CASCADE

Catastrophic shifts in drylands:

How can we prevent ecosystem degradation?

CASCADE REPORT series

Report on structural and functional changes associated to regime shifts in Mediterranean dryland ecosystems

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CASCADE

Catastropic shifts in drylands

Deliverable 5.1

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Deliverable:	*Report on structural and functional changes associated to regime shifts in Mediterranean dryland ecosystems*
Deliverable number:	*5.1*
Authors:	*Alejandro Valdecantos & Ramón Vallejo (CEAM) in cooperation with Study Site members.*

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Contents

1 SUMMARY

Ecosystem services are the benefits societies get from the ecosystems: supporting services are necessary for the production of other services, regulating services are the benefits people obtain from the regulation of ecosystem processes, and biodiversity has intrinsic value independent to any human concern. Fire (Várzea-Portugal and Ayora-Spain) and grazing (Castelsaraceno-Italy, Messara-Greece and Randi-Cyprus) are the two major disturbances in CASCADE field sites and they differ significantly in the way they affect ecosystems. Degradation in Albatera-Spain is very high but more diffuse (climate and land use mainly). This deliverable aims at quantifying the changes of key ecosystem services associated to the pressures acting in the six CASCADE field sites. Information about the structure, function and provision of services of degraded and reference ecosystems at present might be useful in the definition of land management strategies.

Common methodologies have been implemented in all CASCADE field sites with minor modifications to adapt to local specificities. Reference and Degraded states of the ecosystems have been selected in all field sites. An additional intermediate degradation pressure has been included in Messara as well as two opposite directions of the same degradation driver (under- and over-grazing) have been selected in Castelsaraceno. Three spatially replicated plots have been established in each level of pressure and site for the assessment of ecosystem properties and services. Plant cover, biomass in different compartments of the ecosystem, spatial arrangement of vegetation and source areas, ecosystem functioning through Landscape and Function Analysis (LFA) methodology, and different indices of biodiversity have been assessed in all replicates. Measured variables have been grouped into related ecosystem services after standardization to allow comparisons.

Albatera, which has the lowest aridity index, and, to a lesser extent, Randi represent the ecosystems with lower quality and functioning. In general, the plant communities in the Degraded situations are very different from their respective healthy References both in composition and plant species abundance. Pressure resulted in more homogeneous communities than in undisturbed states, except in Randi, where high heterogeneity is observed within both Reference and Degraded ecosystems, and Castelsaraceno, with little variation within degradation levels. The CASCADE field sites affected by grazing showed a generalized decrease in diversity with grazing pressure which can be described as overgrazed. Aboveground biomass was reduced in two out of three grazed sites (Castelsaraceno-overgrazed and Randi) but increased in Messara. The reduction in leaf area associated to grazing severely affected primary production in herbaceous pastures such as Castelsaraceno but did not happen the same in areas where shrubs are more abundant, such as Randi. Plant pattern in the grazed states is markedly different than in the ungrazed ones, with higher interpatch cover and lower length and width of the plant patches in the grazed plots. These changes reduce the resource sink capacity of the system. LFA derived indices are lower in

all Degraded sites than in their respective References suggesting a worsening of soil surface conditions and, hence, soil, water and nutrient conservation. Ecosystem services have shown important losses due to grazing in the order Randi>Messara>Castelsaraceno following a decreasing order of aridity.

The sites with fire pressure represent two stages of secondary succession after wildfires: a very initial stage of vegetation recovery after fire in Várzea, and long-term after fire mature shrubland without forest recovery in Ayora. In the short term, the ecosystem shows important reductions in most measured and calculated variables resulting in an overall significant loss of ecosystem services. But burned areas in the long-term recovered functionality to values of the Reference pine forest, showed a spatial arrangement of vegetation that better conserve the resources, and accumulated similar amounts of understory and belowground biomass and litter. All ecosystem services showed significant losses at the short term after the fire but only biodiversity and C sequestration lasted in the long term. The particular conditions in Várzea, especially the higher water availability suggest that the recovery of these assessed ecosystem services will be faster.

Albatera showed the highest relative losses of all individual and combined ecosystem services values of all CASCADE field sites. It is the most stressed site (aridity index = 0.16) and is affected by multiple diffuse pressures acting for a long time. The main ecosystem properties affected by degradation were those related to the sink/source spatial pattern and biodiversity. Stability is the index that showed the lowest loss in the Degraded as compared to the Reference state of the ecosystem probably due to an increase in exposed rock surface suggesting that the degraded system is in an alternative stable state.

In summary, degradation pressures severely impacted ecosystem properties and services of the selected ecosystems along the Mediterranean Basin in a wide range of ecological, biogeographical and historical characteristics. The higher the aridity, the higher the loss of ecosystem services. Some observed changes from the Reference towards the Degraded states suggest that certain degradation thresholds might have been passed. The recovery of these ecosystem services and properties by external inputs will be evaluated in D5.2 in order to determine the restoration potential in selected field sites.

2 INTRODUCTION

Landscapes of the Mediterranean Basin have been subjected to different human pressures since millennia in addition to the natural ones derived from climate features. These pressures have increased in number and/or intensity during the past century, with severe impacts on the wildland. Current ecosystems reflect this history of disturbances on plant community structure and composition, and environmental services provided. Pristine undisturbed ecosystems are difficult or impossible to find, instead different degraded ecosystems and landscapes can be identified along disturbance gradients.

Ecosystem services are the benefits societies get from the ecosystems. These are classified in four main groups: supporting, regulating, cultural and provisioning services, with biodiversity as structural feature of ecosystems with direct influence in all other services (MA 2005). Following the Millennium Ecosystem Assessment, supporting services are those that are necessary for the production of all other ecosystem services (e.g. primary production, production of oxygen, soil formation, nutrient cycling) while regulating services are the benefits people obtain from the regulation of ecosystem processes (e.g. air quality, climate regulation, erosion control, regulation of diseases, water purification). There are also services that provide both regulating and supporting services such as water and soil conservation. Biodiversity has intrinsic value independent to any human concern.

In general terms, ecosystems have the ability to withstand some level of stress without showing signs of major changes, or to recover at the short- or medium term after disturbances by themselves. However, when pressures act for very long time and/or high intensity, ecosystem functions might overcome degradation thresholds (*tipping points*) and show abrupt changes in key ecological properties and ecosystem services (Scheffer et al. 2001, Daliakopoulos and Tsanis, 2013). Beyond these points, natural recovery is very unlikely to occur or very slow (Whisenant 1999) and degradation might also generate new different ecosystems very dissimilar to the original reference one (Hobbs et al. 2006). Fire and grazing are the two major disturbances in CASCADE field sites. These two stresses differ significantly in the way they affect ecosystems and, as a consequence, in their short-, medium- and long term impacts. Wildfires represent discrete but very strong events of disturbance while grazing usually occurs in a continuous way with smoother effects on affected ecosystems. Therefore, the assessment of impacts and ecosystem services of sites impacted by grazing can be done at any time, but the same assessment in fire-affected ecosystems will largely depend on the time passed since the last fire because soil properties and plant communities change as secondary succession progresses (Baeza et al. 2007).

Restoring biodiversity and maximizing ecosystem services are priorities in the EU Biodiversity Strategy (Lammerant et al. 2014). Biodiversity can be assessed at different scales, from gene to ecosystems and it underlies all ecosystem processes (Mace et al. 2005). Water cycle regulation is a central ecosystem service for maintaining fresh water resources, controlling floods and, hence, protecting people living downstream (Vörösmarty et al. 2005). This ecosystem service is especially important in densely populated drylands due to the combination of high water demand, low availability and, in many places, low water quality derived from the absence of dilution potential. Transitions and movements of nutrients between and within components of the ecosystems is summarized by nutrient cycling which is regulated by a great variety of organisms and its alterations have deep impacts on ecosystem functioning, other ecosystem service and, finally, human well-being (Lavelle et al. 2005). Soil loss could be an irreversible process at the human and ecological scale. Soil retention provides very important ecosystem service to maintain primary productivity and prevent harmful effects because of soil erosion (de Groot et al. 2002). Ecosystems represent a sink for the removal and storage of carbon from the atmosphere in different biotic and abiotic components. In addition to the evident accumulation in plant aboveground biomass, soils of healthy systems can also store large amounts of C mainly in soil organic matter, roots of vegetation and microbial biomass. Furthermore, there are carbon credit markets where C sequestered in ecosystems can be sold (Jose 2009).

The main objective of this deliverable is to assess whether there are any losses of important environmental ecosystem services associated to the pressures acting in all six CASCADE field sites, and to quantify these losses if they occur. Knowing and understanding the structure, function and provision of services of degraded and reference (not necessarily pristine) ecosystems at present is a very useful tool to define restoration and conservation management practices. Whether or not these eventual losses are reversible through restoration actions will be reported in D5.2.

3 SITE DESCRIPTION

This deliverable is organized in two general blocks and a particular case. The two blocks respond to the main degradation driver acting in the study sites: grazing or fire. The Albatera study site is described separately as the current landscape is not a result of a single dominant agent but of many of them. Within the six CASCADE field sites (Fig. 1), we found a clear climatic gradient (Table 1). Two of the sites fall within the humid climate, three belong to the dry sub-humid climate, and one is classified as semiarid. The average annual rainfall ranges from 267 mm yr^{-1} in Albatera to 1289 mm yr^{-1} in Castelsaraceno. There are also large differences in temperatures along the field sites. Castelsaraceno is again the coldest station with average annual mean temperature below 10ºC, while the hottest field site is Randi forest in Cyprus with mean annual temperatures close to 20ºC. The two Spanish sites show the lowest aridity indices (0.16 and 0.26 in Albatera and Ayora, respectively) while Castelsaraceno and, in a lesser extent, Várzea showed the highest aridity indices (1.05 and 0.84, respectively). Therefore, in addition to types and levels of degradation pressures, the CASCADE project includes a great variety of climates, soils, land uses and histories (Table 2) that may eventually condition the loss of ecosystem services as described in Daliakopoulos and Tsanis (2013).

Figure 1. Location of the six CASCADE field sites (taken from D2.1, Daliakopoulos and Tsanis 2013).

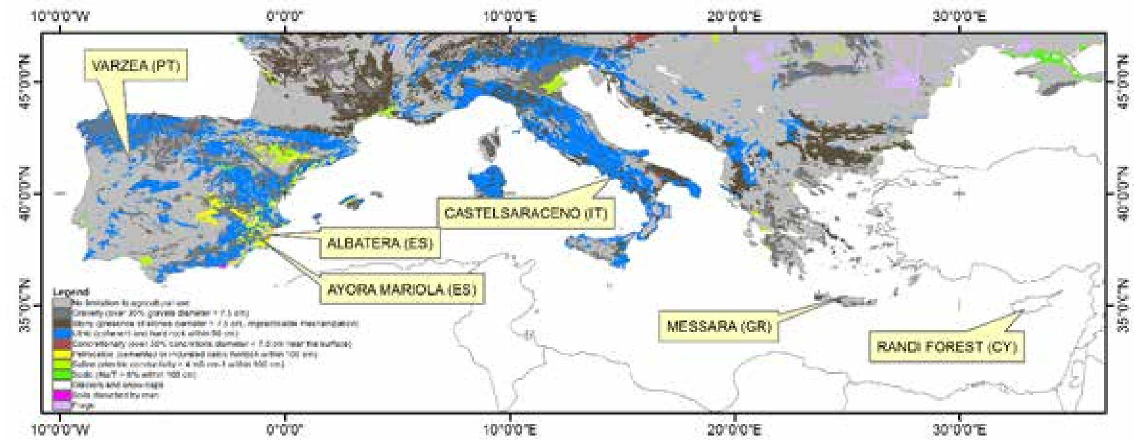

Table 1. Climatic characteristics of the six CASCADE field sites (extracted from D2.1, Daliakopoulos and Tsanis 2013).

	Várzea	Albatera	Ayora	Castelsaraceno	Messara	Randi
Climate	Humid	Semi-arid	Dry sub-humid	Humid	Dry sub-humid	Dry sub-humid
Average anual rainfall (mm)	1170	267	385	1289	503	489
Average mean temperature (ºC)	13.0	18.0	14.6	9.1	17.9	19.5
Aridity Index (mm/mm)	0.84	0.16	0.26	1.05	0.31	0.29
PET (monthly)	118.6	136.0	123.4	102.5	136.0	141.5

Table 2. Summary of main properties of the six CASCADE field sites (extracted from D2.1, Daliakopoulos and Tsanis 2013).

	Varzea	Albatera	Ayora	Castelsaraceno	Messara	Randi
Elevation	450-600 m	225-310 m	830-1030 m	972-1284 m	100-230 m	90-230 m
Bedrock	Schists	Dolomites, conglomerates and sandstones	Marl and limestone colluvium, limestones	Limestones and dolomites	Limestones and marls	Marls
Soils	Cambisols	Calcisols, Cambisols and Fluvisols	Regosols, Cambisols and Leptosols	Regosols	Cambisols and Luvisols	Calcaric regosols
Land use	Forests and shrublands (and agriculture in lesser extent)	Agriculture (52%) and shrublands (24%)	Forests and Shrublands	Cropland, pasturelands and forests	Croplands and shrublands	Croplands and shrublands
History	Recurrent fires (1978, 1985, 2005, 2012)	Abandonment of rainfed croplands, alpha grass harvesting and wood gathering. Affforestations	Fire (1979) and abandonment of wood harvesting	Land abandonment (especially after 1990s)	Overgrazing and overexploitation of water resources	Agriculture and grazing

3.1 Fire-Driven Landscapes

Two contrasting situations are assessed on a very similar ecosystem (*Pinus pinaster* forest): changes of ecosystem services at the very short term on a repeatedly burned site (Várzea) and at the long term on a community without significant recovery of the overstory layer (Ayora).

3.1.1 Várzea

In the Várzea study site, focus is on comparing the land degradation impacts of a recent wildfire (which occurred in early September 2012) for plots that had experienced three previous wildfires since 1975 and plots that had been long unburned (for at least 37 years) (Annex 1). During the last two decades, the predominant land-cover types of the Várzea Study Site have been forests, shrublands and, to a lesser extent, heterogeneous agricultural areas. These agricultural areas revealed little to no changes between 1990 and 2006, whereas this same period exhibited noticeable transitions between forest and shrubland. These transitions corresponded to a change from shrublands to forests between 1990 and 2000, and to a change from forest to shrublands between 2000 and 2006. Wildfires, in 1985 and again in 2005 (with burnt areas of roughly 10 and 1 km^2, respectively) are probably the reason behind these transitions.

The experimental setup in Várzea was highly conditioned by land availability of the four times burned sites. Three spatially replicated plots of ca. 1000 m^2 were established in the Reference ecosystem (mature *Pinus pinaster* forest, > 40 years old) while one single block with three smaller plots was identified in the 4-times burned area (last fire in 2012). As a consequence, the length of transects and the number of subplots to assess plant biomass and litter were reduced (33 m transects and 3 subplots per plot). Biomass data of the overstory layer in the Reference plots are not yet available. As this is a key variable in determining the C sequestration service, we used available published information (in concrete Bert and Danjon, 2006) for a proxy of this ecosystem service in Várzea.

3.1.2 Ayora

Wildfires represent the degradation driver in the Ayora field site with strong effects on the landscape configuration. In the period 1975-2000 several wildfires took place in the area. Of these, the 1979 wildfire was the biggest and most devastating one. As a consequence, within the study site we may find different fire recurrences in such a small period of time. These forest fires have altered the composition of the forest surface, which previous to 1979 was dominated by *Pinus halepensis and P. pinaster* with scattered *Quercus ilex* individuals or small patches. Therefore, the landscape is a mosaic of pine forests and shrublands that differ in their composition and structure. The little economic activity taking place in the area is mostly associated with sheep and goat grazing. Before the 1979 wildfire, animals grazed the rangeland. As forest gave way to dense shrublands after the fire, sheep were mostly confined to croplands that were easier to go across. In limited cases, administrative subsidies promoted grazing in fuelbreaks in order to assist in their maintenance. On the other hand, goats are able to feed in shrublands but the number of animals is much lower than that of sheep (ca 3,000 vs 12,000). Furthermore, beekeeping is an important economic activity in the region. The big 1979 wildfire also resulted in a reduction of the logging exploitation of the forest from 24,000 to 2,000 m^3 of wood per year. Rural tourism is an emergent activity in the area. Land tenure status has changed significantly, especially after the 1979 fire.

Three spatially replicated plots were established under the two states of the ecosystem: more than 50 year old *Pinus pinaster* forest and a secondary successional shrubland recovered after the 1979 wildfire (Annex 2). These two situations represent large parts of the territory of inland areas in the region of Valencia. The assessment strictly followed the above-mentioned protocol.

3.2 Grazing Driven Landscapes

Grazing is the major degradation pressure in three out of six CASCADE field sites. From those, Messara and Randi share many landscape characteristics, physical features and land use histories while Castelsaraceno shows clear specificities. The three sites represent a good example of the most important environmental and socio-economic features of their respective regions.

3.2.1 Castelsaraceno

The vegetation cover for the study site shows that broad-leaved forest is the most representative unit and only a small part of the surface is devoted to agriculture. After 2000, and due to rural exodus, a large part of the territory is, instead of traditional agricultural practices, covered by natural grassland and broad-leaved forest. Land cover under transition is noteworthy and there has been a progressive encroachment of pastures towards woods and shrublands. The target Reference ecosystem is a pastureland characterized by low presence and reduced quality of dominant species together with the disappearance of shrubs because livestock farming is widespread. Since 1991, the land was unevenly grazed resulting in over- and undergrazed zones.

The experimental setup in Castelsaraceno included three spatially replicated blocks, Monte Alpi, Favino and Piano del Campi. We have identified Reference, Overgrazed and Undergrazed ecosystems (Annex 3) in all of them and three replicated plots were established for each block x pressure combination (9 plots). The assessment strictly followed the protocol described in Section 4 *Materials and Methods*.

3.2.2 Messara

The natural landscape in Messara is dominated by the evergreen maquis/phrygana (Annex 4). Many marginal areas under natural vegetation were cleared and planted with olives. Widespread olive production in steep hilly areas in combination with grazing has triggered desertification processes. In addition further land abandonment led to less productive lands susceptible to degradation and at the same time grazing pressure significantly increased (more than 200% increases in sheeps and goats between 1980 and 1990).

In addition to the Reference and Degraded ecosystems, we selected an intermediate state of pressure defined as Semi-Degraded. Three replicated plots were established in all three states but one of the Semi-Degraded plots was completely affected by a fire in summer 2013 before WP5 field assessment. Therefore we conducted WP5 evaluation of this pressure level in two plots.

3.2.3 Randi

The study sites are open areas with shrubs and sparse carob and olive trees. The land is not suitable for agriculture anymore and it is used for grazing, in particular goats and sheep. The major land use change occurred in the 1930s, when Randi was still a forest. Currently, the natural landscape is dominated by scrublands, the typical Mediterranean maquis, garrigue and phrygana (Annex 5). This landscape has been formed by man-made activities such as forest destruction with subsequent periodic burning and overgrazing, followed by soil erosion.

The experimental setup and field assessment strictly followed the protocol described in *Section 4 Materials and Methods*.

3.3 Multifactor Driven Landscapes

3.3.1 Albatera

The natural climate-driven vegetation communities in Albatera site are thermo-Mediterranean shrublands (Annex 6), dominated by deep-rooting tall shrub species that are particularly adapted to water scarcity and extreme summer drought conditions. Intense land exploitation has led to changes in vegetation towards ecosystems dominated by subshrubs and tussock grass species. Before the 1950s, the mountain range area supported some marginal activities such as alpha-grass harvesting for fiber production and wood gathering for firewood while grazing was moderately important. In Albatera, agriculture abandonment during the second half of the 20th century mostly affected rainfed crops and agricultural terraces located on (or near to) the mountain range. Most activities also ceased on the mountain range.

The experimental setup followed the protocol described in *Section 4 Materials and Methods*. Plant volume per hectare was evaluated by multiplying, for a hectare, the average height with the plant cover and then plant biomass was estimated by applying a correction factor (Abdelmoula 2005). Belowground biomass and litter are not yet available.

4 MATERIALS AND METHODS

A common methodology has been designed to be applied in all six CASCADE field sites to assess Ecosystem Services in, at least, two ecosystems representative of a healthy reference and a degraded state. However, the protocol has been adapted locally to fit singularities, constraints and possibilities of the different field sites (see section *3 Site description* for details). The general framework includes the identification of representative Reference and Degraded ecosystems according to the pressure acting in each specific site (Table 3).

We established three spatially replicated plots for every level of pressure in every field site to conduct the assessment of different variables of ecosystem structure and functioning. Replicated plots in every specific field site shared most physiographic, climatic, and edaphic variables as well as land use history. From these variables, we calculated a balanced set of ecosystem services. The effects of degradation on the ecosystem structure and function as well as on ecosystem services were derived through a comparison of the Reference with the Degraded state.

The three aspects of the evaluation process carried out are: 1) the determination of plant composition, 2) quantification of stand plant biomass, litter and belowground biomass, and 3) the application of the methodology of Landscape and Function Analysis.

Table 3. Summary of pressures, reference and degraded ecosystems in the six CASCADE field sites.

