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SSS8.8 – Experimental ecosystem development research and ecological model systems

Dynamics and patterns of plant development in restored mining areas. Practical examples

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3. **FINAL REFLECTION: empirical value of succession studies in revegetation.**

Succession on anthropogenic susbtrates

- **Peculiarities of succession on mine wastes**
  - on an undeveloped "soil"
  - not previously colonized by plants
  - without hardly a seed bank (colonization from surroundings)

- **Type of succession: primary, autotroph and autogenic.** That is, succession on new inorganic substrates, where the first step must be colonization from the outside by green plants, and in the absence of changing abiotic influences.

- Also **partially allogenic** suscession, if the waste is covered with topsoil cointainig seeds or other finer materials, fertilized or amended.

  Covering substrates ⇒ physical agents (**allogenics**, external to the new substrate, mine wastes) responsably in part of succession acceleration?

Martínez-Ruiz & Fernández-Santos (2001)

Background

● **PRIORITY → to base restoration programs and decisions**

on the knowledge of

- **Succession mechanisms**
- **Ecological processes**

Challenge:

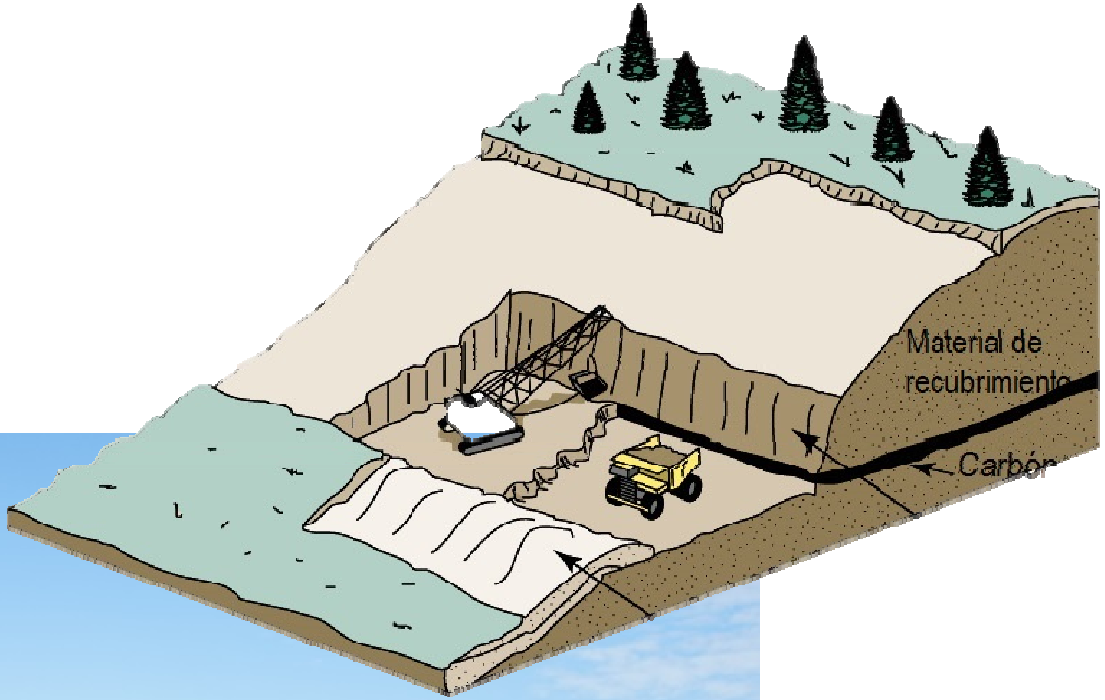
- **To identify the environmental factors that prevent or restrict the vegetation establishment and its subsequent dynamics**
- **And those that facilitate and enhance revegetation.**

Premise: if we are able to successfully restore an ecosystem it is because we really know how it works.

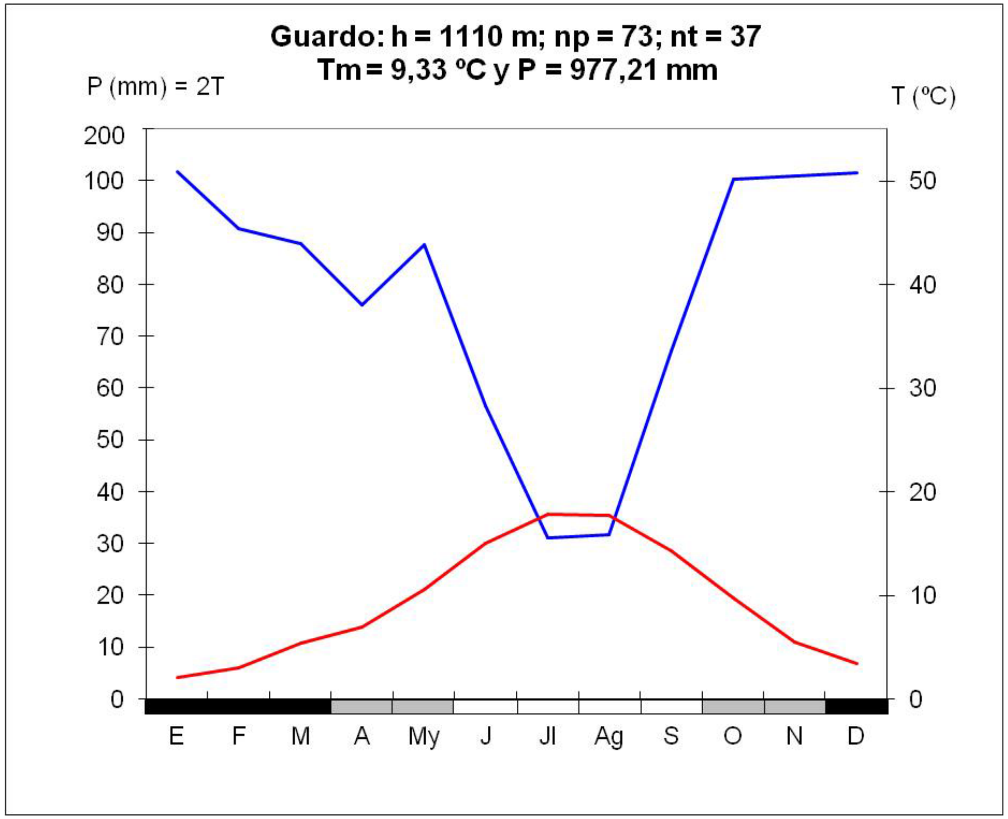
2. Vegetation dynamics after coal mining restoration in Northern Spain

(Sub-humid Mediterranean climate)

