Enhancing ecosystem services in agricultural watersheds through riparian restoration

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Introduction

✓ 40% of terrestrial natural ecosystems have been transformed into croplands (FAO, 2018) → biodiversity loss and **ecosystem services (ES)**

↑ provisioning ES, ↓ supporting, regulating and cultural ES

Introduction

- ✓ Agricultural land-use is one of the **main drivers** of riparian forest fragmentation and water extraction, particularly in Mediterranean semiarid areas.
- ✓ Riparian forest in agricultural landscapes represent only a **small portion, while contributing disproportionately to biodiversity.**
- ✓ This high biodiversity supports **key ecological processes and ES**, **complementary** to that supplied by croplands.
- ✓ **Restoration** of degraded riparian areas has increased but proper **evaluation** of restoration success is usually lacking.
- ✓ Little empirical evidence of the effects of **riparian restoration on ES supply**.

Objectives

1. We investigated the effect of hydrological and soil feature on **survival and growth** of saplings planted in degraded riparian areas in NE Spain.

Objectives

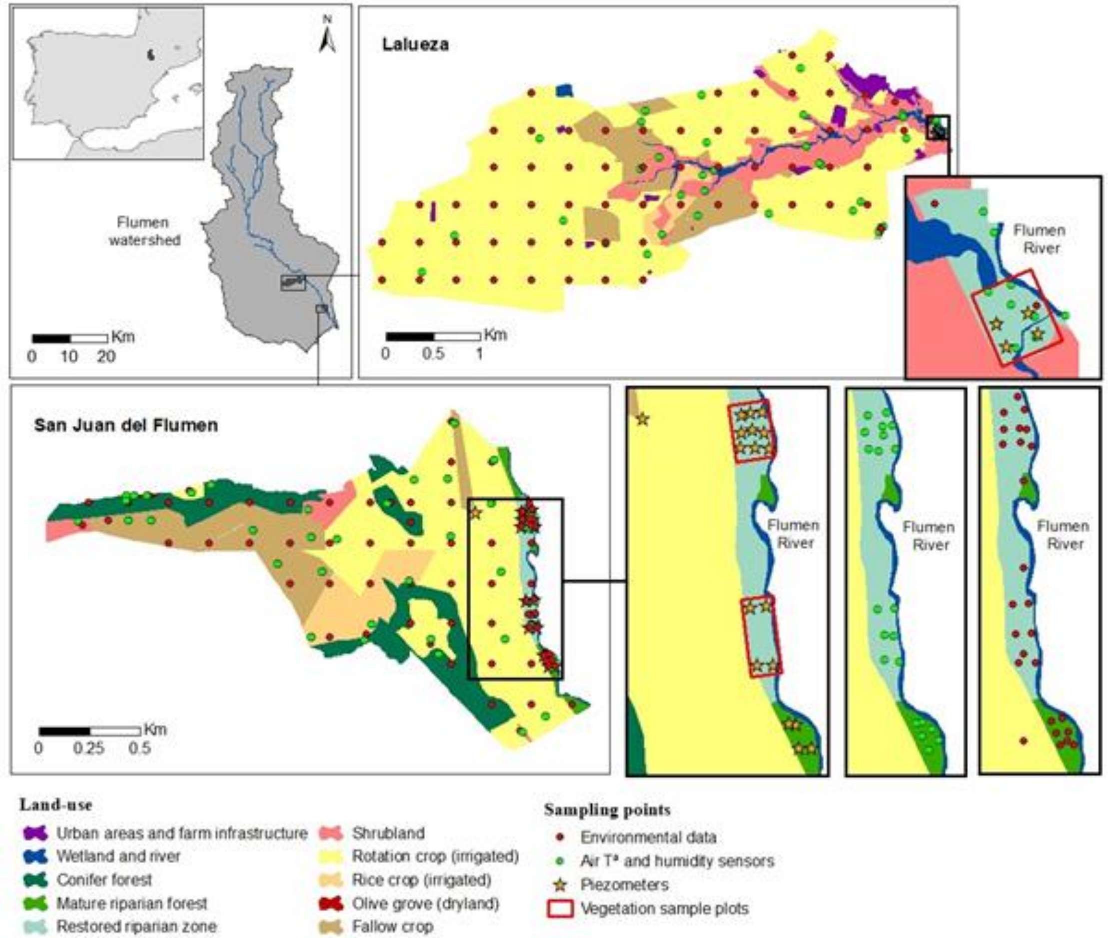
2. We assessed 9 **regulating and supporting ES** in riparian areas with different conservation status (mature-restored-degraded) and compared them with other natural and agricultural land-use types in the same watersheds.