Field Site	Pressure	Reference Ecosystem	Degraded Ecosystem
Várzea, PT	Fire	*Pinus pinaster* forest	4-times burned areas (2-years after last fire)
Albatera, SP	Multifactor (climate, historical use and mismanagement)	Semi-steppe dry shrubland	Dwarf shrubland
Ayora, SP	Fire	Unburned *Pinus pinaster* and *P. halepensis* forest	Shrubland. Areas burned in 1979
Castelsaraceno, IT	Grazing	Productive pastureland	1.Overgrazed lands 2. Undergrazed lands
Randi, CY	Grazing	Shrubland	Unpalatable community
Messara, GR	Grazing	Shrubland	Unpalatable community

4.1 Plant composition

Three 33-m linear transects (should be as straight as possible) were deployed following the maximum slope and the line intercept method was applied. A metal rod (<5 mm diameter) was placed vertically every 50 cm along the tape (66 points per transect) and the contacts of plant species recorded. The contact at the soil level was also described (bare soil, stone, rock outcrop, litter, biological crust). Several plants may touch the rod in a particular point and all of them were recorded as well as the height where the plant contacts the rod. Note that this allows plant cover percentages above 100% due to overlapping.

Transects were deployed avoiding 'strange' or artificial features of the plot such as pathways, stone accumulation points, gullies… In case that the size of the plot did not allow 33-m long transects, more shorter transects were established but always totalling 100 m per plot.

4.2 Plant biomass

Three 1-m^2 quadrats (subplots) were defined in every single transect. The placement of the quadrats was predefined to avoid subjective selection of microsites. For instance and in the case of a 33 m transect, we placed the subplots at 10-11 m, 20-21 m and 30-31 m (one meter away from the tape, Fig. 2). Within these subplots we evaluated biomass of shrubs by two alternative approaches:

- By clipping, drying and weighing. When possible, we cut all the individuals whose stems were within the quadrat limits and took them separately (one bag per species and subplot) to the lab. We dried the plant samples at 60ºC for 48h in an oven and weighted them. Grasses were not separated by species.

- By allometric relations. There are available allometric equations for many of the most common shrub species in the Mediterranean Basin (e.g. Blanco and Navarro 2003). By knowing a morphological variable (basal diameter, total height or biovolume of the plant), we calculated the biomass of the individuals. Alternatively, as was the case of some shrub species in Messara and Randi field sites, we built up our own allometric equations by harvesting, drying and weighing a pool of individuals outside the plots covering the range of plant sizes present within the plot.

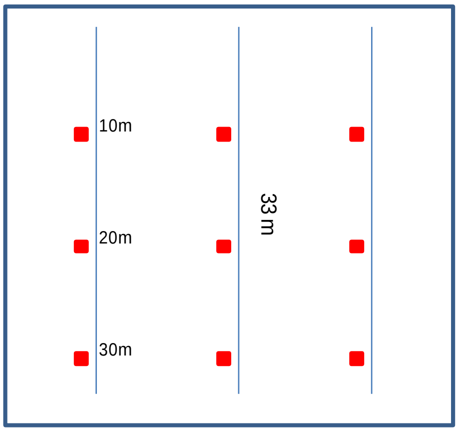

Figure 2. Example of systematic placement of the 1m^2 subplots for biomass assessment (red quadrats).

4.3 Litter and belowground biomass

After harvesting grasses and shrubs, we collected the litter layer in a 25 x 25 cm sub-subplot. We avoided taking mineral soil particles in the samples as they are much heavier than the litter fractions. Samples were taken to the lab to dry them at 60ºC for 48h. In the same sub-subplot once the organic layer was removed we took a soil core of the uppermost soil (0-10, 0-15 or 0-20 cm depending on the site). Once in the lab, roots were separated from the soil by sieving and washing gently with water before drying at 60ºC for 48h.

4.4 Landscape and Functional Analysis (LFA)

This method was used for the assessment of ecosystem functioning in WP5.

Following is a much resumed procedure of the method (extracted from Tongway and Hindley 2004).

- Transects set-up: Transects started at the downslope edge of a patch following the maximum slope and as taut as possible.
- Patch and inter-patch identification: By definition, patch accumulates or diverts resources by restricting flow of water, topsoil and organic matter (e.g. perennial plants[1], stones > 10 cm). They act as a sink of resources. But not all patches behave the same and we discriminated when possible between

[1] *If the width of the interception at the soil level is higher than 4-5 cm*

different patches, e.g. resprouter shrub, seeder shrub, grasses, chamaephytes… Inter-patches represent areas where resources do not accumulate and even act as net export of resources (source areas).We measured three parameters along the transects: the number of patches (sinks), the width of every single patch (at the soil level, not the canopy and up to a maximum of 10 m), and the distance between patches (inter-patch length) (Fig. 3). However, in some field sites (e.g. Ayora) the continuity of vegetation hindered clear measurements of patch characteristics.

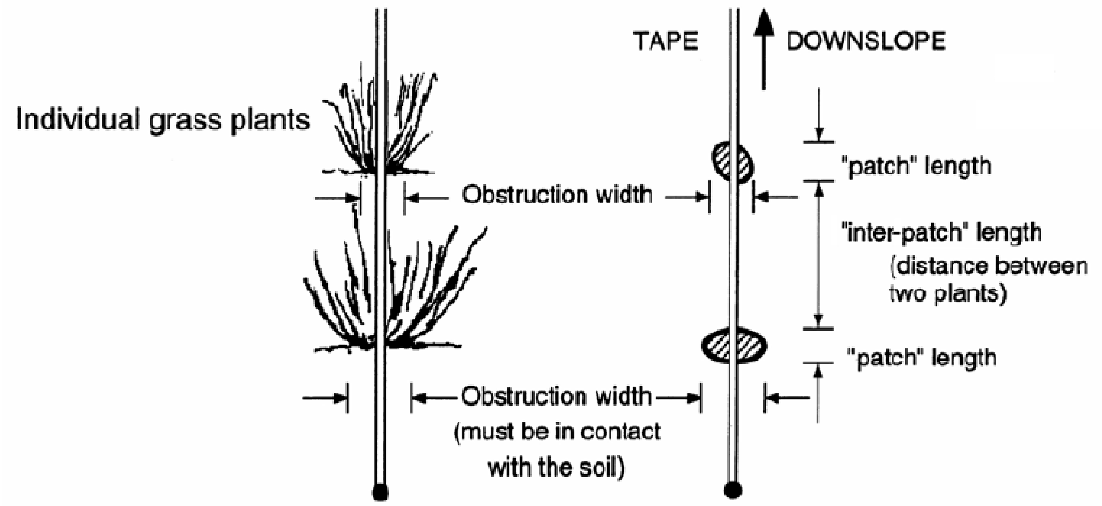

Figure 3. Measurement of patch-interpatch pattern along the transect and individual measures of the patch.

- Soil Surface Assessment: This assessment was conducted per plot in five 50 x 50 cm areas per type of identified patch and inter-patch. These five replications were distributed throughout the plot. The soil surface assessment is rapidly made by the use of simple visual indicators. These indicators are:

  · Rainsplash protection: ephemeral grasses, foliage at heights above 50 cm and litter were excluded.

  · Perennial vegetation cover

  · Litter: amount, origin and degree of decomposition. It includes annual grasses and ephemeral herbage (both standing and detached) as well as detached leaves, stems, twigs, fruit, dung, etc. There are three properties of litter that were assessed in the following order: Cover (% and thickness of the litter layer), Origin (whether it is local or transported) and Degree of Decomposition/Incorporation.

  · Cryptogam cover

  · Crust brokenness

  · Soil erosion type and severity: Five major forms of erosion were assessed: Sheet erosion (progressive removal of very thin layers of soil across extensive areas, with few if any sharp discontinuities to demarcate them), Pedestal (is the result of removing soil by erosion of an area to a depth of at least several cm, leaving the butts of surviving plants on a column of soil above the new general level of the landscape), Terracette (abrupt walls from 1 to 10 cm or so high, aligned with the local contour), Rill (channels cut by the flowing water), and Scalding (is the result of massive loss of A-horizon material in texture-contrast soils which exposes the A2 or B horizon).

· Deposited materials: presence of soil or litter materials transported from upslope.

· Soil surface roughness: due to soil surface micro-topography or to high grass density.

· Surface nature: resistance to disturbance.

· Slake test: The test was performed by gently immersing air-dry soil fragments of about 1-cm cube size in distilled water and observing the response over a period of a minute or so. If the soil floats in water (high organic matter), then it is stable (Class 4), and if it cannot be picked (loose soils) was scored as not applicable.

· Texture

Spreadsheets were prepared and were filled out with the collected information and Stability, Infiltration and Nutrient Cycling indices were automatically calculated (Table 4). These indices varied between 0 and 100% depending on ecosystem functionality (100% represents fully functional systems).

We conducted two training exercises for scientist working in the CASCADE study sites to guarantee the homogeneous application of the methodology in the field. These exercises were conducted during the Alicante plenary meeting in 2013 and in a specific workshop in April 2014 in Albatera and reinforced in several other field sites.

Table 4. List of the soil functional indicators and their contribution to the indices of stability, infiltration and nutrient cycling (following Tongway and Hindley 2004). Shadowed cells mean that the indicator is scored in the calculation of the index given above.

Indicator	Indices		
	Stability	Infiltration	Nutrient Cycling
Rainsplash protection			
Perennial vegetation cover			
Litter cover			
Litter origin and decomposition			
Cryptogam cover			
Crust brokenness			
Soil erosion type and severity			
Deposited materials			
Soil surface roughness			
Surface nature			
Slake test			

4.5 Data analysis

In every CASCADE field site we conducted t-test (sites with one Reference and one Degraded state of the ecosystem) or one-way ANOVA followed by post-hoc analysis (where three ecosystem states were identified) to assess if observed differences in all composition, functional, diversity and service variables were statistically significant. F, t and p values are presented in the text for each study site (chapter 5). We conducted Principal Component Analysis (PCA) on specific plant cover data to assess general changes in vegetation composition and cover between Degraded and Reference sites.

Acquired data of structural and functional ecosystem properties were then grouped into related ecosystem services through standardization. We have selected regulating and supporting services as well as biodiversity, which underpins all services (Table 5). Each variable was standardized using

$$ZPlot=(XPlot-AvgTot)/SDTot,$$

where *ZPlot* is the standardized variable, *XPlot* the original variable, *AvgTot* the average of the variable of all plots within a field site and *SDTot* the standard deviation of all the plots within a field site. Variables were assigned to services as they were derived from validated methodologies selected on the basis of being appropriate indicators for this service (Table 5). When several variables were combined into one service, each variable was weighted equally, as all of them are considered to be good indicators for the respective service and no available information points to a better performance of any of them. The five selected ecosystem services were also weighted equally and averaged for Degraded and Reference plots in each field site as a global result of ecosystem service losses. This way, the assessment provides a baseline integrated and global evaluation based on the simplest assumption. However, it is worth mentioning that stakeholders' preferences regarding ecosystem services could be incorporated in the assessment in the form of different weights for each service, which could yield different global outcomes.

The selection of the key common indicators and assessment methods has been based on the work developed by the EU-funded PRACTICE project on ground-based assessment indicators (Bautista and Mayor, 2010). They represent few essential indicators that could characterize ecosystem function for a majority of drylands worldwide, mostly focusing on water and soil conservation, nutrient cycling, carbon sequestration, and biological diversity. Most provisioning and cultural services are considered to be very much context dependent (Rojo et al. 2012). Furthermore, half of the sites included in CASCADE are natural areas that are not expected to directly deliver goods. Therefore, our across-site comparative assessment of ecosystem services provision has been only based on supporting-regulating services, which together with biodiversity, are considered to be baseline services and properties that underpin other types of services (Bautista and Lamb, 2013).

Table 5. List of ecosystem services measured, variables from which their relative states were estimated through standardization, and the methodology used to obtain the data of the variables.

Ecosystem Service	Variables	Methodology
Water Conservation	Infiltration Index	LFA + Point-intersect
	Interpatch Cover	
	Plant Cover	
Soil Conservation	Stability Index	LFA + Point-intersect
	Interpatch Cover	
	Plant Cover	
Nutrient Cycling	Nutrient Index	LFA
	Litter	
Carbon Sequestration	Plant biomass	Allometries + direct quantification
	Root biomass	
	Litter	
Biodiversity	Richness	Point-intersect
	Diversity	
	Evenness	

5 RESULTS

5.1 Fire Driven Landscapes

5.1.1 Várzea

Total plant cover in Várzea field site was, obviously, significantly lower in the 4-times burned state than in the reference forest (Fig. 4, left). The Reference pine forests showed canopy closure and, hence, 100% plant cover while the four times burned sites showed 76.1% of plant cover just two years after the last fire. Removing trees form the analysis, the cover of the herbaceous and shrub layers was significantly higher in the Degraded state than in the Reference (Fig. 4, right) associated to the reduction of light reaching the soil in the former and the natural secondary succession dynamics in the latter.

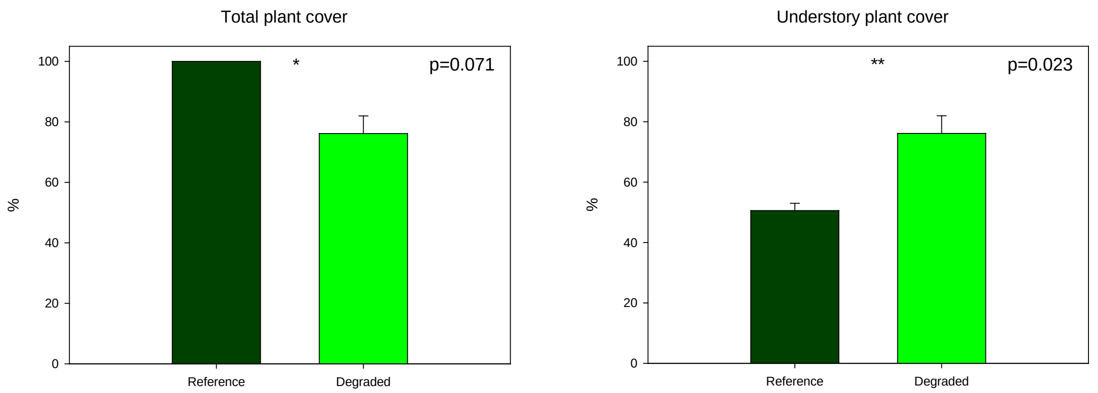

Figure 4. Total (left) and understory (right) plant cover in the Reference and Degraded states in Várzea field site. Mean, standard errors and significance are shown.

The most represented species in the understory of the Reference ecosystem are *Ulex minor*, *Agrostis curtisii* and *Pteridium aquilinum* with 15.4, 14.3 and 9.6% of specific plant cover, respectively. The Degraded state showed, as mentioned above, higher development in the understory layer due to the removal of the tree layer and the short time elapsed since the fire. *Agrostis curtisii*, *Pterospartum tridentatum* and *Erica umbellata* averaged 45.8, 35.5 and 25.9% of specific plant cover, respectively. Only six species appeared in the Degraded state, four of them were common with the Reference state. The PCA analysis conducted on specific plant cover data of the understory showed a clear separation of Reference and Degraded plots, especially according to the first axis records (46.5% of variance explained; Fig. 5). Four species showed high positive eigenvalues on this axis: *U. minor*, *Arrhenatherum sp.*, *P. aquilinum* and *P. pinaster* (0.971, 0.971, 0.945 and 0.919, respectively). Of these species, only *U. minor* and *P. aquilinum* are abundant in two out of three replicated Reference plots, and the other species represent less than 1% of plant cover. The three Degraded plots showed negative values of PC1, associated to high cover of *P. tridentatum* and *A. curtisii* (eigenvalues -0.857 and -0.719, respectively). One of the Reference plots showed different plant cover than the others, both Reference and Degraded, with very positive values of PC2 (20.3% variance explained) associated to high cover of *Simethis mattiazzi*, the presence of *E. umbellata* and low cover of *P. tridentatum* (eigenvalues 0.978, 0.936 and -0.562, respectively). This could be related to different fuel management strategies affecting the understory vegetation.

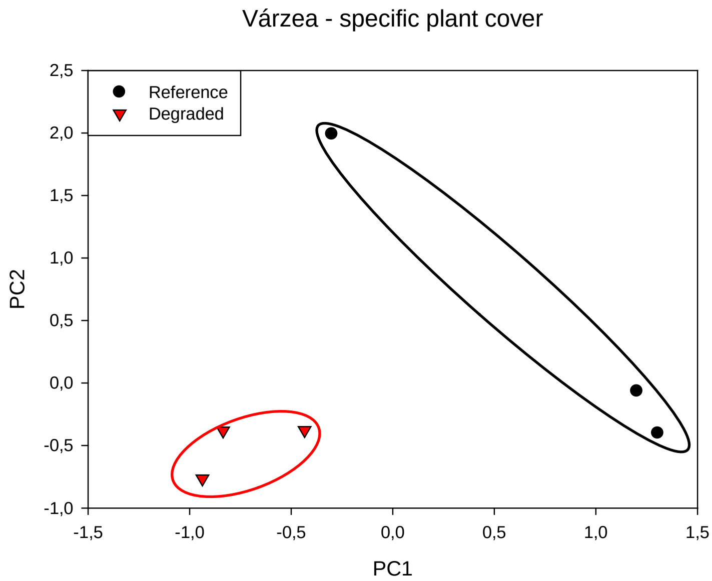

Figure 5. Plot distribution in Várzea according to the two first axis of PCA conducted on plant cover. Plots are marked and grouped by the fire pressure level.

The number of plant species was also significantly lower in the Degraded than in the Reference sites, with a reduction of more than 50% of species richness due to fire (recurrence and time since the last one, Fig. 6). The Shannon-Wiener index of diversity (H) did not show significant differences between states with total values around 1.2. However, the Degraded sites showed significantly higher evenness values than the Reference state (0.84 vs 0.58, respectively) suggesting that plant individuals in the Degraded areas are more evenly distributed than in the understory of the Reference sites.

Interpatches in reference plots were covered by pine litter and cryptogams. In the degraded plots, interpatch was bare soil with stones and remains of ashes and charcoal.

The Degraded and Reference states differed significantly in the percentage of ground that corresponded to interpatches, amounting to 43.4 and 15.2%, respectively, but not in interpatch length (Fig. 7). The size of the vegetated patches was also larger in the Reference state, with an average of 13.5 m in length and 5.6 m in width, as compared to the Degraded state (0.8 m long and 1.1 m wide).

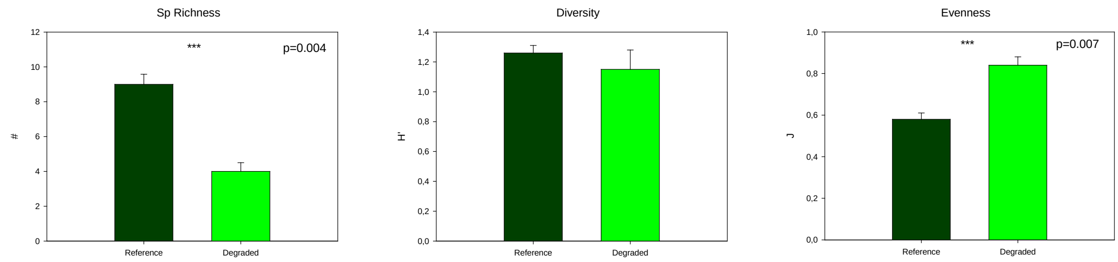

Figure 6. Number of plant species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference and Degraded states in Várzea field site. Mean, standard errors and significance are shown.

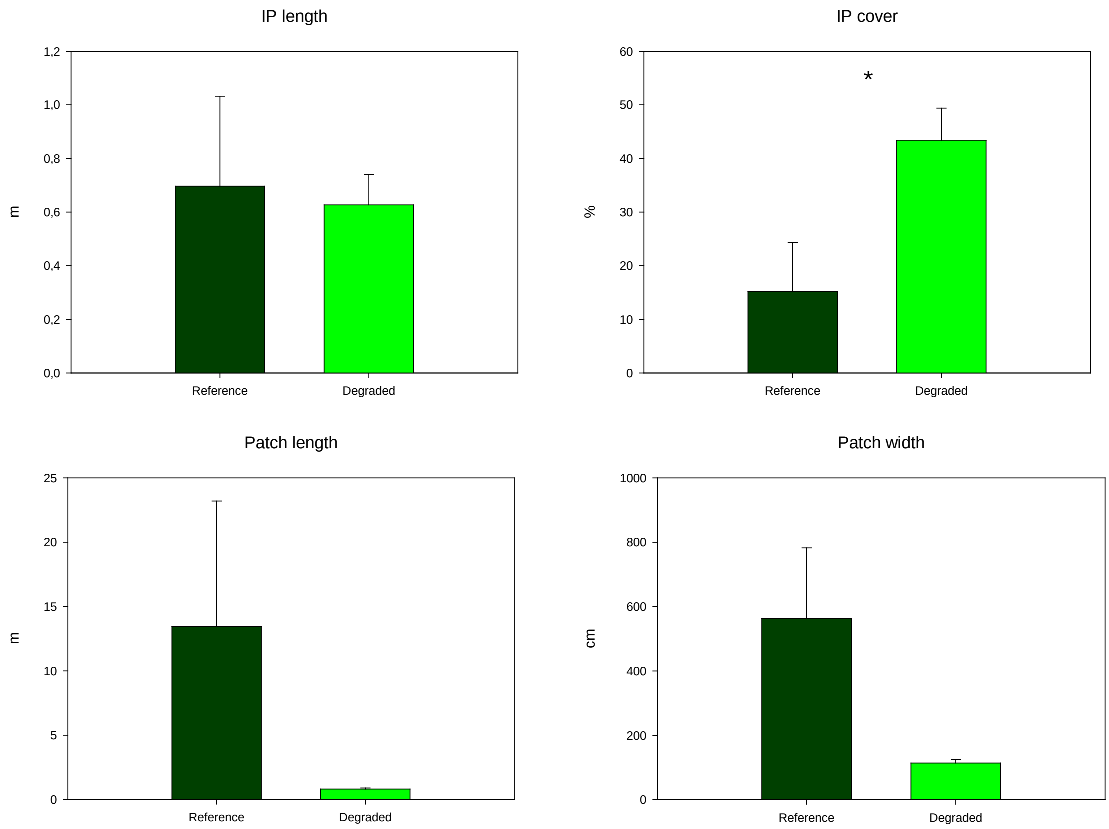

Figure 7. Values of Interpatch length (up, left), cover (up, right), patch length (bottom, left) and width (bottom, right) in the Reference and Degraded states in Várzea field site. Mean and standard errors are shown (*: 0.05<p<0.1).