Contour mining



Climate

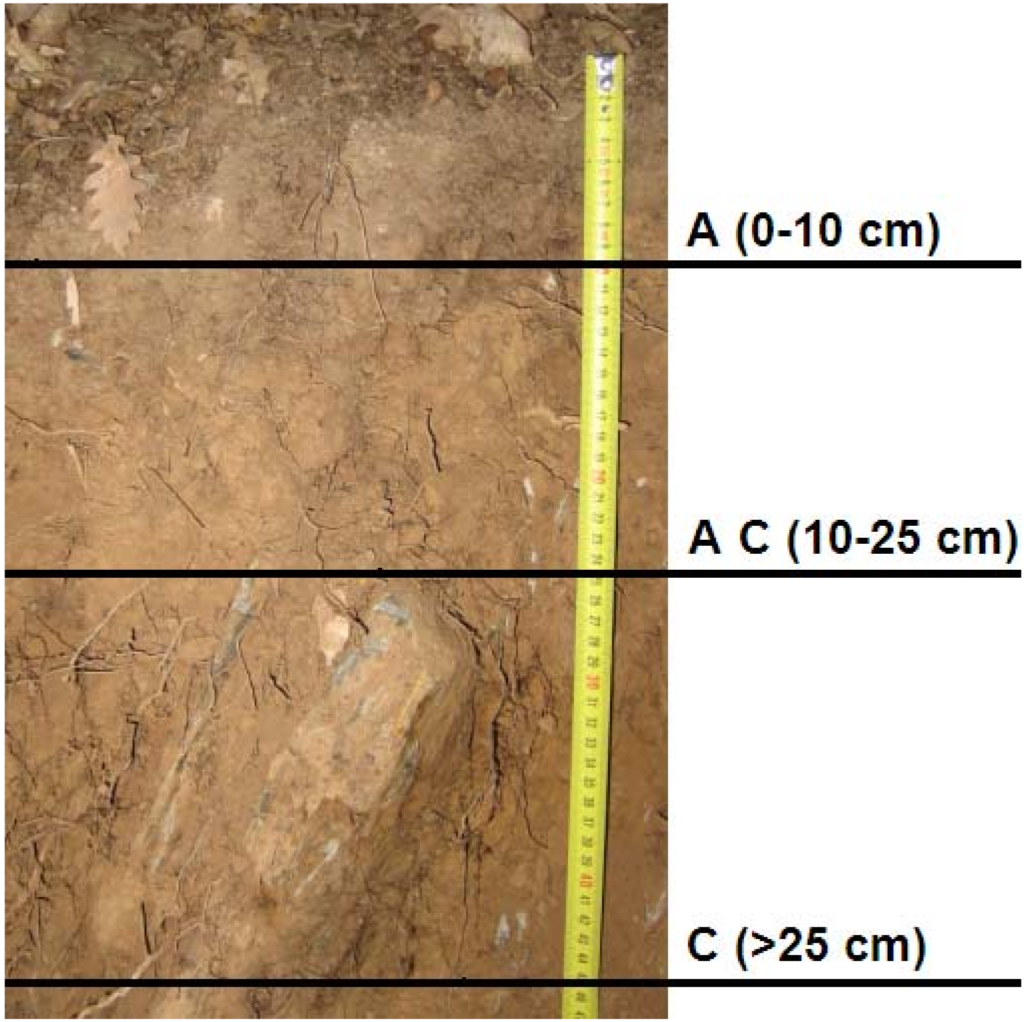


Sub-humid Mediterranean climate

This period of summer drought is easily surpassed by vegetation by having the soil with a good structure and water retention capacity, as shown by the surrounding planocaducifolios forests.

Vegetation

Soil profile in the natural forest of *Quercus pyrenaica* and *Q. petraeae*



Soil profile in the rehabilitated coal mines

- without edaphic structure
- with low water holding capacity (López-Marcos *et al*., 2020)

Main limiting factors for revegetation

Summer drought + absence of soil structure of mine substrates (low capacity to store water)

Grazing: domestic livestock and wild ungulates (deer, wild boar)

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Previous results

- **Without topsoil** → unstable and poor in species plant communities ('arrested succession') (Alday *et al*., 2014)
  → woody colonization can take more than 40 years

- **Topsoil addition** → improve soil properties → ↑ vegetation cover
  → doesn't return the original seed bank (it barely contains seeds; González-Alday *et al*., 2009)

  ⬇ it is necessary

  - the introduction of seeds (hydroseeding) (to achieve a rapid plant cover of herbaceous species)
  - and/or to activate the natural colonization processes

Previous results

- **Topsoil** + **Hydroseeding** → ↑ **revegetation?**

✓ A more o less continuous coverage of non-native herbaceous species

✓ No more restoration actions by humans

✓ Natural woody colonization from surroundings

- **plant succession relatively fast**
- in 15 years → a community of native shrubs (whose seeds were not present in the mixture of hydroseeding)

  → with cover of 36 to 85 %

  → colonizing the soil sparsely

(Alday *et al*., 2011a)

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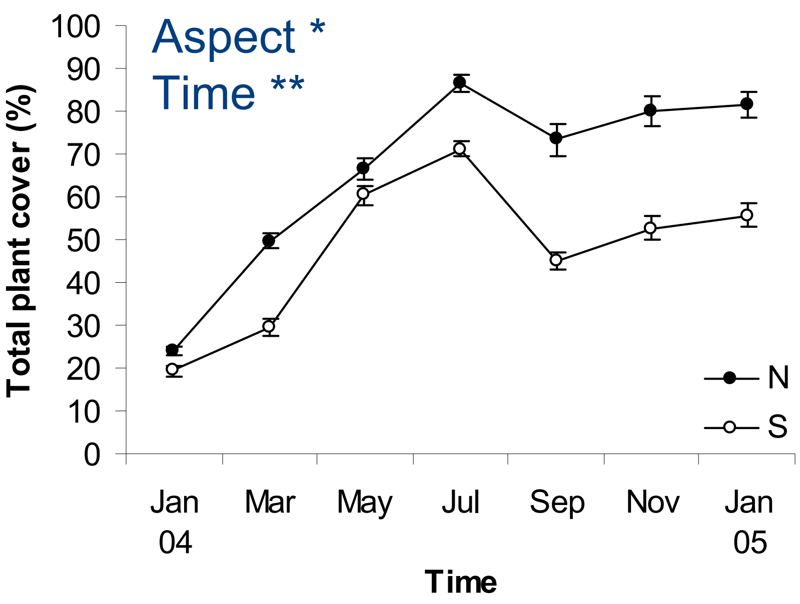
2.1. Influence of aspect

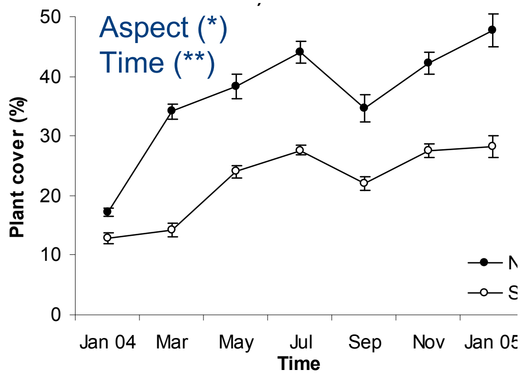
The development of herbaceous vegetation after hydroseeding is affected by aspect (no initial differences in soil properties exist)