Study area

- Agricultural sub-catchment
- Semi-arid climate
- Precipitation 434 mm
- Temperature 24.7-3.8 ºC
- Habitat 92A0
- *S. alba* and *P. alba* galleries
- River floodplains transformed for agriculture: 80%
- Irrigated crops (corn, rye, rice)
- Riparian restoration 2011-2012 (LIFE CREAMAGUA)



Methods: restoration success

1. We monitored 436 individuals of saplings of 10 species (*Populus alba, P. nigra, Fraxinus angustifolia, Rosa canina, Celtis australis, Salix alba, S. atrocinerea, Ulmus minor, Lonicera implexa* and *Phillyrea angustifolia)*

2. Indicators of riparian revegetation success (twice a year 2012-2016): survival rate, percentage of living branches, height and diameter growth

3. Mixed models (*glmulti*) with the following predictors: water table depth, salinity, bulk density, clay (%), and soil concentration of total N, Olsen P, K^+ and Mg^{2+} (fixed effects) and species identity as random factor.

4. Complementary, NMDS and Kruskal-Wallis with post hoc to test for differences in **riparian vegetation composition and richness**, respectively, between mature-restored-unrestored riparian areas

Results: restoration success

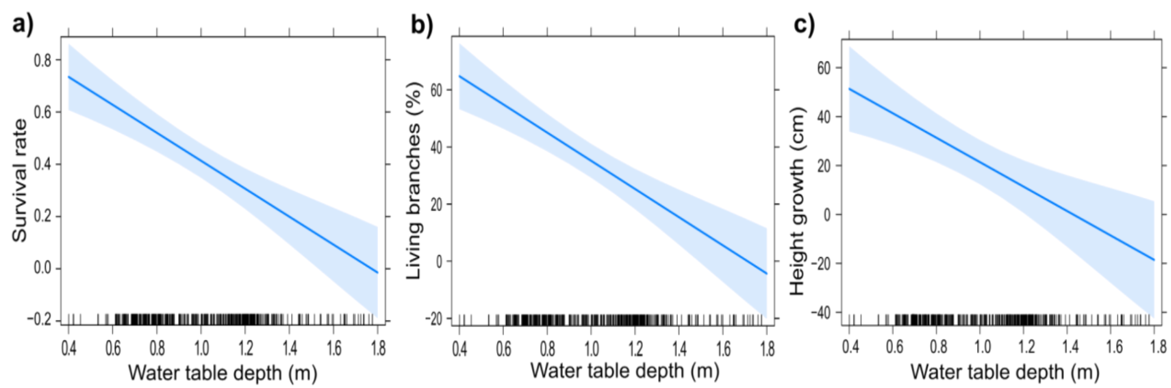
- Survival = 55% (14-83%)
- Living branches = 47% (13-75%)
- Height growth = 26 cm (5-104 cm)
- Diameter growth = 6 cm (0.4-20 cm)

Growth in diameter and height, except for Salix spp., was slow (0.8 cm/year and 5.6 cm/year on average for all studied species except for *Salix* spp.).

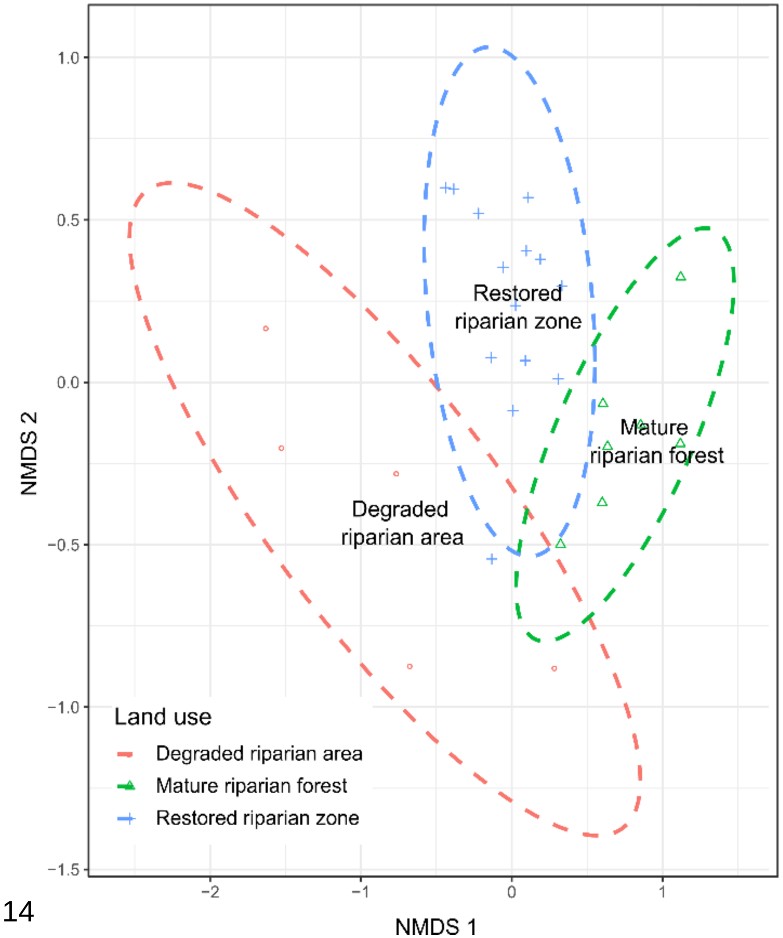
As expected, water table depth, salinity, bulk density and soil nutrients (i.e., Mg^{2+}, K^+ and Olsen P) predicted riparian revegetation success

Significant interactions point that the negative effect of soil salinity can be palliated with a high concentration of nutrients (Mg^{2+}, K^+ and Olsen P).