All three indexes derived from the LFA, stability, infiltration and nutrient cycling, were significantly reduced in the Degraded state (Fig. 8). The sharpest reduction was observed in the nutrient cycling index which dropped from 53.1% in the Reference to 20.1% in the Degraded. The infiltration index in the Reference showed a value of 53.4% and only 34.4%in the Degraded. Similar decrease was observed in the stability index, from 75.4% in the mature pine forest to 51.1% in the four times burned sites.

Most ecosystem services derived from these variables experienced a significant decrease due to recurrent fire (Fig. 9). In the case of C sequestration, only the understory biomass has been quantified in the assessment. Using available data of biomass of the overstory layer of *Pinus pinaster* forests (110.2 Mg ha^{-1}), the loss of

C sequestration service is increased (C seq.* bars in Fig. 9). The remaining services, soil and water conservation, nutrient cycling and biodiversity, showed similar losses due to recurrent fires. The combination of all standardized ecosystem services in Várzea showed a significant decrease in the Degraded sites in relation to the Reference sites suggesting a global loss of ecosystem services.

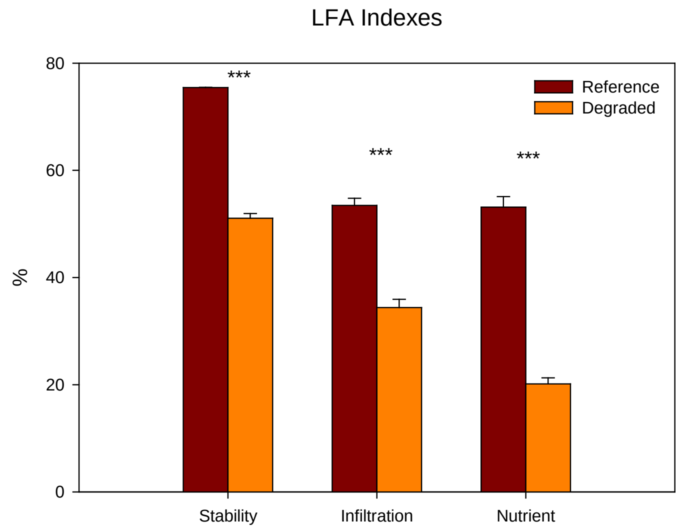

Figure 8. Values of the Stability, Infiltration and Nutrient Cycling indexes derived from LFA in the Reference and Degraded states in Várzea field site. Mean and standard errors are shown (*: p<0.01).**

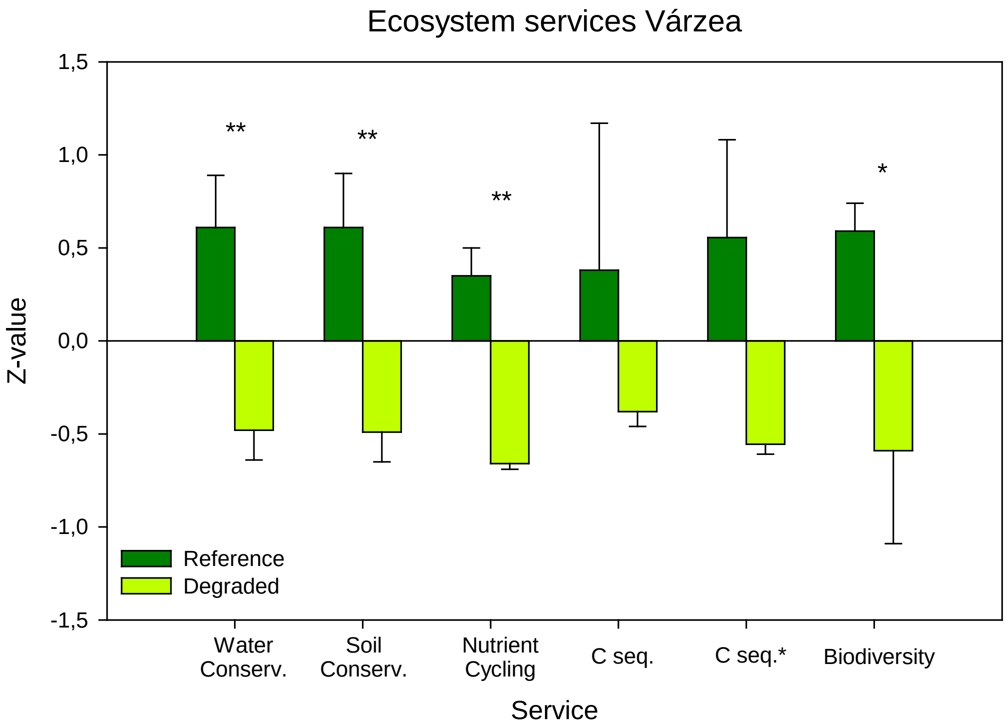

Figure 9. Standardized values of the list of ecosystem services in Várzea, as derived from combinations of the different variables acquired. Mean and standard errors are shown (: 0.01<p<0.05; *: 0.05<p<0.1). C seq* refers to the estimated C sequestration service including biomass of the overstory with bibliographic available information.**

Figure 10 shows a summary of the observed changes between the Degraded and the Reference states in the ecosystem properties assessed. All of them, except evenness, decrease in the four times burned sites, suggesting important losses of these characteristics. Note that positive values of interpatch cover represent larger areas of bare soil, stones and, in general, without woody vegetation.

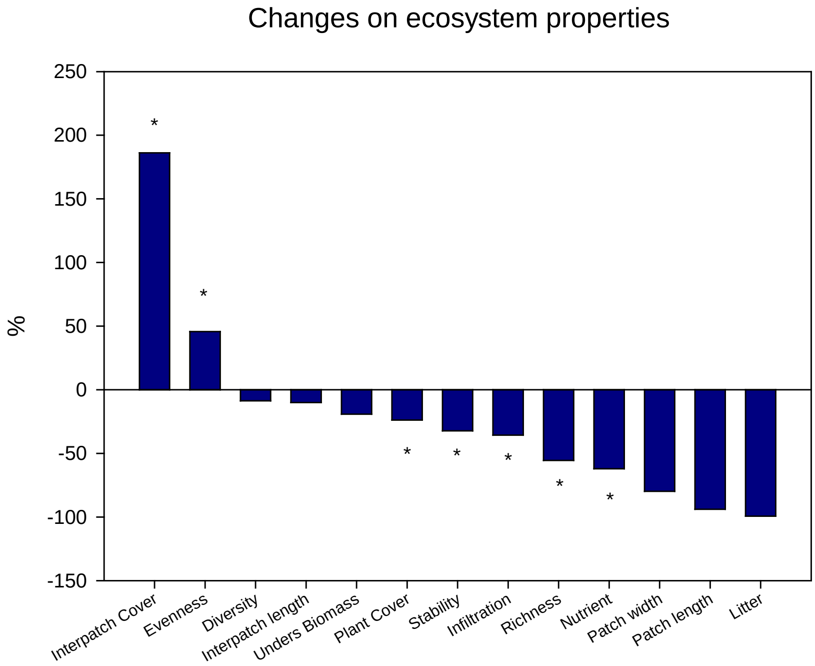

Figure 10. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Degraded areas of the Várzea field site in relation to the References. Asterisks denote significant differences between the two ecosystem states.

Results highlights - Várzea

- Fire produced a temporal reduction of total plant cover but higher understory plant cover only 2-years after fire
- Fire opened the space for the recovery of pre-existing (both resprouters and obligate seeders) species but changed sp composition and abundance
- Recurrent fires reduced habitat heterogeneity
- Recurrent fires eradicated sensitive species to short fire interval (e.g. *Pinus pinaster*)
- Ecosystem functioning, e.g. stability, infiltration and especially nutrient cycling, was severely reduced by fire
- Degradation produced by recurrent fires produced significant losses for all ecosystem services considered

5.1.2 Ayora

Total plant cover in Ayora has been reduced by more than 10% from the reference pine forest to the secondary mature shrubland (89.6 and 78.8%, respectively; t=-4.443, p=0.011; Fig. 11). The Reference plots are characterized by a mature overstory of maritime pine (*Pinus pinaster*, 47.9%) and, in a lesser extent, Aleppo pine (*P. halepensis*, 11.4%) and an understory dominated by *Rosmarinus officinalis* (26.4%), *Ulex parviflorus* (13.3%) and grasses (especially *Brachypodium spp*, 14.6%).The degraded community is a shrubland dominated by *R. officinalis* (44.3%) and *Erica multiflora* (15.7%), with an herbaceous layer with *Brachypodium spp* (22.0%) and *Helichtotrichon filifolium* (10.8%). Only 19 out of the 41 species found are common in the Reference and the Degraded states.

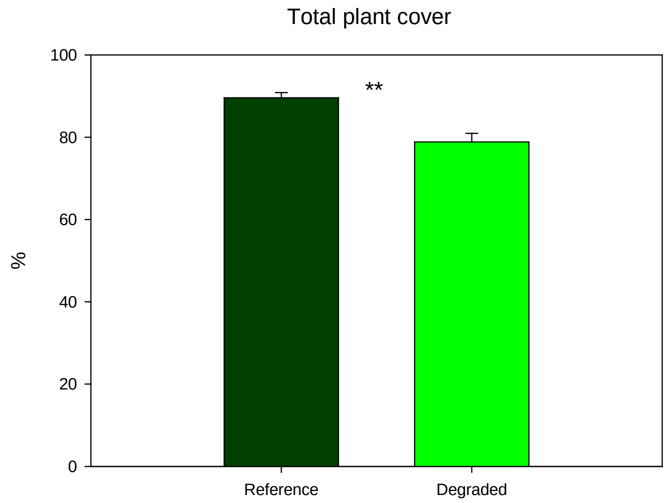

Figure 11. Total plant cover in the Reference and Degraded states in Ayora field site. Includes pine canopy cover. Mean and standard errors are shown (: 0.010<p<0.050).**

PCA analysis of specific plant cover data separated the Reference and the Degraded plots based on the values obtained on the first axis (Fig. 12). The unburned Reference plots showed positive values on the first axis and the burned Degraded plots showed negative values. *Pinus pinaster* and *Juniperus phoenicea* are the species with higher positive weight on axis 1 (eigenvalues 0.914 and 0.804, respectively) and, hence, characteristics of the References while the shrub *Quercus coccifera* and the grasses *Carex humilis*, *Helichtotrichon filifolium* and *Brachypodium retusum* were negatively extracted on the second axis (-0.811, -0.789, -0.787 and -0.756, respectively) and abundant on the Degraded plots. The References sites showed higher variability of composition than the Degraded ones, which were much closer to each other in the PCA graph.

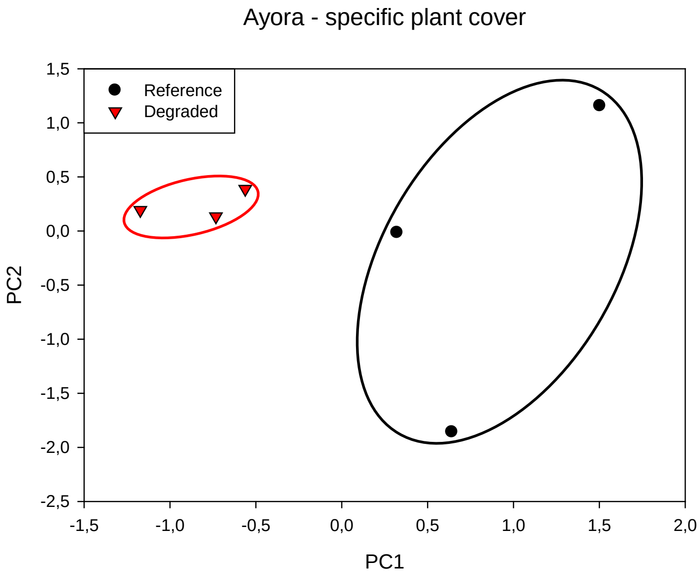

Figure 12. Plot distribution in Ayora according to the two first axis of PCA conducted on specific plant cover. Plots are marked by the level of pressure.

The highest contrast between biomass fractions of the ecosystem was observed in tree canopy biomass as the Degraded plots showed almost no tree recovery after fire (Fig. 13). Biomass of the understory layer was 40% higher in the Degraded sites than in the Reference but differences were not significant (t=1.915, p=0.128). *Rosmarinus officinalis* was the species of the undestory that showed the highest biomass accumulation in the Reference plots (6.9 Mg ha^{-1}), with less than 10% of this biomass as dead material. The second species with higher biomass was *Ulex parviflorus* with 3.0 Mg ha^{-1}, 50% of it as necromass. The same two species accumulated the highest amount of biomass in the Degraded communities; rosemary has a biomass of 14.0 Mg ha^{-1}, in this case with less than 5% as dead biomass, and gorse presented 2.7 Mg ha^{-1} but 76% of it as dead material confering a high fire risk to the degraded community. Due to the important component of the overstory on the total biomass of the ecosystem, significant differences were observed in this variable (87.6 and 18.9 Mg ha^{-1}, in the Reference and Degraded sites, respectively; t=-18.013, p<0.001). Root biomass showed the same trend as the understory biomass, with a not significant increase in the Degraded in relation to the Reference plots. Litter accumulation was very similar in both states of the ecosystem (≈ 25 Mg ha^{-1}), though composition was different (data not shown).

The three diversity indices evaluated decreased in the Degraded sites in relation to the Reference ones (Fig. 14) but only the total number of plant species showed significant differences (t=-2.688, p=0.055). Shannon’s diversity index and evenness also showed reductions in the Degraded plots but differences were not significant statistically (t=-1.968, p=0.120 and t=-1.195, p=0.298, respectively).

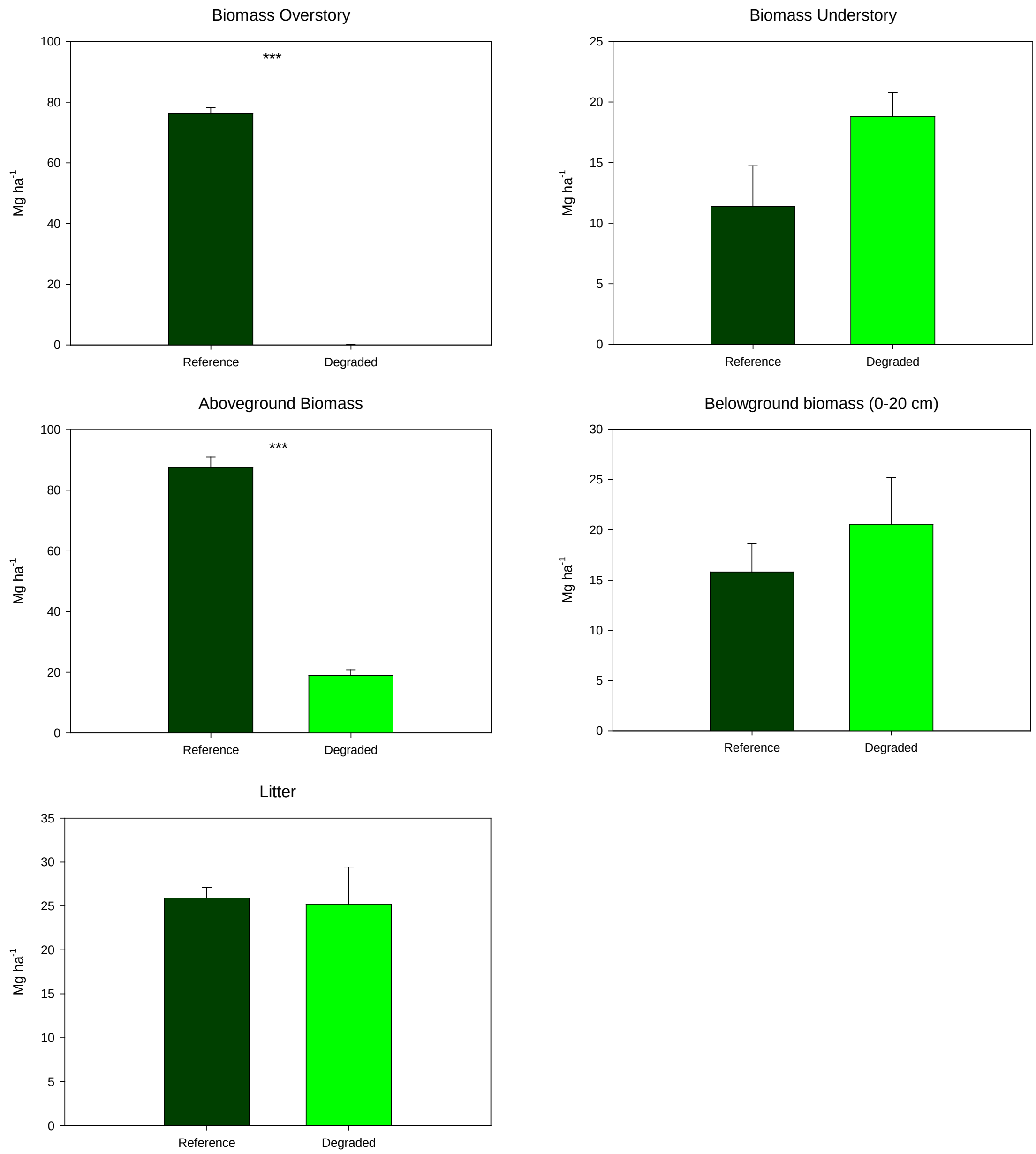

Figure 13. Plant biomass of the tree canopy (top left), understory (top right), total aboveground biomass (centre left), root biomass in the uppermost 20 cm of soil (centre right) and litter accumulation (bottom left) in the Reference and Degraded states in Ayora field site. Mean, standard errors and significance are shown (*: p<0.010).**

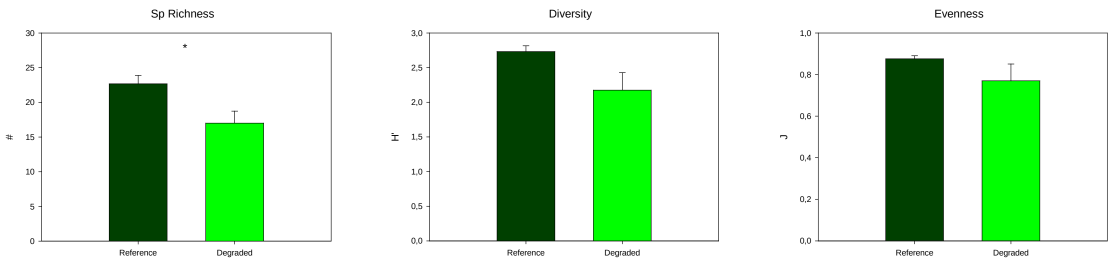

Figure 14. Number of species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference and Degraded states in Ayora field site. Mean and standard errors are shown (*: 0.050<p<0.100).

In Ayora the considered interpatches included bare soil but also the herbaceous matrix and litter, very abundant in the two levels of pressure as commented above.

The proportion of land considered Interpatch was higher in the Reference state than in the Degraded (50.3 vs 33.1%, respectively) but differences were not significant (Fig. 15). A similar trend was observed in the average length of the interpatches, which was slightly higher in the Reference than in the Degraded. Vegetated patches showed similar width (≈ 2.9 m) but different length, higher in the Degraded than in the Reference (1.8 vs 1.1 m, respectively). This is a consequence of the huge continuity of the mature secondary shrubland of the Degraded plots. However, none of these variables showed significant differences between ecosystem states.