Aspect effect → through a combination of direct effects of differences in microclimate (different amounts of solar radiation) **+** the relationship of solar radiation to water availability González-Alday *et al.* (2008)

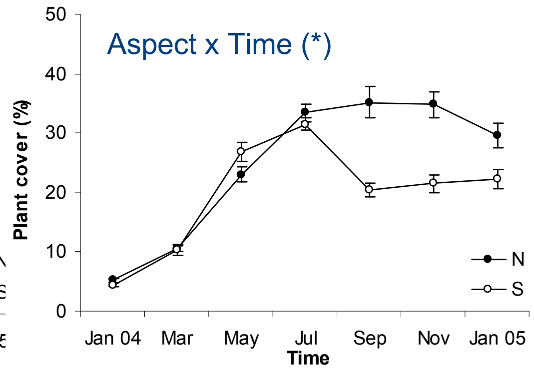
Lower plant cover on southern slopes (S) compared to northern ones (N)



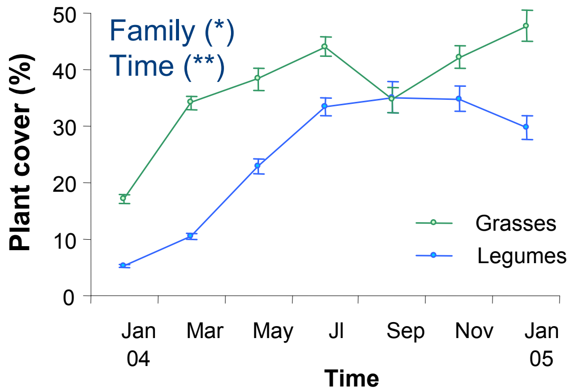
Grasses



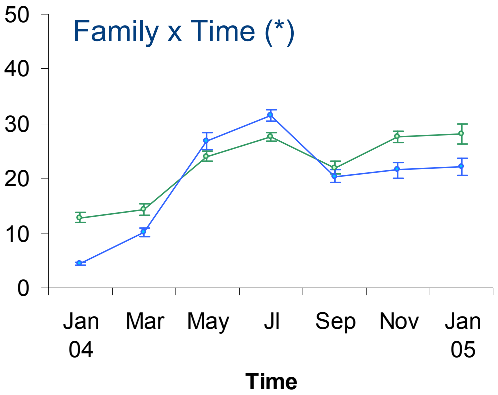
Legumes



North



South



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Conclusions

- Vegetation structural parameters change along time depending on aspect (richness, diversity, hydroseeded and non-hydroseeded species cover).
- Soil properties change along time regardless of aspect, but there is little relationship between floristic compositional dynamics and soil parameters (mainly related to the accumulation of organic matter and sand content, and pH reduction).
- If soil forming material is sufficiently good for vegetation development, floristic compositional differences are mainly driven by a combination of abiotic and stochastic factors in the short-term.
- Differences in topography determine different trajectories of plant communities dynamics with respect to the reference community, greatest between flat and sloping areas.

Alday *et al.* (2010) Alday *et al.* (2011b) Alday *et al.* (2012)

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2.1. Influence of slope gradient

Linking soil variability with plant community structure and dynamics in mine slopes

- Plant succession advances at different rates on different parts of the slope and, in turn, the plant species compositional change along the mine-slope topographic gradient is related to stages of different maturity of vegetation and soil properties.

- The water and organic-matter content were the soil properties most strongly related to the vegetation dynamics towards more mature stages.

(López-Marcos *et al*., 2020)