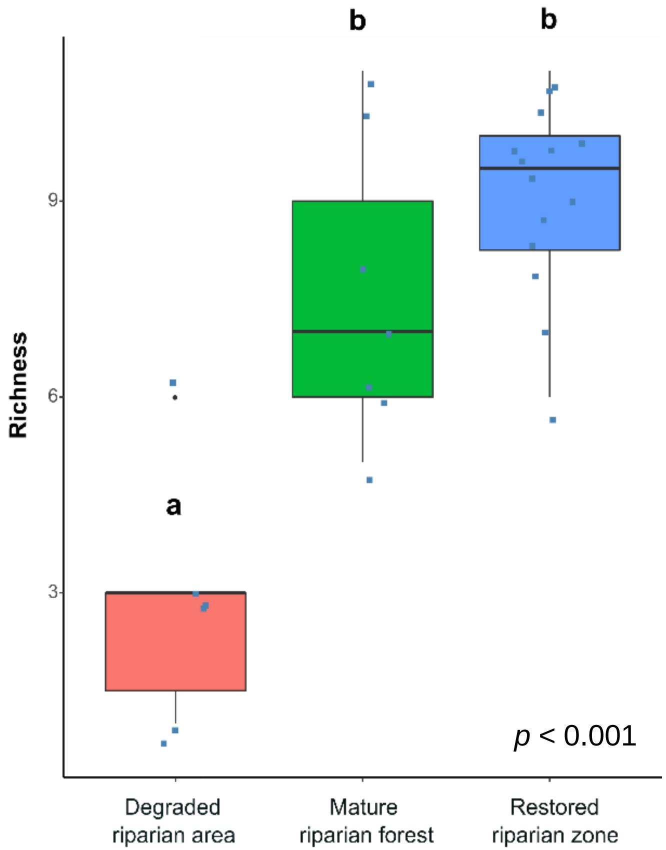
Explanatory variable	Survival rate $R^2 = 0.34$		Living branches $R^2 = 0.33$		Height growth $R^2 = 0.29$		Diameter growth $R^2 = 0.3$	
	Estimate	**P**	**Estimate**	**P**	**Estimate**	**P**	**Estimate**	**P**
Water table depth	↓	<0.001***	↓	<0.001***	↓	<0.001***	↓	<0.001***
Soil Mg^{2+}	↑	0.008**	↑	<0.001***	↑	<0.001***	↑	0.006**
Salinity	=	ns	↓	0.042*	↓	0.001**	↓	<0.001***
Soil P Olsen	=	ns	=	ns	=	ns	↑	0.045*
Soil Mg^{2+} : Salinity	↑↓	<0.001***	↑↓	<0.001***	↑↓	<0.001***	=	ns
Water table depth: Salinity	=	ns	=	ns	=	ns	↓↓	<0.001***
Soil Olsen P: Salinity	=	ns	=	ns	=	ns	↑↓	<0.001***