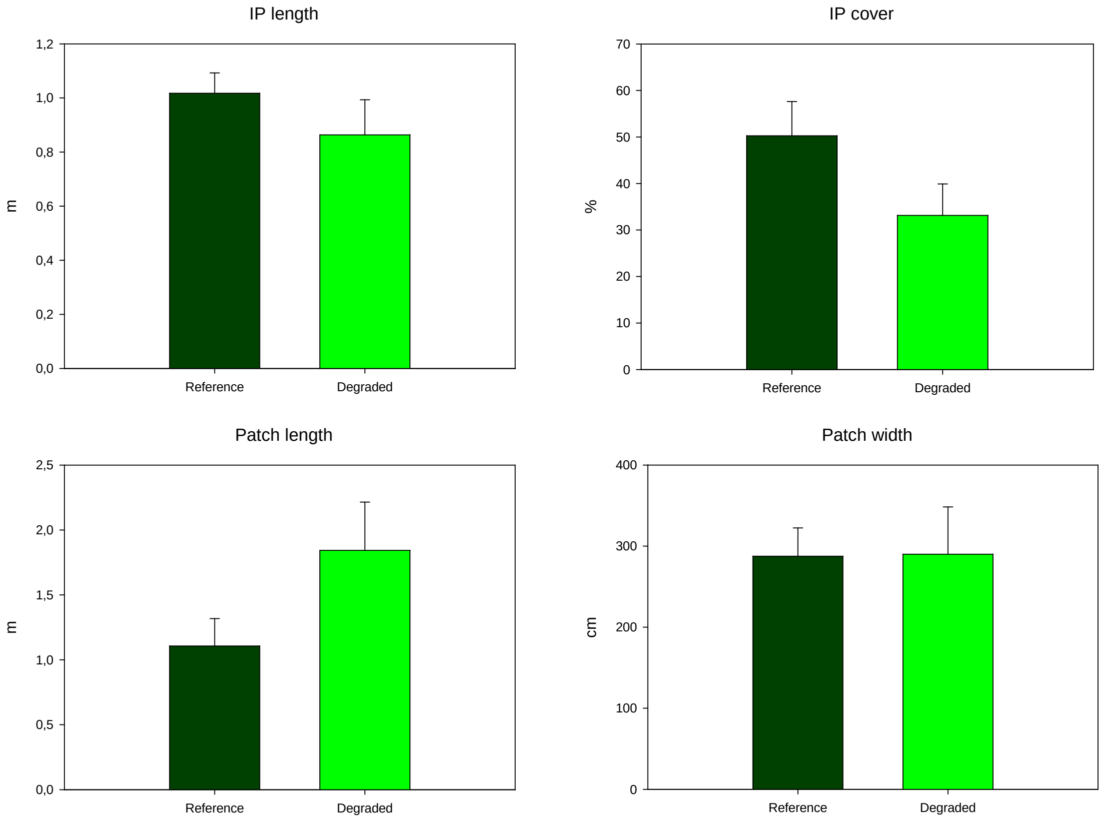

Figure 15. Values of Interpatch length (top left), cover (top right), patch length (bottom left) and width (bottom right) in the Reference and Degraded states in Ayora field site. Mean and standard errors are shown (: 0.010<p<0.050;***: p<0.010).**

The three ecosystem funtioning indices derived from LFA assessment showed very similar values in the two ecosystem states (Fig. 16). Stability was around 71%, infiltration 55% and nutrient cycling 53% both in the Reference and Degraded ecosystems. As a consequence, the services with high weight of these indices (Water and Soil conservation and Nutrient cycling) did not show significant losses in the Degraded burned sites (Fig. 17). Nevertheless, all these services were slightly lower in the Degraded than in the Reference. The largest loss of ecosystem services were recorded in C sequestration and Biodiversity ($t=-2.206$, $p=0.092$; and $t=-2.311$, $p=0.082$, respectively). The loss of the tree layer by the fire and the small recovery of pine species are responsible for this lower amount of C stored in the ecosystem. The lower percentage of interpatches and their smaller size in the Degraded than in the Reference sites could have affected the diversity indices and, hence, the biodiversity service. In Ayora field site, the mature secondary shrubland developed more than thirty years after the fire did not show a global loss of the assessed ecosystem services as compared to the Reference pine forest (Fig. 17).

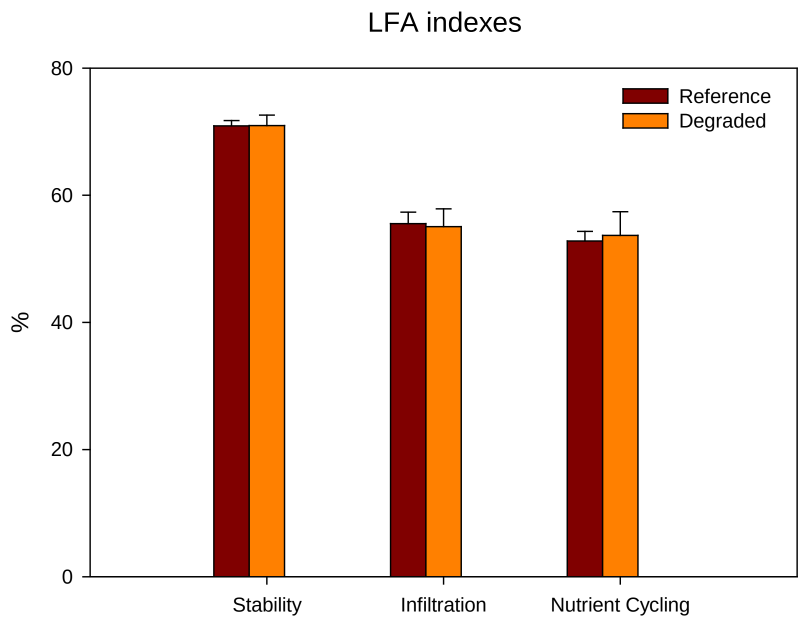

Figure 16. Values of the Stability, Infiltration and Nutrient Cycling indexes derived from LFA in the Reference and Degraded states in Albatera field site. Mean and standard errors are shown (*: p<0.010).**

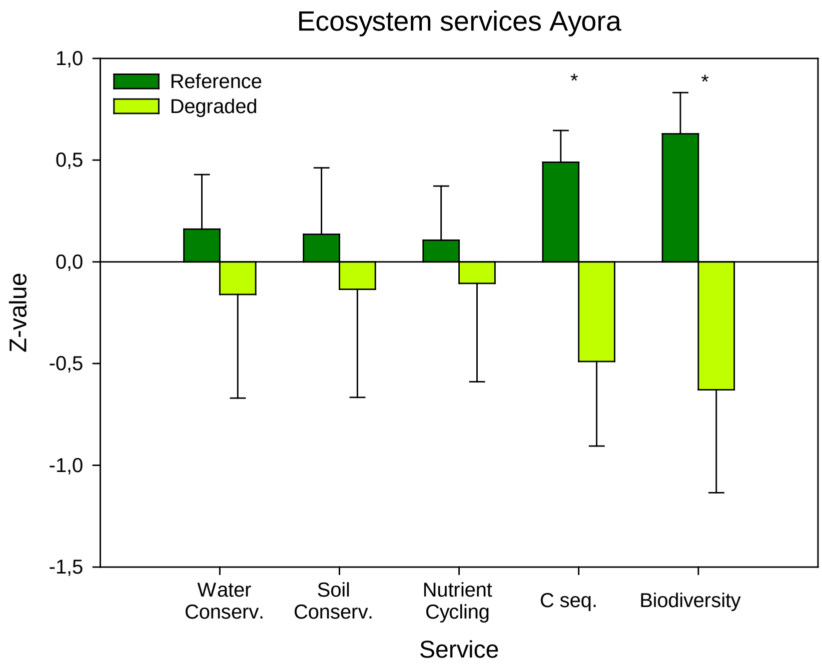

Figure 17. Standardized values (mean and standard errors) of the list of ecosystem services in Ayora, as derived from combinations of the different variables acquired. Mean and standard errors are shown (*: 0.05<p<0.1).

The summary of the ecological variables evaluated in this study shows a 60% increase in the length of the patches of shrubs in the Degraded plots as well as in the biomass of the understory layer (Fig. 18). The highest loss of ecosystem properties wasfound in the biomass of the overstory, as pines did not recover after the fire in the Degraded sites, and, as a consequence, in total aboveground biomass.

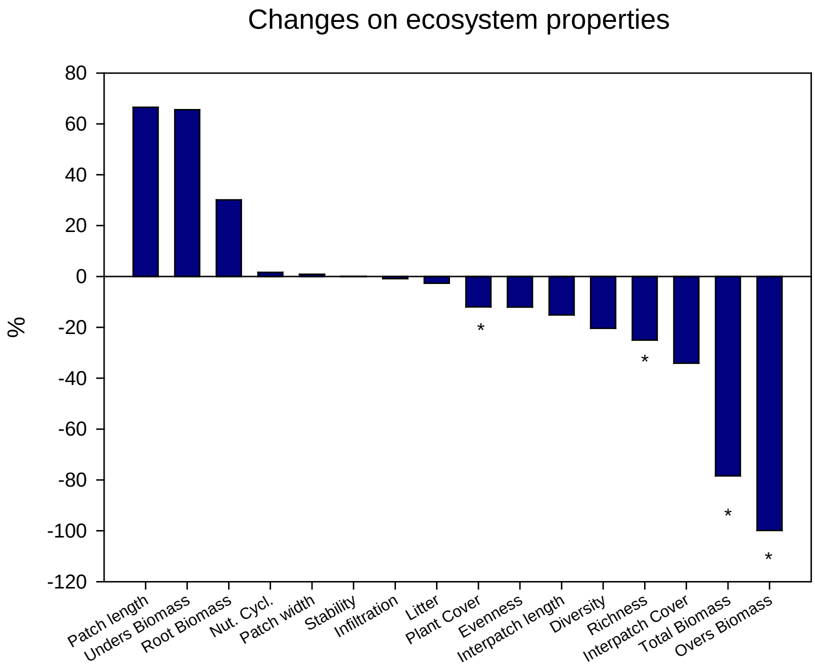

Figure 18. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Degraded areas of the Ayora field site in relation to the References. Asterisks denote significant differences between the two ecosystem states.

Results highlights - Ayora

- Thirty-four years after the fire plant cover in the burned sites is still lower than in the pine forest
- Grasses and resprouter shrubs characterize the mature shrubland while trees are the key species in the Reference
- Secondary shrubland accumulates large proportion of dead fraction in its biomass conferring a very high fire risk to the ecosystem
- Patches of vegetation at the ground level are more abundant and larger in the burned sites than in the forest with lower habitat heterogeneity and diversity
- Ecosystem functioning was very similar in both ecosystem states
- Biodiversity and C sequestration, and their contributing variables, are the services that present the highest losses

5.2 Grazing Driven Landscapes

5.2.1 Castelsaraceno

Plant cover was very high in all three different ecosystem states in Castelsaraceno field sites. Both the Reference and the Undergrazed communities showed total plant cover percentages above 90%, while the average of this value was 86.1 % in the overgrazed plots (Fig. 19). The most characteristic species in the Reference were *Scorzonera villosa*, *Botrhiocloa ischamum* and *Brachypodium rupestre* (12.8, 11.9 and 10.5%, respectively). The Overgrazed areas also showed high cover of *S. villosa* and *Stipa austroitalica* (12.1 and 10.8%, respectively), while the Undergrazed sites showed the most different species abundance. *Spartium junceum*, a legume shrub, and *B. rupestre* were the most abundant species in these areas, with 41.3 and 38.2% total cover, respectively. This is the only situation in which a shrub became the most represented species in the whole Castelsaraceno field site. *Poaceae* is the family that presented higher number of different species and cumulative cover in the Reference (15 species, 66.0%), Overgrazed (13 sp, 60.2%) and Undergrazed states (13 sp, 73.3%). Species of *Fabaceae* contributed with 46.3% to total plant cover in the Undergrazed, mostly due to *S. junceum*, 16.9% in the Reference and 14.8% in the Overgrazed.

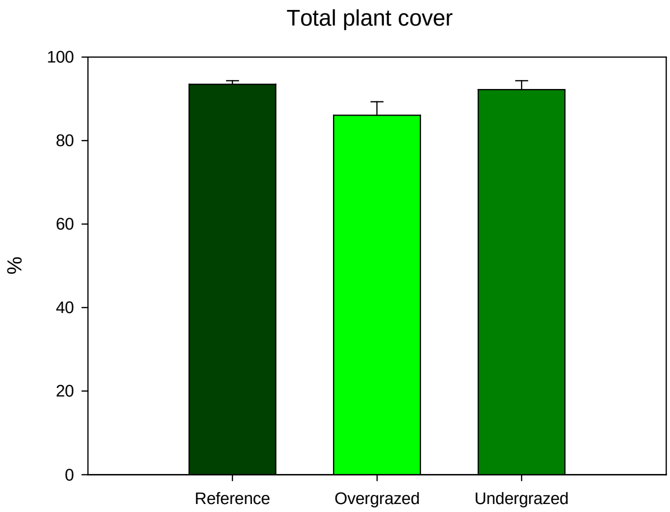

Figure 19. Total plant cover in the Reference,Overgrazed and Undergrazed states in Castelsaraceno field site. Mean and standard errors are shown.

In Castelsaraceno we found a marked effect of the three spatially replicated sites on plant cover and community composition (Fig. 20 left). In Piano del Campi, plots showed positive values of PCA first axis and negative ones of the second axis, in Monte Alpi values of PC1 were close to 0 and positive in PC2, and in Favino both axis showed negative values except for the three undergrazed replicates. Species with higher eigenvalues on axis 1 are *Micromeria graeca*, *Stipa austroitalica*, *Linum tryginum*, *Triticum ovatum* and *Sanguisorba minor* (values 0.595, 0.573, 0.541, 0.524 and 0.508, respectively). *Medicago minima*, *Capsella bursa-pastoris*, *Agropyron repens*, *Trifolium repens*, *Hordeum murinum* and *Holcus lanatus* are negatively extracted on the first axis (-0.814, -0.714, -0.705, -0.655, -0.624 and -

0.618, respectively). On the second axis, *Triticum ovatum*, *Scorzonera villosa*, and *Botrhiochloa ischamum* were associated to negative values (-0.733, -0.719 and -0.655, respectively, while *Brachypodium rupestre* showed the highest positive weight (0.784). According to the main effects of pressure, no major distinctions between the three levels were observed (Fig. 20 right). However, plots showed differences due to degradation within each spatial replicate (Fig. 21). In general, the Overgrazed plots were more similar to the References in composition and cover than the Undergrazed plots. Both in Favino and Piano del Campi, the Undergrazed plots had higher values of axis 1 than the Reference and Overgrazed ones. Lower differences between those two were observed in the second axis values. All nine plots in Monte Alpi were very close but grouped by degradation pressure. The first two axis of the PCA analysis on specific plant cover explained only 20% of the total variance but it is noteworthy that it included all species present in any of the 27 evaluation plots (126 species).

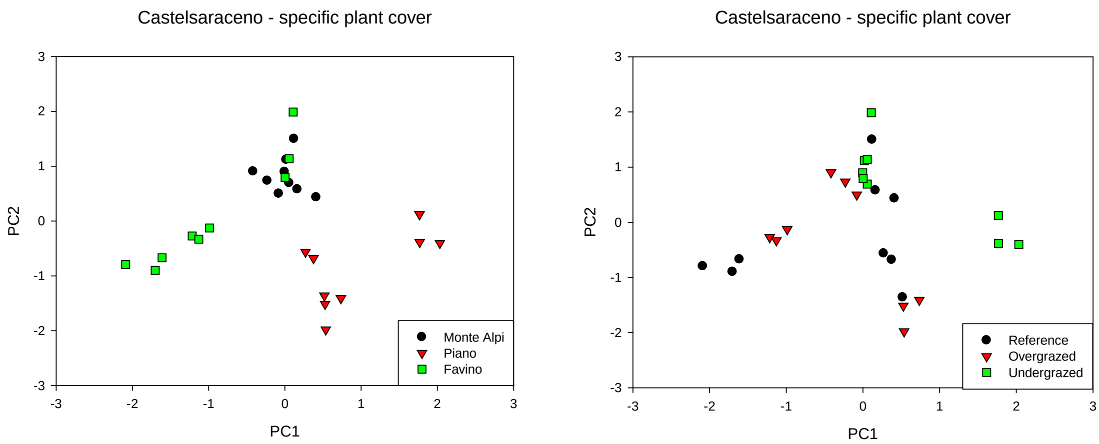

Figure 20. Plot distribution in Castelsaraceno according to the two first axis of PCA conducted on plant cover. Plots are marked by field site(left) and by level of pressure (right).

Overgrazing resulted in a not significant decrease of total aboveground biomass, from 7.78 Mg ha^{-1} in the Reference to 5.50 Mg ha^{-1}. Overgrazed areas showed a reduction of 23% in biomass of grasses but also a 54% reduction in shrub biomass. Removing grazing implied a significant recovery of the biomass of the plant community (F=8.522, p=0.002; Fig. 22) mostly due to shrub biomass build up. Shrub biomass in the Reference systems averaged 1.6 Mg ha^{-1} while in the Undergrazed lands it was above 12 Mg ha^{-1} (F=8.932, p=0.001). Changes in grass biomass were not so pronounced, from 6.2 Mg ha^{-1}in the Reference to 7.3 Mg ha^{-1}in the Undergrazed (F=1.595, p=0.224).

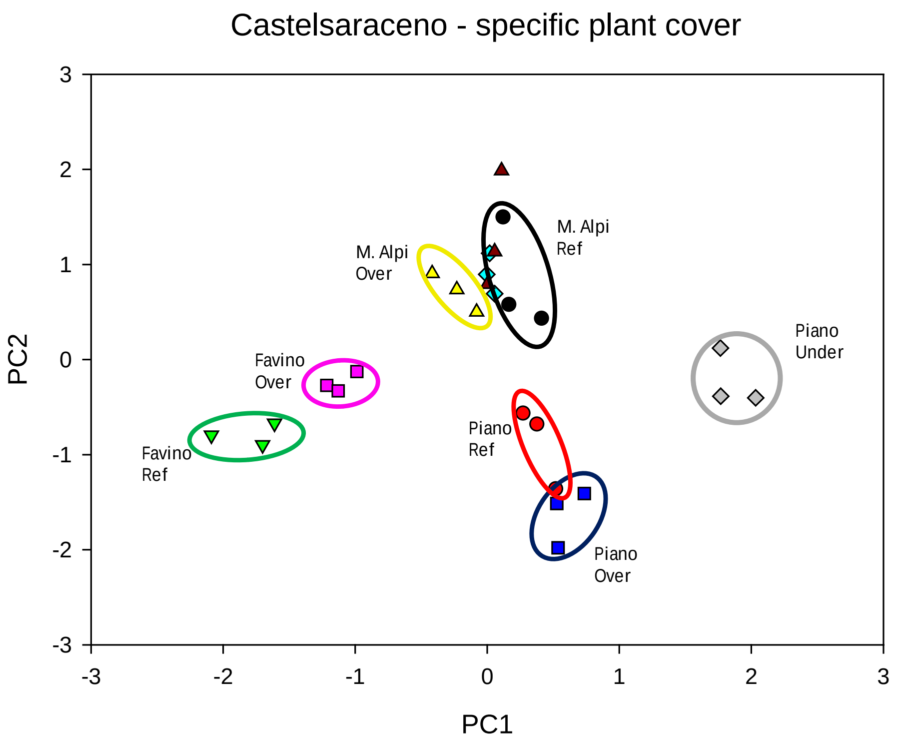

Figure 21. Plot distribution in Castelsaraceno according to the two first axis of PCA conducted on plant cover. Plots are marked by the interaction between field site and level of pressure. The undergrazed plots of Favino (brown triangles) and Monte Alpi (light blue diamonds) are not grouped for clarity.

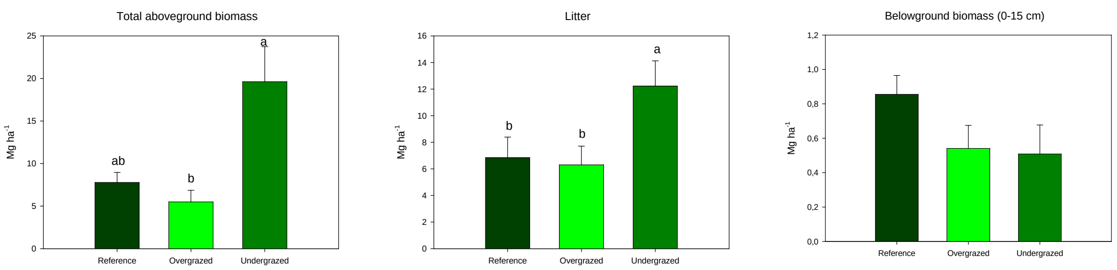

Figure 22. Total aboveground biomass (left), litter accumulation (centre) and belowground biomass on the uppermost 15 cm of soil (right) in the Reference, Overgrazed and Undergrazed states in Castelsaraceno field site. Mean and standard errors. Different letters show significant differences (p<0.050).

Litter accumulation on the Reference and Overgrazed areas was very similar (around 6.5 Mg ha^{-1}) while in the Undergrazed sites this amount significantly increased to twice those values (F=4.003, p=0.032). But belowground biomass in the uppermost 15 cm showed a trend to decrease from the Reference to both types of pressure in a similar way.

The three diversity indexes we evaluated did not show significant changes in relation to the degradation state in Castelsaraceno (Fig. 23). Number of plant species was highest in the Undergrazed plots and lowest in the Overgrazed ones (36 and 29, respectively). Reference areas showed intermediate number of species richness. Something similar was observed both in Shannon’s diversity index and

Evenness with all three communities showing very close figures. It does not seem that either over- or undergrazing had important impacts on plant diversity.

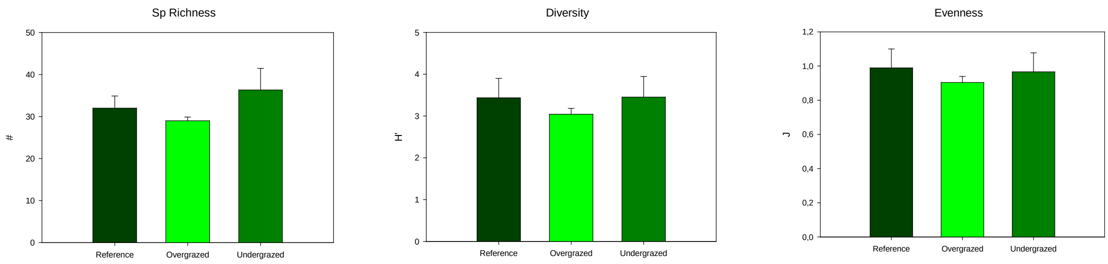

Figure 23. Number of species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference, Overgrazed and Undergrazed states in Castelsaraceno field site. Mean and standard errors are shown.

Interpatches in the Castelsaraceno field site are not bare soil areas but pieces of land covered mostly by small isolated annuals, with perennials or not, but without forming clumps. Patches included compact vegetated spots with shrubs, perennials and/or annuals.