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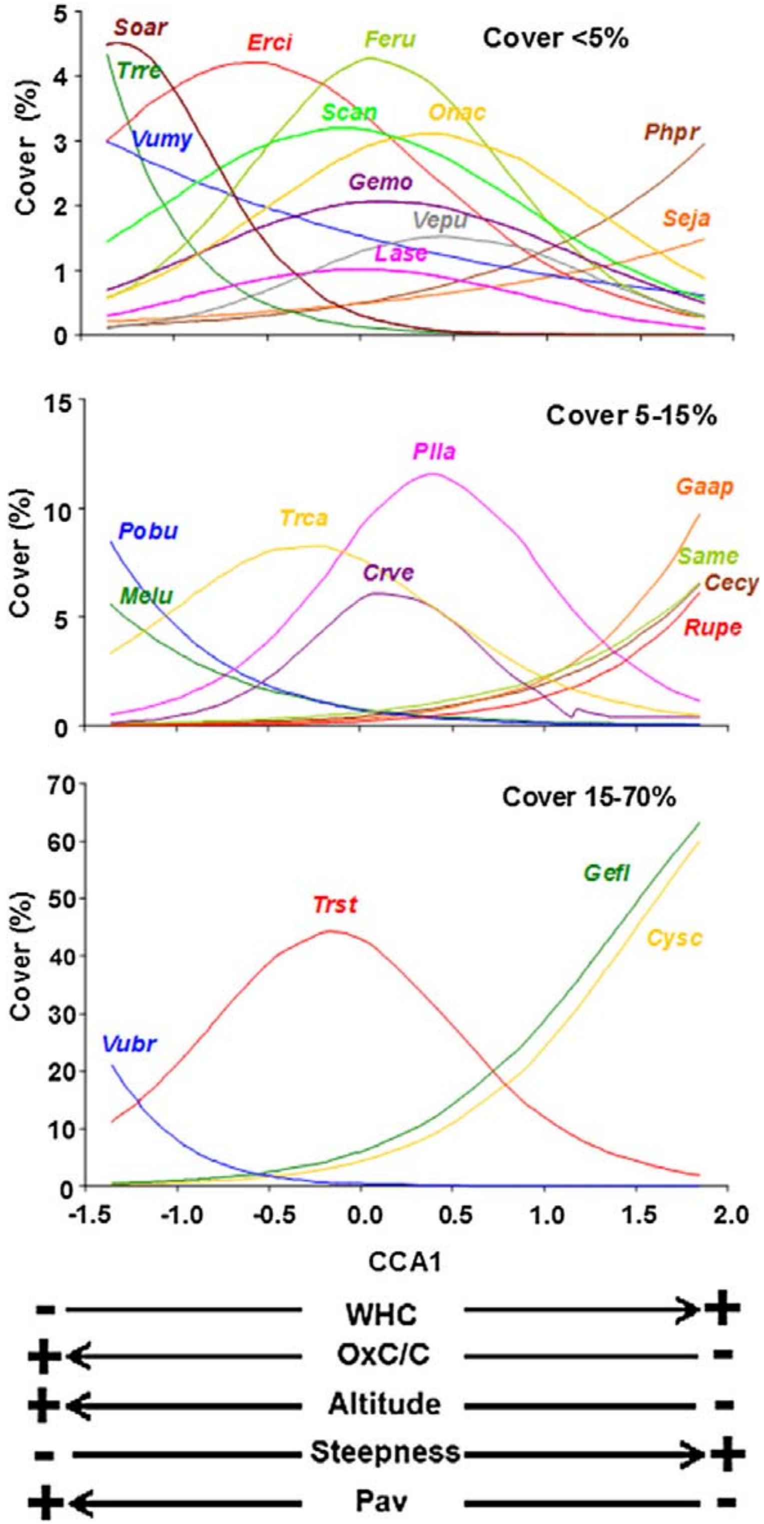
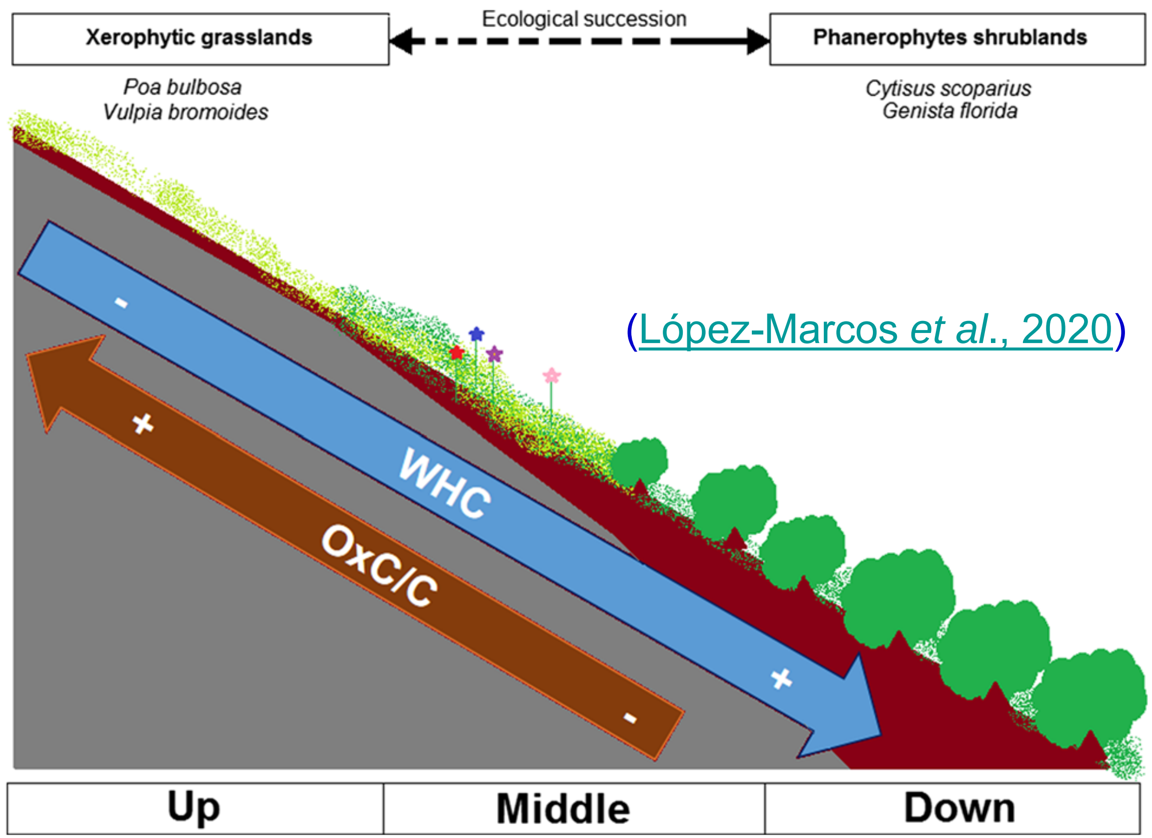
2.1. Influence of slope gradient



- A segregation in the abundance of individual plant species was observed according to changes in soil properties along the mine-slope topographic gradient.
- This segregation mainly responds to the gradient of water availability and organic matter content in the soils.



(López-Marcos *et al.*, 2020)

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2.2. Influence of grazing

Effects of short-term grazing exclusion on vegetation and soil

- Grazing exclusion influence many soil properties, and many traits of plant community structure and floristic composition (but did not affect global species diversity).
- However, only few soil parameters were related to the differences in floristic composition.
- Species responses to the soil gradient from ungrazed to grazed areas were also related to their particular life history traits.

