongly on the degree of disturbances, ecological knowledge, objectives, available budget, and the restoration scale

Approaches and methods: restoring tree cover (passive and active)

INCREASING DEGRADATION, RESTORATION INTENSITY AND COST

Restoration interventions	Advantages	Disadvantages/limitations
Protected tree natural regeneration with minimal intervention. Remove causes of degradation or obstacles to tree regeneration (e.g., cattle) and let forest recover on its own	Inexpensive, except if the area needs to be fenced; can be achieved over large areas	Expensive if weeds, fire or pests need to be controlled; compensation for land users

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Assisted or enhanced tree natural regeneration. Weed control, mulching, improve soil conditions, reduce competition from other plants (woody and weedy species), use of plant facilitation, placement of artificial bird perches	Inexpensive	Limited by lack of knowledge on biotic interactions (plant-plant, plant-animal) and on tree recruitment cycle; outcomes are highly variable

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Enrichment planting. Plant key species of single trees or clumps of trees across the landscape; improve soil conditions; create hedgerows to enhance landscape connectivity and soil regeneration	Relatively inexpensive but more expensive than seeding; trees can serve as seed producers and perches for seed dispersers such as birds; forest patches can increase landscape connectivity	Limited by lack of knowledge on biotic interactions (plant-plant, plant-animal) and on tree recruitment cycle

Approaches and methods: restoring tree cover (passive and active)

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The Framework Species Method (FSM). Densely planting open sites (close to natural forests) with woody species indigenous to the reference ecosystem, and selected for their ability to accelerate ecological succession (tolerant of open conditions, weed suppresser, attractiveness to seed-dispersing animals)	Accelerates ecological succession and enhances landscape connectivity	Costly; it involves raising seedlings, site preparation and planting. Effective if there are forest remnants and seed dispersers populations

Approaches and methods: restoring tree cover (passive and active)

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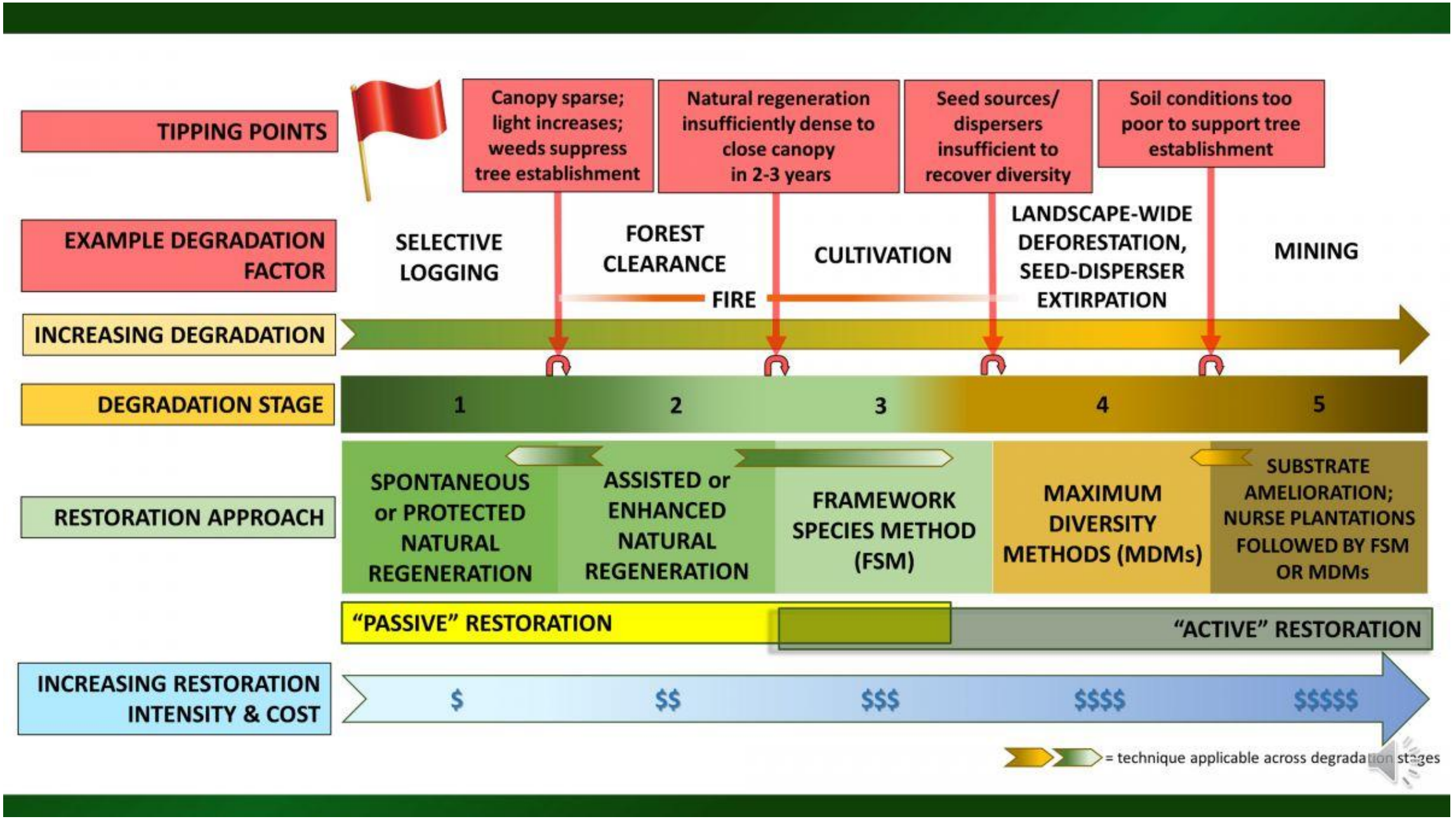
The Many species diversity method (MSDM): Densely planting with larger percentage of late-successional species and fewer pioneer species	Accelerates ecological succession	Costly as FSM but maintenance may continue longer, due to slower growth of late-successional species.

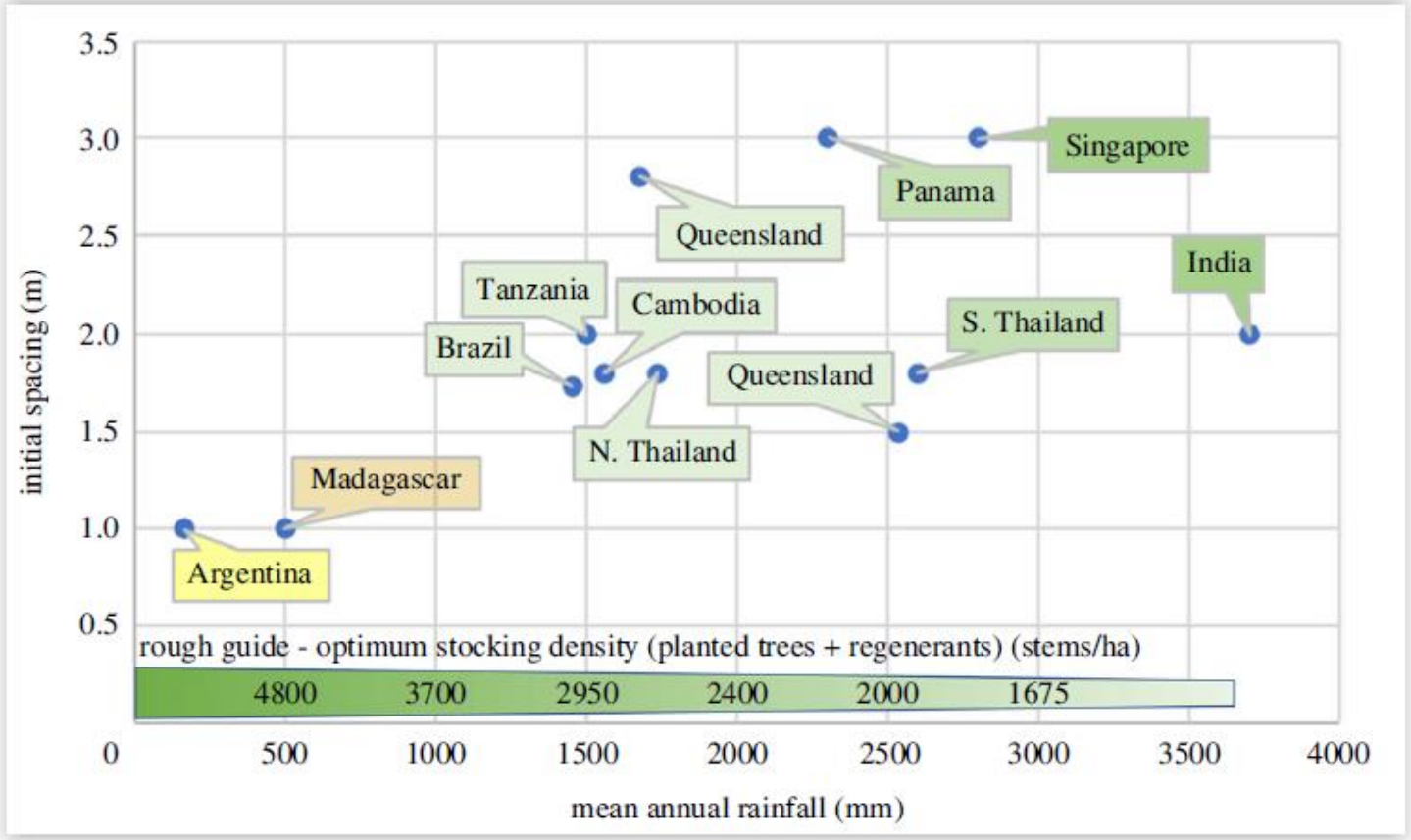


Elliott et al. (2022) Phil. Trans. R. Soc. B 378:20210073. https://doi.org/10.1098/rstb.2021.0073

The Framework Species Method (FSM)

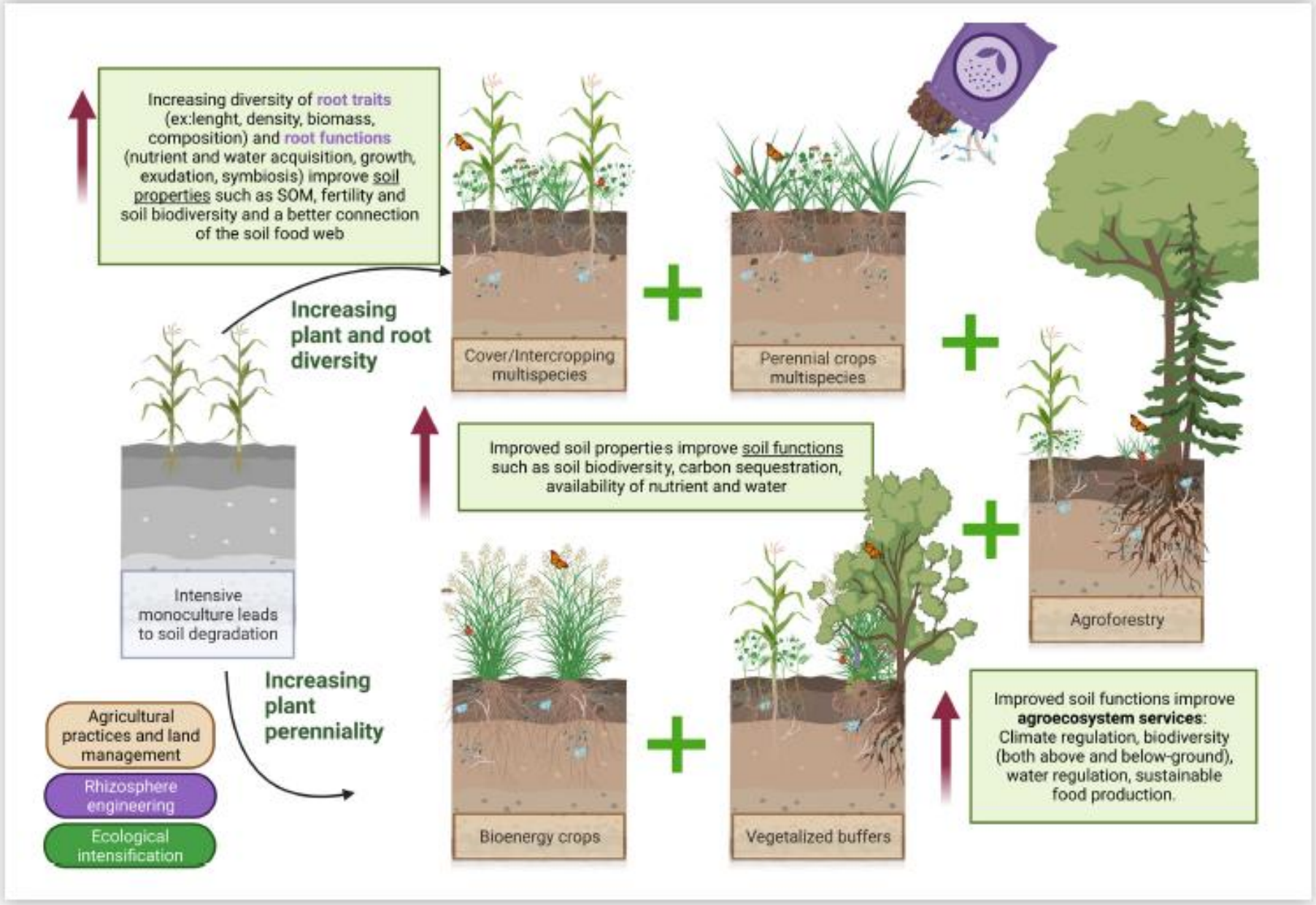
(a) Degraded forest patch in northern Thailand (1998)

(b) Same location after planting **framework tree species** (3100 trees/ha) (2013)



Source: *Elliott et al. (2022) Phil. Trans. R. Soc. B 378:20210073. https://doi.org/10.1098/rstb.2021.0073*

Soil restoration: the phytotechnology toolbox

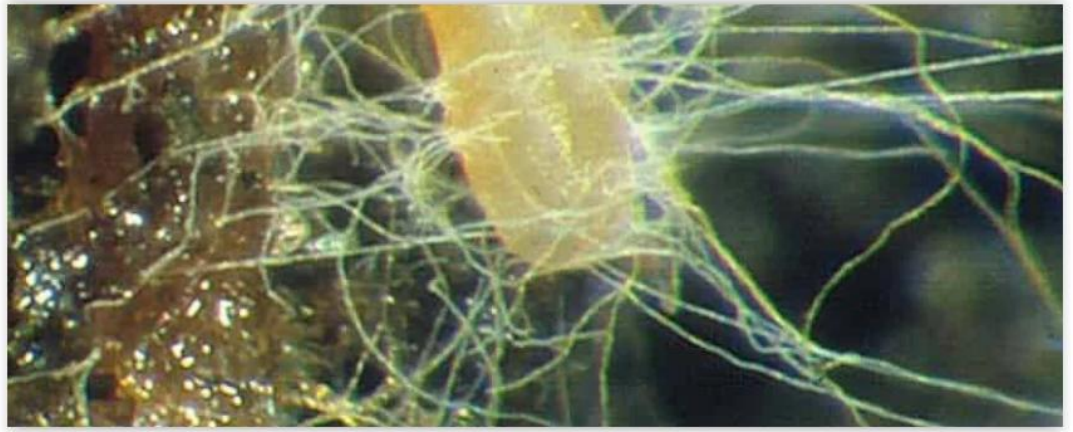


Source: Dessureault-Rompré J. (2022) Restoring Soil Functions and Agroecosystem Services Through Phytotechnologies. Frontiers in Soil Science 2:927148. doi: 10.3389/fsoil.2022.927148

Soil restoration: the phytotechnology toolbox

1) **Agricultural practices**: cover crops and multispecies intercrops, perennial crops, agroforestry

2) Rhizosphere engineering: soil amendments, inoculation with mycorrhizae, selection of plant species based on root and other traits for a specific goal (improving soil fertility? physical conditions?)



3) Ecological intensification: multiply the beneficial agricultural practices at the farm scale

Source: Dessureault-Rompré J. (2022) Restoring Soil Functions and Agroecosystem Services Through Phytotechnologies. Frontiers in Soil Science 2:927148. doi: 10.3389/fsoil.2022.927148

Soil restoration: examples of soil amendments

Coconut coir (sandy soils)

Compost (lack of OM; improve soil structure)

Vermiculite (sandy soil, improve water retention)

Manure (lack of OM; improve soil structure)

Straw (sandy soil, improve water retention)

Biochar (improve nutrient availability to plants and water retention)

Approaches and methods for restoration

Inoculation process of coffee seedlings with arbuscular mycorrhizal fungi

Corazon-Guivin *et al.* (2023) Rhizoglomus variabile and Nanoglomus plukenetiae, native to Peru, promote coffee growth in Western Amazonia. Microorganisms 11: 2883. https://doi.org/10.3390/microorganisms11122883

Ectomycorrhizal morphotypes

Examples of successful agroforestry restoration: African drylands

Regreening Africa is an initiative co-led by the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) to restore 5 million hectares by 2030, by Integrating trees into farming systems, conserving soils and water (with water harvest techniques) and community engagement. It is boosting biodiversity and supporting local communities. https://regreeningafrica.org/

Water harvesting

https://www.youtube.com/watch?v=QLH-b6sL_Pk

Examples of successful agroforestry restoration: African drylands

The Great Green Wall is an African-led initiative with tree planting into farming systems. It started in 2007, with the ambition to grow an 8000 km green wall across the entire width of Africa by 2030.

Examples of successful agroforestry restoration: coffee plantations in China

Coffee production in southwest China was strongly affected by droughts, soil degradation, and pests. In 2022 an agroforestry project was implemented with local farmers and coffee companies.

The project promotes the planting of shade and fruit trees, which improves the quality of the coffee beans and helps mitigate the impact of climate change, reducing pest attacks.

Planting multiple tree species can also increase revenue for smallholder farmers. Good Agriculture Practices were also adopted such as mulching and/or cover crops.