Regarding the spatial distribution of vegetation, over- and undergrazed areas showed the opposite arrangement of interpatches (Fig. 24). IP in the Overgrazed state were shorter than in the Undergrazed (35 vs 72 cm, respectively) but a higher proportion of the landscape was due to IP (58.4 and 39.2% in Over- and Undergrazed, respectively). Average size of vegetated patches was also higher both in length and width in the Undergrazed than in the Overgrazed sites, suggesting a higher concentration of vegetation when grazing reduced.

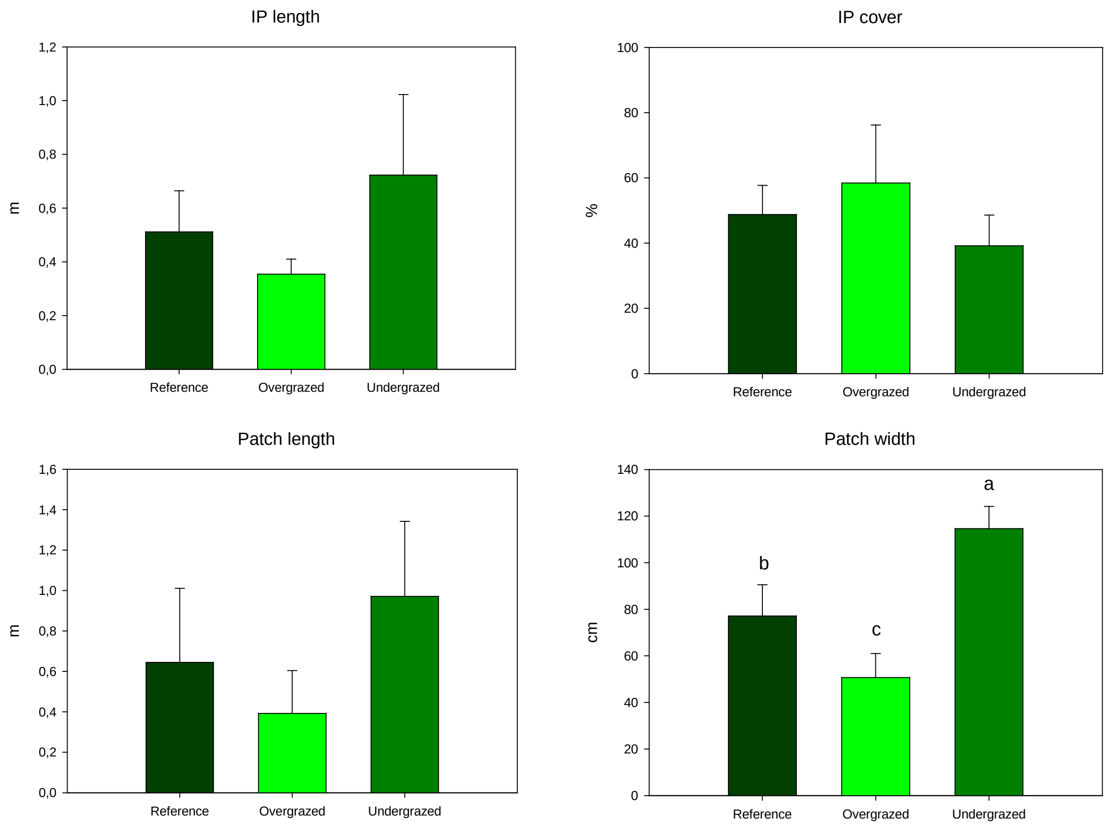

Figure 24. Values of Interpatch length (top left), cover (top right), patch length (bottom left) and width (bottom right) in the Reference, Overgrazed and Undergrazed states in Castelsaraceno field site. Mean and standard errors are shown.Different letters show significant differences (p<0.050).

From the point of view of ecosystem functioning, the three states of pressure showed very similar results in the three indexes derived from the LFA assessment (Fig. 25). The biggest change was observed in the Stability index that reduced from 54.9% in the Reference to 50.1% in the Undergrazed. However, none of the changes on those indexes were statistically significant.

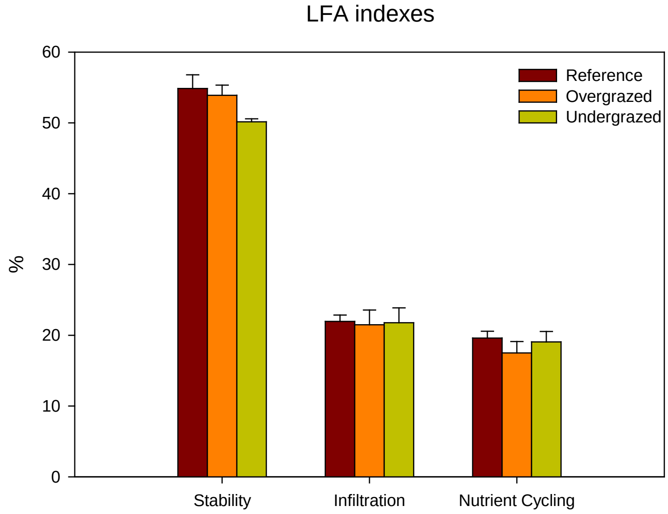

Figure 25. Values of the Stability, Infiltration and Nutrient Cycling indexes derived from LFA in the Reference, Overgrazed and Undergrazed states in Castelsaraceno field site. Mean and standard errors are shown.

Soil and water conservation and nutrient cycling are the three services that showed a trend to decrease as affected by over- and undergrazing (Fig. 26). However, variability was very high and prevented significant differences. On the other hand, C sequestration was significantly improved in the Undergrazed sites, especially when compared with Overgrazed areas. In general, environmental ecosystem services were reduced in the Overgrazed plots in relation to the Reference while the Undergrazed showed intermediate overall loss of services.

The two degraded states of the ecosystem in Castelsaraceno field site showed the opposite changes in the ecological variables assessed (Fig. 27). All variables showed losses in the Overgrazed in relation to the References, especially the width of vegetated patches and total aboveground biomass. Reductions in the length of interpatches can be seen as a positive change. On the other hand, Undergrazed sites showed gains in all properties, especially in total aboveground biomass, litter accumulation and the size of vegetated patches.

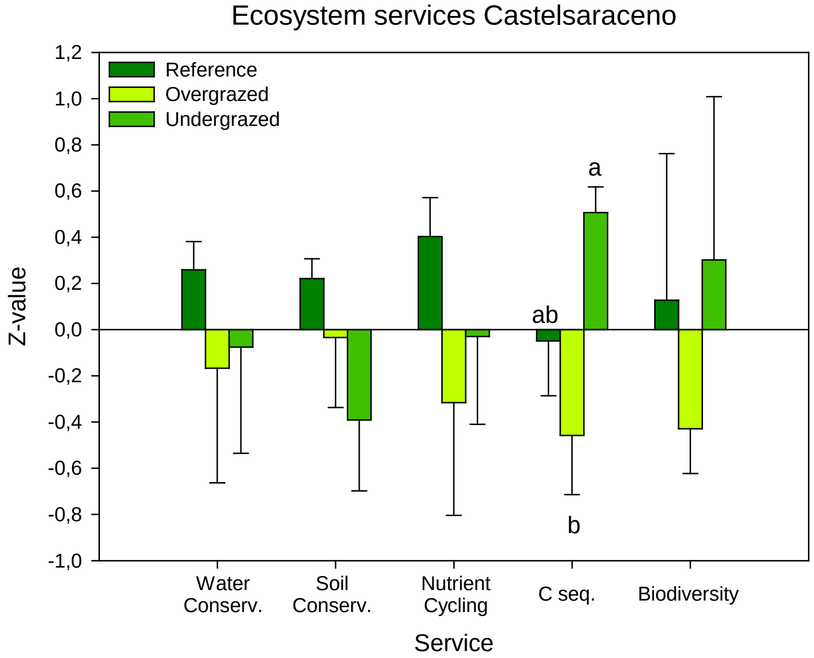

Figure 26. Standardized values of the list of ecosystem services in Castelsaraceno, as derived from combinations of the different variables acquired. Mean and standard errors are shown. Different letters show significant differences (p<0.050).

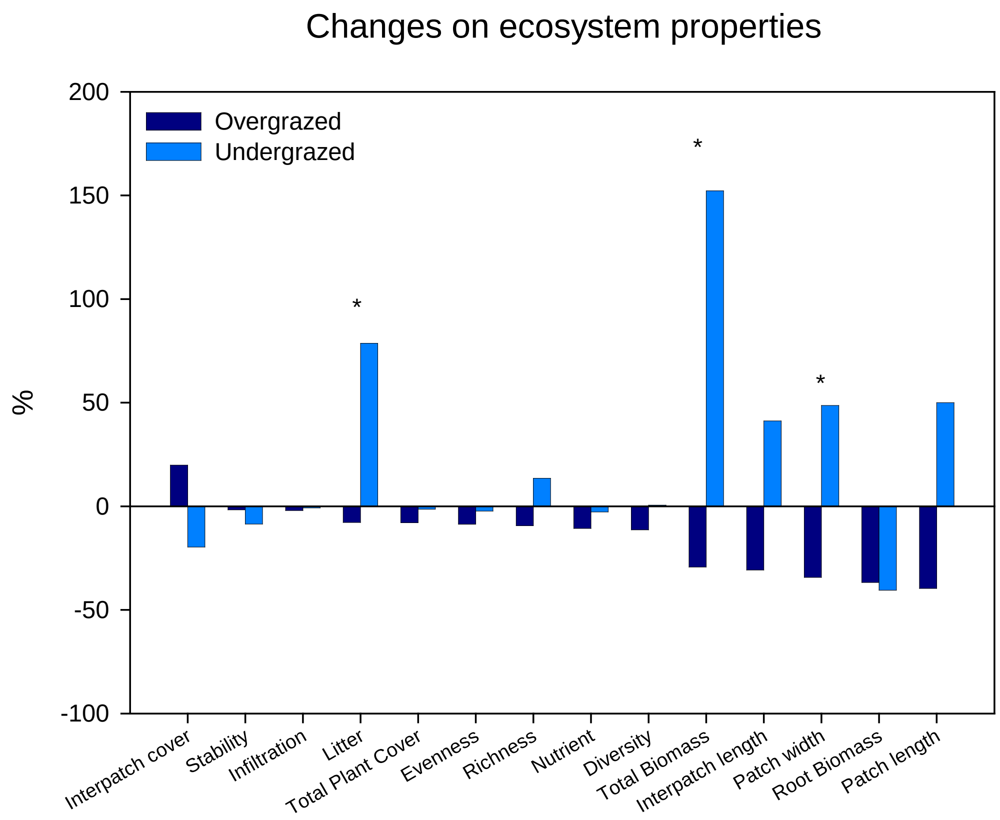

Figure 27. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Over- and Undergrazed areas of the Castelsaraceno field site in relation to the References. Asterisks denote significant differences between ecosystem states.

Results highlights - Castelsaraceno

- In general, Undergrazed areas show more dissimilarities to both Reference and Overgrazed sites associated to changes in plant composition and biomass
- Different directions of the grazing pressure (under- and over-grazing) changed in opposite ways the spatial distribution and size of vegetation and interpatches
- Ecosystem functioning was very similar in all three ecosystem states
- C sequestration, biodiversity and nutrient cycling are the ecosystems services that showed higher losses due to Overgrazing
- Undergrazed resulted in gains of C sequestration and biodiversity (shrub encroachment) and in losses in the soil conservation service

5.2.2 Messara

The degradation pressure in Messara resulted in a trend to reduce total plant cover under the highest pressure level (Fig. 28 left). Both Reference and Semi-degraded ecosystems showed percentages of plant cover slightly below 80% while this variable dropped to 62.5% in the highly degraded sites. *Sarcopoterium spinosum* was the most abundant species in the Reference state, with 13.3%, followed by *Salvia fruticosa* and *Crepis conmutata* that both presented cover values below 10% . In the Semi-degraded plots, three shrubs were the most abundant species: *Thymbra capitata*, *Crepis cretica* and *S. spinosum*, with cover percentages of 18.0, 14.5 and 11.6%, respectively. *Avena sp* also showed cover values above 10%. *Thymbra capitata* was the most common species also in the Degraded sites, but with lower cover percentages than in the Semi-degraded (14.5%). This was the only species that showed cover values above 10% in the highly Degraded plots. The Reference and the Degraded were the situations that shared the higher number of species (19) while the Semi-degraded showed lower number of common species with the other two ecosystem states (12 and 13 with the Degraded and Reference, respectively). However, the PCA conducted on the specific plant cover data (42.0% of explained variance with the two first axis) showed that the plots of the two considered degradation states are closer than with the undisturbed ones (Fig. 28 right). The three Reference plots showed high variability regarding specific plant cover as the only well-represented species in all three plots was *S. spinosum* (17.7, 12.1 and 10.1%). One of the plots showed a high percentage of *Avena sp* (20.7%) and another one was rich in *Salvia fruticosa* and *Calicotome villosa* (26.8 and 12.6%, respectively). These species were almost absent in the other two plots. *Olea europaea*, *S. furticosa*, *Gladiolus italicus*, *Ononis sp*, *Phagnalon graecum*, *C. villosa* and *Leontodon tuberosum* were positively extracted on PC1 (eigenvalue ≈ 0.9) while *Hyparrhenia hirta* was the species with higher positive weight on PC2 (eigenvalue = 0.881).

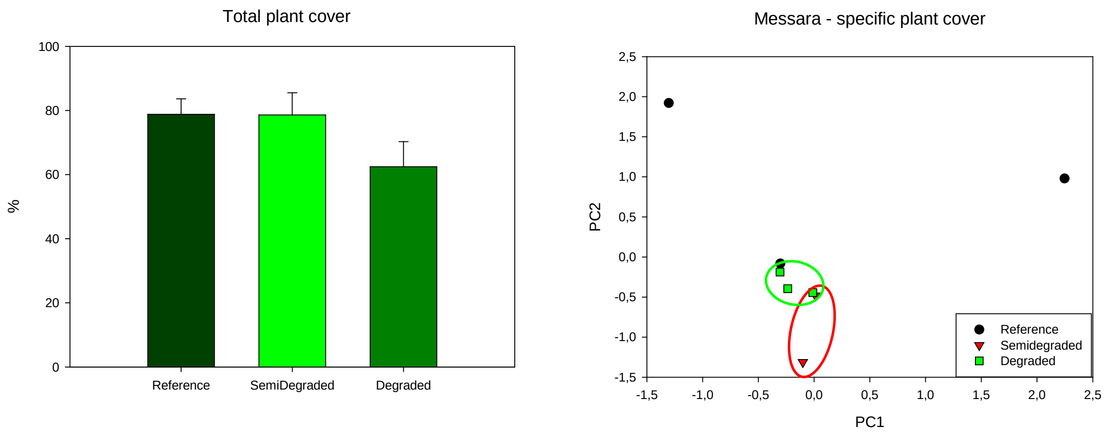

Figure 28. Total plant cover in the Reference, Semidegraded and Degraded states (left) and distribution of plots according to the two first axis of the PCA conducted on specific plant cover (right) in Messara field site. Mean and standard errors are shown in the plant cover figure.

The three plant biodiversity variables showed the same decreasing trend as the grazing pressure increased (Fig. 29). Total number of plant species was highest in the Reference state (17.7) and lowest in the Degraded plots (13.3). The Shannon-Wiener index of diversity was marginally affected by grazing (F=3.815, p=0.099) with values of 2.09, 1.63 and 1.56 in the Reference, Semi-degraded and Degraded states, respectively. Similar effect was observed in evenness with marginal significant differences (F=4.201, p=0.085) between Reference and Degraded states (0.73 and 0.60, respectively).

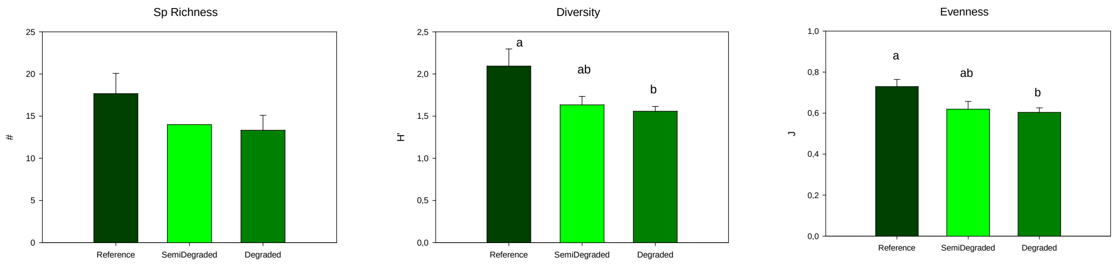

Figure 29. Number of species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference, Semidegraded and Degraded states in Messara field site. Mean and standard errors are shown.

Surprisingly, the Degraded plots showed the highest values of aboveground biomass (Fig. 30) but differences were not statistically significant (F=0.774, p=0.509) as a large range of values were observed (from 9.14 to 46.72 Mg ha^{-1}). This fact could have been related to the higher amount of annuals in the degraded sites and the sampling time (spring). Litter and belowground biomass in the uppermost 10 cm of soil did not result neither in significant differences between pressure states but showed a trend to increase in the intermediate pressure state (Fig. 30).

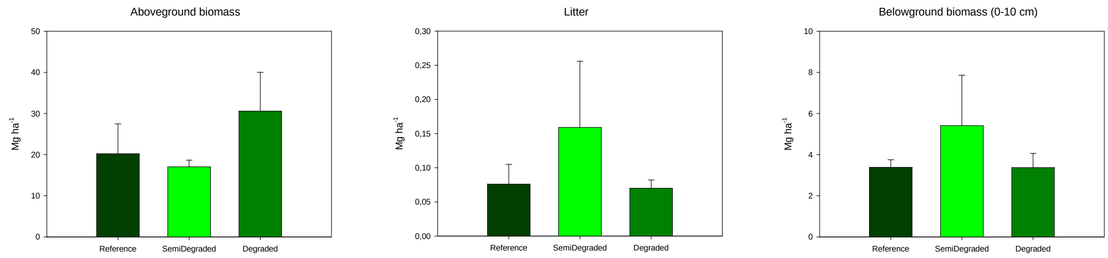

Figure 30. Aboveground biomass (left), litter accumulation (centre) and belowground biomass (right) in the Reference, Semi-degraded and Degraded states in Messara field site. Mean and standard errors are shown.

Interpatches in Messara consisted of bare soil and ground covered by litter or herbs and patch areas were shrubs, subshrubs and tussock grasses. The spatial distribution of vegetation showed very similar patterns in the three pressure states (Fig. 31). There was a trend to increase the interpatch length and cover as the grazing pressure increased with more than 50% of the land of the Degraded state corresponding to source areas with an average length of 72 cm. On the contrary, the length of vegetated patches in the Reference was 122 cm as compared to 77 cm in the Degraded plots. Semi-degraded areas showed intermediate values of these features of spatial distribution of vegetation. The width of the vegetated patches was very similar in all states.

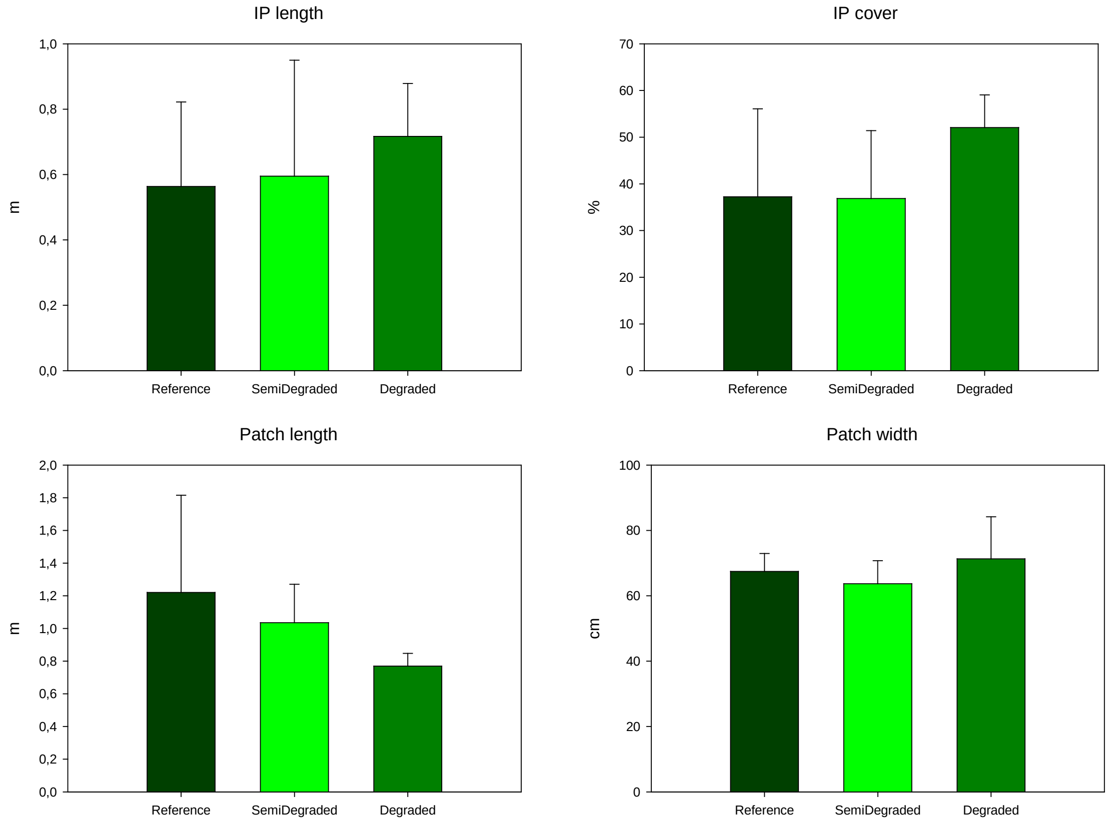

Figure 31. Values of Interpatch length (up, left), cover (up, right), patch length (bottom, left) and width (bottom, right) in the Reference. Semidegraded and Degraded states in Messara field site. Mean and standard errors are shown.