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2.2. Influence of grazing

Effects of short-term grazing exclusion on soil properties

Ungrazed

Grazed

O, oxOM, N, K, P, Ca, Mg, EC, clay

Sand

Silt, pH, Na

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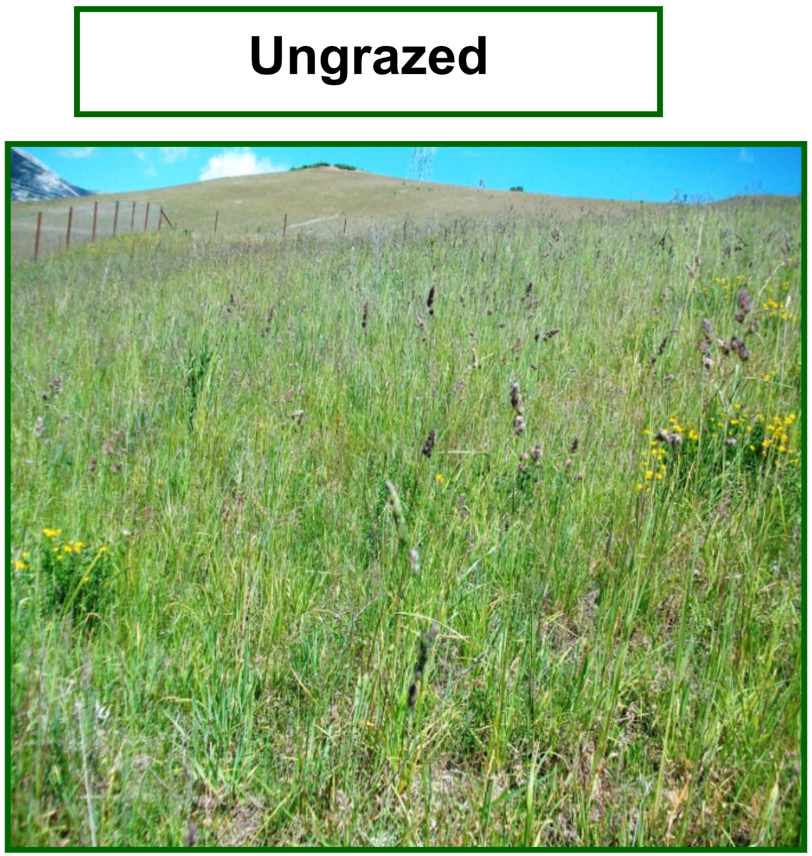
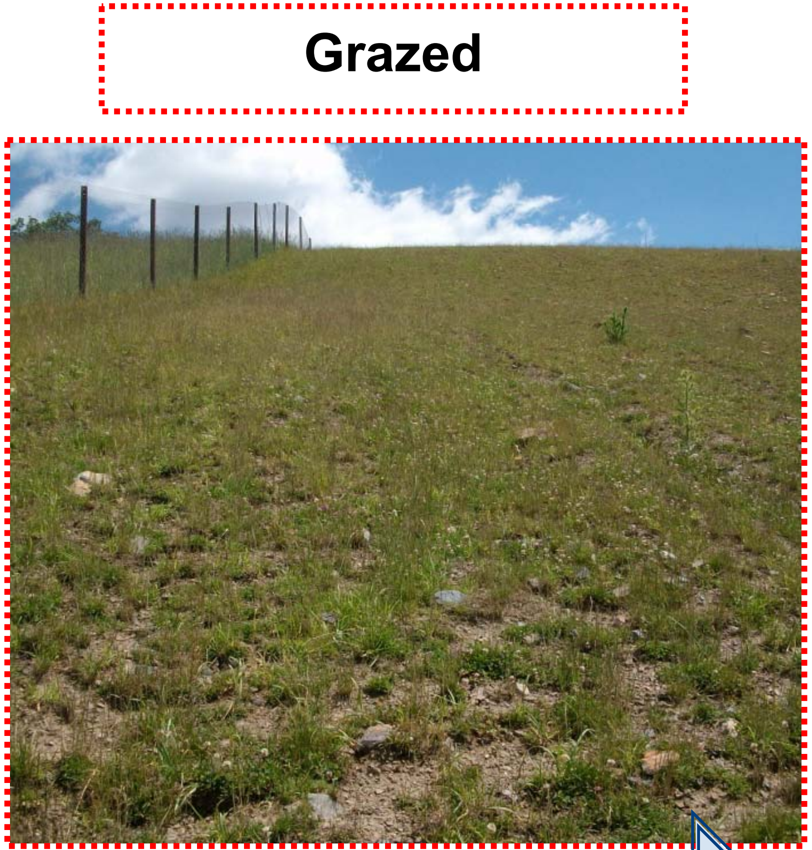
2.2. Influence of grazing

Effects of short-term grazing exclusion on vegetation structure





Bare soil, Richness of endo-zoochorous spp.

Total cover and biomass; Maximun height; Cover of perennials, anemochorous and authocorous spp.; Cover and biomass of grasses, legumes and compositae; Cover and richness of hemicriptophytes.

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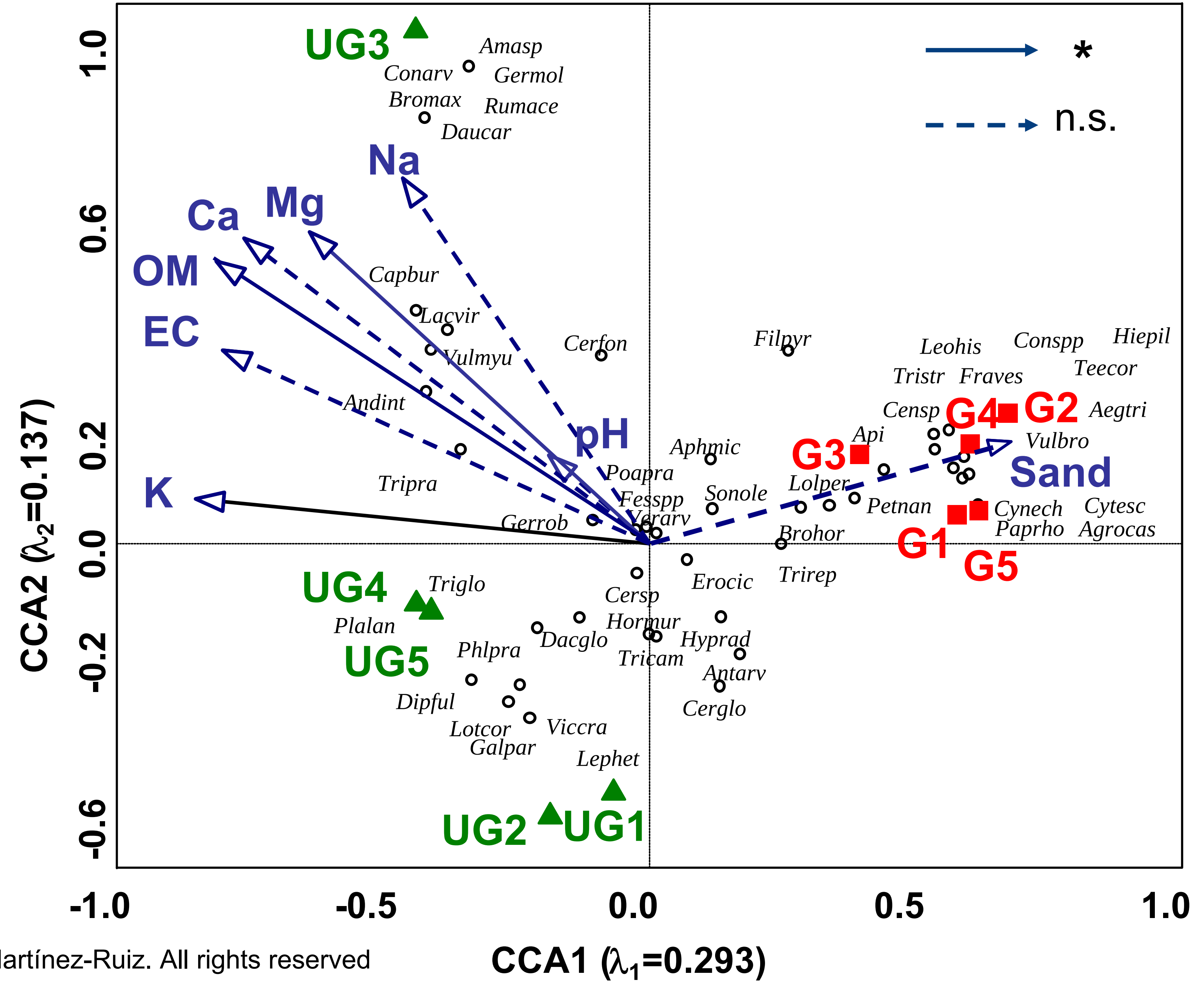
2.2. Influence of grazing

Effects of short-term grazing exclusion on vegetation composition and its relationship with differences in soil properties



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2.3. Influence of the forest edge

The colonization pattern of woody species is affected by fine-scale variations in abiotic factors, including soil properties, which change from the forest to the mine

- Grasslands communities install in reclaimed coal-mine areas are colonized by woody species from the surrounding forest.
- The structure of the new plant community varies not only in time (succession) but also in space (distance to the seed source), and the process is strongly determined by interactions between the forest edge and the initial grassland patch.