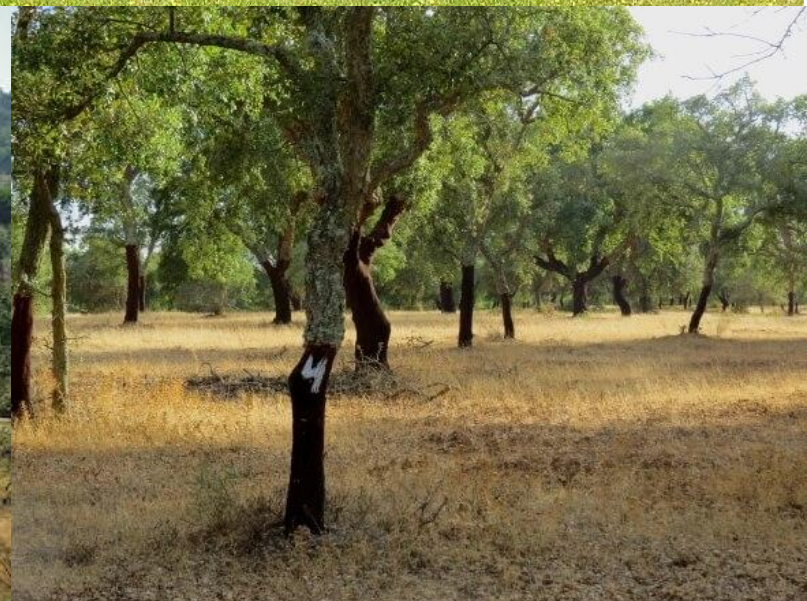
Coffee berry borer (*Hypothenemus hampei*)

Cover crops - growing a variety of different crops in a planned sequence on the same piece of land over a series of seasons or years.

2. CASE STUDY: MEDITERRANEAN OAK AGROFORESTRY SYSTEMS IN PORTUGAL





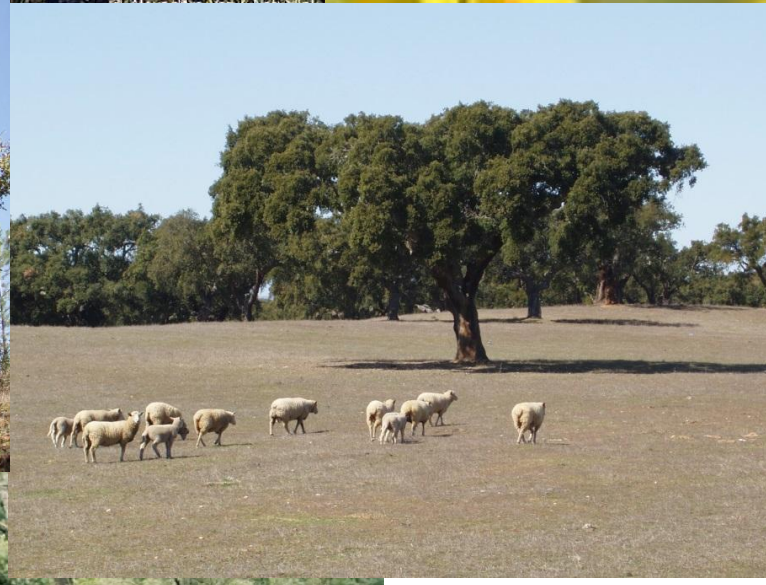


Mediterranean oak woodlands

- ✓ Global Ecoregion 200 (high biodiversity, WWF)
- ✓ Protected ecosystems (Natura 2000 Network)
- ✓ Provision of many ecosystem services (est. in 100€ / ha / year)

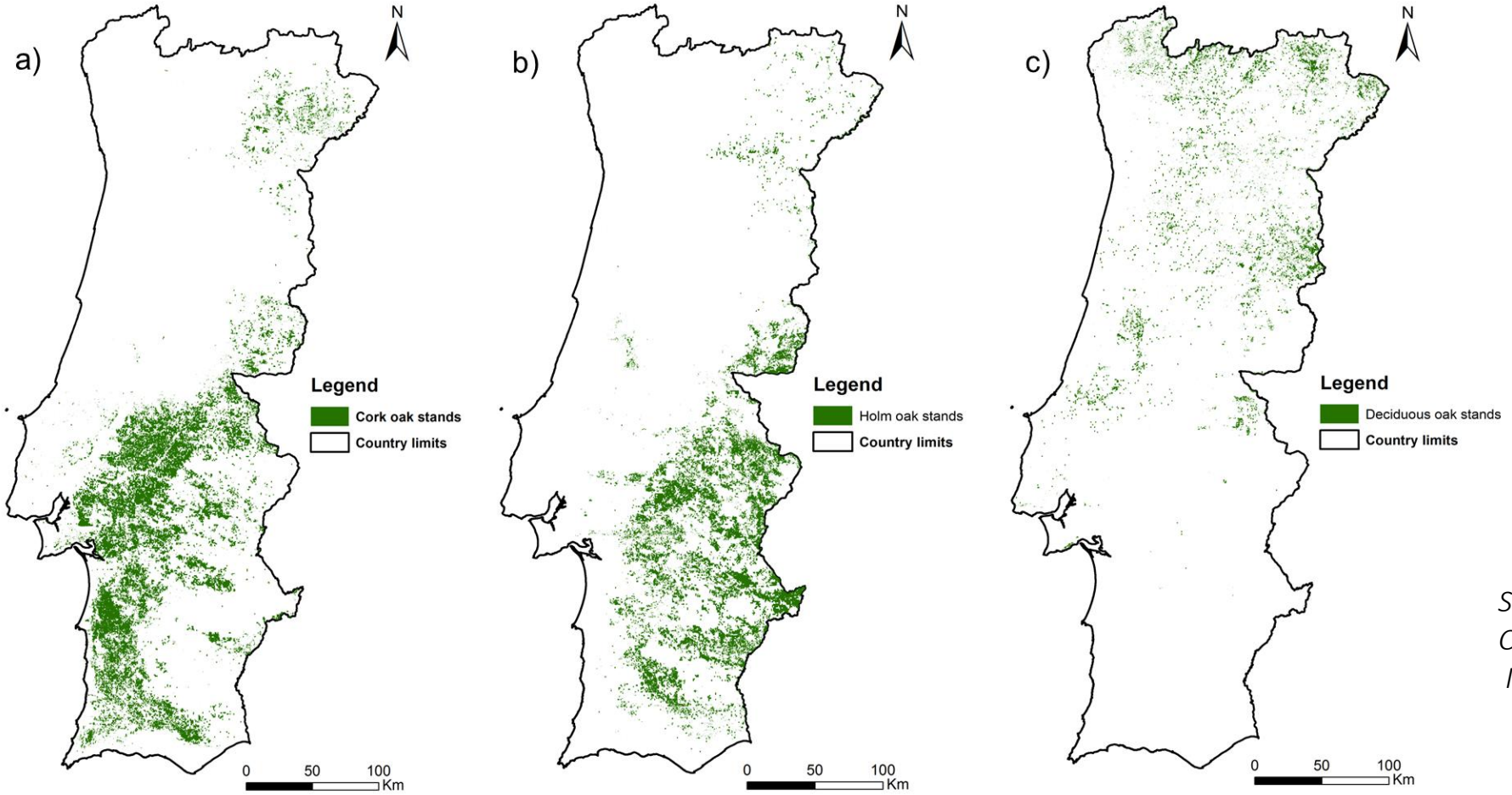








Distribution of native oak species in Portugal



Source:
Capelo and Catry (2007a, 2007b)
Inventario Florestal Nacional(IFN) 2015

Cork oak (*Quercus suber* L.)
737 000 ha (23% of forest area)

Holm oak (*Quercus rotundifolia* L.)
330 000 ha (11% of forest area)

Deciduous oaks (*Q. pyrenaica* Willd., *Q. faginea* Lam., *Q. robur* L.)
67 000 ha (2% of forest area)

A medieval tax named "*montaticum*" (in latin) was paid per livestock head for the use of a grazing area

The Latin word *"deffensa"* means a fenced pasture or enclosed area that allows controlled grazing

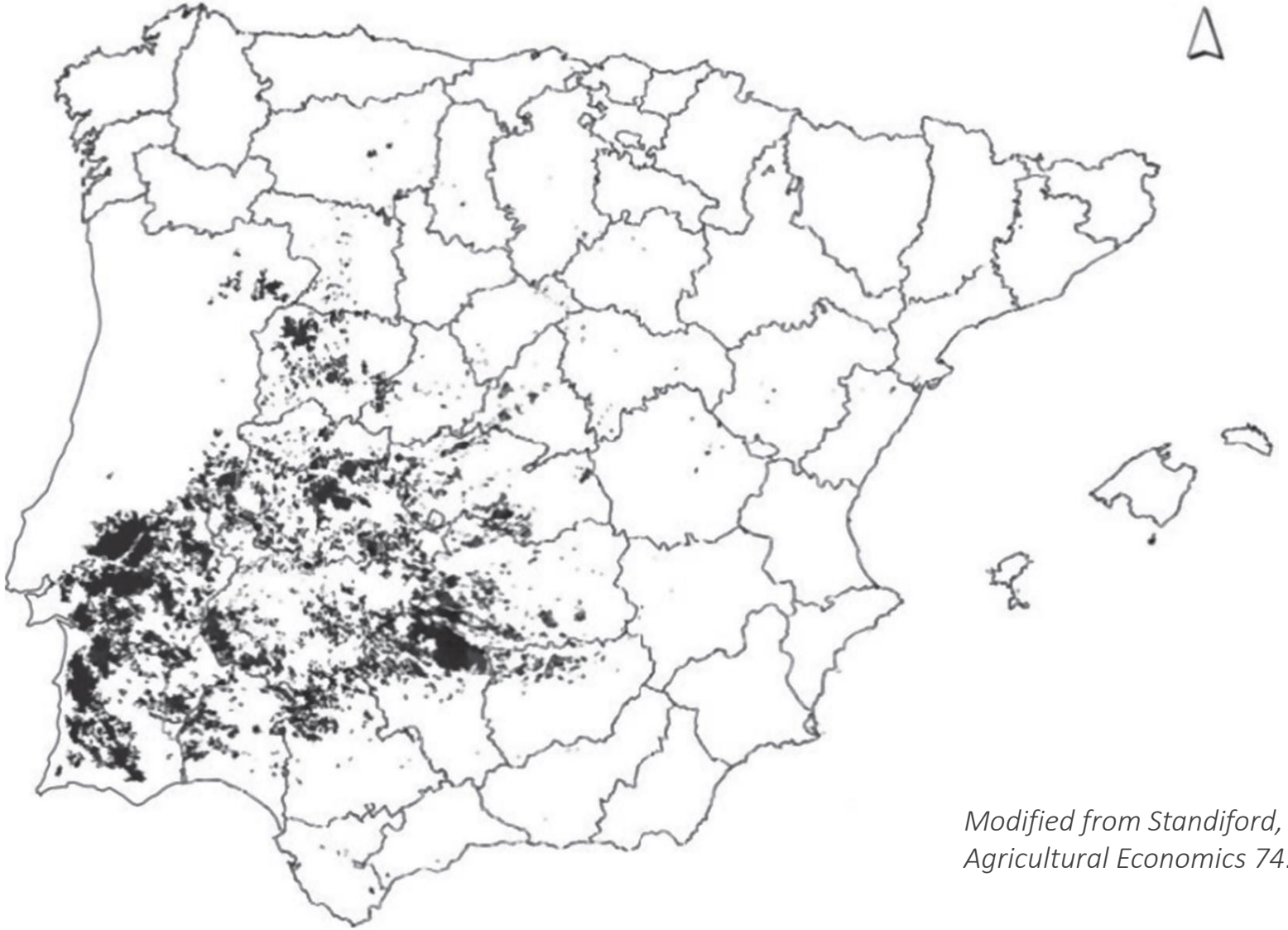
The montado / dehesa

Agrosilvopastoral land use system

- Open overstory of oak trees (typically cork oak or holm oak) of varying density (20 – 100 trees/ha)
- Understory of cropland (usually cereals), native grasses or improved pastures for livestock grazing (and patches of native shrublands)
- Needs human management to maintain its structure

The montado / dehesa in Iberian Peninsula

Montados are among the most widespread agrosilvopastoral systems in Europe



Spain: 3.6 million ha
Portugal: 1 million ha

Modified from Standiford, R.B. and R.E. Howitt. 1992. American Journal of Agricultural Economics 74:421–433

Oak woodlands and montados: a diversity of uses and products

- **Cork**
- Cereal crops
- Livestock feed (holm oak acorns, pastures)
- Meat and cheese: free-raging pigs (**black pig ham** from holm oak montados), cattle, sheep, goats
- Fuel (firewood, charcoal)
- Shrub products (strawberry tree fruits distilled for liquor)
- Wild game (red deer, wild boar, hares, wild rabbit, partridges)
- Aromatic and medicinal plants, edible mushrooms, honey





© Víctor Manuel Pizarro FOTOGRAFÍA
http://ciudad-dormida.blogspot.com

Cork

Extracted every 9 years from the cork oak, is composed of suberin, a hydrophobic substance, used in wine stoppers and many other applications.

Portugal produces approximately half of the cork harvested annually worldwide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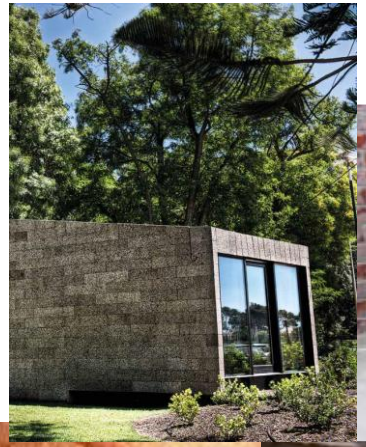
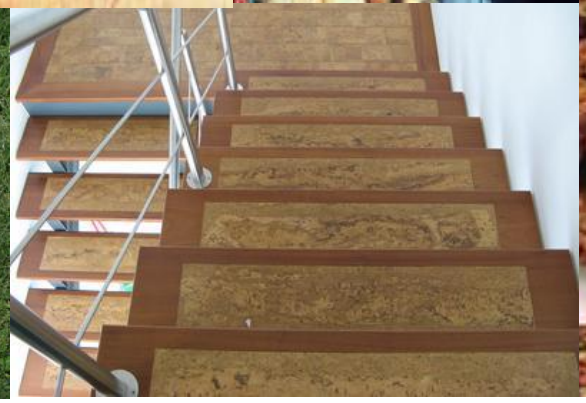
Cork products










Oak woodlands

Oak montados

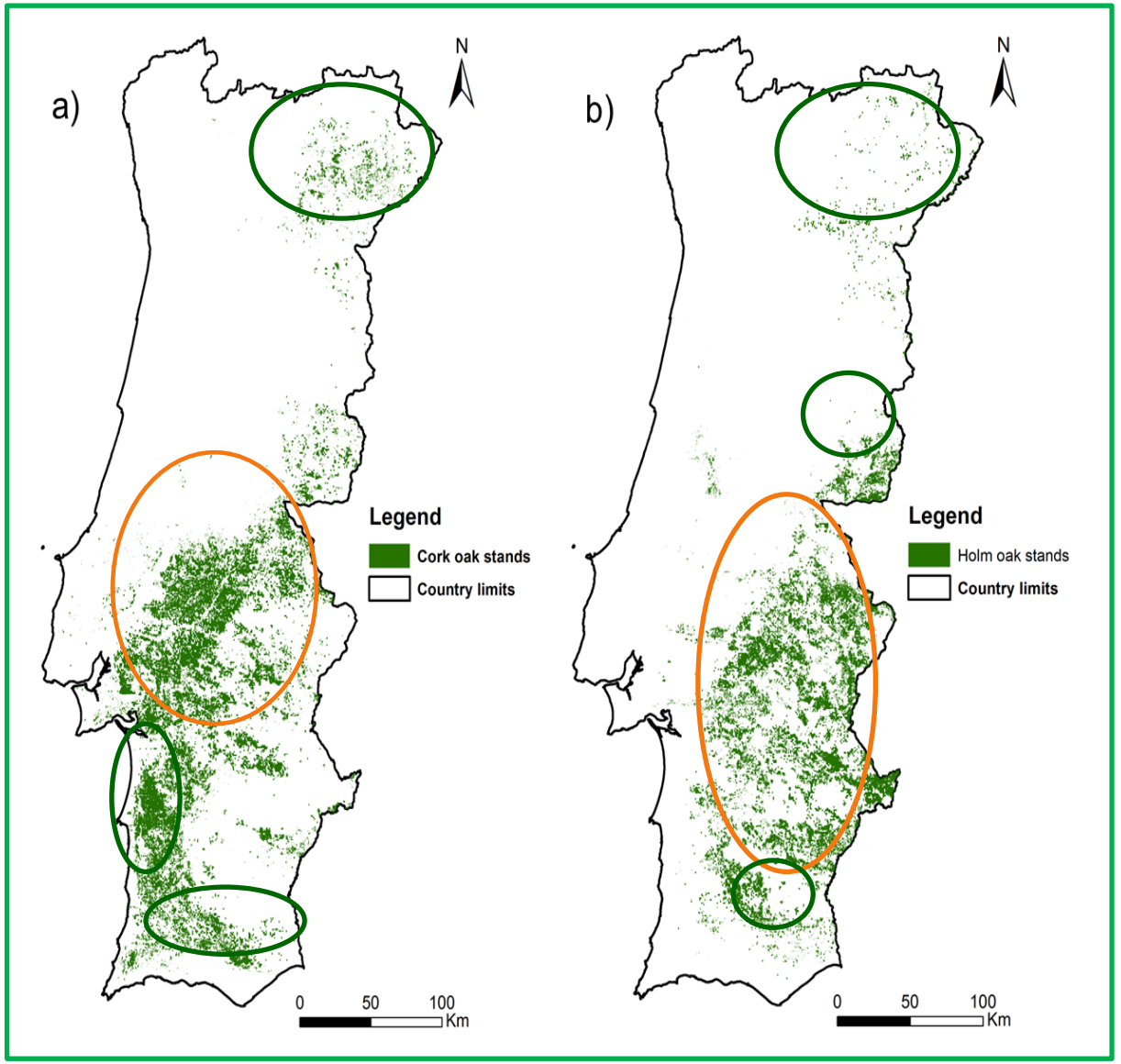
Land management systems in Portugal

Two main types of land management systems with contrasting structure?

Intensity of human management

- **Oak woodlands structure**
  - Higher oak canopy cover
  - Presence of developed understory shrub cover
  - Higher quantity of litter
  - (smaller scale land holdings)

- **Oak agroforestry systems (montados) structure**
  - Lower oak canopy cover
  - Absence or scattered understory shrub cover, with lower species diversity
  - Less complex community structure
  - Presence of native or improved herbaceous cover
  - (larger scale land holdings)



Legal and political framework

- Cork oak and holm oak are protected species in Portugal since 2001 by legal regulations that limit their cut and land conversion.