The stability index derived from LFA assessment showed similar values in all pressure states while there was a trend to decrease in both the infiltration and nutrient cycling indices as the pressure level increased (Fig. 32). However, no significant differences were observed in the stability (F=0.368, p=0.709), infiltration (F=0.343, p=0.725) and nutrient cycling indices (F=0.393, p=0.694).

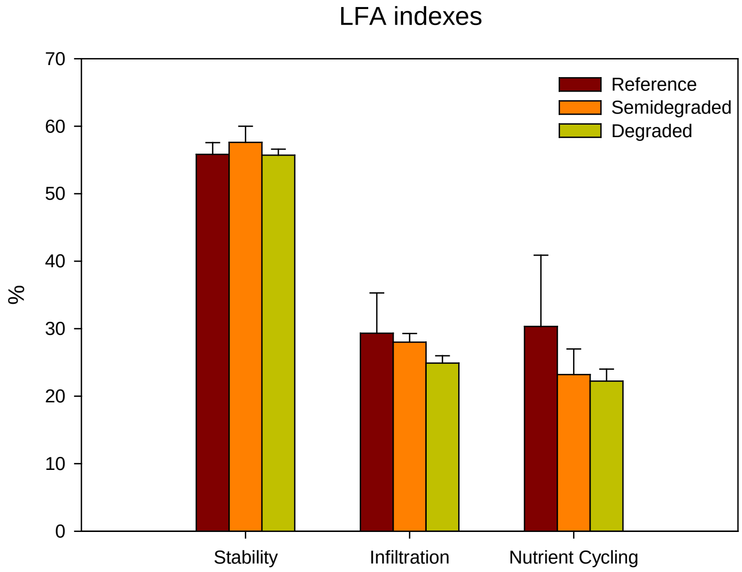

Figure 32. Values of the Stability, Infiltration and Nutrient Cycling indices derived from LFA in the Reference, Semidegraded and Degraded states in Messara field site. Mean and standard errors are shown.

The Degraded state showed a loss of most calculated ecosystem services except C sequestration (Fig. 33). The most pronounced and significant loss was observed in the Biodiversity service that combines data from plant species richness, diversity and evenness. The standardized value of Biodiversity dropped from 0.87 in the Reference to -0.60 in the highly Degraded sites. Soil and water conservation and nutrient cycling showed similar losses with increasing the grazing pressure. In spite of aboveground biomass showed a trend to increase in the Degraded ecosystem, the observed values of litter and belowground biomass (higher in the Semi-Degraded) resulted in higher C sequestration potential in the Semi-Degraded system than both in the Reference and degraded ones. Probably changes on plant composition also affected to C sequestration. There is a trend to decrease the values of ecosystem services as the grazing pressure increases.

Heavily degraded sites showed an increase just in one property of the ecosystems in relation both to the Reference and the Semi-degraded sites that is aboveground biomass (Fig. 34). Positive changes in interpatch cover and length can be interpreted as a negative consequence of pressure as they increase the proportion of bare soil. Significant losses have also been observed regarding evenness and diversity as well as the size of the plant patches. However, the magnitude of losses of the Degraded areas in relation to the Reference does not exceed 40%.

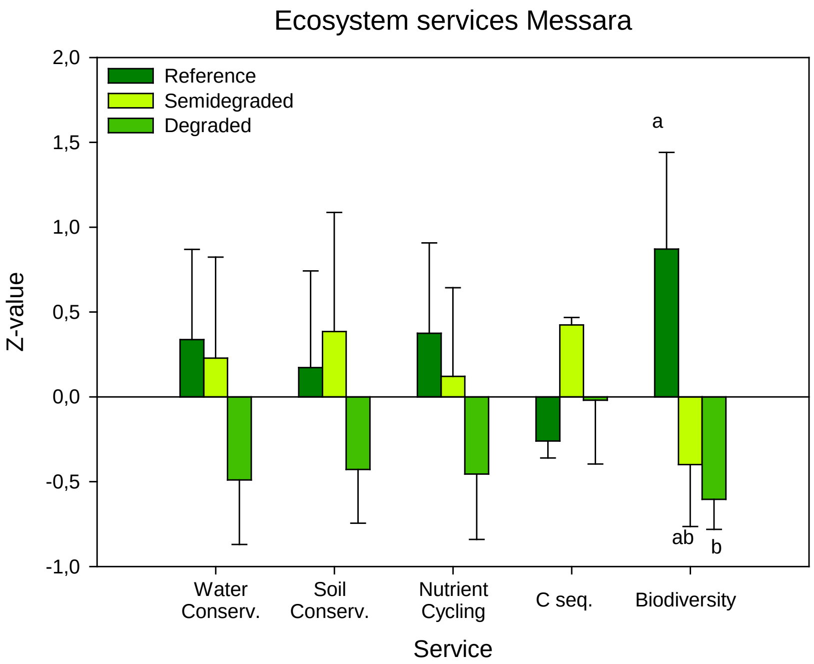

Figure 33. Standardized values of the list of ecosystem services in Messara, as derived from combinations of the different variables acquired. Mean and standard errors are shown. Different letters show significant differences (p<0.050).

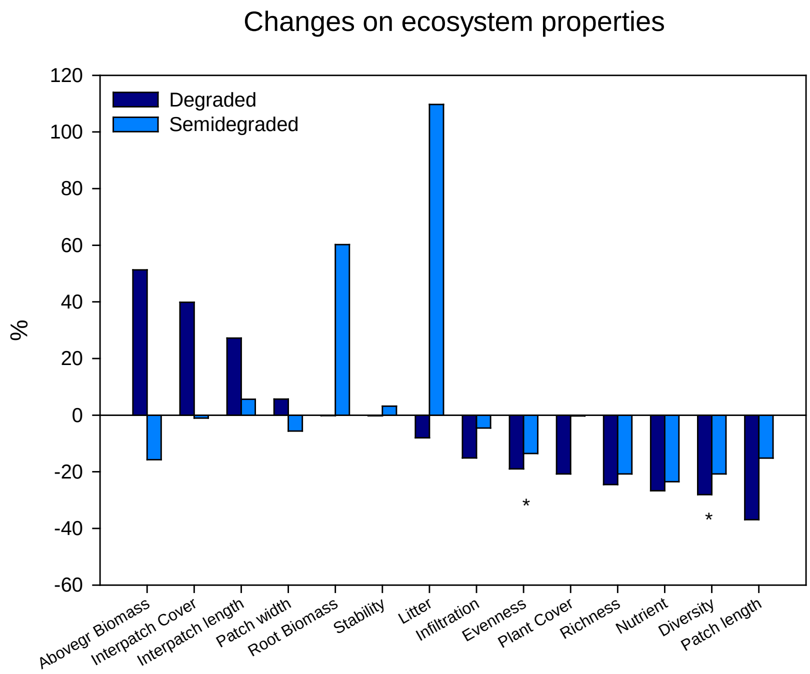

Figure 34. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Degraded and Semidegraded areas of the Messara field site in relation to the References. Asterisks denote significant differences between ecosystem states.

Results highlights - Messara

- Grazing pressure changed species composition and cover but Reference and Degraded sites showed more common species than with the Semi-Degraded
- Intermediate grazing pressure produced higher ground biomass while high pressure increased plant biomass mostly associated to annuals
- The most important losses related to grazing were observed in Biodiversity with lower values as pressure increased
- Soil and water conservation and nutrient cycling were also severely impacted by high grazing pressure

5.2.3 Randi

The grazing degradation pressure resulted in a trend to decrease the total plant cover values in Randi field site with a significant decrease from 79.6 to 46.0% (t=-3.226, p=0.032; Fig. 35). We observed a great variability of plant cover in the three replicates of the Degraded state of the ecosystem with values running from 28.3 to 61.1%. Local conditions and/or pressure levels might be differentially acting in the three degraded plots.

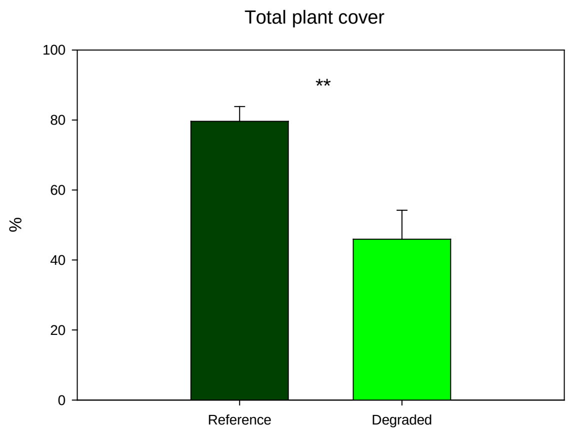

Figure 35. Total plant cover in the Reference and Degraded states in Randi field site. Mean and standard errors are shown.

We found a total of 21 plant species in all Randi plots but only 7 were common to the Reference and the Degraded sites. *Cistus creticus* was the species with highest cover in the Reference sites with 36.7%, followed by *Calicotome villosa*, *Lithodora hispidula* and *Pistacia lentiscus* with 15.5, 15.3 and 12.0%, respectively. On the contrary, only one species of the *Asteraceae* family overcame 10% of cover in the Degraded sites (12.5%) while *Sarcopoterium spinosum* and *C. villosa* showed very similar and lower percentages (6.6 and 6.4%, respectively). We found a clear separation of the plots according to the degradation pressure after the PCA analysis that included all 21 species found (Fig. 36). The first axis explained 45.8% of the variance and the second one an additional 22.7%. Plot separation was significant in the first axis where woody shrubs *C. creticus*, *L. hispidula*, *Genista sphacelata*, *P. lentiscus* and R*osmarinus officinalis* were positively extracted (eigenvalues 0.858, 0.812, 0.760, 0.732 and 0.703, respectively) and the shrub *Rhamnus oleoides*, the bulb *Asphodelus aestivus*, and the herbaceous *Trifolium campestre*, *Arum italicum* and the *Asteraceae* were negatively extracted (eigenvalues of -0.937, -0.852, -0.740, -0.740 and 0.723, respectively). Reference plots showed positive values of PC1 associate to high woody shrub cover while Degraded plots showed negative values of this axis with more abundance of herbs and grasses. The second axis did not contribute to any further separation of plots under the different pressure states.

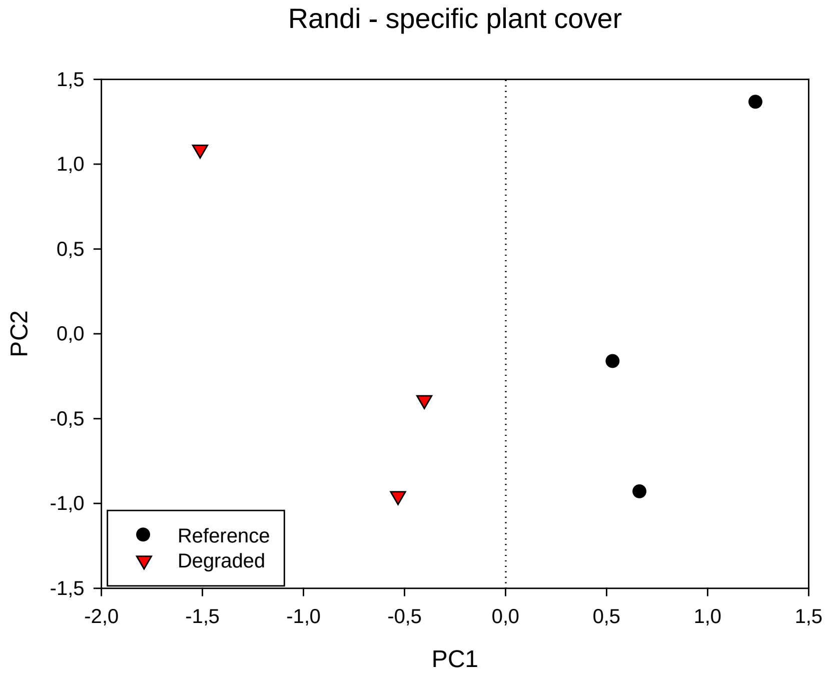

Figure 36. Plot distribution in Randi according to the two first axis of PCA conducted on plant cover. Plots are marked by the level of pressure.

There are clear differences in biomass build up and its fractioning between plant life traits according to degradation in Randi forest plots (Fig. 37). The biomass of grasses in the sampling in Spring 2015 in the Degraded sites is six times higher than in the Reference ones but the large variability among Degraded plots (from 0.83 to 5.12 Mg ha^{-1}) prevented significant differences to appear (t=1.387, p=0.238). The absence of grazing resulted in significant higher biomass of woody species and overall biomass (t=-4.293, p=0.013 and t=-3.229, p=0.32, respectively). Woody biomass was 3.5 times higher in the Reference than in the Degraded plots, mostly due to the high presence of *Cistus creticus* in the ungrazed plots (6.6 Mg ha^{-1}) while this species was absent in the Degraded ones. This lower development of shrubs resulted in sharp and significant (t=2.079, p=0.045) reduction of litter accumulation in the Degraded areas.

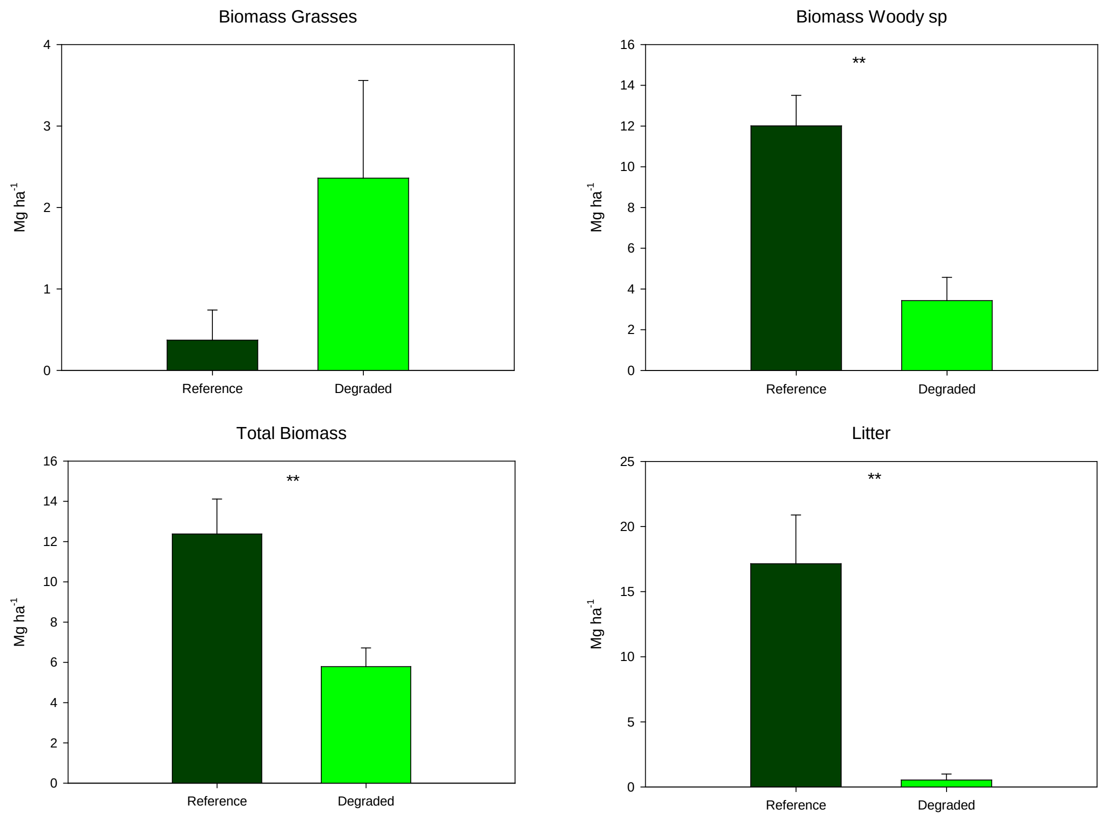

Figure 7 Biomass of grasses (top left), woody species (top right), total biomass (bottom left) and litter accumulation (bottom right) in the Reference and Degraded states in Randi field site. Mean, standard errors and significance are shown (: 0.01<p<0.05).**

Degradation did not affect the total number of plant species (Fig. 38) but, as mentioned above, it affected species identity. The average number of species per plot found in Randi was 10 and the Reference sites showed higher diversity according to the diversity and evenness indices. Shannon's index was 1.76 and 0.99 in the Reference and Degraded plots, respectively, while the evenness was significantly lower (t=-2.605, p=0.060) in the Degraded than in the Reference (0.43 vs 0.75, respectively).

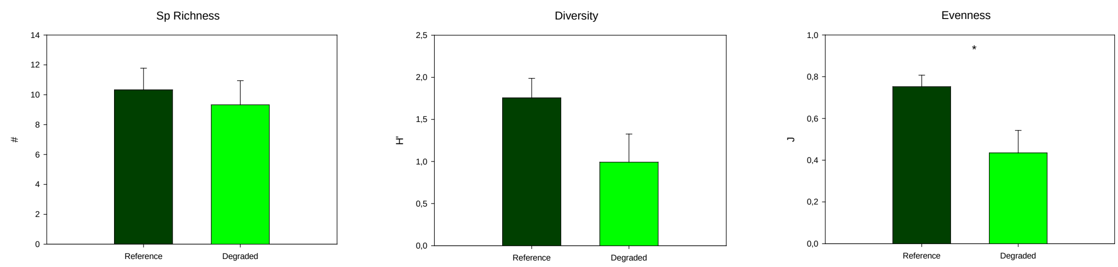

Figure 38. Number of species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference and Degraded states in Randi field site. Mean and standard errors are shown (*: 0.05<p<0.1).

We found a clear modification in the arrangement and morphology of vegetation patches and interpatches in relation to degradation (Fig. 39). Firstly, 81.4% of the land in the Degraded communities was occupied by interpatches (soil, grasses and stones) while they occupied 51.2% of the Reference plots (t=11.205, p<0.001). In addition, these interpacthes were more than two times larger in the Degraded than in the Reference (3.86 vs 1.54 m) but difference were not statistically significant (t=2.102, p=0.167). Similarly, the typology of patches (shrubs and subshrubs) was also significantly different between degradation states, with more than three times longer (t=-6.7018, p=0.003) and wider (t=2.968, p=0.092) patches in the Reference than in the Degraded. As a consequence, degraded sites presented higher connectivity between export/source areas and had small, scarce and dispersed patches of woody vegetation that affect ecosystem functioning (Fig. 40). All three indices derived from the LFA assessment showed significant decreases as affected by degradation pressure. The highest differences were observed in the Nutrient Cycling index with a reduction from 45.8% in the Reference to 9.9% in the Degraded (t=-7.125, p=0.002). This represents a dramatic alteration of the maintenance and recycling of nutrient resources in the system. The infiltration index was also sharply reduced by grazing with a decrease from 52.8 to 20.8% (t=-7.771, p=0.001) with a significant impact on water conservation. The stability index was also significantly affected by grazing (t=-2.242, p=0.088) but differences were not as marked as for the previous two indices.

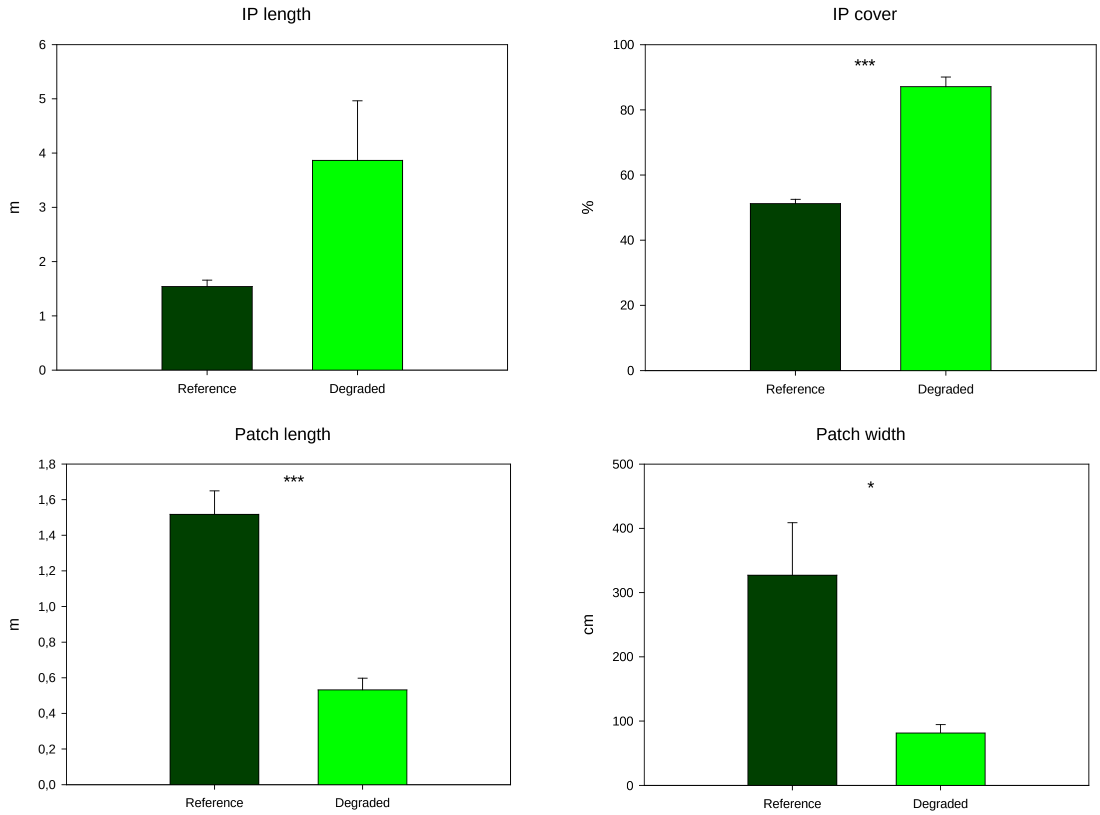

Figure 39. Values of Interpatch length (top left), cover (top right), patch length (bottom left) and width (bottom right) in the Reference and Degraded states in Randifield site. Mean and standard errors are shown (*: 0.05<p<0.1; ***: p<0.01).