Results: restoration success



Stress = 0.14



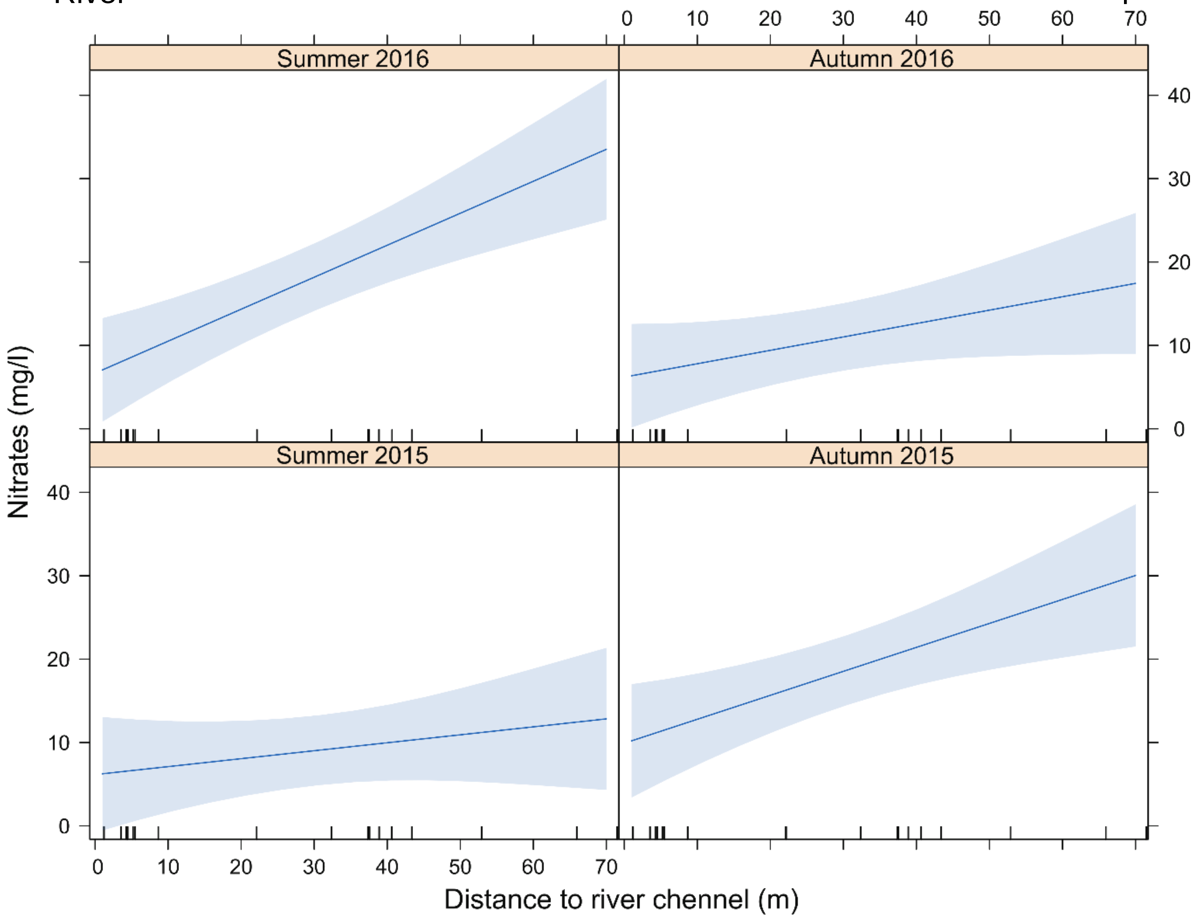
Methods: ecosystems services

- 9 different land-uses
- 3 riparian
- Mixed-effect models
- ANOVAs + Tukey
- Kruskal + Dunn
- Model assumptions checked

MEA category*	Ecosystem service	Indicator	Unit
Supporting	Habitat provision	Tree cover	%
		Number of vegetation strata	-
Supporting	Soil formation	Soil microbial biomass	Kg C m^2
Regulating	Water purification	NO_3^- in groundwater	mg l^{-1}
		SO_4^{2-} in groundwater	mg l^{-1}
		PO_4^{3-} in groundwater	mg l^{-1}
Regulating	Soil Carbon storage	Soil organic C	Mg ha^{-1}
Regulating	Soil storage capacity of organic pollutants	Soil CEC	$cmol_c$ dm^{-2}
Regulating	Soil water holding capacity	Saturated soil water content	cm^3 cm^{-3}
Regulating	Soil water infiltration rate	Hydraulic conductivity of topsoil	mm s^{-1}
Regulating	Mitigation of surface runoff	Sorptivity of topsoil	mm $s^{-0.5}$
Regulating	Microclimate regulation	Inverse DTR	adimensional
		Inverse DHR	adimensional
		Mean daily air T^a	° C
		Mean daily air H	%

Results: ecosystems services

River | Nitrate concentration | Crops



Water purification

Interactive effects of date and distance to river channel on groundwater nitrate concentration tested by mixed-effect models.

Retention rate 51-79%

We did not find significant differences between mature and restored areas (woody and herbaceous buffer strips can show similar responses; Sabater et al., 2003; *Ecosystems*)