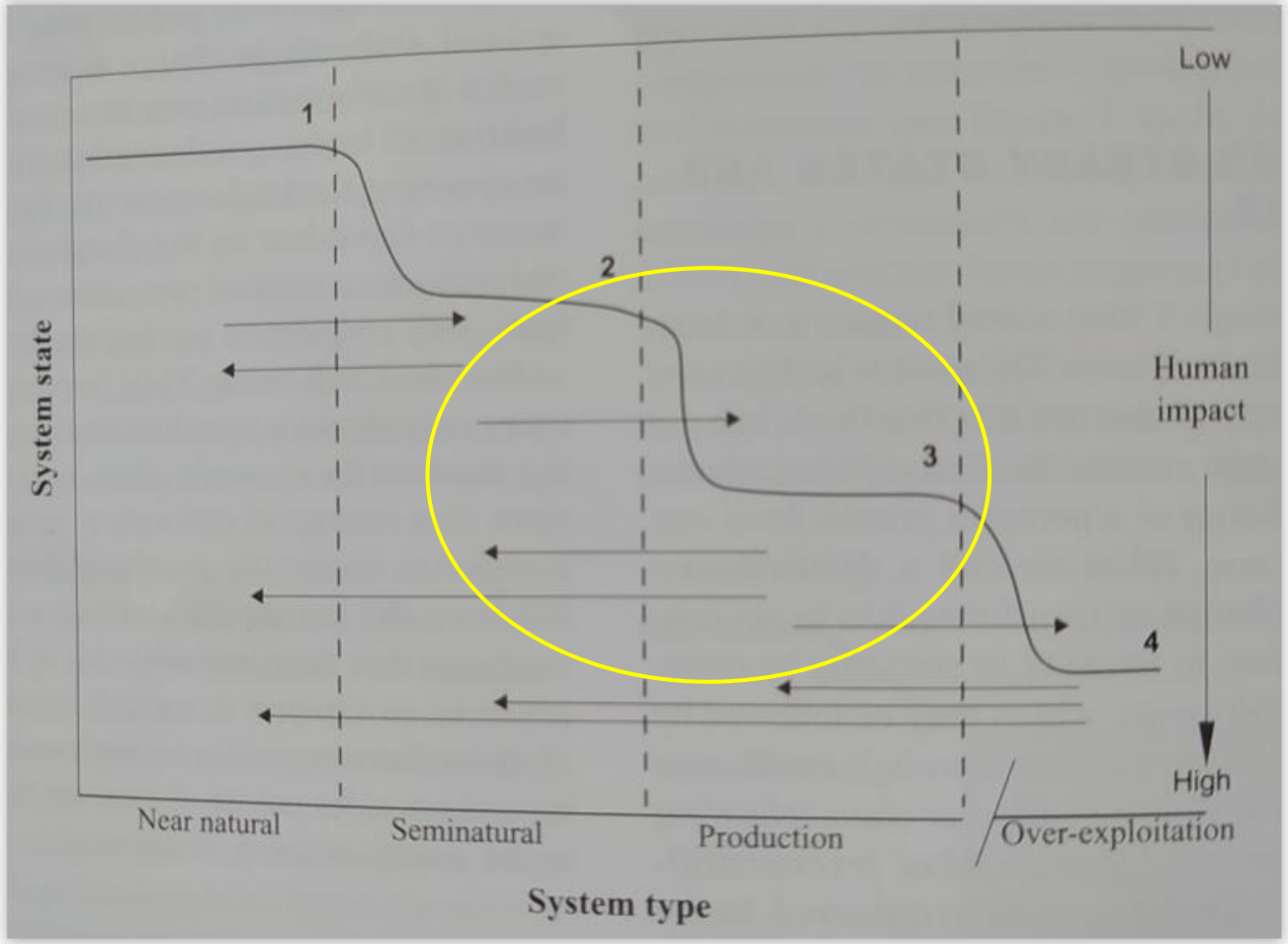
- Cork extraction is legally regulated (minimum requirements for debarking related to tree age, height, and years between cork extraction).

- Since 2000, there is national and EU funding specifically for oak forests and montados (measures include: reforestation, afforestation, sanitary protection), with increasing concern for environmental and biodiversity protection.

- Cork oak was legally declared as the national tree of Portugal in 2012.

A Socioecological Mosaic Landscape

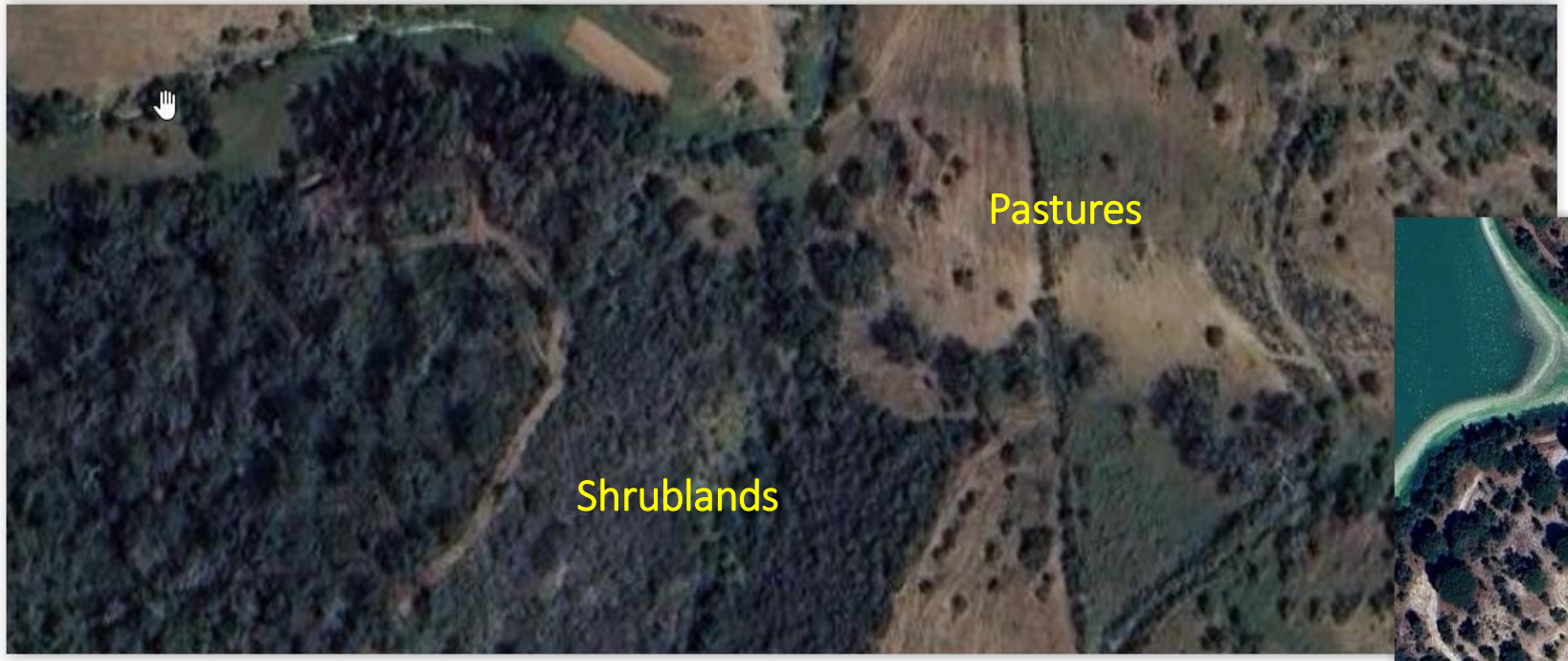
- Montados and oak woodlands are often interspersed **in a mosaic landscape,** with a gradient of management intensity, varying oak density and canopy cover
- For restoration purposes, the landscape mosaic is treated as a single, heterogenous ecosystem



Montado landscapes are socioecological systems determined by human management, balanced by ecological conditions (especially water availability). Oak density is determined by the need for space for cereal and pastures cultivation.

The landscape mosaic includes distinct patches (states) that range from seminatural to production systems.

A Socioecological Mosaic Landscape

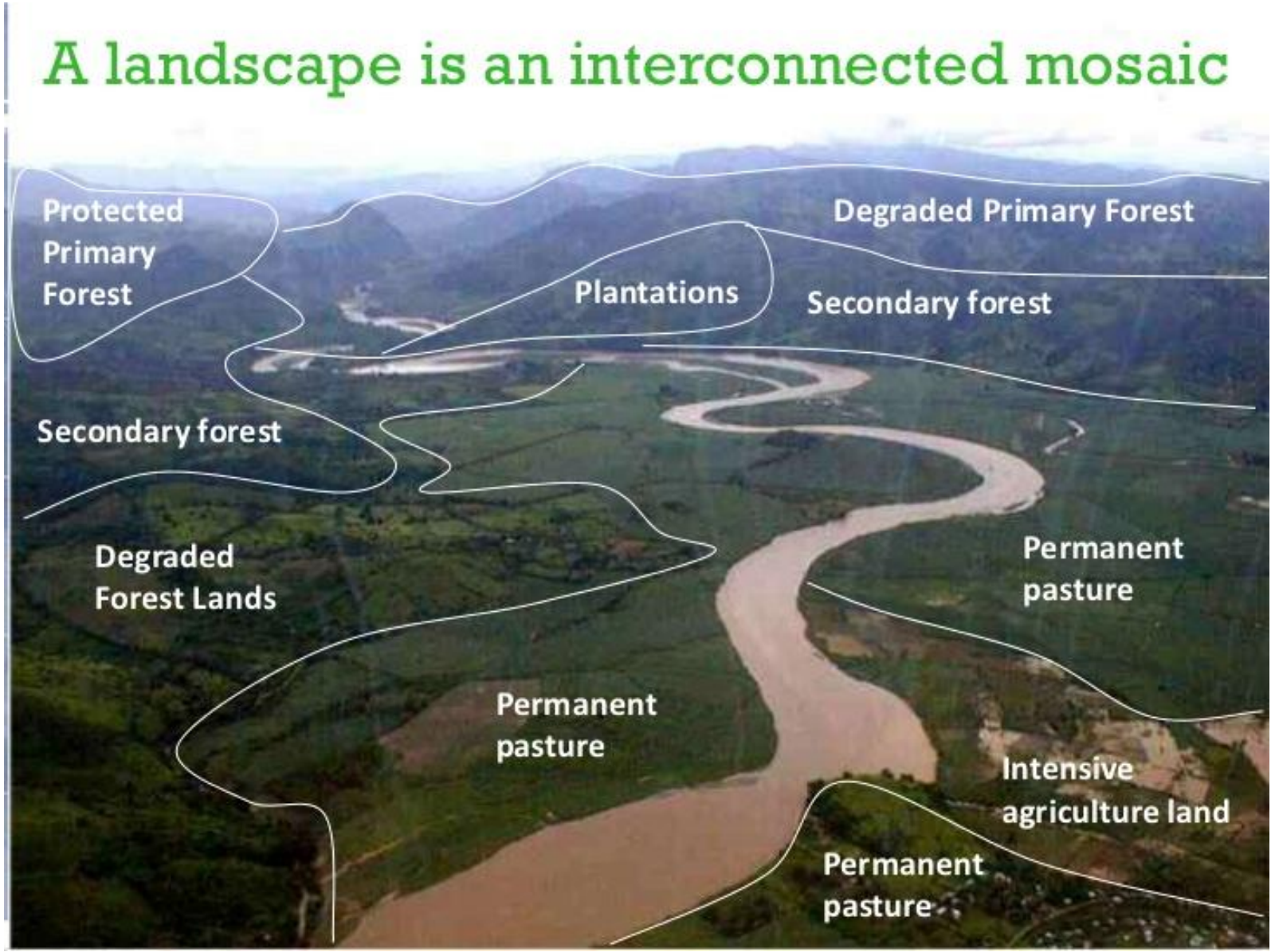


A Socioecological Mosaic Landscape

Emerging framework for forest landscape restoration

- restoration at a broader landscape scale, including several ecosystems and land uses;
- achieve trade-offs among conflicting interests;
- balance social, cultural, economic, and environmental benefits.

The Global Partnership on Forest and Landscape Restoration
http://www.forestlandscaperestoration.org/



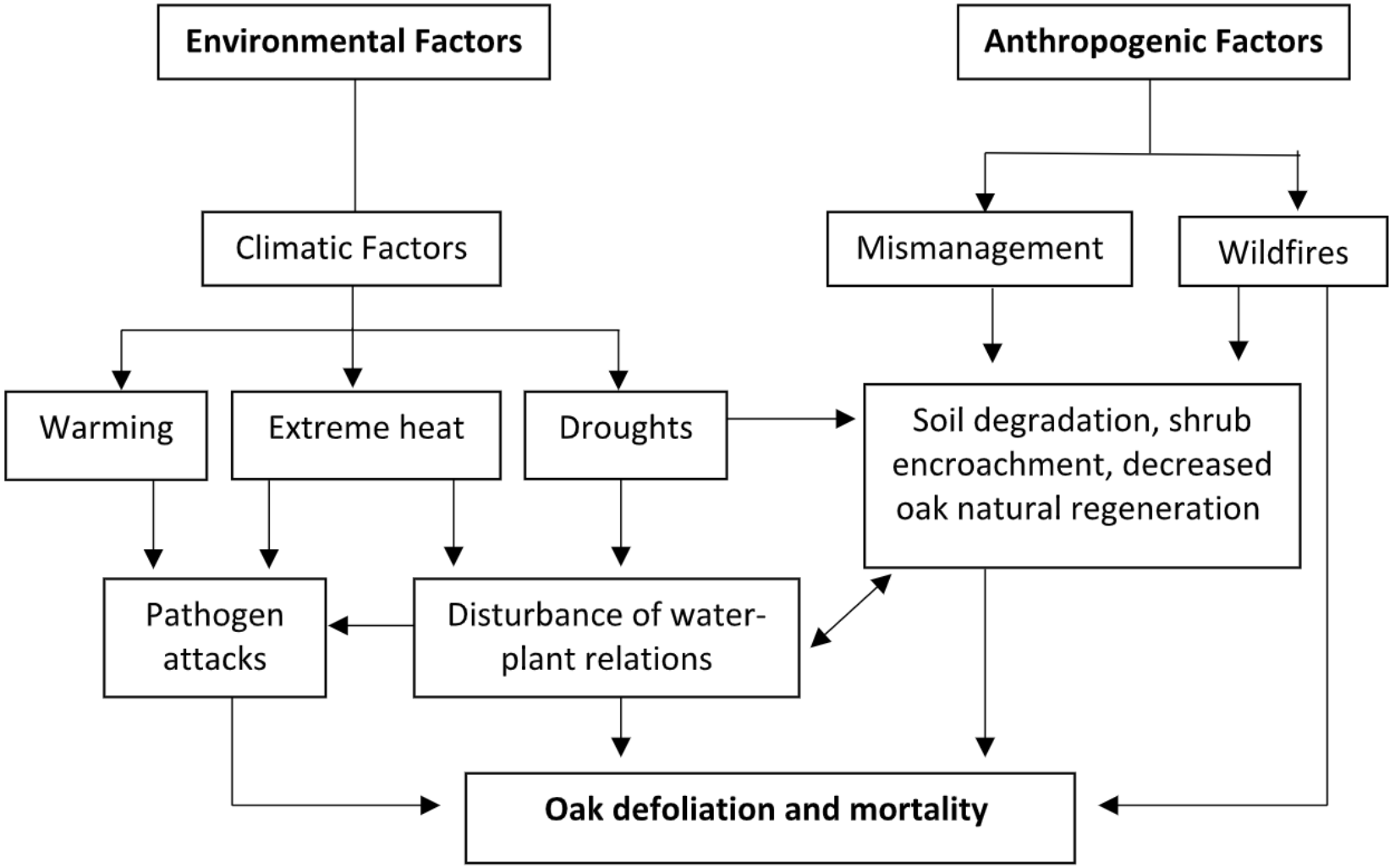
Degradation and disturbances

How resilient are Mediterranean oak landscapes in Portugal?