Milder *et al.* (2013)

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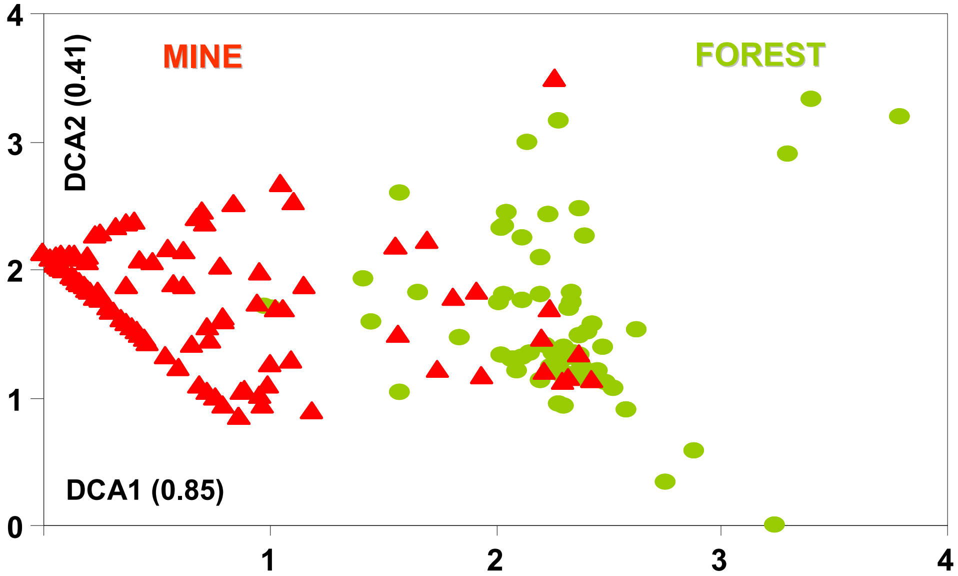
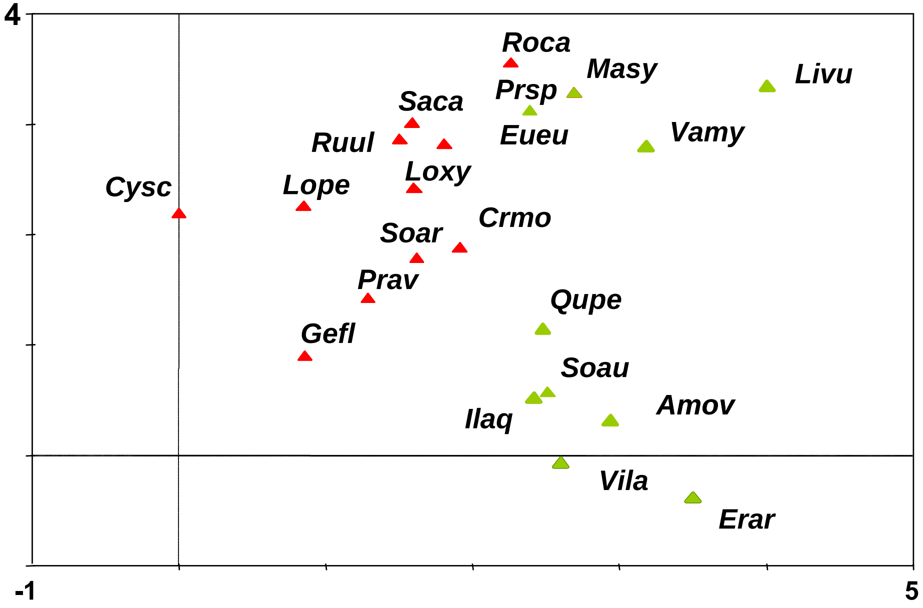
2.3. Influence of the forest edge

Relationship between woody vegetation composition and abiotic factors alog the forest-mine gradient





OM, K, N, C/N, F

Kendall Correlation Coefficient

pH, P, L

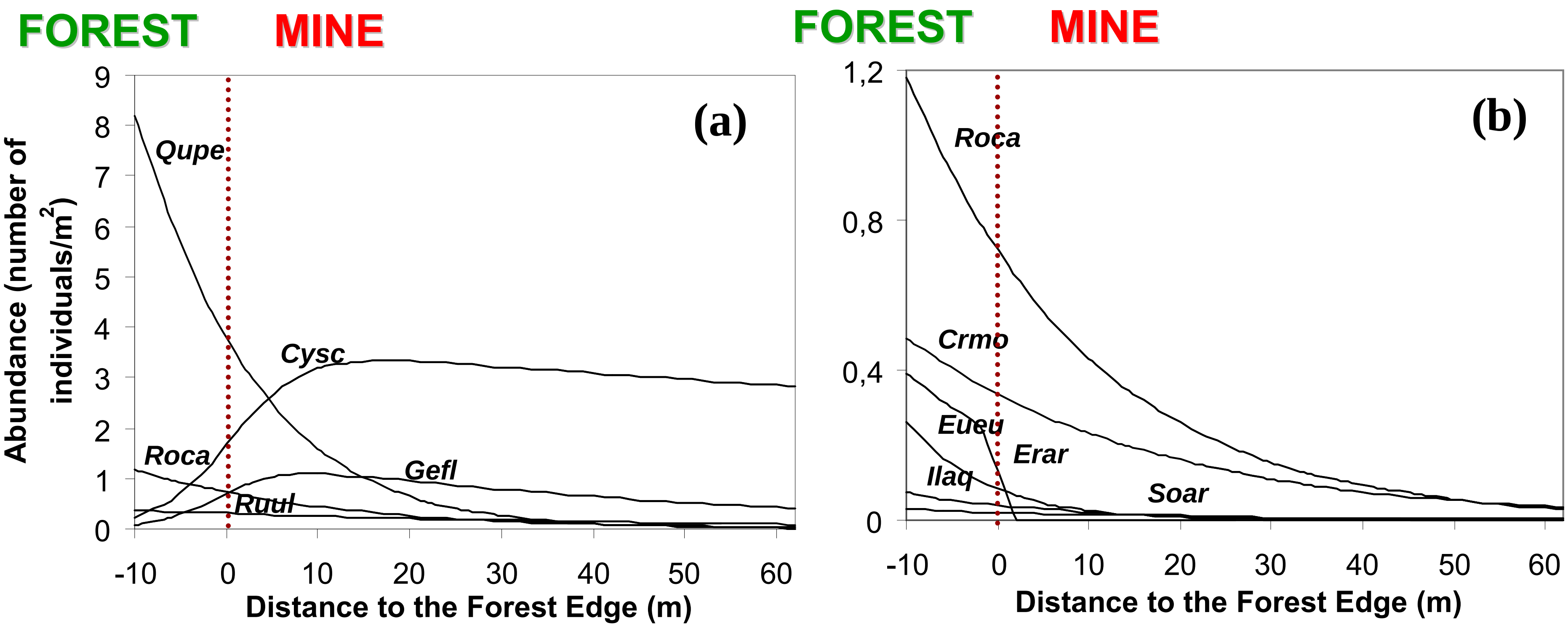
(***) Correlation between DCA1 and Forest-Mine position, and Distance to the forest edge.