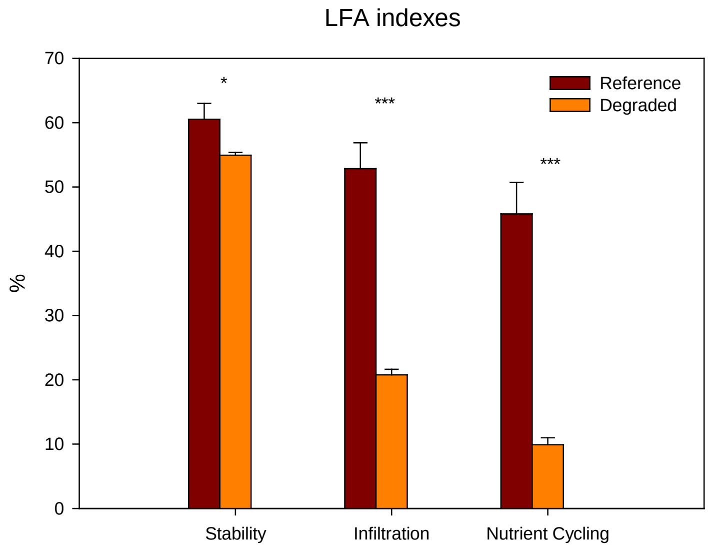

Figure 40. Values of the Stability, Infiltration and Nutrient Cycling indexes derived from LFA in the Reference and Degraded states in Randi field site. Mean and standard errors are shown (*: 0.05<p<0.1; ***: p<0.01).

All the ecosystem services considered were severely affected by grazing (Fig. 41). Water conservation (t=-4.062, p=0.015), soil conservation (t=-3.373, p=0.028), nutrient cycling (t=-4.003, p=0.016) and C sequestration (t=-4.152, p=0.014) showed significant losses due to grazing practices conducted on the sites. Biodiversity was also reduced but the magnitude of the loss was not significant (t=-1.474, p=0.215). The combination of all these results reveals a severe loss of environmental services in Randi associated to heavy grazing activities.

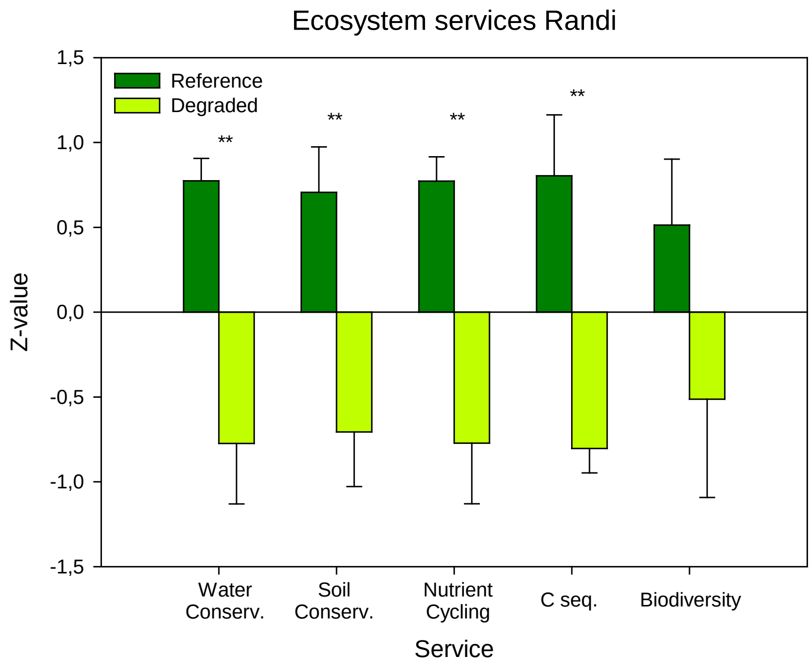

Figure 41. Standardized values (mean and standard errors) of the list of ecosystem services in Randi, as derived from combinations of the different variables acquired. Mean and standard errors are shown(*: 0.05<p<0.1).

All ecosystem properties were negatively affected by grazing (Fig. 42). The positive values of biomass of interpatch lengths can be considered as a degradation effect of the given pressure. Only the biomass of grasses was promoted by grazing.

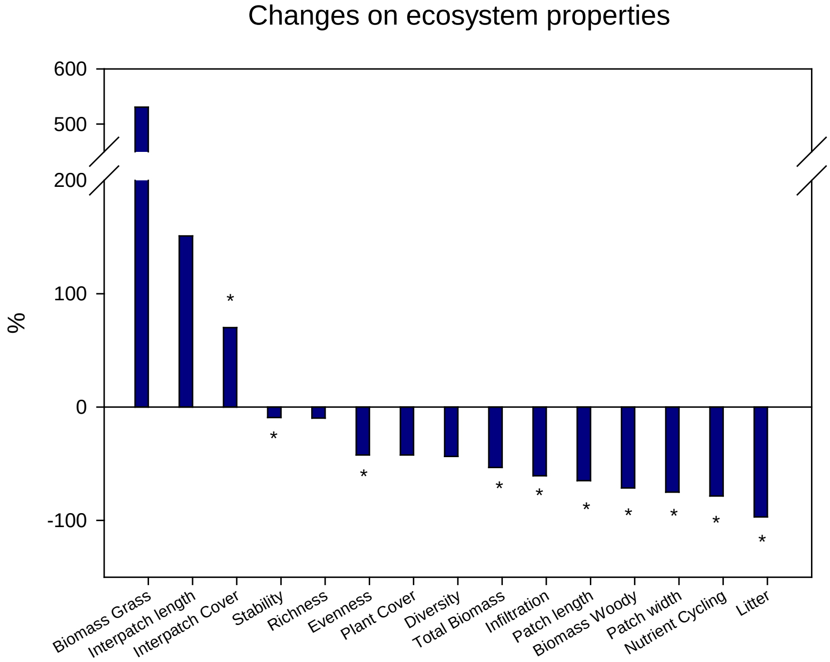

Figure 42. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Degraded areas of the Randi field site in relation to the References. Asterisks denote significant differences between ecosystem states.

Results highlights - Randi

- Plant cover and composition was significantly affected by grazing with shrubs and grasses characterizing the Reference and Degraded sites, respectively
- Grazing generated smaller patches of vegetation and more open sites
- Ecosystem functioning is severely decreased by grazing, producing losses in all ecosystem services assessed
- All variables but grass biomass are reduced in the Grazed areas, interpatch related properties being the most sensitive to pressure
- Degradation threshold might be highly exceeded

5.3 Multifactor Driven Landscapes

5.3.1 Albatera

Twenty-five species were found in the Degraded and Reference plots in Albatera. The multiple stresses acting resulted in a significant reduction of plant cover that reduced from 55.6% in the Reference to 36.7% in the Degraded site (t=-5.776, p=0.004; Fig. 43). The three species that showed the highest cover percentage were *Artemisia barrelieri*, *Fagonia cretica* and *Ephedra fragilis* in the Reference (17.9, 13.1 and 6.7%, respectively), and especially *Fumana thymifolia* in the Degraded sites (24.3%). Only six species were common to the two pressure levels: *Brachypodium retusum*, *Stipa tenacissima* (grasses), *F. cretica*, *Globularia alypum*, *E. fragilis* and *Anagallis arvensis*. This difference in composition and abundance of plant species resulted in a clear separation between plots of the two pressure levels according, mainly, to the first axis of the PCA (Fig. 44). PC1 and PC2 account for 39.2 and 23.0% of the variance after including in the analysis all the 25 species found. *Echium creticum*, *Rhamnus lycioides* and *Anthyllis cytisoides* were positively extracted in the significant first axis (eigenvalues of 0.916, 0.867 and 0.820, respectively) while *F. thymifolia* was heavily negatively extracted on PC1 (-0.959). As mentioned above, this species presented very high cover percentages in the Degraded sites while it was not present at all in the Reference sites. The distance observed in one of the Reference plots along the second axis was due to the low cover of *Artemisia barrelieri* (7.5%) in relation to the other two plots (20.1 and 26.2%) as this species was negatively extracted on PC2 (-0.644). On the other hand, the three Degraded plots were very close in the PCA representation suggesting more similar plant species composition and cover than the References.

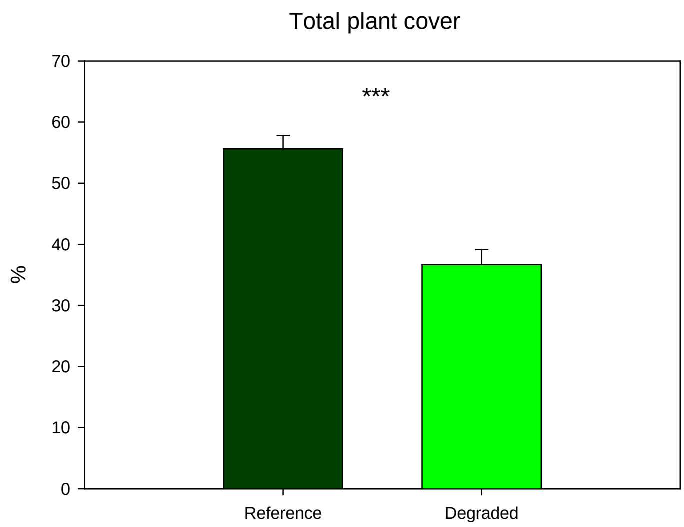

Figure 43. Total plant cover in the Reference and Degraded states in Albatera field site. Mean and standard errors are shown (*: p<0.05).**

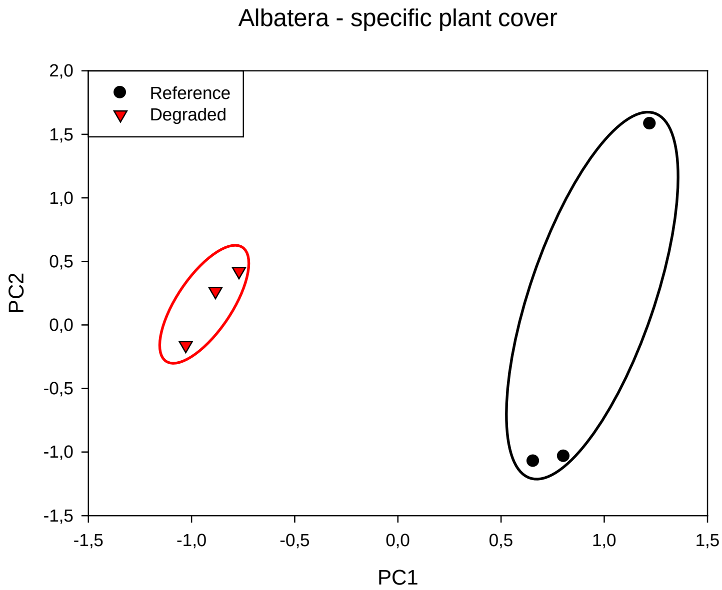

Figure 44. Plot distribution in Albatera according to the two first axis of PCA conducted on plant cover. Plots are marked by the level of pressure.

Plant biomass in Albatera was 2.3 times lower in the Degraded than in the Reference plots ($t=-14.232$, $p<0.001$; Fig. 45) due to the combination of lower total plant cover and the biomass accumulation pattern of the different species occurring in each site.

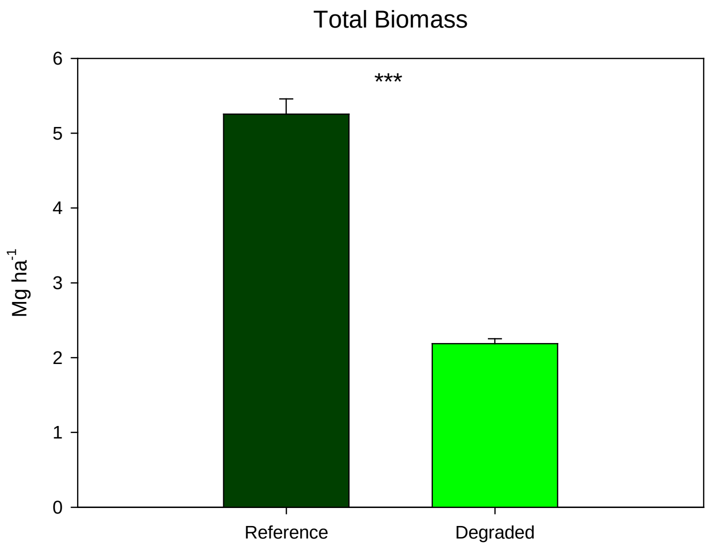

Figure 45. Plant biomass (Mg ha^{-1}) in the Reference and Degraded states in Albatera field site. Mean, standard errors and significance are shown (*: p<0.010).**

The three diversity indices assessed were significantly reduced as a consequence of the degradation pressure in Albatera (Fig. 46). Total number of plant species was reduced in a 40% in the Degraded plots as compared to the Reference (10.3

and 17.3, respectively; t=-2.806, p=0.049). Shannon's diversity index and evenness also showed significant reductions in the Degraded plots (t=-5.885, p=0.004 and t=-7.846, p=0.001, respectively).

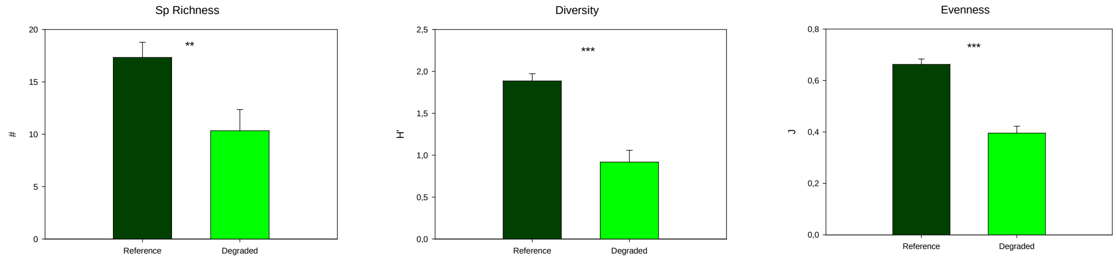

Figure 46. Number of species (left), Shannon-Wiener Index of diversity (center) and evenness (right) in the Reference and Degraded states in Albatera field site. Mean and standard errors are shown (: 0.010<p<0.050;***: p<0.010).**

Degradation also significantly modified the spatial distribution of the sink and source areas and the morphology of the vegetation patches (Fig. 47). The Degraded sites showed a very high proportion of interpatch areas (91.8%) that were significantly higher than those observed in the References (66.9%; t=9.352, p=0.001). In this site interpatches are mainly bare soil areas heavily exposed to heating and erosion. In addition, the average length of interpatches was significantly higher as well in the Degraded plots (1.69 vs 0.82 m; t=4.812, p=0.037). Similarly, the size of vegetation patches (shrubs, grasses, mixed spots and standing dead plants) were higher in the Reference both in length (50 vs 16 cm; t=-5.957, p=0.004) and width (64 vs 19 cm; t=-6.151, p=0.004). These features have profound consequences in the overall functioning of the resulting ecosystems.

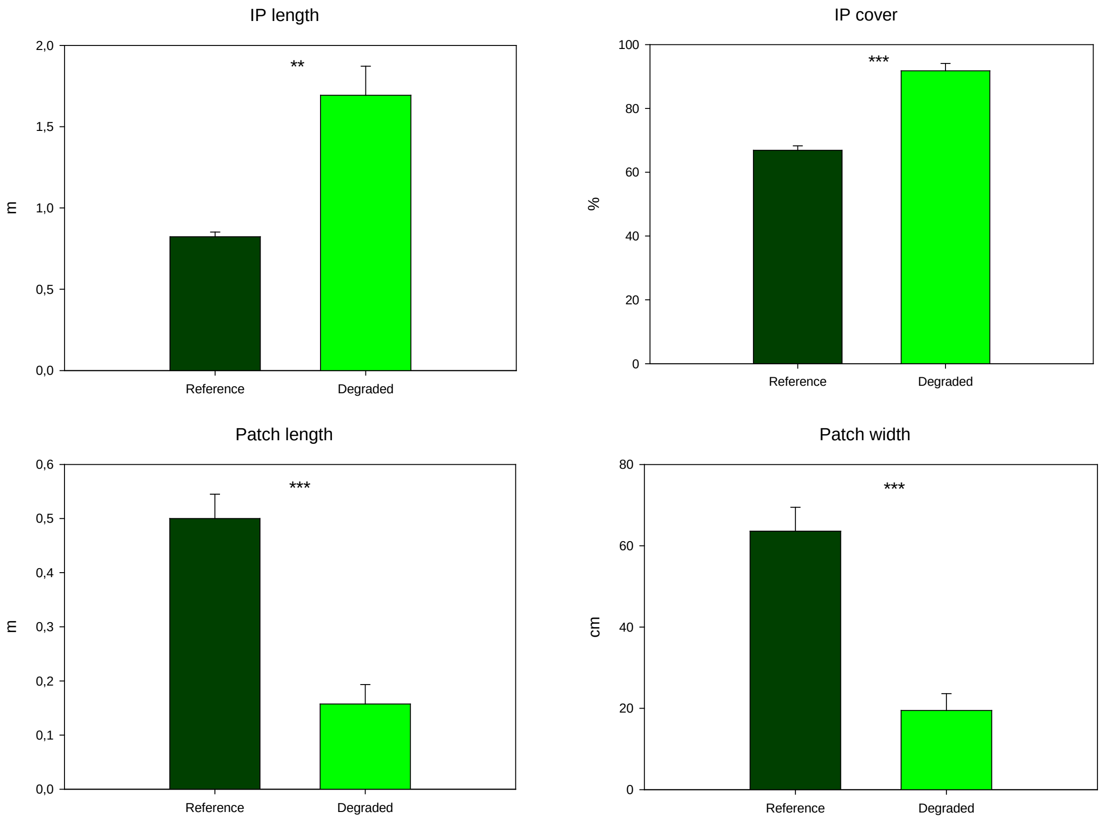

Figure 47. Values of Interpatch length (top left), cover (top right), patch length (bottom left) and width (bottom right) in the Reference and Degraded states in Albatera field site. Mean and standard errors are shown (: 0.010<p<0.050;***: p<0.010).**

Both systems showed similar degree of stability (54.5 and 52.2% the Reference and the Degraded, respectively) but differed in both the infiltration and the nutrient cycling indices (Fig. 48). The loss was highest in the nutrient cycling index as it dropped almost 44% (relative percentage), from 21.5 to 12.0% ($t=-8.265$, $p=0.001$), while the infiltration index relatively reduced by 32% (from 27.3 to 18.5%; $t=-8.309$, $p=0.001$).

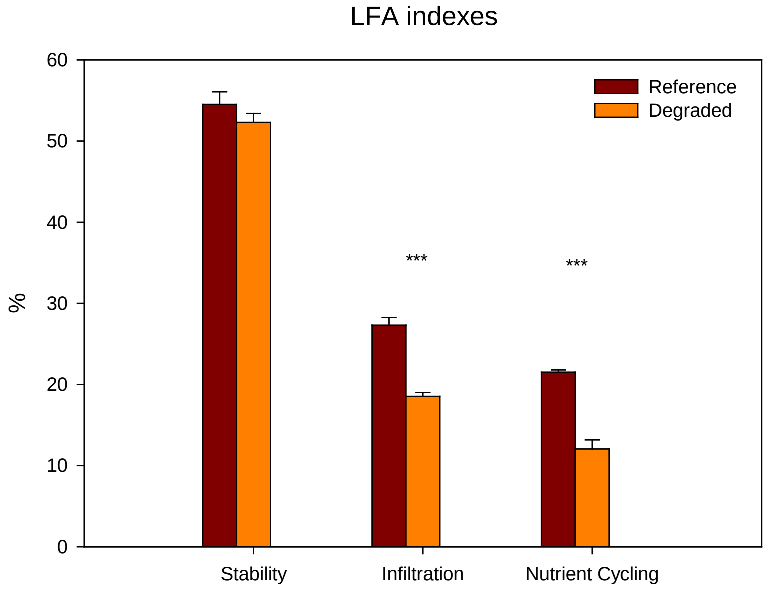

Figure 48. Values of the Stability, Infiltration and Nutrient Cycling indexes derived from LFA in the Reference and Degraded states in Albatera field site. Mean and standard errors are shown (*: p<0.010).**

In this field site, the long term degradation due to the combination of climate and land use and mismanagement has led to a significant loss of all ecosystem services assessed (Fig. 49). The highest losses were observed in C sequestration ($t=-14.055$, $p<0.001$), water conservation ($t=-7.838$, $p=0.014$) and nutrient cycling ($t=-6.538$, $p=0.018$). This represents a very severe loss of the environmental services provided by the semiarid shrublands in Eastern Spain.