- Widespread oak tree mortality
- Crown defoliation
- Decreased stand density
- Lack of oak natural regeneration widespread in montados (and dehesas)

Degradation and disturbances

Ecosystem degradation and oak decline is attributed to a complex interaction of human and environmental factors …



Cork oak mortality in Portugal, Algarve (Serra do Caldeirão)

Degradation and disturbances

Heavy shrub clearing on steep slopes (promoting erosion and soil degradation)

Shrub encroachment in drier areas with degraded soils (dominated by *Cistus ladanifer* shrubs in southern Portugal)

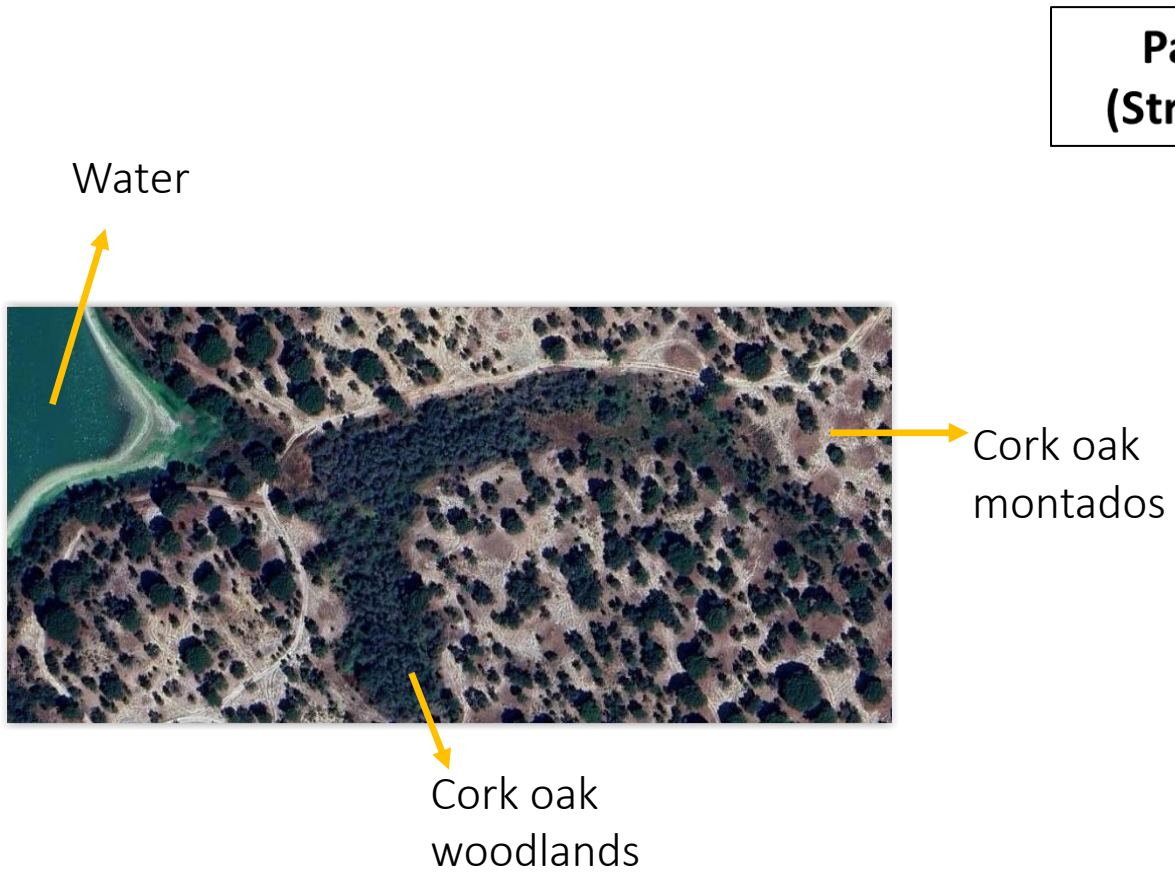
Degradation and disturbances

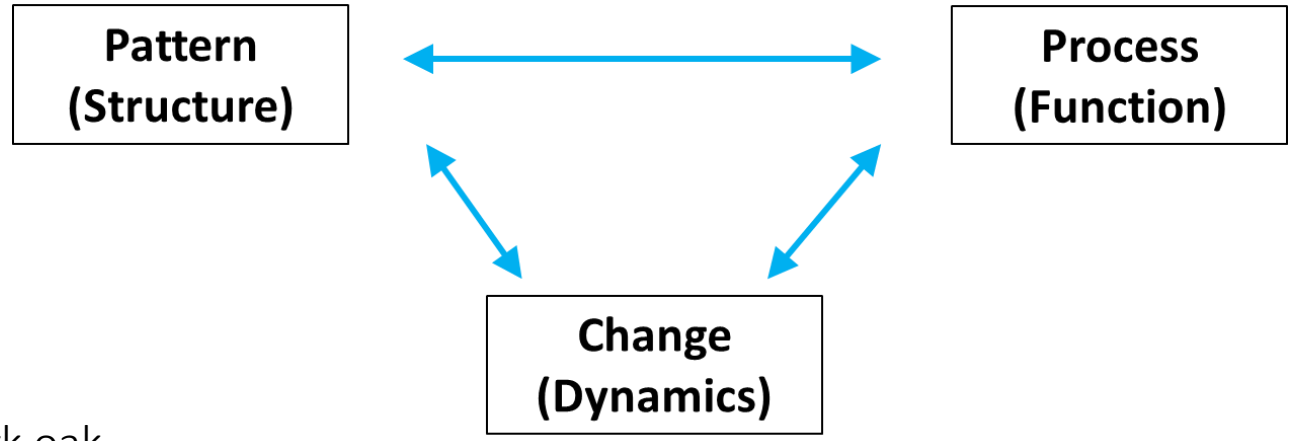
- Intensive cattle and sheep grazing that leads to lack of oak natural regeneration

- Use of heavy machinery that damages tree roots and leads to soil degradation

Assessment of oak landscape dynamics

- ❑ Patterns: How have oak landscapes changed in Portugal in the last decades?
- ❑ Processes: What have been the drivers of observed changes?





Main actors in the landscape

Cork oak tree
(*Quercus suber* L.)

Holm oak tree
(*Quercus rotundifolia* Lam. or *Quercus ilex* L.)

Rockrose shrub
(*Cistus ladanifer* L.)

Wood mouse
(*Apodemus sylvaticus* L.)

Jay (*Garrulus glandarius* L.)

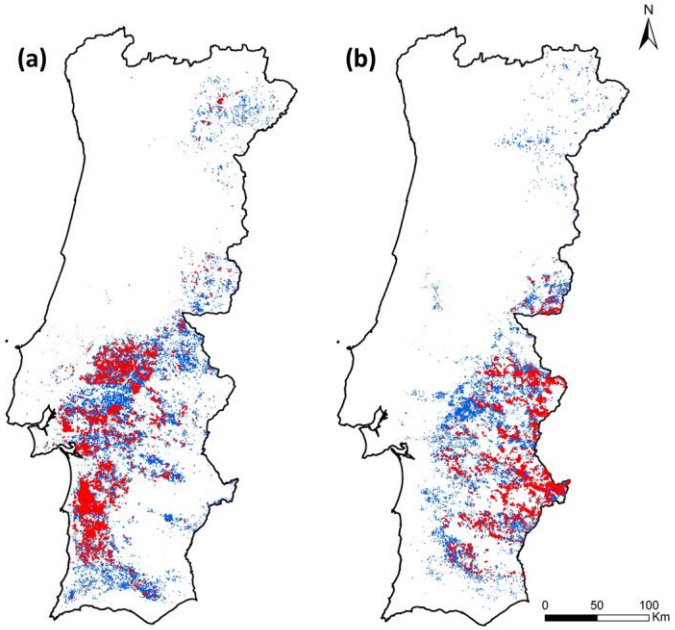
Assessment of oak landscape dynamics at the national scale

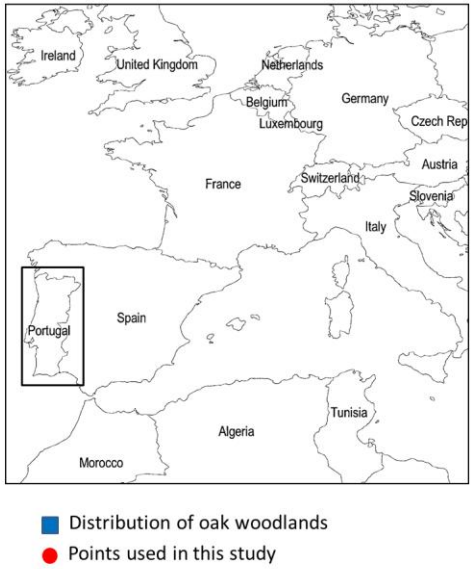
Oak landscape dynamics in Portugal in 1965-2015 (50-year period)

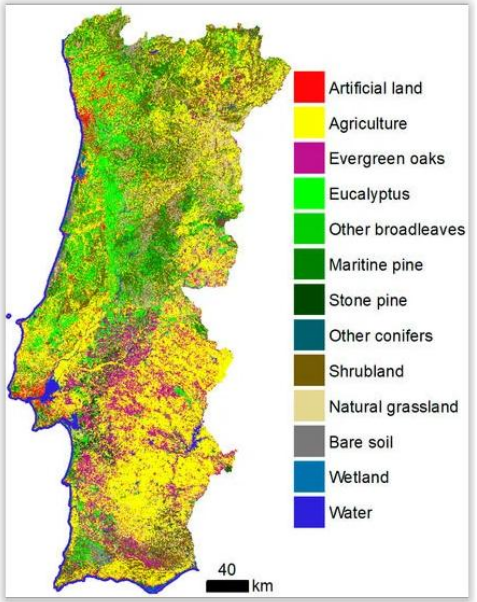
✓ Data collected from National Forest Inventories and National Land Cover Cartography (COS)

✓ Transition matrices to quantify changes in land cover classes (%) and in oak canopy cover (<10%, 10-30%, 30-50% and >50%)

✓ GIS analysis and statistical models to relate observed changes with drivers of change (e.g., topography, wildfires, droughts, climatic extremes, population density) (underlying processes)





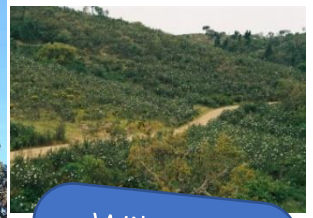


Assessment of oak landscape dynamics at the national scale

Oak landscape dynamics in Portugal in 1965-2015 (50-year period)

Cork oak landscapes

40% changed to other land covers (19% to pine and eucalypt forest, 8% to shrubland)



from the persistent landscape, 58% lost canopy

Increasing mean temp. and flatter areas

Wildfires and extreme temp.

Holm oak landscapes

50% changed to other land covers (20% to agric., 18% to cork oak forest)

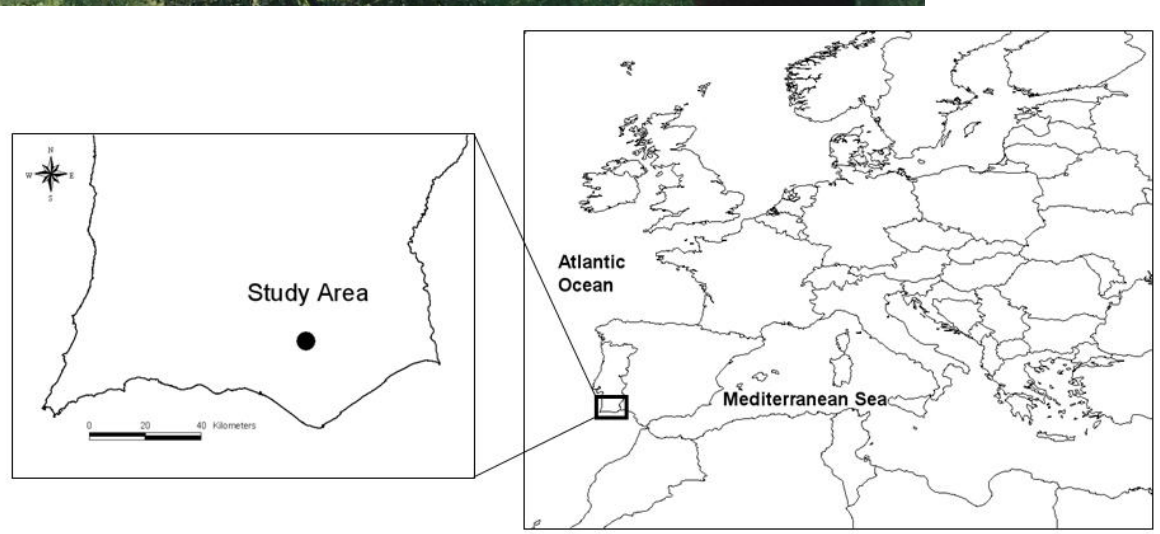
from the persistent landscape, 71% lost canopy

Increasing cattle numbers and flatter areas

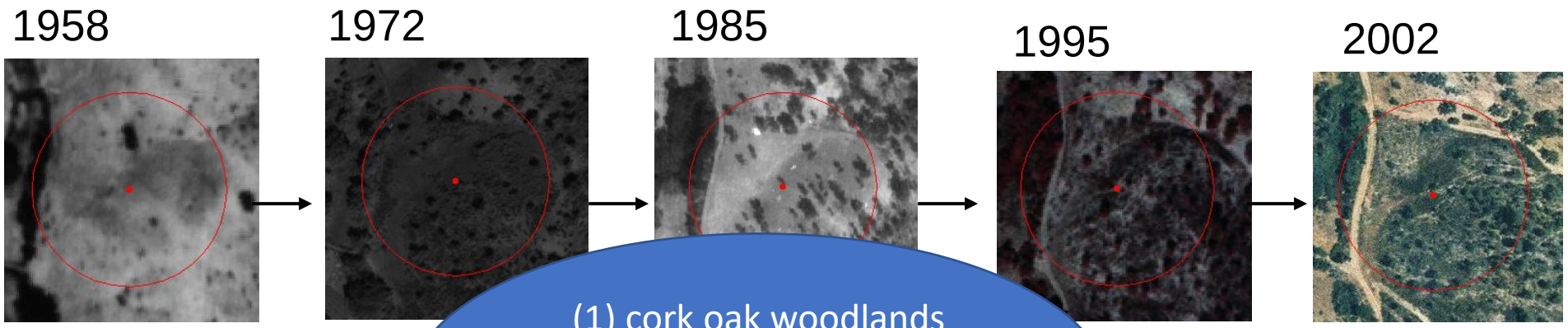
Acácio et al. (2017) Global Change Biology. https://doi.org/10.1111/gcb.13487
Acácio et al. (2021) Ecosystems. https://doi.org/10.1007/s10021-021-00617-9

Assessment of oak landscape dynamics at the regional scale

Oak landscape dynamics in Serra do Caldeirão (Algarve) in 1958-2002



Assessment of oak landscape dynamics at the regional scale

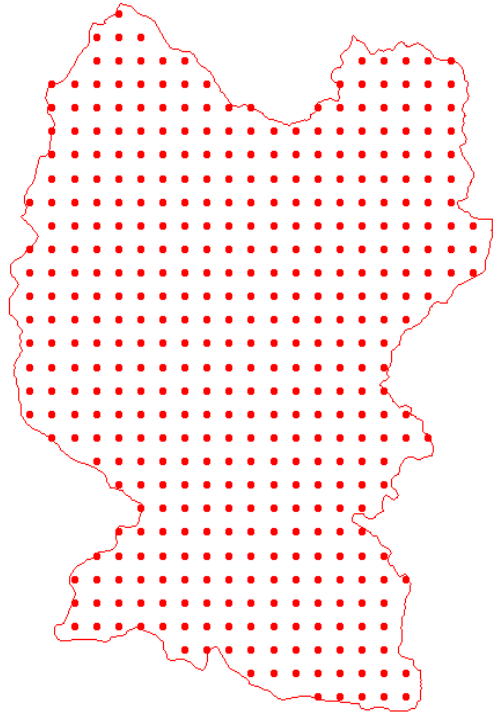


(1) cork oak woodlands
(2) cork oak montados
(3) shrublands
(4) agriculture/pastures

Oak landscape dynamics in [redacted] 1958-2002

✓ Aerial photographs and trans[redacted] to quantify changes in land cover classes (%)

✓ GIS analysis and logistic regression to relate observed changes with topography and wildfire history

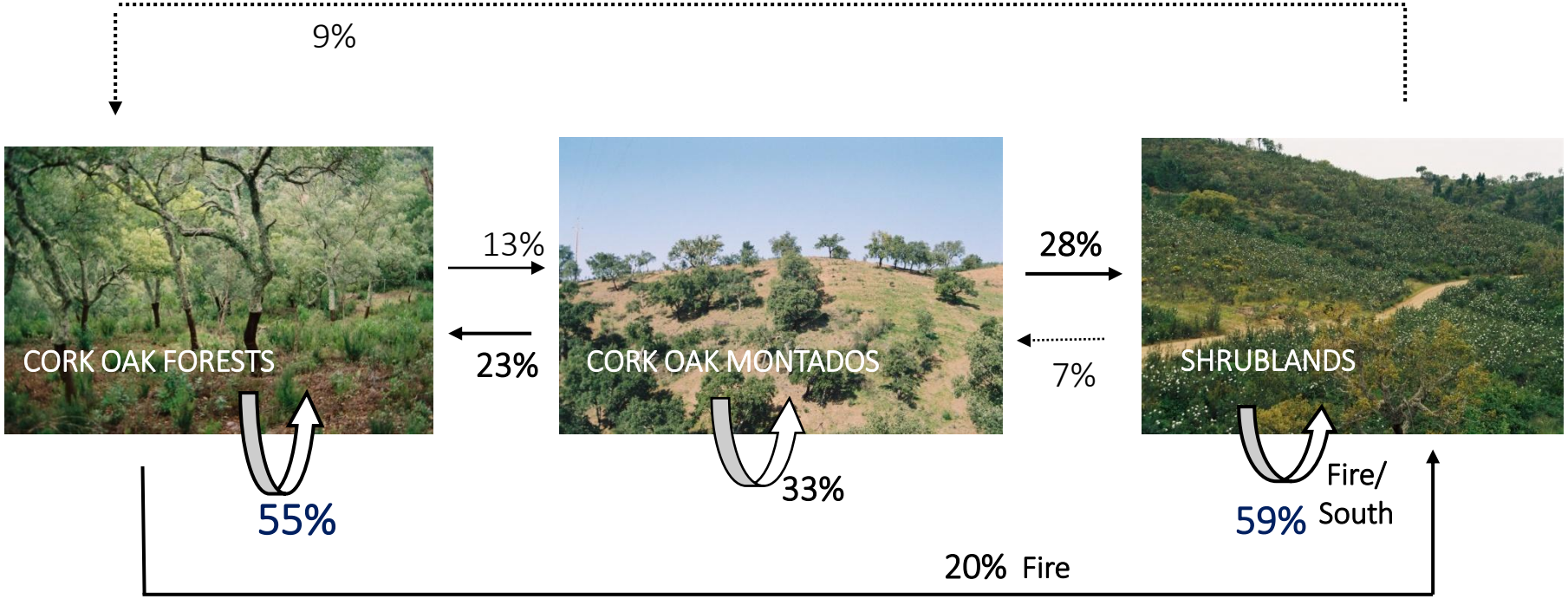


Acácio et al. (2009) Agroforestry Systems. https://doi.org/10.1007/s10457-008-9165-y

Assessment of oak landscape dynamics at the regional scale

In 1958-2002 (45-year period):

- Oak woodlands and montados decreased in area
- Changes from oak land cover to shrublands (dominated by *Cistus ladanifer)* associated with wildfires
- Shrublands were very persistent…**why?**



Assessment of cork oak regeneration processes at the local scale

Effects of shrubs on cork oak regeneration (plant interactions)
Companhia das Lezírias
(2016-2019)

Patterns of cork oak regeneration
Colos, Odemira
(2017)

Patterns of cork oak regeneration and seed dispersal
Serra do Caldeirão, Algarve
(2004-2006)