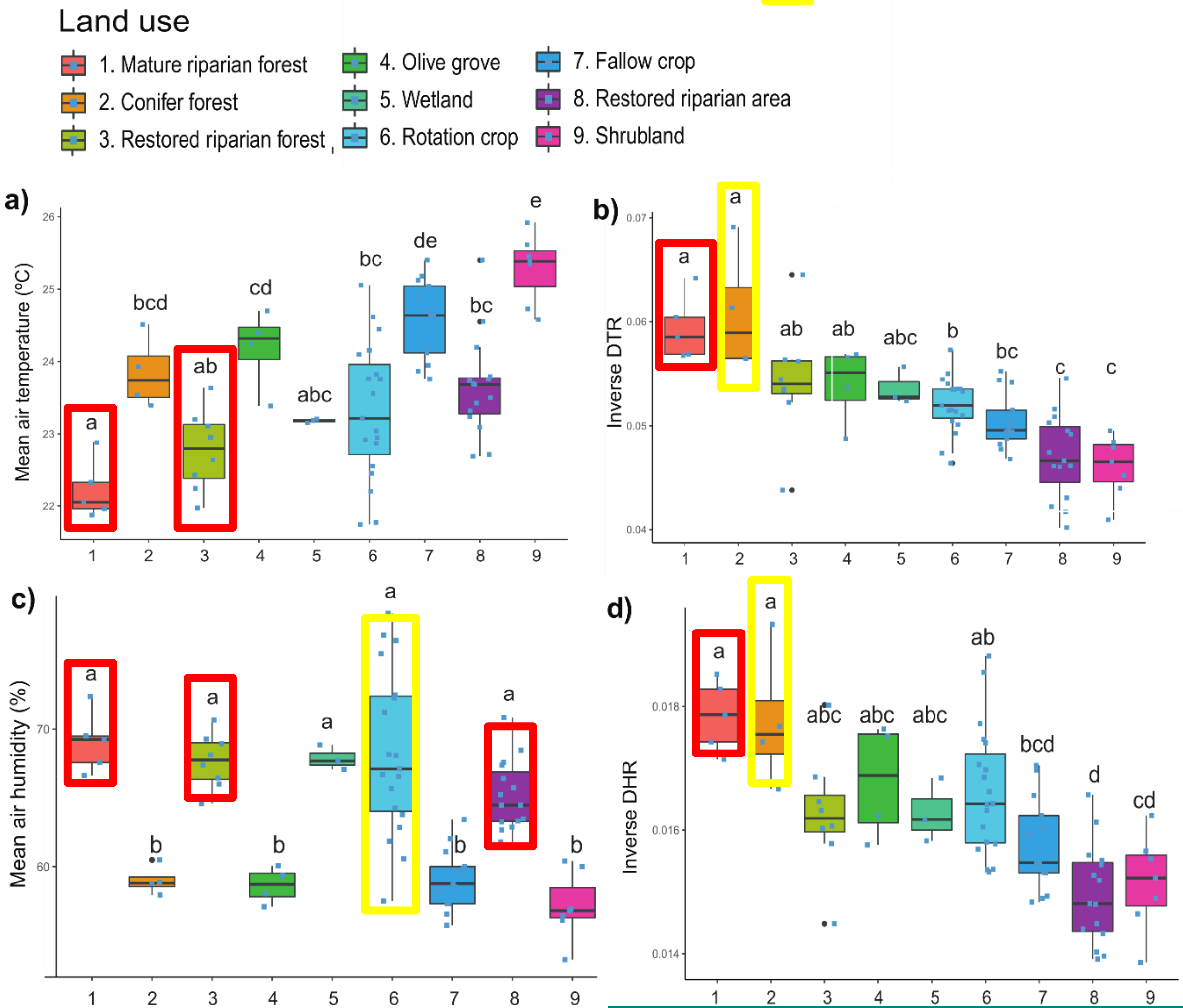
No significant effect of riparian area was found for sulphates and phosphates

Results: ecosystems services

When a riparian land use obtained the best result

When other land uses also obtained the best result

Microclimate regulation



Forests (riparian, pines), olive groves and wetlands had more stable air temperature and humidity in comparison with non-arboreal land-uses.

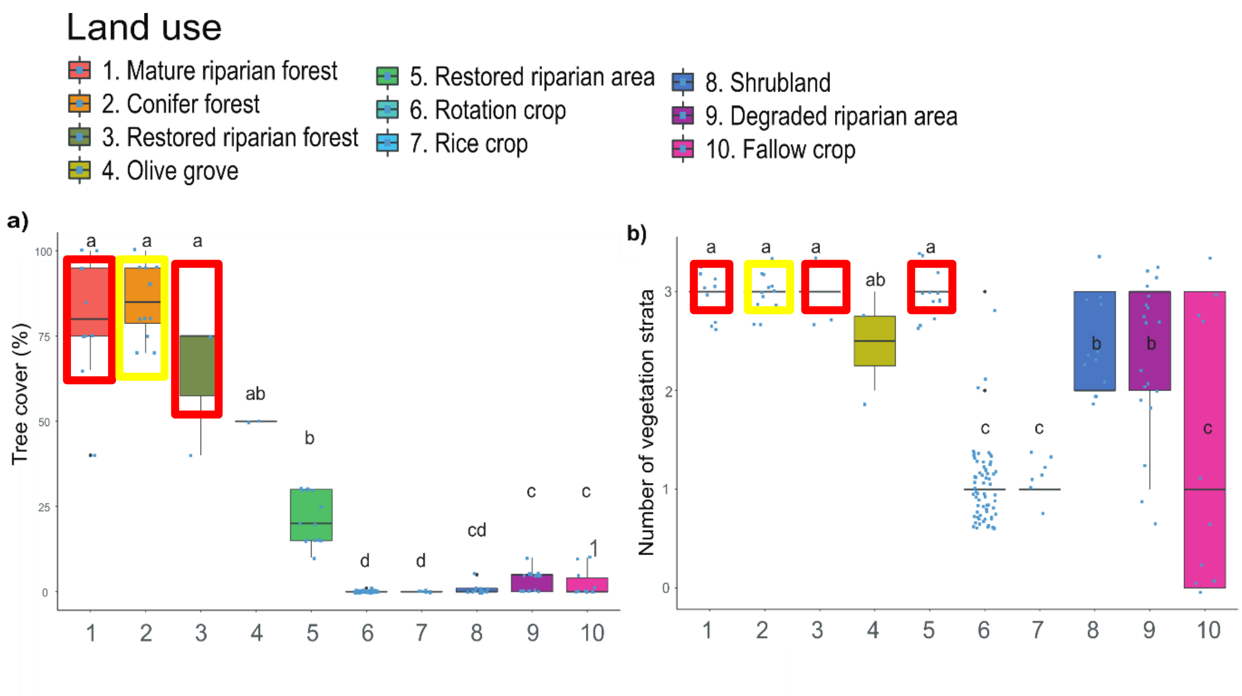
Mature riparian forest and restored riparian forest showed the lowest air temperature values and air humidity values.