L, F = Ellenberg indicator values for light and soil moisture, respectively

Milder *et al.* (2013)

Response pattern of main woody colonizing species alog the forest-mine gradient

Milder *et al.* (2013)



Qupe = Quercus petraea	*Crmo = Crataegus monogyna*
Cysc = Cytisus scoparius	*Eueu = Euonymus europaeus*
Gefl = Genista florida	*Ilaq = Ilex aquifolium*
Roca = Rosa canina	*Erar = Erica arborea*
Ruul = Rubus ulmifolius	*Soar= Sorbus aria*

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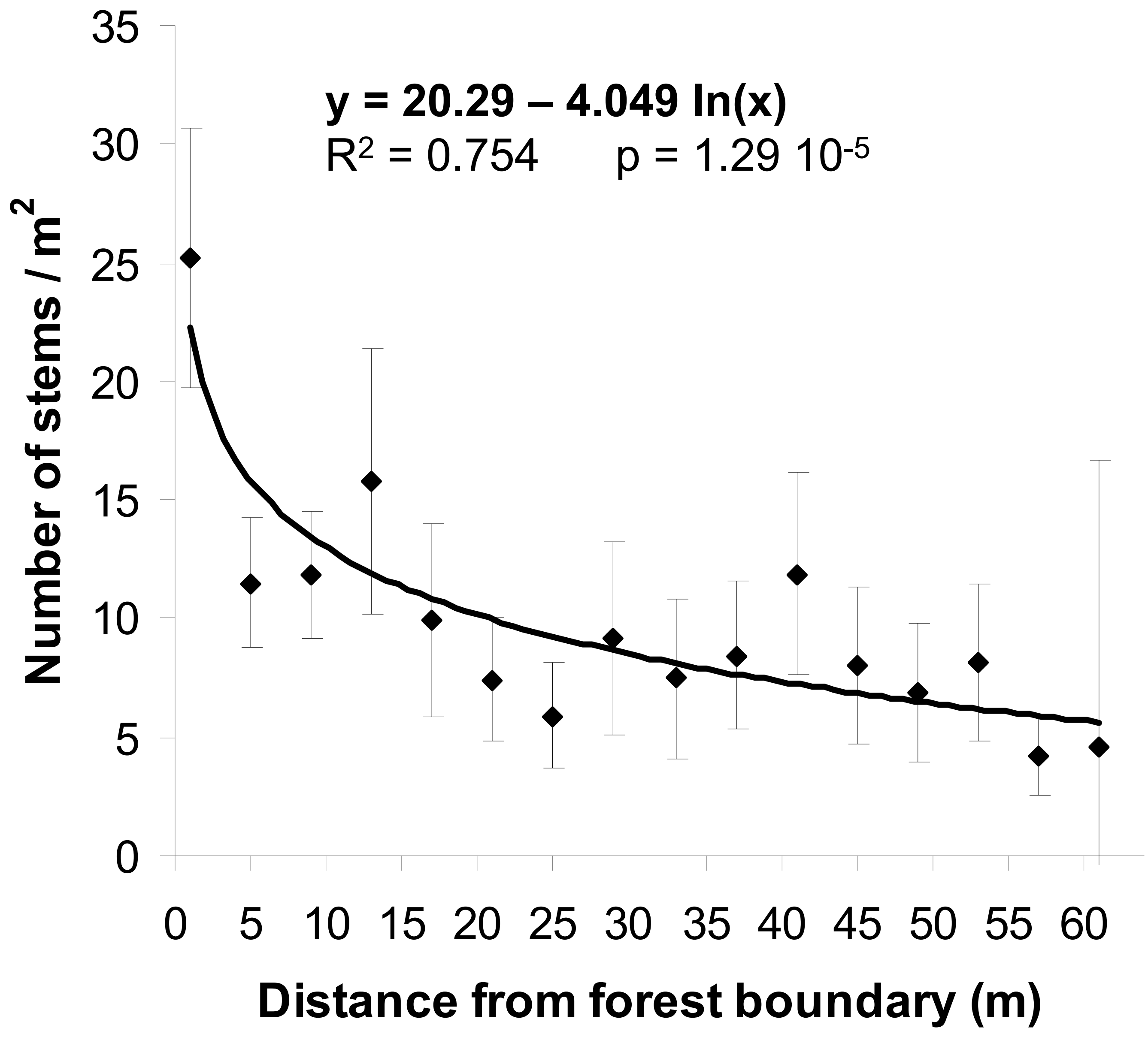
2.3. Influence of the forest edge

Influence of the distance to the forest edge in the woody colonization intensity



Milder *et al.* (2008)