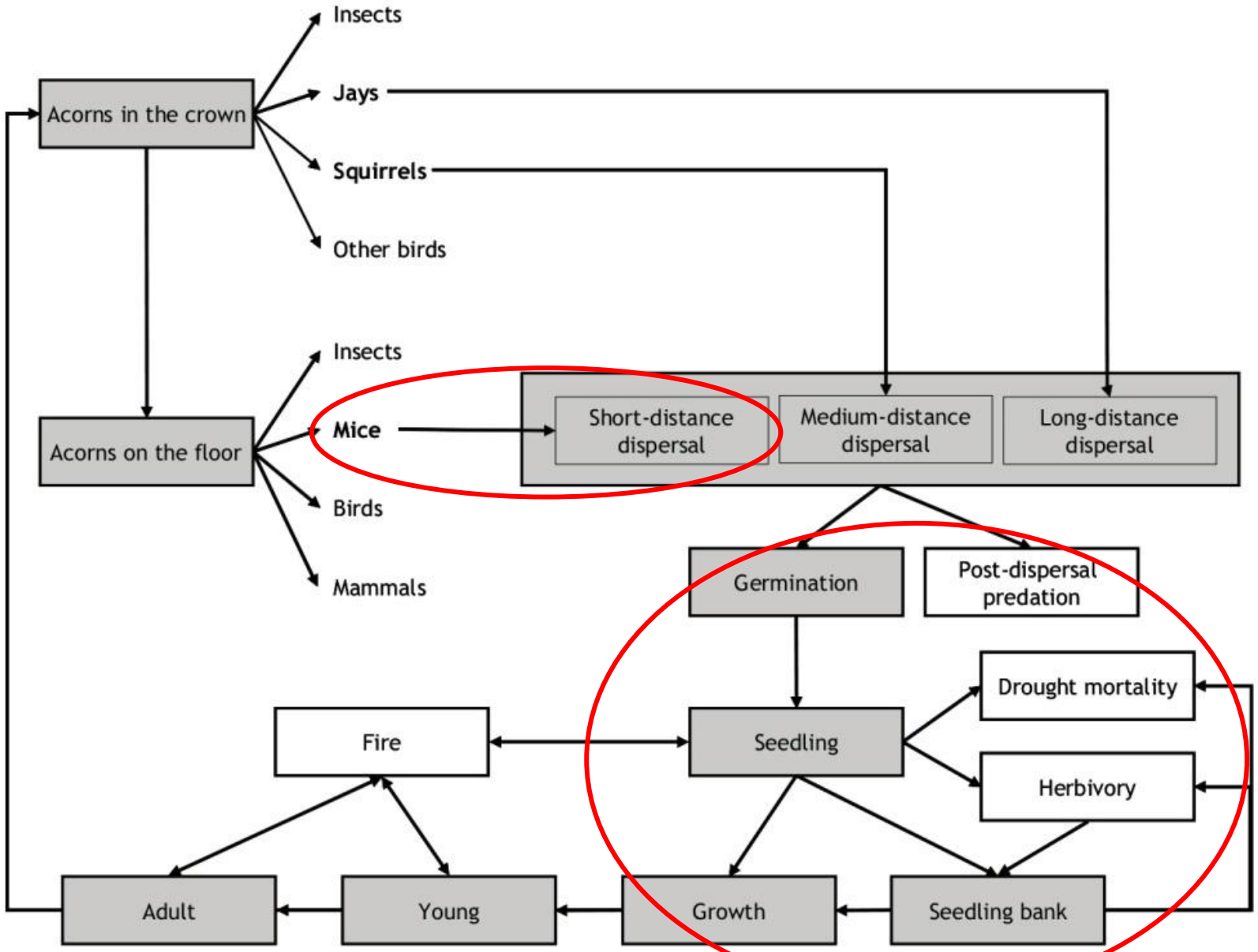


FIGURE 10.1. Conceptual model of the cork oak regeneration process (simplified). Gray boxes indicate the pathway of successful regeneration.

Pausas et al. (2009) Natural regeneration. In: Aronson et al (Eds) Cork oak woodlands on the edge, pp 115-124

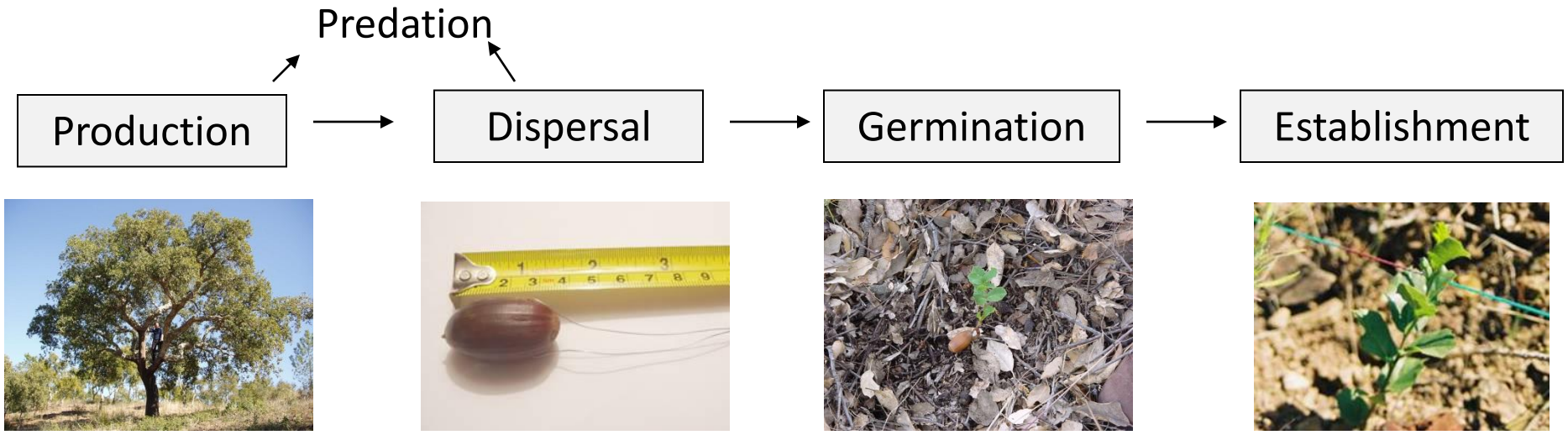
Assessment of cork oak regeneration processes at the local scale

Patterns of cork oak regeneration and seed dispersal (Serra do Caldeirão, Algarve, 2004-2006)

Cork oak forests
(280 ± 14 oaks/ha)

Cork oak montados
(165 ± 22 oaks/ha)

***Cistus* shrublands**
(86 ± 17 sob./ha)



Experimental design with 800 acorns seeded in 16 plots (replicated per vegetation type)

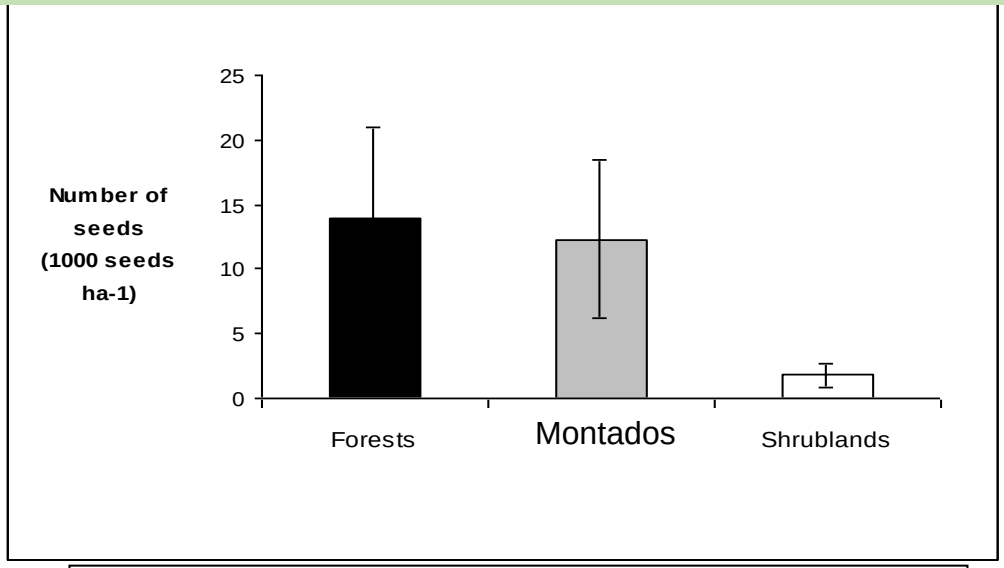
Acácio et al. (2007) Ecosystems. https://doi.org/10.1007/s10021-007-9089-9

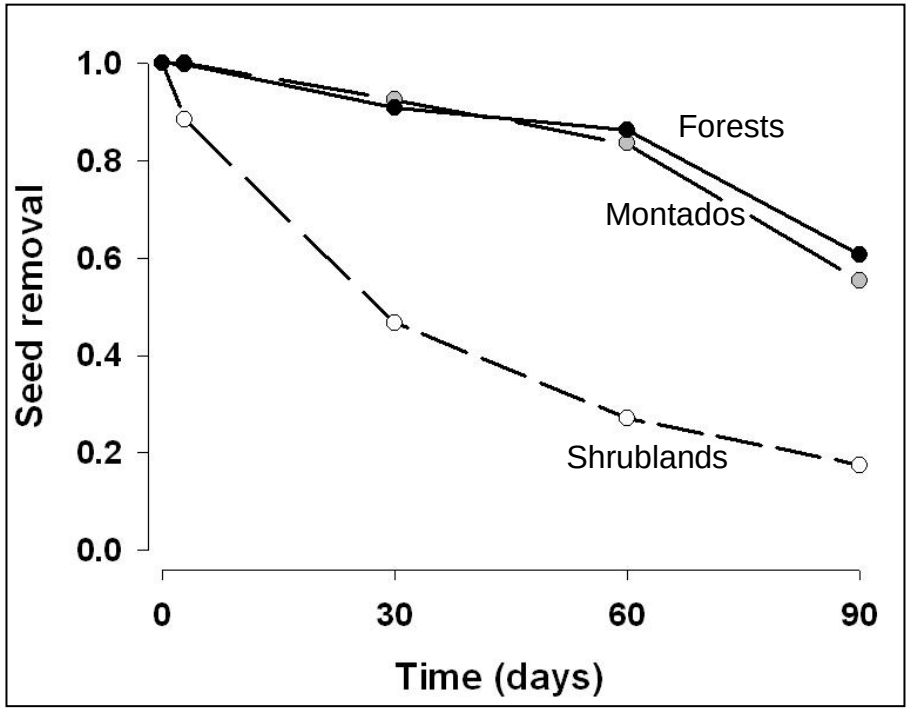
Assessment of cork oak regeneration processes at the local scale

Patterns of cork oak regeneration and seed dispersal
Serra do Caldeirão, Algarve (2004-2006)

Cistus shrublands:
less seeds,
faster removal,
higher predation

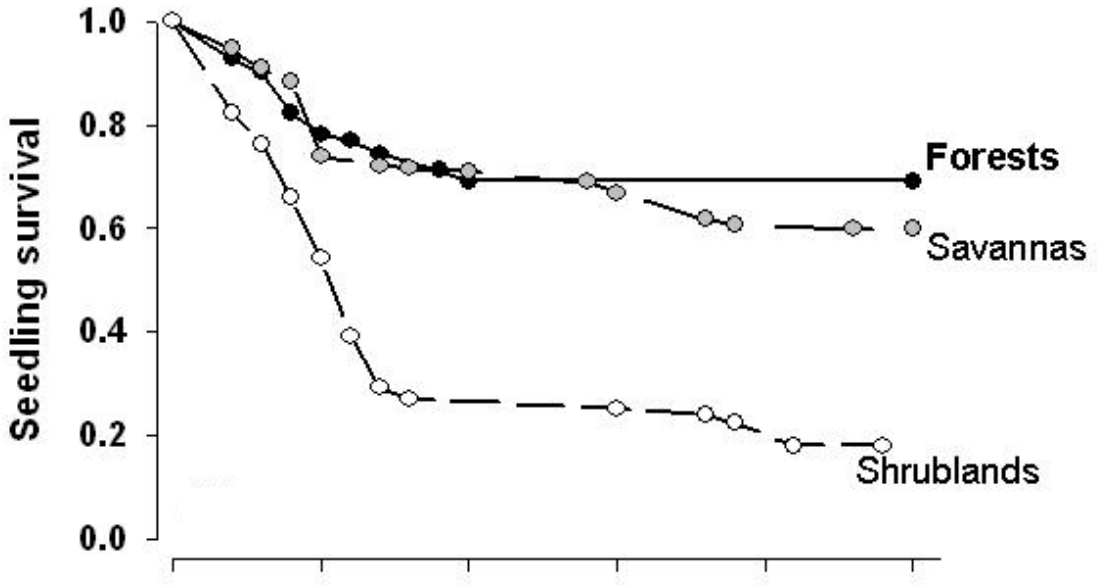
An arrested succession?





Assessment of cork oak regeneration processes at the local scale

Cistus shrublands:
very low cork oak seedling survival



Survival of 2-year old seedlings was significantly lower in shrublands than in forests and montados

- Competition between shrubs and seedlings for water and soil nutrients?

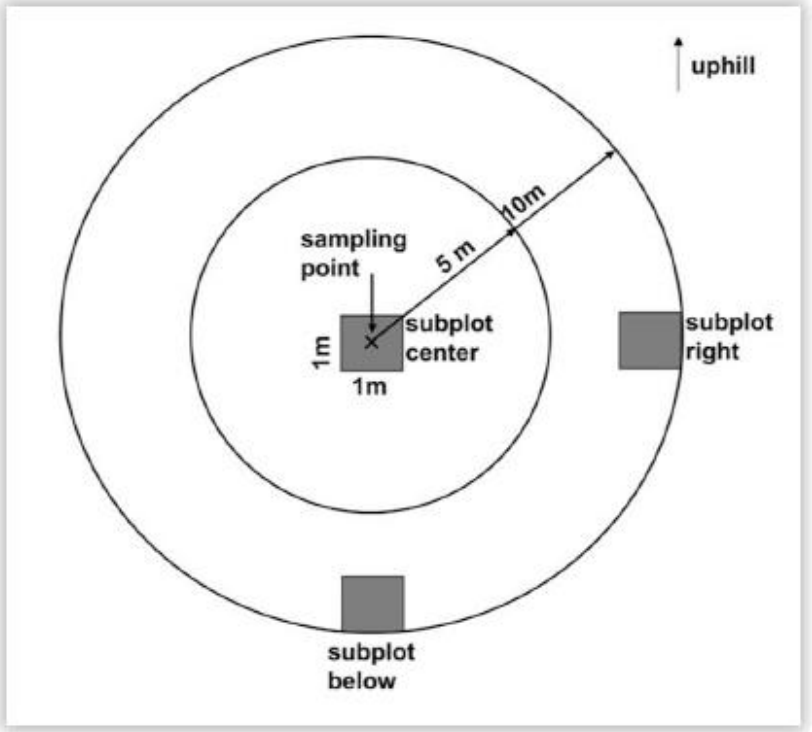
Assessment of cork oak regeneration processes at the local scale

Assessment of cork oak natural regeneration in Colos, Odemira (2017)

Cork oak forests
(535 oaks/ha)

Cork oak montados
(136 oaks/ha)

Cistus shrublands
(138 oaks/ha)



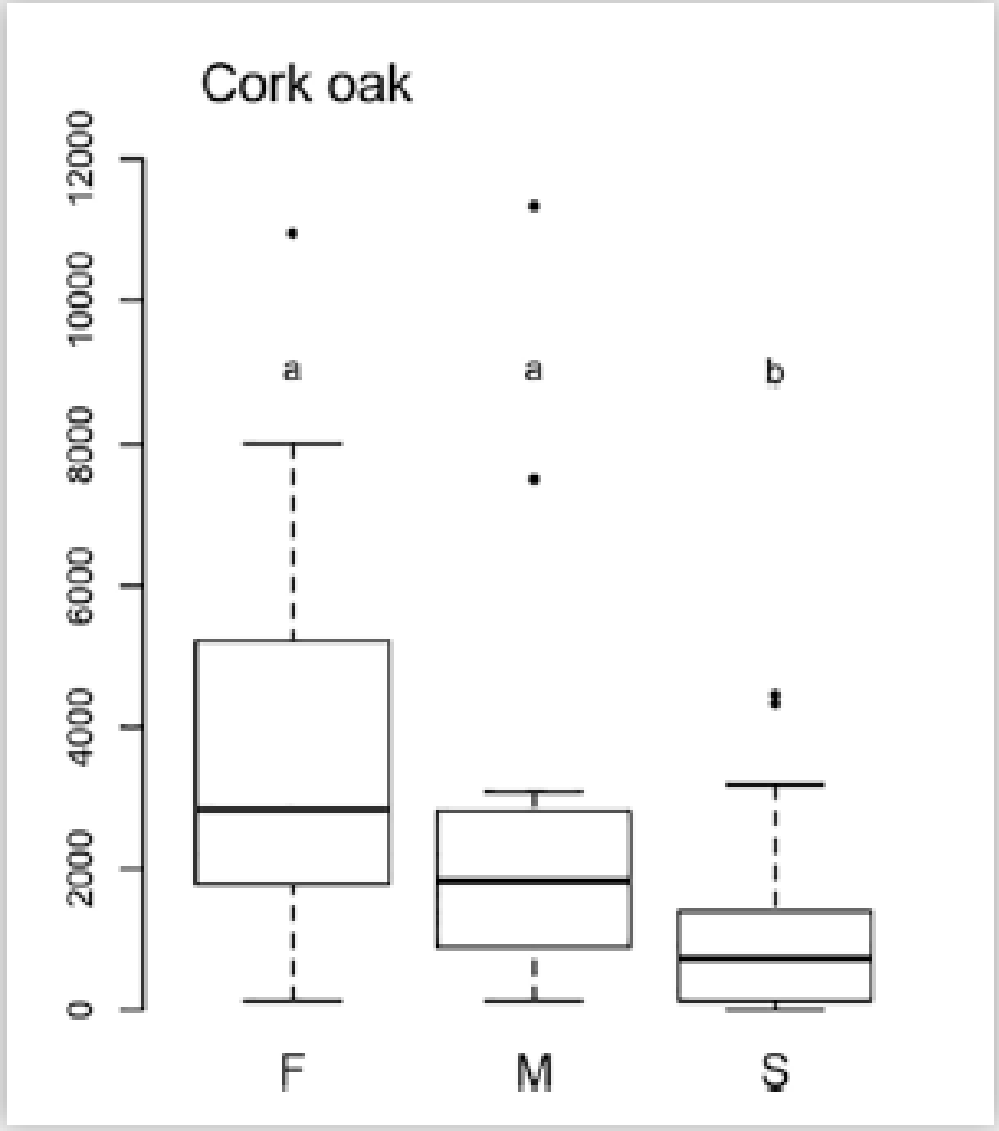
Nested plot design for data collection

- Adult tree composition and density
- Tree natural regeneration
- Understory vegetation composition
- Soil characteristics, soil depth
- Light
- Topography (slope and aspect)

Ritsche J., Katzensteiner K., Acácio V. (2021) FEM 486, 118970
https://doi.org/10.1016/j.foreco.2021.118970

Assessment of cork oak regeneration processes at the local scale

Assessment of cork oak natural regeneration in Colos, Odemira (2017)



Regeneration density (individuals/ha)

small seedlings (height < 50 cm)
large seedlings (height 50 cm – 130 cm)

- *Cistus* shrublands showed the lowest cork oak natural regeneration (competition for water and nutrients)
- In montados, regeneration was higher under shrubs (facilitative effects against sun radiation and herbivory)

Ritsche J., Katzensteiner K., Acácio V. (2021) FEM 486, 118970
https://doi.org/10.1016/j.foreco.2021.118970

Assessment of cork oak regeneration processes at the local scale

Effect of shrub dominance and diversity on cork oak germination and survival (plant interactions)
Companhia das Lezírias (2016-2019)

Study questions

1. How does the availability of abiotic resources influence the emergence and survival of cork oak seedlings in microhabitats with different types of shrub dominance and in open areas?