Wooded riparian zones provide shade to the river channel, moderating fluctuations in water temperatures and dissolved oxygen, which contributes to buffer eutrophication and, consequently, improves water quality.

Riparian gallery forests provide cooler and more stable conditions within highly disturbed agricultural watersheds, which is particularly important in semi-arid areas

Results: ecosystems services

Habitat provision



Mature riparian forest, restored riparian forest, and conifer forest showed the highest tree cover (>70%) and number of vegetation strata (trees, shrubs, and herbs) and consequently the highest habitat provision values.

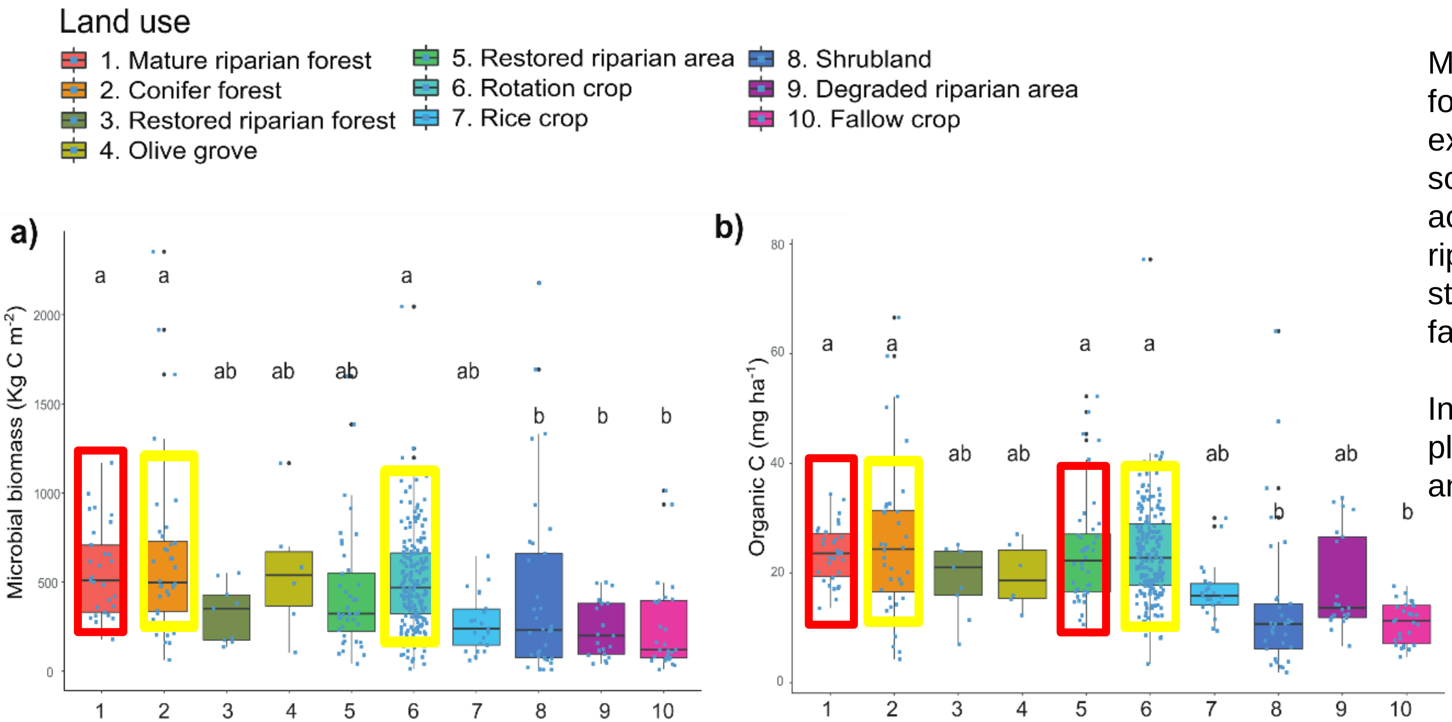
Rotation and rice crops showed the lowest values for both variables

- Small forest patches in fragmented landscapes can act as “lifeboat” habitats. Microhabitats offer short-term protection from anthropogenic disturbances and act as “transit shelters” for species that could deliver other complementary ES (pollination, pest control), Cole et al., 2020; *Agriculture, Ecosystems and Environment*).