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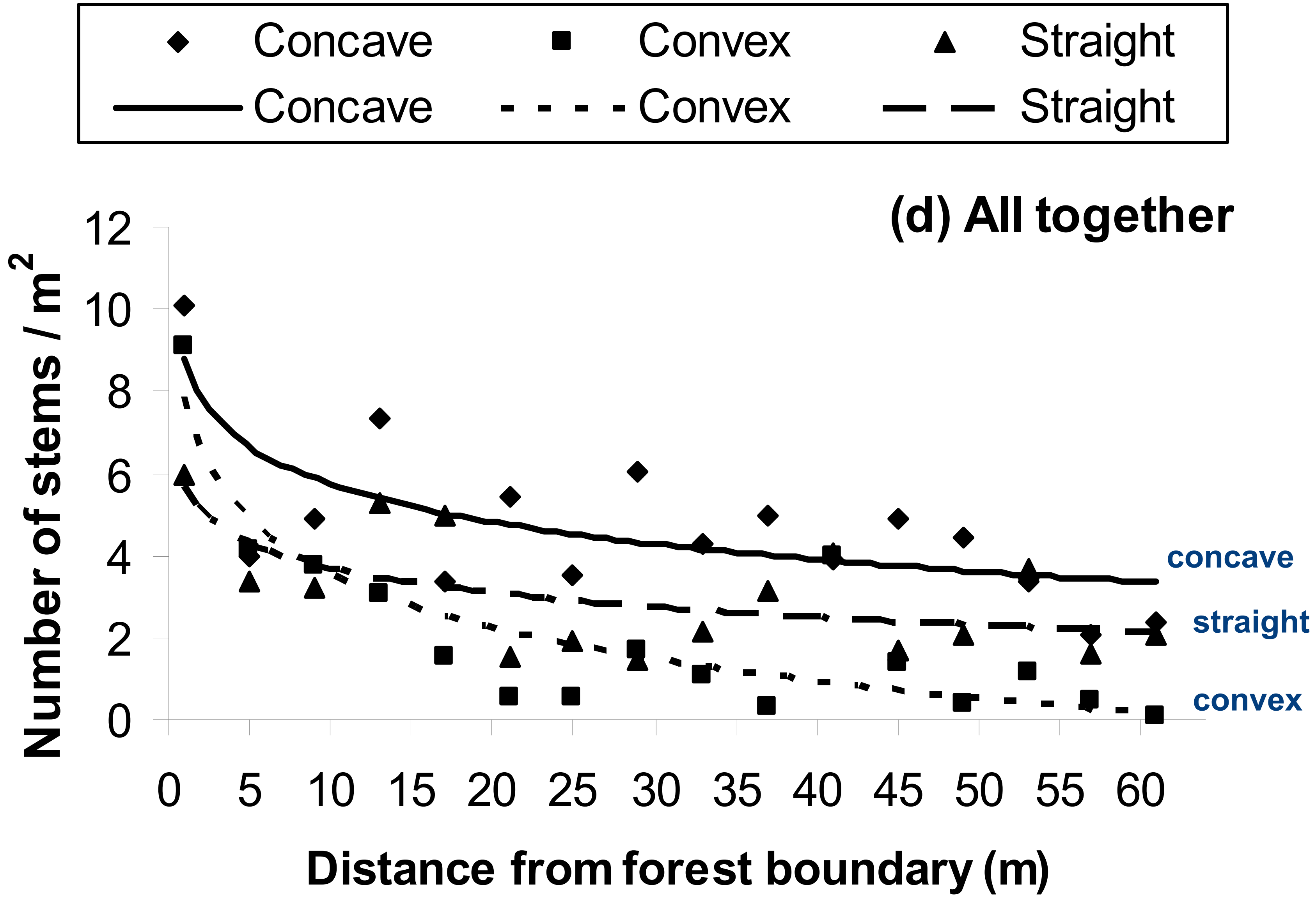
2.3. Influence of the forest edge

Influence of forest-edge form in the distance and woody colonization intensity

Milder *et al.* (2008)



concave $y = 8.772 - 1.317 \ln(x)$
$R^2 = 0.5349$ $p = 0.001285$

convex $y = 7.989 - 1.908 \ln(x)$
$R^2 = 0.7789$ $p = 6.027\ 10^{-6}$

straight $y = 5.693 - 0.867 \ln(x)$
$R^2 = 0.4172$ $p = 0.06872$

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2.4. Nurse effect of native shrubs

The native shrubs that colonize the mines (*Genista florida* and *Cytisus scoparius*) facilitate the establishment of native oaks (*Quercus pyrenaica* and *Q. petraea*) and thus the natural forest expansion

94% *Q. petraea* → in the first 5 m

Alday *et al.* (2016)

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2.4. Nurse effect of native shrubs

Effect of shrubs on survival of planted trees (1-yr saplings) of native oaks (*Quercus pyrenaica* and *Q. petraea*)

Plantation in February of 2011

Percentage of tree survival				
	UNDER Shrub		In open sites	
Date	*Q. petraea*	*Q. pyrenaica*	*Q. petraea*	*Q. pyrenaica*
October 2011	**90.7**	**91.0**	**5.5**	**17.0**
August 2012	**44.6**	**54.3**	**2.5**	**11.5**
October 2013	**42.5**	**48.5**	**2.0**	**7.0**
October 2014	**35.0**	**41.5**	**2.0**	**5.5**
October 2015	**34.0**	**39.0**	**2.0**	**5.5**
October 2016	**33.5**	**39.0**	**1.0**	**4.5**
October 2017	**29.5**	**35.0**	**0.5**	**4.5**
October 2018	**25.0**	**32.0**	**0.5**	**2.0**
October 2019	**24.5**	**30.0**	**0.5**	**2.0**

Partially unpublished data

Torroba *et al.* (2015)

Nurse effect of shrubs on oak establishment mediated, in part, by soil improvement

Unpublished data

Soil parameters	Under shrub		Open sites
pH	5.3±0.10 a	<	5.7±0.13 b
Conductivity (mS/cm)	0.117±0.011 a	>	0.088±0.006 b
Sand (%)	58.18±1.23 a	>	58.02±1.13 b
Clay (%)	23.41±1.42 a	<	26.17±1.24 b
Silt (%)	18.41±0.77	=	17.80±0.61
Organic matter (%)	6.12±0.45 a	>	5.20±0.48 b
Total N (g/100g)	0.47±0.02 a	>	0.37±0.03 b
C/N	10.87±0.25 a	>	9.58±0.40 b
Available P (mg/kg)	2.5±1.14	=	2.5±1.14
Exchangeable K^+ (meq/100g)	184.40±12.80 a	>	147.25±8.98 b
Exchangeable Na^+ (meq/100g)	0.052±0.01 a	<	0.076±0.01 b
Exchangeable Ca^{2+} (meq/100g)	6.77±0.81	=	7.87±1.15
Exchangeable Mg^{2+} (meq/100g)	1.27±0.41 a	>	0.99±0.27 b
Cation exchange capacity (meq/100g)	22.86±0.90 a	>	20.28±0.68 b

Conclusions

- The successful colonization patterns and positive neighbor effect of native shrubs on *Quercus* seedlings support the use of shrubs (especially *Genista florida*) as ecosystem engineers to increase heterogeneity in micro-environmental conditions improving late-successional *Quercus* species establishment in the coal mines.
- The positive effects of shrubs upon seedling survival and growth and acorn emergence found in our studies is partially mediated by soil improvement. Also, the microclimate amelioration under shrubs to reduce water stress for plants is suspected, as well as a defensive mechanical effect against ungulates.
- Future reclamation strategies in similar areas should include shrub species (seeds or seedlings), especially *G. florida*, in order to create a quick and heterogeneous shrub cover that will provide suitable microsites for *Quercus* seedling establishment.

3. Final reflection

- In order to improve the decision-making during restoration management, it is necessary to be based on the knowledge of the mechanisms that condition the establishment of vegetation and the underlying succession processes.
- The long-term monitoring of existing experimental devices and their extension to other areas and restoration objectives are essential to establish a protocol of performance to adjust decisions to the particular circumstances of each area to be restored and thus reconcile environmental restoration with the economic activity of the area.

Bradshaw (1996):

‘restoration is an acid test of our ecological understanding’

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Many thanks




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Thank you
for your attention!