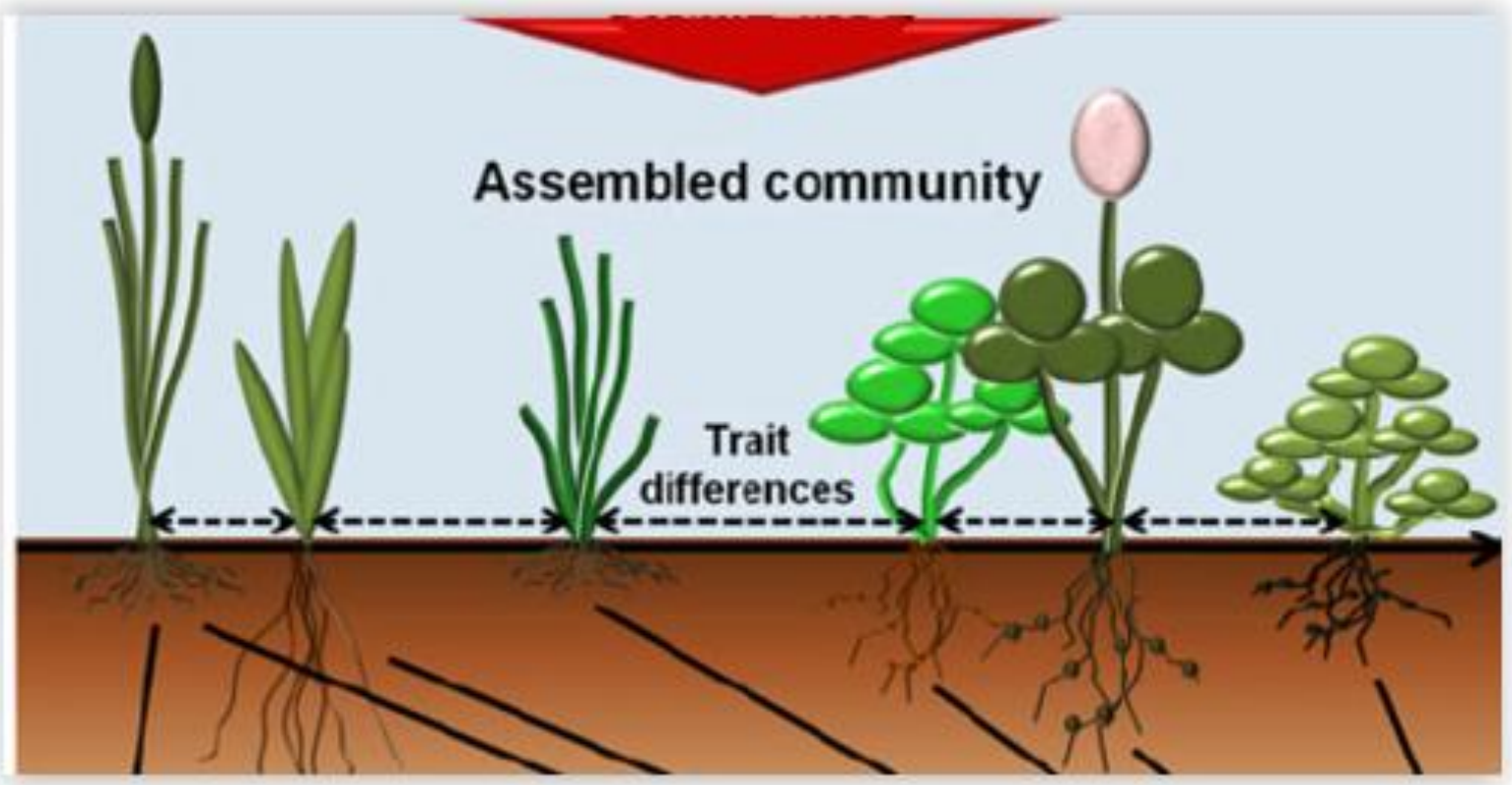
2. Does the survival of cork oak seedlings increase with the diversity of the shrub community?

Assessment of cork oak regeneration processes at the local scale

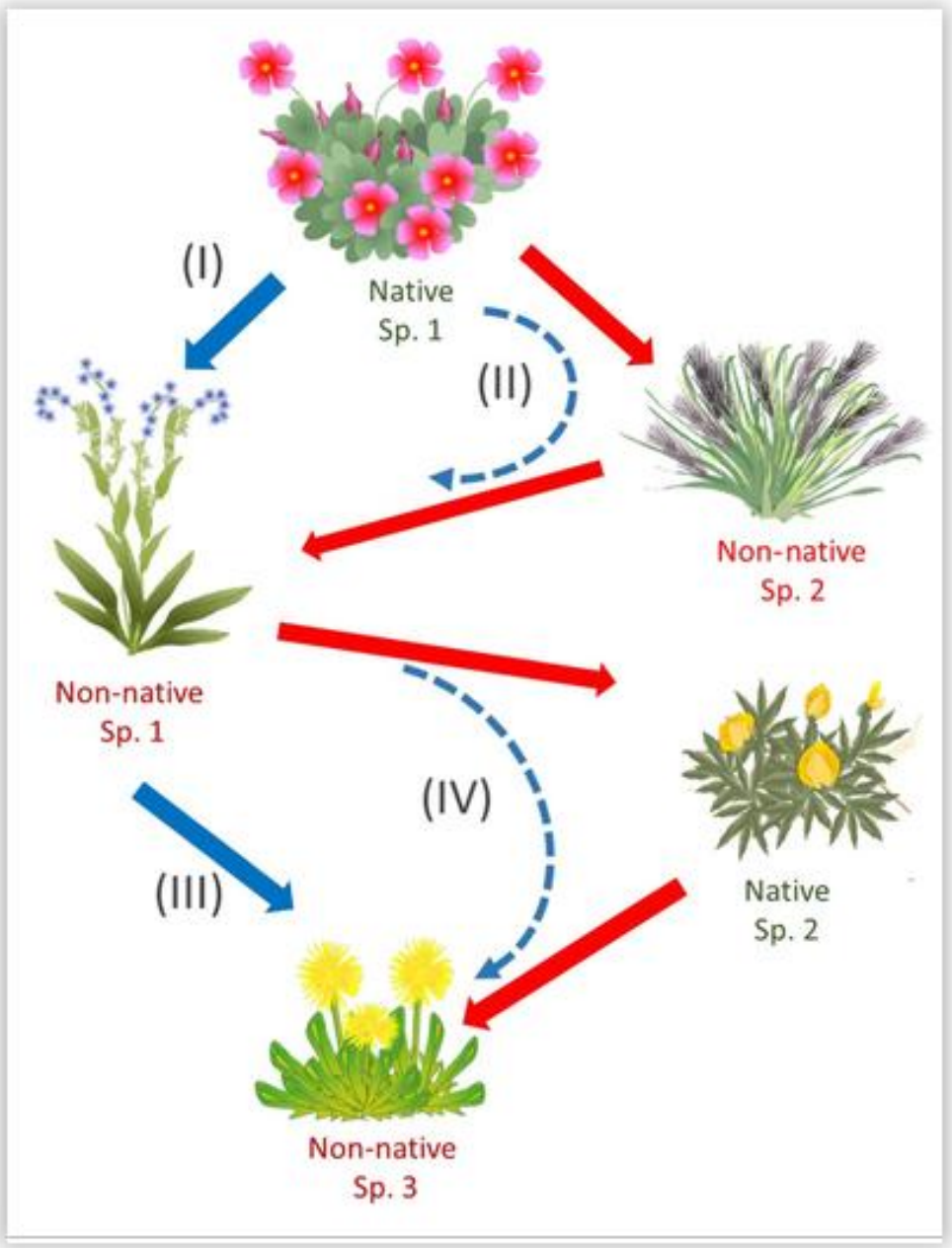
Hypothesis

Higher floristic diversity (with distinct plant traits) may amplify the facilitative effect of the community as a whole:

1. Improvement of the physical environment (e.g., buffer temperature variation, increase humidity)
2. Increasing complementarity in resource use
3. Promotion of indirect facilitation



Assessment of cork oak regeneration processes at the local scale



Graphical example of plant interactions

Direct facilitation

Indirect facilitation

Competition

Cavieres L.A. (2020) Journal of Ecology DOI: 10.1111/1365-2745.13627

Assessment of cork oak regeneration processes at the local scale

Effect of shrub dominance and diversity on cork oak germination and survival (plant interactions)
Companhia das Lezírias (2016-2019)

Experimental design with 20 plots

Four plot types (with 5 replicates each):

1. Dominated by *Cistus ladanifer* L. (rockrose)

2. Dominated by *Cistus salviifolius* L. (sageleaf rockrose)

3.Dominated by *Ulex australis* subsp *welwitschianus* (Planch.) (gorse)

4. Without a specific dominance, with higher species diversity (*U. australis*, *Lavandula stoechas*, *C. salviifolius, C. ladanifer*)

960 acorns seeded in November 2015
(24 by subplot)

Assessment of cork oak regeneration processes at the local scale

Effect of shrub dominance and diversity on cork oak germination and survival (plant interactions)
Companhia das Lezírias (2016-2019)

Data collection in 2016-2019 (3 years):
- Acorn germination and seedling survival
- Species diversity of the shrub community
- Abiotic variables (soil temperature and water, soil characteristics, leaf area index)

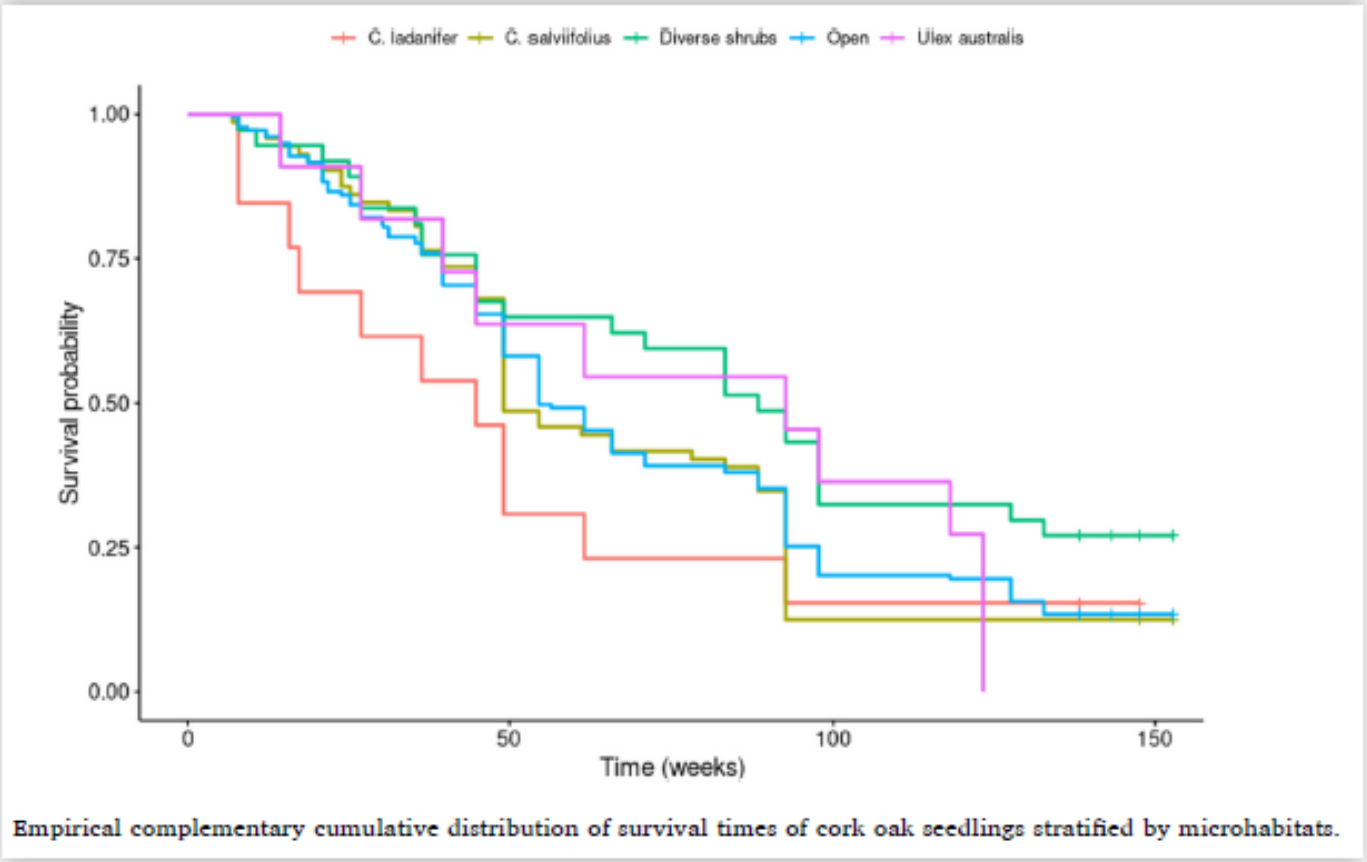
Assessment of cork oak regeneration processes at the local scale

Effect of shrub dominance and diversity on cork oak germination and survival (plant interactions)

Companhia das Lezírias (2016-2019)

Assessment of cork oak regeneration processes at the local scale

- **Cork oak seedling survival decreased in time and was very low (13%) after 3 years**
- Survival was highest in microhabitats with higher shrub diversity
- Survival was lowest in microhabitats dominated by *Cistus ladanifer* shrublands



Empirical complementary cumulative distribution of survival times of cork oak seedlings stratified by microhabitats.

Acácio et al. (2024) Forest Ecology and Management
https://doi.org/10.1016/j.foreco.2024.121713

Assessment of cork oak regeneration processes at the local scale

Cork oak seedling survival was highest with higher shrub diversity:

- The different functional traits of the shrubs improved environmental conditions, promoted complementarity in resource use, and indirect facilitation.

***Lavandula stoechas*:** improves micorrhizal community in the soil

Ulex australis: Dense canopies that protect seedlings from herbivory and high summer temperatures; nitrogen-fixing species, tall shrub (second greatest height observed)

Cistus salviifolius: Semi-deciduous, low shrub, with small leaves arranged in multiple layers

Cistus ladanifer: Extensive and shallow root system, strong competitor for soil water, allelopathic, tall shrub

Assessment of cork oak regeneration processes at the local scale

Effect of shrub dominance and diversity on cork oak germination and survival (plant interactions)
Companhia das Lezírias (2016-2019)

	+	-
Acorn emergence 36.5% (N = 350)	**Plots dominated by *Cistus salviifolius* and open plots** (higher soil temperature*)*	All plots *(water logging in winter)*
Cork oak seedling survival 13% (N = 45)	**Plots with highest shrub diversity** *(facilitation)* **Most plots** (more soil K – high leaching of this nutrient)	Plots dominated by *Cistus ladanifer* (water competition) Plots dominated by *Cistus salviifolius* and open plots *(higher soil temperature and no shade from summer drought)* All plots (*water logging in winter)*

Implications for management and restoration (objetives 2 and 5 of Agenda 3i9)

Agenda 3i9 - Agenda Portuguesa de Investigação e Inovação no Sobreiro e na Cortiça

- **Maintain, whenever possible, the existing shrub vegetation** (it facilitates the initial survival of cork oak, although it hinders its emergence) *(how to deal with these trade-offs?)*

- **Reduce tall and dense patches of *Cistus ladanifer*** (for example, by creating corridors) to decrease competition for water with cork oak seedlings

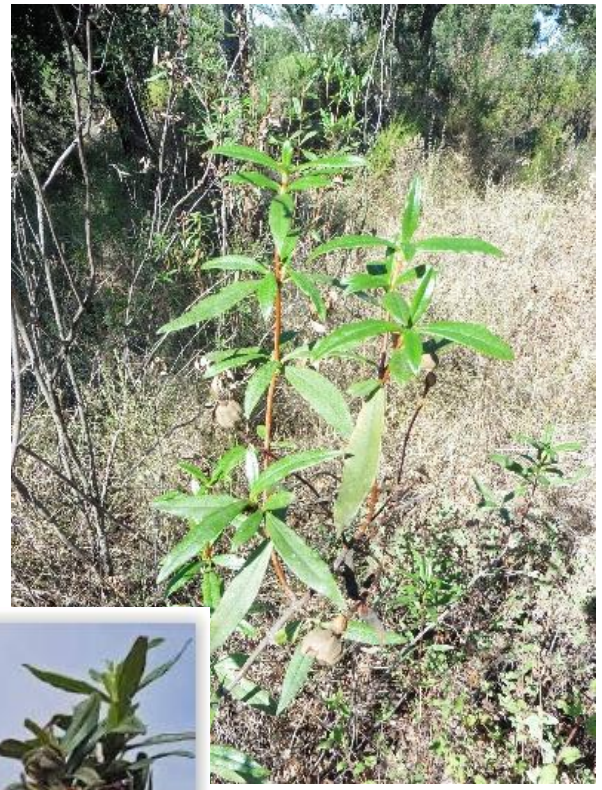
- **Increase/Maintain the diversity of the shrub cover**, selecting native species with a facilitative effect or soil-improving properties (e.g., *Lavandula stoechas*, *Pistacia lentiscus*, *Ruscus aculeatus*)