Results: ecosystems services

Soil formation

Soil Carbon accumulation



Mature riparian forest, conifer forest, and rotation crops exhibited the highest values of soil formation and C accumulation (also restored riparian area for soil C storage) while shrublands and fallow crops the lowest

In forests, higher amounts of plant litter enhance C storage and microbial activity

- Although we could expect much higher values of soil C storage and soil formation in natural forests than in rotation crops: 1) many farmers in our study area adopted conservation tillage practices, reducing the number of interventions on soil and leaving plant residues, and 2) fertilization and nitrogen fixation increase soil C

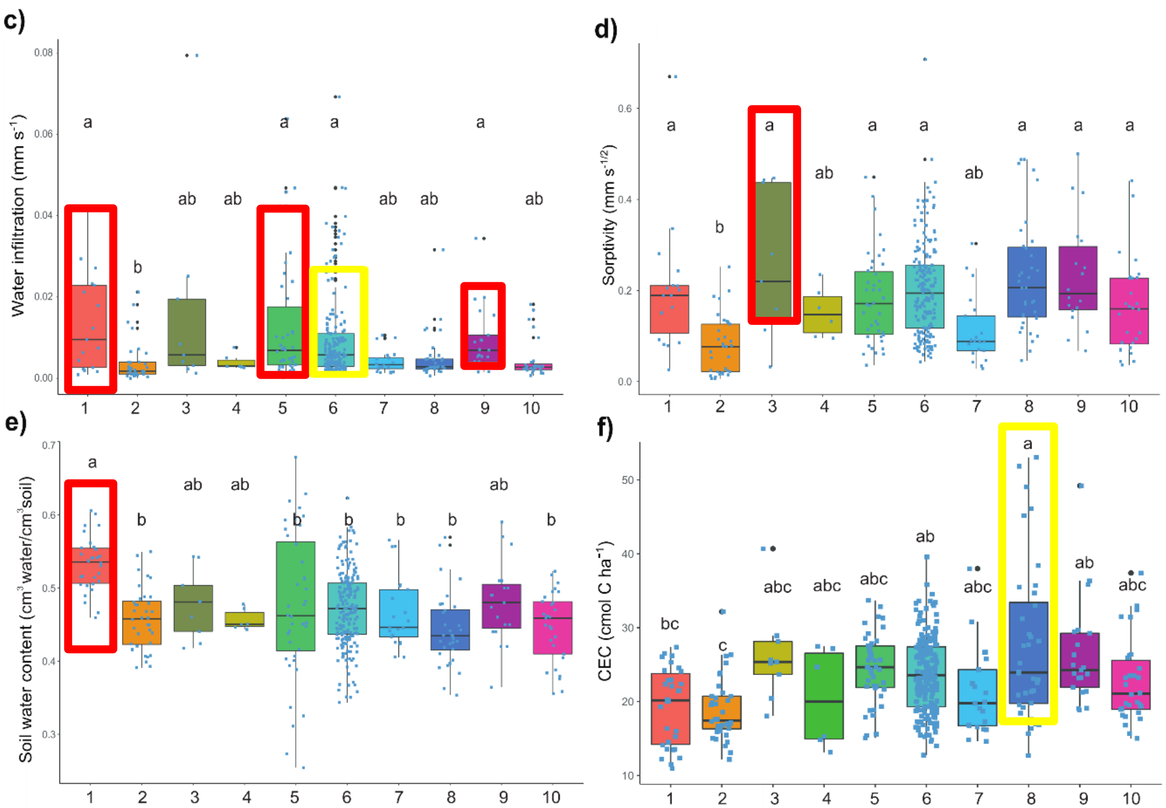
Results: ecosystems services

Land use

- 1. Mature riparian forest
- 2. Conifer forest
- 3. Restored riparian forest
- 4. Olive grove
- 5. Restored riparian area
- 6. Rotation crop
- 7. Rice crop
- 8. Shrubland
- 9. Degraded riparian area
- 10. Fallow crop