All the ecosystem properties evaluated in Albatera have been reduced by degradation (Fig. 50). Increases in interpatch length and cover indicate lower functioning of the ecosystem in soil and water conservation and nutrient cycling. The size of the patches, both in length and width, is the characteristic that showed the highest loss followed by plant biomass and diversity, all of them with losses above 50%.

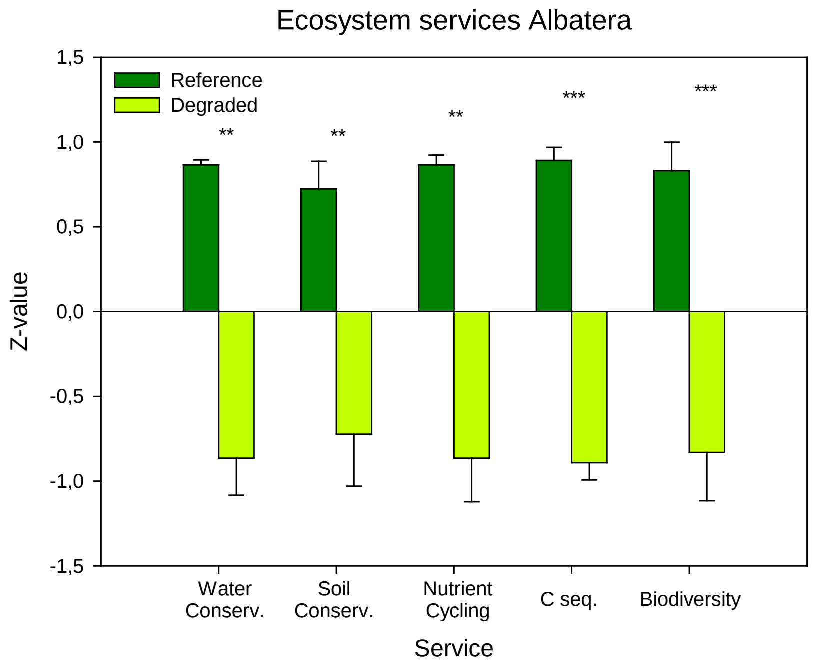

Figure 49. Standardized values (mean and standard errors) of the list of ecosystem services in Albatera, as derived from combinations of the different variables acquired. Mean and standard errors are shown. Different letters show significant differences (: 0.010<p<0.050;***: p<0.010).**

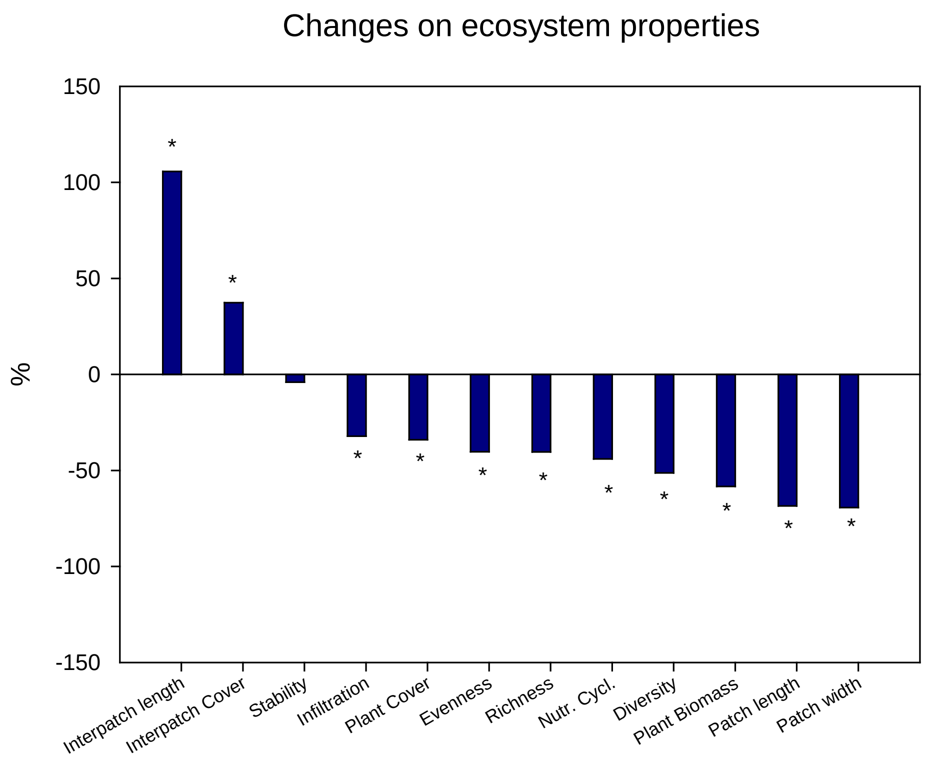

Figure 50. Losses or gains (negative and positive values, respectively) of assessed ecosystem properties in the Degraded areas of the Albatera field site in relation to the References. Asterisks denote significant differences between ecosystem states.

Results highlights - Albatera

- Significant plant species substitution and dominance was observed between the Degraded and References decreasing plant cover and diversity indices
- Higher connectivity between source areas is found in the Degraded and, hence, higher risk to loss of resources
- Infiltration and nutrient cycling were sharply altered by stress but stability was not
- Sink-source pattern distribution is the most sensitive ecosystem property to degradation
- All ecosystem services showed significant losses to the long-term multifactorial degradation pressures

6 GENERAL DISCUSSION

CASCADE field sites include different Mediterranean ecosystems in a wide range of climates and degradation pressures and, as a consequence, the range of values of ecosystem properties obtained is also very large (Table 6). Although comparisons between such different sites is not straightforward, Albatera, which holds the lowest aridity index, and, in a lesser extent, Randi represent the ecosystems with lower quality and functioning. Albatera presents the worst values of plant and interpatch cover, patch size (both Reference and Degraded states), diversity and infiltration (Degraded) and stability indices (Reference) of all six sites. On the contrary, Ayora offered the highest values of the Degraded states of all sites in plant spatial distribution and LFA indices. Biodiversity indices were highest in Castelsaraceno both for the Reference and the Degraded (Undergrazed) states and lowest in Várzea (Reference) and Albatera (Degraded). Várzea showed the two extreme values for aboveground biomass: the lowest in the Degraded (just two years after the last fire) and the highest in the Reference. In general, climate conditions frame degradation vulnerability through their effect on plant productivity and, probably, in plant community resilience to disturbances.

In general, the plant communities in the Degraded situations are very different from the respective healthy References both in composition and abundance. Pressure resulted in more homogeneous communities than in undisturbed states, except in Randi, where high heterogeneity is observed within both Reference and Degraded ecosystems, and Castelsaraceno, with little variations within degradation levels. Intense grazing may represent a stronger effect than soil texture in determining vegetation pattern distribution (Fuhlendorf and Smeins 1998). However, Adler et al. (2001) suggested that grazing might lead either to higher or lower heterogeneity depending on both the pre-grazing spatial pattern of vegetation and grazing.

Our field sites affected by grazing showed a generalized decrease in diversity with grazing pressure and, hence, can be described as overgrazed (Perevolotski and Seligman 1998). Papanastasis et al. (2015) applied the same methodology to assess the change in ecosystem services due to grazing in rangelands in Greece. They obtained very similar results to those we observed in CASCADE grazing sites, with a significant loss of biodiversity, stability, infiltration and nutrient cycling indices, plant cover and size and cover of vegetated patches in heavily grazed areas. But they also reported increases in some properties and ecosystem services when grazing pressure is moderate. Some authors have observed an increase in plant species diversity when disturbed by grazing (Belsky 1992), partly because of the change of competitive relationships between plant species (Crawley 1983). In addition to these change in diversity, we observed a profound change in species composition in all grazed sites, more modest in Castelsaraceno, as demonstrated in the PCA analysis and figures. Holocheck et al. (1989) reported a shift in species composition due to heavy grazing, partly due to an increase in the competitive ability of unpalatable species. But many dominant species of grazed rangelands present morphological and biochemical mechanisms to withstand grazing providing a relatively high resilience to the system (Perevolotsky 1995). Aboveground biomass was reduced in two out of three grazed sites (Castelsaraceno overgrazed and Randi) but increased in Messara. The reduction in leaf area associated to grazing severely affects to primary production in herbaceous pastures such as Castelsaraceno but the same does not happen in areas where shrubs are more abundant such as Randi. Shrubs have longer annual growth cycles and allocate photosynthates to woody parts and roots, often showing compensation growth responses (Tsiouvaras et al. 1986; Perevolotski and Seligman 1998). However, in sites that present a long history of grazing, higher levels of pressure may not significantly affect productivity. Plant pattern in the grazed states is markedly different than in the ungrazed ones, with higher interpatch cover and lower length and width of the plant patches in the grazed plots. These changes reduce the resource sink capacity as observed in other areas subjected to grazing (Papanastasis et al. 2015). Similarly, LFA derived indices are lower in all Degraded sites than in their respective References suggesting a reduction of soil surface conditions and, hence, soil, water and nutrient conservation in the system (Papanastasis et al. 2015). Ecosystem services have shown important losses due to grazing in the order Randi>Messara>Castelsaraceno (Fig. 51) following a decreasing order of aridity (Table 4). Wang et al. (2014) established 0.32 as the threshold value of the aridity index that determines net N losses or accumulations. Castelsaraceno and Randi are well above and below this value of aridity, respectively, while Messara is just in that supposed threshold. On the other hand, grazing, especially when intense, represents an important tool to reduce fire risk in areas like the Mediterranean basin with prolonged drought periods by reducing the amount of fuel susceptible to burn during them. In these cases, grazing systems provides another service to people as it is the reduction of fire hazard.

Biodiversity and ecosystem functions in drylands have been observed to depend on the relative cover of woody species, with linear relationships in dry-subhumid sites and hump-shaped curves peaking at relative woody covers of 40-60% in semiarid (Soliveres et al. 2014). Isbell et al. (2015) suggested that the reduction in biodiversity generates an 'ecosystem service debt’ and defined it as 'a gradual loss of biodiversity-dependent benefits that people obtain from remaining fragments of natural ecosystems'. These authors highlighted the relevance not only of the extension of ecosystems but also the necessity of preserving and enhancing their quality in order to guarantee a sustainable provision of ecosystem services.

The sites with fire pressure offer two complementary pictures of secondary succession after wildfires: a very initial stage of vegetation recovery in Várzea and a mature continuous shrubland without tree-canopy recovery in Ayora. In the short term, the ecosystem shows important reduction in species richness, biomass, vegetation patches, stability, infiltration and nutrient cycling. All these things result in an overall significant loss of ecosystem services (Fig. 51). But this maritime pine forest system has the ability to recover with time most of them, if not all. Thirty-five years after the fire, the Ayora burned areas recovered ecosystem functionality to values of the Reference pine forest, and showed a spatial arrangement of vegetation that better conserves the resources, and accumulated similar amounts of understory and belowground biomass and litter (Fig. 18). Pine regeneration after fire depends on many factors such as fire-interval, pre-fire basal area, slope aspect, land use history or competition with grasses at the seedling stage (Pausas et al. 2003, 2004; Baeza et al. 2007). The scarce presence of pines in the Degraded states of Ayora field site resulted in a significant reduction of the C sequestration service and could be improved by appropriate post-fire management.

The observed shift from forest to non-forest (shrubland) vegetation observed in Ayora is not uncommon especially in drylands. The very high fire recurrence of the Degraded plots in Várzea and the short interval between the two latest fires (2005 and 2012) may cause the change from forest to non-forest vegetation in this area as the time for the first flowering in *Pinus pinaster* may take between 4 and 10 years (Tapias et al. 2004). This imbalance between fire regime and dominant plant species' life histories or unfavorable post-fire conditions may result in a failure to recover pre-fire carbon stocks and hence C sequestration service (Rocca et al. 2014). Stephens et al. (2013) suggested that this shift might not be catastrophic but would affect most ecosystem services. All ecosystem services showed significant short-term losses after the fire (Várzea) but only biodiversity and C sequestration losses lasted in the long term (Ayora). However, the particular conditions in Várzea, especially the higher water availability (0.84 and 0.26 aridity indices in Várzea and Ayora, respectively) suggest that the recovery of these assessed ecosystem services will be faster.

Albatera showed the highest relative losses of all individual ecosystem services and the combined value of all CASCADE field sites (Fig. 51). It is the most stressed site as reflected by the very low aridity index (0.16 classified as semi-arid) and multiple diffuse pressures are and have been acting in the place for long. The main ecosystem properties affected by degradation were those related to the spatial distribution of vegetation and open areas (sink/source spatial pattern) (Fig. 50). The Degraded landscape showed a reduction of vegetation cover, with less and smaller patches of vegetation at longer distances from each other, and higher proportion of bare soil, which in turn reduces capacity of water infiltration and nutrient cycling, and decreases water conservation and soil conservation, and, finally, reduces productivity (Boeschoten 2013). The loss of water conservation is said to be the most essential function in semi-arid ecosystems (Whitford, 2002). Biodiversity was also highly reduced in the Degraded areas probably related to the absence of tall shrubs that act as keystone species in these semiarid shrublands (Maestre and Cortina 2004). Rey Benayas et al. (2009) observed a positive relationship between biodiversity and ecosystem services and suggested that restoration efforts should be directed to increase biodiversity. Stability is the index that showed the lowest loss in the Degraded as compared to the Reference state. Previous works in semiarid Mediterranean areas have showed that the Stability index is less sensitive than the other LFA indices to detect differences between land uses and/or degradation levels (Mayor and Bautista, 2012). However, it could also be that current erosion in the degraded state is actually low due to accumulated effects of past erosion. Thus, higher surface stone cover due to past soil loss may be protecting the soil from further severe erosion. Similarly, higher surface compaction due to accumulated disturbance and the loss of the top soil layers, richer in organic matter, may result in higher runoff but lower soil loss (Mayor et al. 2009). López et al. (2013) found lower values of the LFA stability index as degradation increased associated to lower vegetation cover and patch density, length and width, but a further increase of the index with more intense degradation as the exposed rock surface is higher and the sediments susceptible to be transported is lower. These results could therefore suggest that the system might have overcome a threshold of irreversibility (Scheffer and Carpenter 2003).

In summary, degradation pressures severely impacted ecosystem properties and services of the selected ecosystems along the Mediterranean Basin in a wide range of ecological, biogeographical and historical characteristics. The higher the aridity, the higher the loss of ecosystem services. Some observed changes from the Reference towards the Degraded states suggest that certain degradation thresholds might have been passed.

Table 6. Direct comparison of ecosystem properties between the Reference and the Degraded states of the ecosystem in the six CASCADE field sites.

	FIRE-DRIVEN LANDSCAPES				GRAZING-DRIVEN LANDSCAPES							MULTIFACTOR-DRIVEN LANDS.	
	VARZEA		AYORA		CASTELSARACENO			MESSARA		RANDI		ALBATERA	
	Ref	Deg	Ref	Deg	Ref	Over	Under	Ref	Deg	Ref	Deg	Ref	Deg
Plant Cover (%)	**100.0**	76.1	**89.6**	78.8	**93.5**	86.1	92.2	**78.8**	62.5	**79.6**	46	**55.6**	36.7
Sp richness (#)	**9**	4	**23**	17	32	29	**36**	**18**	13	**10**	9	**17**	10
Diversity (H)	**1.26**	1.15	**2.73**	2.17	3.44	3.04	**3.45**	**2.09**	1.56	**1.76**	0.99	**1.89**	0.92
Evenness (J)	0.58	**0.84**	**0.88**	0.77	**0.99**	0.90	0.97	**0.73**	0.60	**0.75**	0.43	**0.66**	0.40
Aboveground Biomass (Mg ha^{-1})	**113.7**[a]	2.9	**88.0**	18.9	7.8	5.5	**19.6**	20.2	**30.6**	**12.4**	5.8	**5.3**	2.2
Litter (Mg ha^{-1})	**37.8**	0.2	**25.9**	25.2	6.8	6.3	**12.2**	0.1	0.1	**17.1**	0.5	n.d.	n.d.
Interpatch cover (%)	**15.2**	43.4	50.3	**33.1**	48.8	58.4	**39.2**	**37.2**	52.1	**51.2**	87.1	**66.9**	91.8
Interpatch length (m)	0.7	**0.6**	1.0	**0.9**	0.5	**0.4**	0.7	0.6	**0.7**	**1.5**	3.9	**0.8**	1.7
Patch length (m)	**13.5**	0.8	1.11	**1.84**	0.6	0.4	**1.0**	**1.2**	0.8	**1.5**	0.5	**0.5**	0.2
Patch width (m)	**5.6**	1.1	2.9	2.9	0.8	0.5	**1.1**	0.7	0.7	**3.3**	0.8	**0.6**	0.2
Stability index (%)	**75.4**	51.1	70.9	**71**	**54.9**	53.9	50.1	**55.8**	55.7	**60.5**	54.9	**54.5**	52.3
Infiltration index (%)	**53.4**	34.4	**55.5**	55.1	**21.9**	21.5	21.8	**29.3**	24.9	**52.8**	20.8	**27.3**	18.5
Nutrient Cycling index (%)	**53.1**	20.1	52.8	**53.7**	**19.6**	17.5	19.1	**30.3**	22.2	**45.8**	9.9	**21.5**	12.0

[a]: Includes canopy biomass estimated from bibliographic information. n.d.: not determined. Highlighted in bold red the best values.

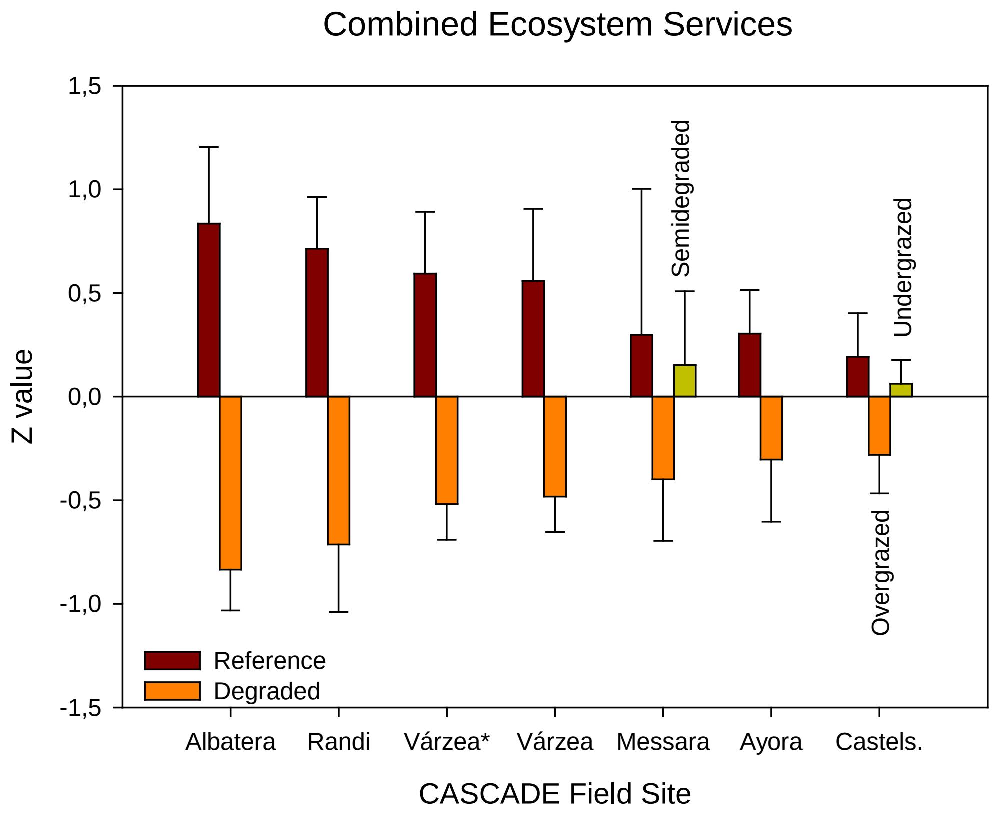

Figure 51. Summary of the loss of standardized ecosystem services due to the local degradation pressure in all CASCADE field sites . Bars represent an average of all five environmental services evaluated. Várzea* refers to the C sequestration service including estimated biomass of the overstory with bibliographic data.

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8 ANNEXES

ANNEX 1. Pictures of study plots with different pressure levels in Várzea.

Photo 1. Reference plot. Mature *Pinus pinaster* forest unburned for 30 years at least.

Photo 2. Degraded plot: area burned four times in the last 37 years. Last fire in 2012 (picture taken soon after the fire).

ANNEX 2. Pictures of study plots with different pressure levels in Ayora.

Photo 3. Reference plot. Mature *Pinus pinaster* forest.

Photo 4. Degraded plot: shrubland.

ANNEX 3. Pictures of study plots with different pressure levels in Castelsaraceno.

Photo 5. Reference plot: productive pastureland.

Photo 6. Degraded by overgrazing plot.

Photo 7. Degraded by undergrazing plot.

ANNEX 4. Pictures of study plots with different pressure levels in Messara.

Photo 8. Reference plot: shrubland.

Photo 9. Degraded plot.

ANNEX 5. Pictures of study plots with different pressure levels in Randi.

Photo 10. Reference plot: shrubland.

Photo 11. Degraded plot.

ANNEX 6. Pictures of study plots with different pressure levels in Albatera.

Photo 12. Reference plot: open shrubland with tall shrubs. Photo by M. Boeschoten.

Photo 13. Degraded plot. Photo by M. Boeschoten.