- **Amend degraded soils with potassium (K)**, when necessary

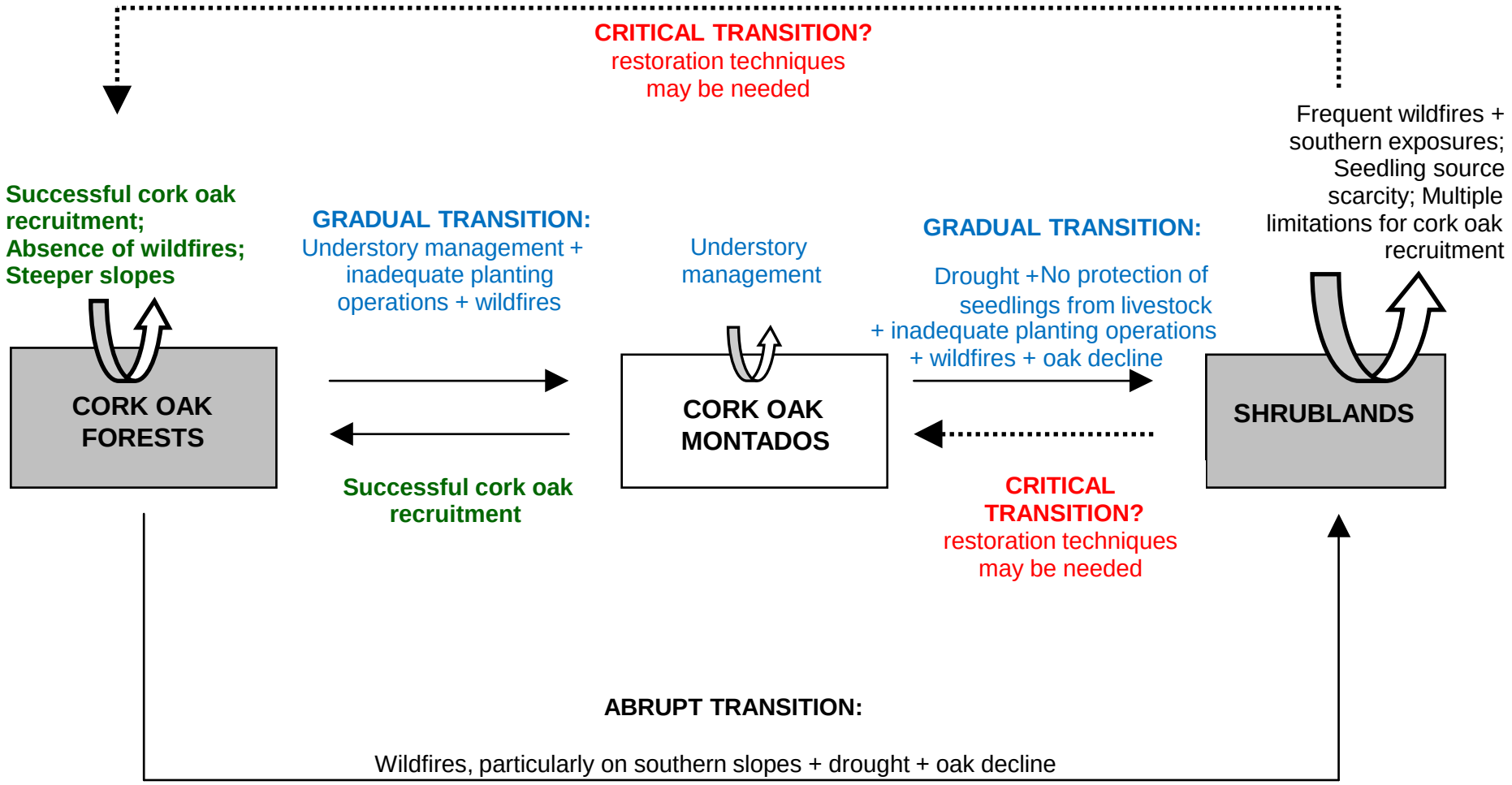
Shrub encroachment in cork oak landscapes

Shrublands dominated by rockrose (*Cistus ladanifer* L.): multiple limitations for cork oak seedling establishment (less acorns, faster removal, higher predation by mice, lower survival)

Cistus ladanifer is a pioneer pyrophytic species, favored by frequent fires, and a strong competitor for soil water

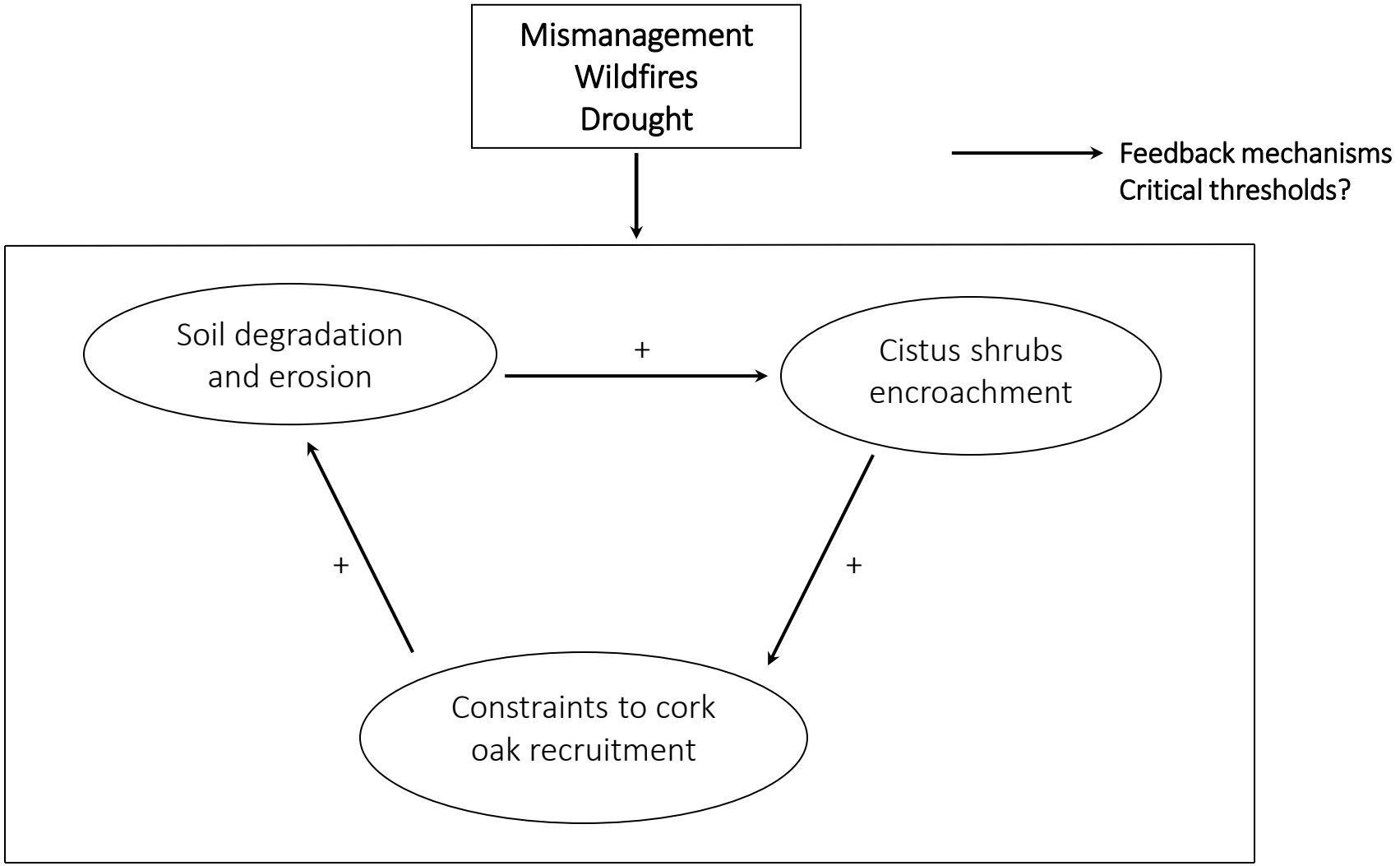


State and transition model: are shrublands an “arrested state”?



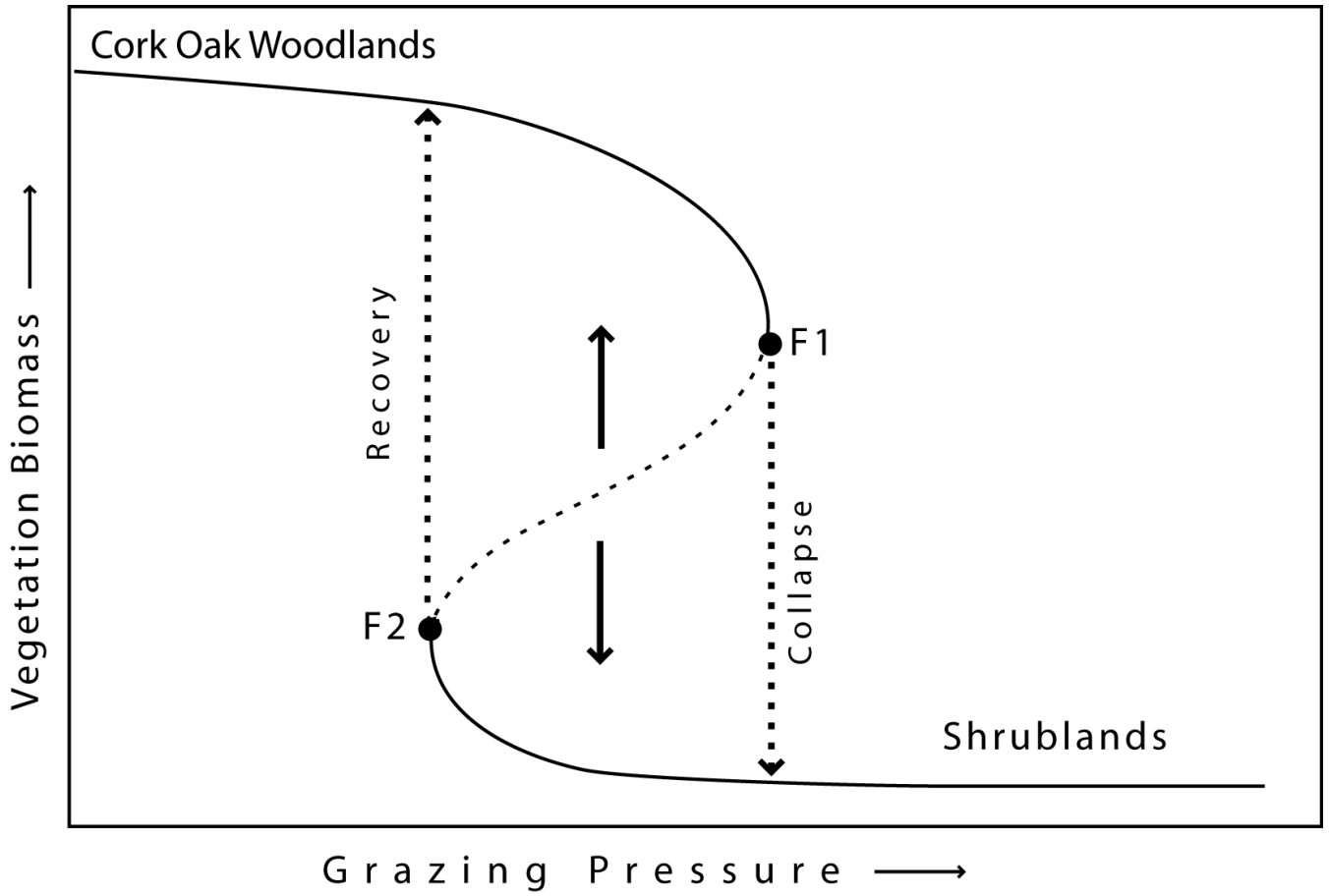
Acácio *et al*. (2007) Ecosystems DOI: 10.1007/s10021-007-9089-9
Acácio and Holmgren (2014) Annals of Forest Science DOI 10.1007/s13595-012-0197-0

Ecological feedbacks: mechanisms that keep shrublands in an "arrested succession state"



Resilience, thresholds and critical transitions

Hypothetical alternative states for cork oak woodlands



Ecological Resilience: the capacity of a system to absorb disturbances and reorganize to retain the same functions, structures and feedbacks

Restoration thresholds: breakpoints that need to be addressed by restoration efforts for recovery to occur (ex: oak natural regeneration)

Degradation thresholds: the point where environmental change prevents recovery to the same state without management or restoration (ex: biotic – herbivory, shrub encroachment; abiotic – changes in soil structure)

Resilience, thresholds and critical transitions

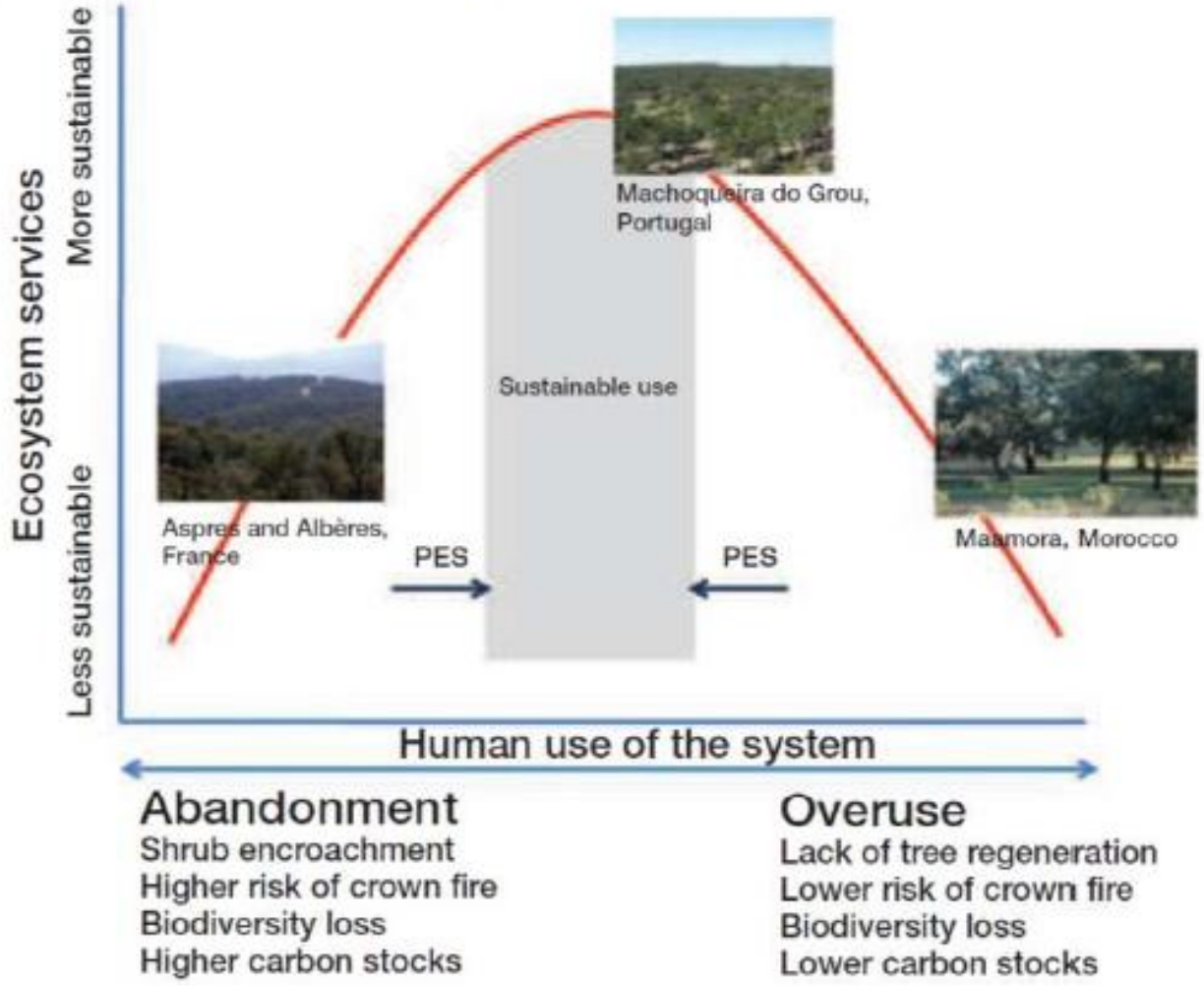
Are montados and oak woodlands sustainable?

Present natural regeneration and tree recruitment may not be sufficient to compensate for natural or induced oak mortality, jeopardizing their long-term sustainability (despite being a subject of intense debate).

Anthropogenic drivers have been the most important but climatic extremes seem to have interacted with these to accelerate changes in Mediterranean oak woodlands.

What to do? Adequate agrosilvopastoral practices and active restoration are needed!

Montados/dehesas (open oak woodland/oak savanna): agrosilvopastoral land use system consisting of an open overstory of oak trees (typically cork oak or holm oak) of varying densities (20–100 trees/ha) and an understory with croplands (usually cereals), native grasses or improved pastures for livestock grazing, and patches of native shrublands.



Bugalho et al. (2011) Frontiers in then Ecology and the Environment 9: 278–286

Approaches and techniques for the restoration of Mediterranean oak agroforestry systems

Table 14.1 Framework for the restoration of Mediterranean ecosystems. Drivers for restoration are identified, as well as actions that can be undertaken to attenuate them, and available techniques to implement these actions. Each driver must be offset to ensure successful restoration.

Driver	*Action*	*Technique*
Persistent stress (disturbances, unwanted species)	Release stress	Limited access to people, herbivores, etc. Fire prevention, windbreaks Species control (fire, herbicides, clearing)
Low propagule availability	Artificial introduction	Seeding, planting
	Promote dispersion	Bird-mediated restoration, frugivory-mediated restoration (artificial perches, catches, habitat amelioration)
Adverse environmental conditions	Reduce soil losses	Emergency seeding, mulching, sediment traps
	Ameliorate soil properties	Amendments, nutrient immobilization, mulching, drainage, soil preparation
	Improve microclimate	Shelters, mulching, microsite selection

Vallejo et al. (2012) In: Van Andel and Aronson (eds.) Restoration Ecology. The new frontier.