Water infiltration

Mitigation of runoff



Soil water holding capacity

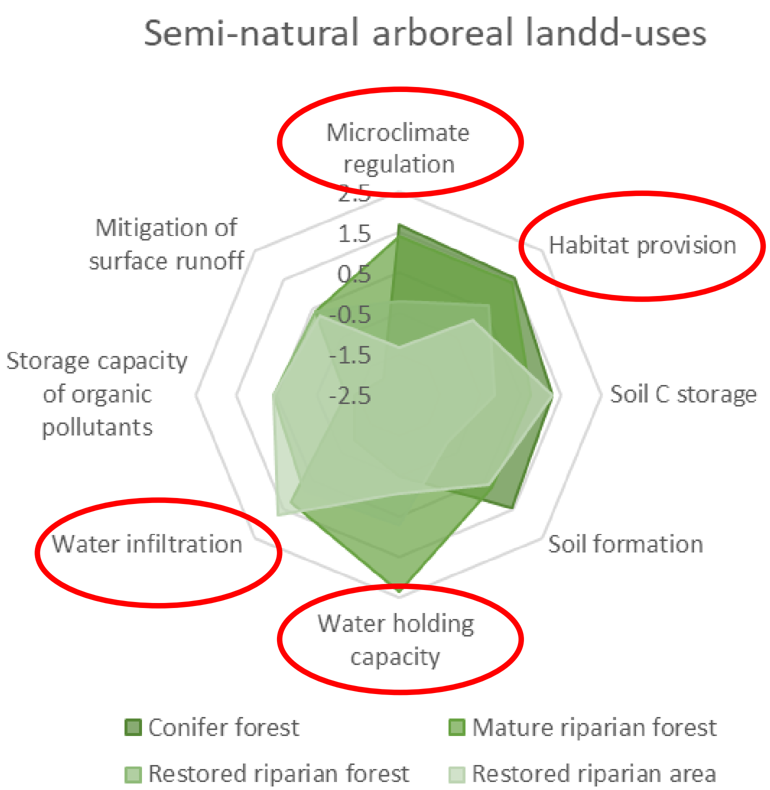
Storage of pollutants

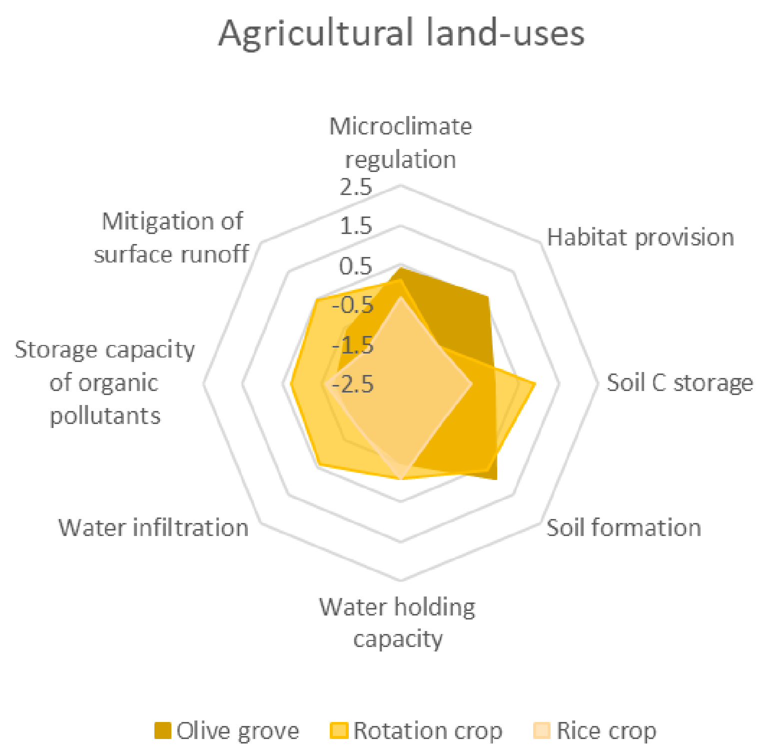
Lowest water infiltration and mitigation of surface runoff rates were found in conifer forests (water repellency)

Mature riparian forest had the greatest values of water holding capacity. As high-water-retention ecosystems, riparian forests decrease both flood peaks and low flows, which is especially relevant in Mediterranean basins

Shrubland had the highest values of storage capacity of organic pollutants

Results: ecosystems services





Conclusions

- Riparian restoration was relatively successful since most of the planted species had a **survival rate over 50%,** reaching over 80% in *Fraxinus angustifolia, Rosa canina* and 65% in *Salix alba* and *S. atrocinerea*
- **Survival and growth** mainly depended on **water table depth** (-), **soil salinity** (-), **bulk density** (-) and **soil nutrients** (+; namely Mg^{+2}, K^{+} and Olsen P).
- **Higher nutrient availability may overcome some of the inhibitory effects of soil salinity.**
- **Forest patches,** particularly riparian ones**,** provides meaningful and complementary **regulating and supporting ES** in agricultural landscapes.
- **Riparian restoration** increased the supply of water purification, habitat provision, microclimate regulation, water infiltration and soil C storage in comparison with other land-uses as agricultural crops.
- They were still far from the magnitude and range of ES provided by **mature riparian forests**.
- **Riparian restorations to recover ES**, contributing to build **multifunctional landscapes**
- Prioritize **management practices** on conserving riparian forest patches and restoring degraded ones to reconcile agricultural production with the maintenance or enhancement of ES in agricultural basins.

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FIRE

Burgeon

CONVERGES
European Riparian Ecosystems

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Thank you!
Ďakujem!

COST CONVERGES meeting, Bratislava, 2022

Time to act…
Fall is coming!