Approaches and techniques for the restoration of Mediterranean oak agroforestry systems

Protect oak natural regeneration and assist natural succession (passive restoration)

- Exclusion or restriction of grazing in montados; or rotational grazing (can be achieved over large areas but is difficult in small land holdings)
- Protect oak natural regeneration with artificial shading or nurse shrubs (especially in drier areas or exposed to south/west)
- Install bird perches for long distance dispersal (especially in areas with very low seed availability)
- Relatively inexpensive; passive restoration is preferable where ecosystem structural/functional damage is limited and resilience is high

Seeding

- Seeding acorns to increase oak tree cover; relatively cheap and does not require nurseries; cheaper than planting. However, seeds may be eaten by animals
- Seeding a mixture of herbaceous species (perennials and annuals, grasses and legumes) to improve pastures

Planting and managing native shrub cover

- Increase shrub cover diversity by planting native shrubs with a nursing (facilitating oak seedling survival) and/or soil-improving effect (N-fixing) (ex: *Lavandula stoechas*, *Pistacia lentiscus, Ruscus aculeatus, Retama spp, among others)*
- Reduce patches of tall and dense *Cistus ladanifer* shrubs (e.g., by creating rows within the shrub layer) to diminish competition with seedlings for water
- Control the dispersion of monospecific *Cistus* spp. formations through harvesting for *Cistus* distillation, and diversifying them through plantation of fruit and honey shrub species

Planting native tree species in open woodlands and montados (oak species and others)

- Use of genetic material of good quality and adapted to local conditions; use seedlings inoculated with mycorrhizas (nursery-based mycorrhization)
- Select microsites for planting (near nurse shrubs); lack of knowledge on plant interactions may be a constraint
- Use well-designed artificial tree shelters (to improve seedling survival and growth under harsh conditions, and protect seedlings from herbivory)
- Control invasive species

Soil and water conservation

- Improve soil conditions (fertilization; mulching using forest debris; controlled soil mycorrhization to improve water uptake of seedlings)
- Site stabilization with structures (e.g., rocks, branches, logs) to prevent soil loss and erosion, and to regulate water fluxes

Examples of restoration projects of cork oak landscapes in Portugal

WWF

WWF Mediterranean Cork Oak Landscapes Programme

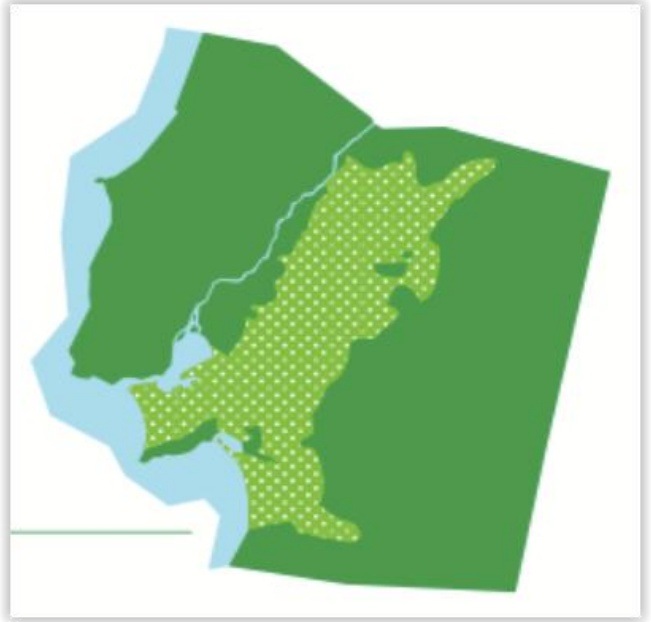
- Cork oak forest certification
- Project *Green Heart of Cork* - Payment for Ecoystem Services (Tejo and Sado river basins)
- *Southern Portugal Green Belt Project*

Project Green Heart of Cork - Payment for Ecoystem Services

Promoted by ANP (Associação Natureza Portugal, NGO) and WWF since 2011

Where?

Lower Valley of the Tejo and Sado (5000 ha) – the heart of the world´s cork oak forests, where the largest Iberian aquifer is located. This aquifer provides water to about one million people, thousands of ha of irrigated land and to industries



Why? Sustainable management and restoration of cork oak forests here located will contribute significantly to the improvement of water quality and to the increase of the aquifer recharge

How does it work? Public or private entities who benefit from such ecosystem services can join the project and pay landowners for the good management and restoration of cork oak woodlands. Entities will further promote its public image as a result of social and environmental responsibility

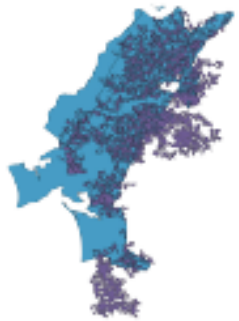
https://www.natureza-portugal.org/o_que_fazemos_222/florestas/green_heart_of_cork_/

The Green Heart of Cork project

The Coca-Cola Portugal – APFCertifica PES case

Type:
Payment for bundle ecosystem services in voluntary market

- **Partner providing the service:** APFCertifica Group Scheme - Forests landowners formed an association and adopted sustainable forest management practices in order to receive Forest Stewardship Council (FSC) certification.
- **Beneficiaries:** Coca-Cola Portugal – Refrige, beverage factory, located over the Tagus Aquifer (T3), consuming 500.000m3/year of groundwater.



Location: Portugal, Alentejo and Ribatejo regions

Services: Forest landowners committed to maintain good forest management practices within the 16.000 ha FSC certified areas. FSC certification places a strong focus in criteria related to biodiversity conservation and watershed protection. Approximately 600 hectares (ha) were considered to be of critical importance for biodiversity and water recharge of the aquifer T3 and therefore were considered High Conservation Value Areas.

HCV	High Conservation Value Areas (HCVA) identified by APFC (ha)
Seasonal Concentrations of Species	24,79
Watershed Protection	569,63

Examples of restoration projects of cork oak landscapes in Portugal

The Southern Portugal Green Belt Project

Aims: to promote ecosystem restoration at the landscape scale (with pilot sites), increase forest surface, and improve the structure and density of forest habitats

How? Tree/shrub production and plantation, and effective long-term management practices. With involvement of key-stakeholders.

The "Green Belt" concept aims to set up a sustainable network of forest reserves, surrounded by large buffer zones where land-use planning takes into account the need to preserve habitats and wildlife, in combination with community-based participatory measures.

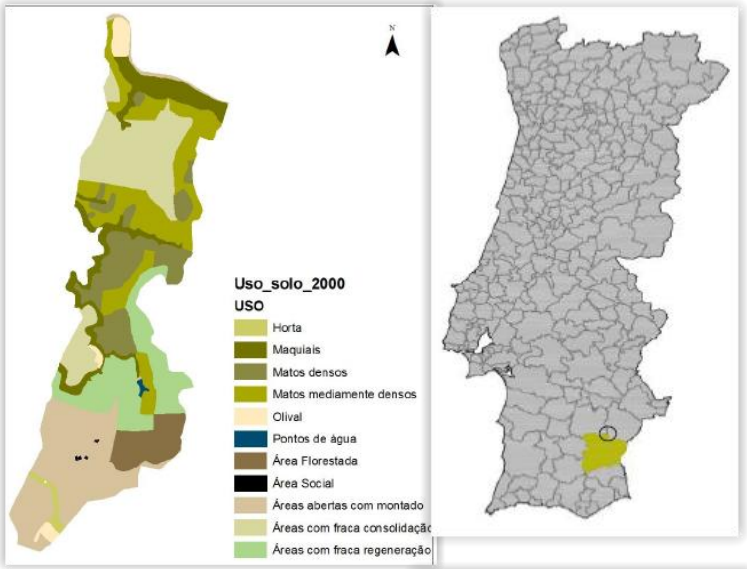
Examples of restoration projects of cork oak landscapes in Portugal

The Southern Portugal Green Belt Project
Pilot Site: Monte do Vento, Mértola

- A partnership between a local NGO that owns the land estate (*ADPM – Associação de Defesa do Património de Mértola)*, *WWF* and a private forest company (*Imobiente*)

- Aims: to demonstrate ecological restoration techniques to prevent forest fires and combat desertification, while maintaining agroforestry production and preserving biodiversity (200 ha). Using governmental subsidies (Ruris and AGRO).

- Restoration was based on the mosaic of the forest landscape by maintaining patches of native vegetation as genetic reserves, herbaceous strips on hilltops, and plantation of 20 species, including cork oak, holm oak, *Arbutus unedo*, riparian species, *Retama* spp. (facilitative shrub)



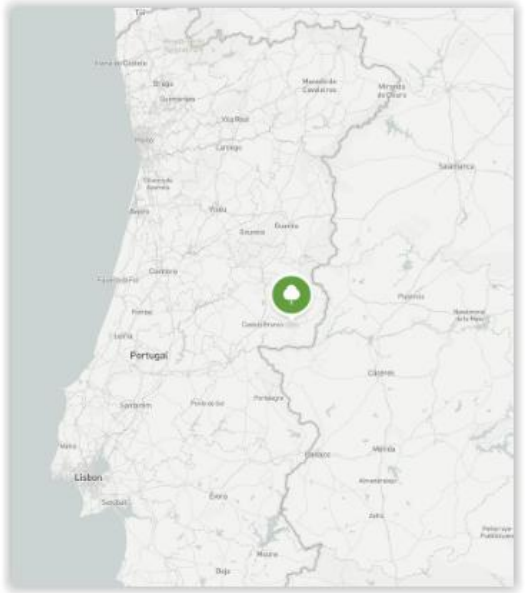
Monte do Vento
Centro de Estudos e Sensibilização Ambiental
POR UM FUTURO PARA A TERRA

Examples of restoration projects of cork oak landscapes in Portugal

Reforest ACTION Idanha-a-Nova (2023-2024)

Area: 19 ha

Number of trees: 11500

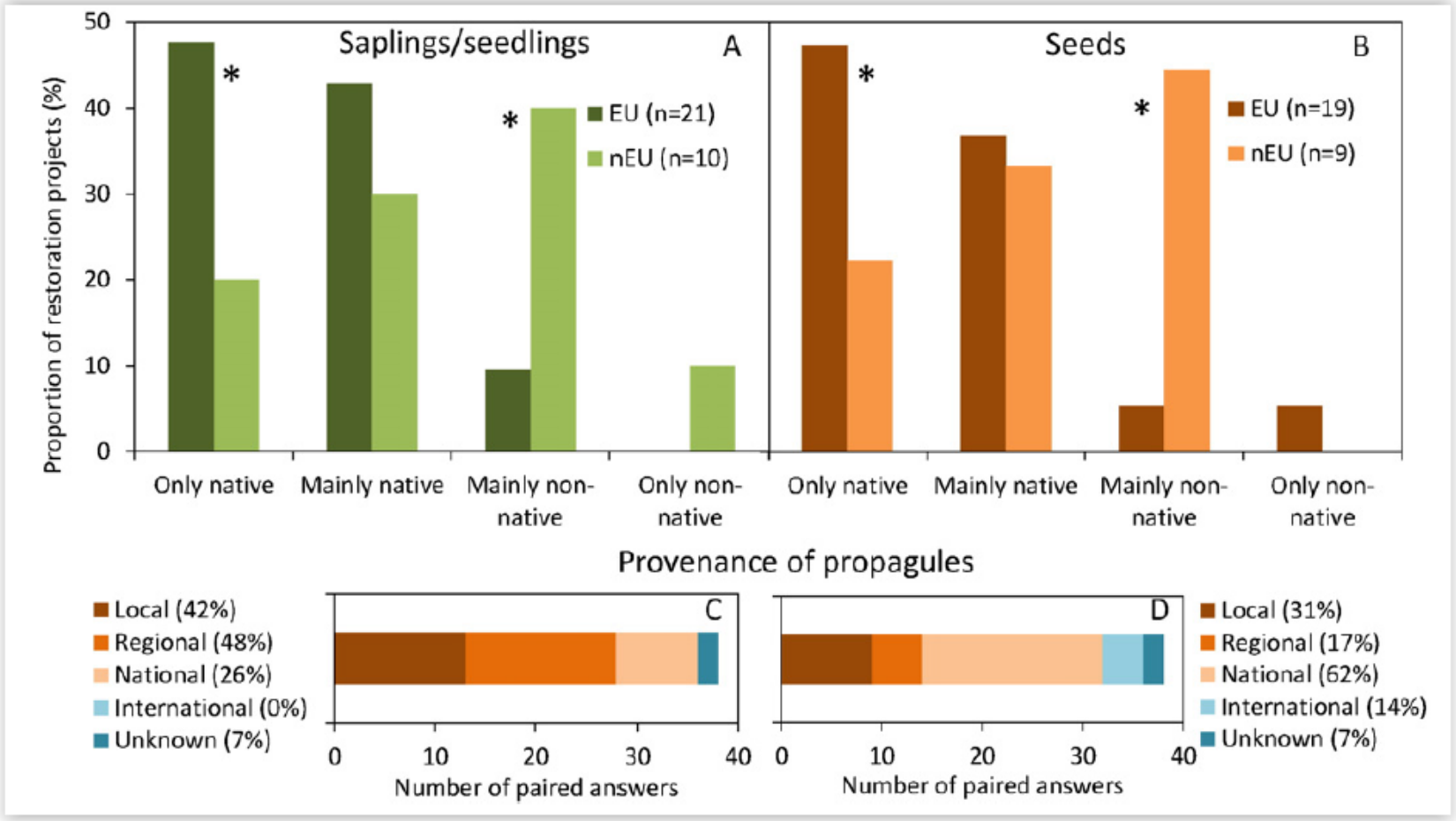


Actions in the field

- Clearing of previous vegetation (removal of shrubs)
- Site preparation (ripping)
- Low density planting of cork oaks
- Individual plant protection
- Summer irrigation (pending)
- Annual maintenance - Monitoring - Replanting

Assessment of restoration projects in Mediterranean landscapes

- **Are native species being used in restoration projects? What about their provenance?**
- **Are restoration outcomes evaluated, how, and for how long?**
- **Are results as good as expected?**



Source: Nunes *et al*. (2016) Science of the Total Environment 566–567: 722-732 http://dx.doi.org/10.1016/j.scitotenv.2016.05.136

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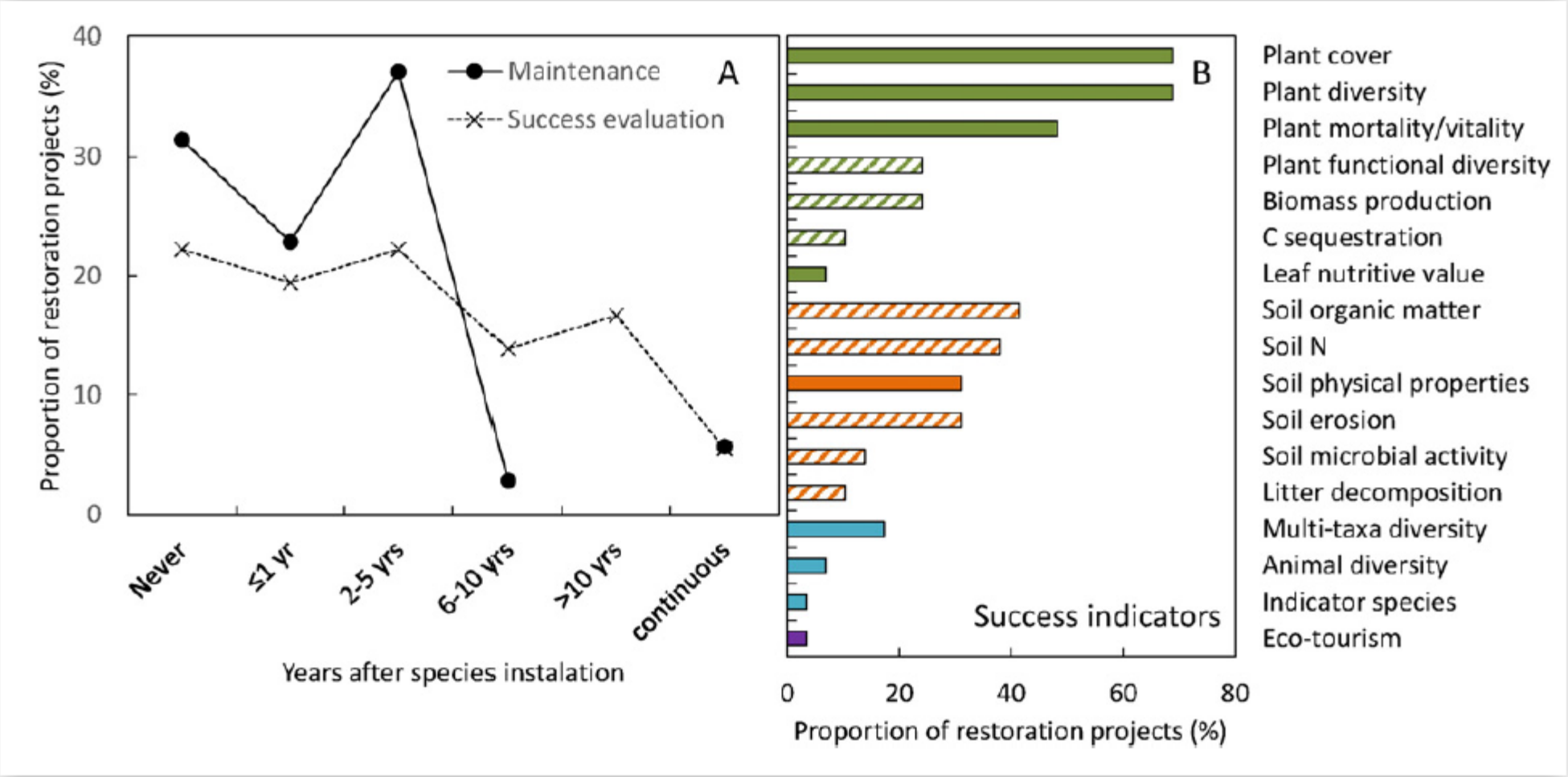

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Assessment of restoration projects in Mediterranean landscapes

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Number of times each probable cause was reported for each unexpected negative result in the restoration projects (number of paired answers) (n = 18). The darker the color the higher the value.

Probable causes	High mortality	Low or inadequate biodiversity	Dominance of a native species	Low plant cover	Low natural recruitment
Drought	11	4	3		1
Low soil quality	7	1	1		1
High erosion	3	1	1	1	1
Pests	2	1	1		
Inappropriate planting techniques	2	1	1		
Excessive irrigation		1			
Wildfire	1				
Invasive species		1			
High fragmentation				1	
Short elapsed time				1	

Source: Nunes *et al*. (2016) Science of the Total Environment 566–567: 722-732 http://dx.doi.org/10.1016/j.scitotenv.2016.05.136

Suggested Reading

- Aronson *et al*. (Eds.) (2009) Cork oak woodlands on the edge. Ecology, adaptive management, and restoration. Society for Ecological Restoration International, Island Press

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- Vallejo *et al*. (2012) Restoration of Mediterranean-type woodlands and shrublands. In: Van Andel and Aronson (eds.) Restoration Ecology. The new frontier. Wiley-Blackwell. pp130-144