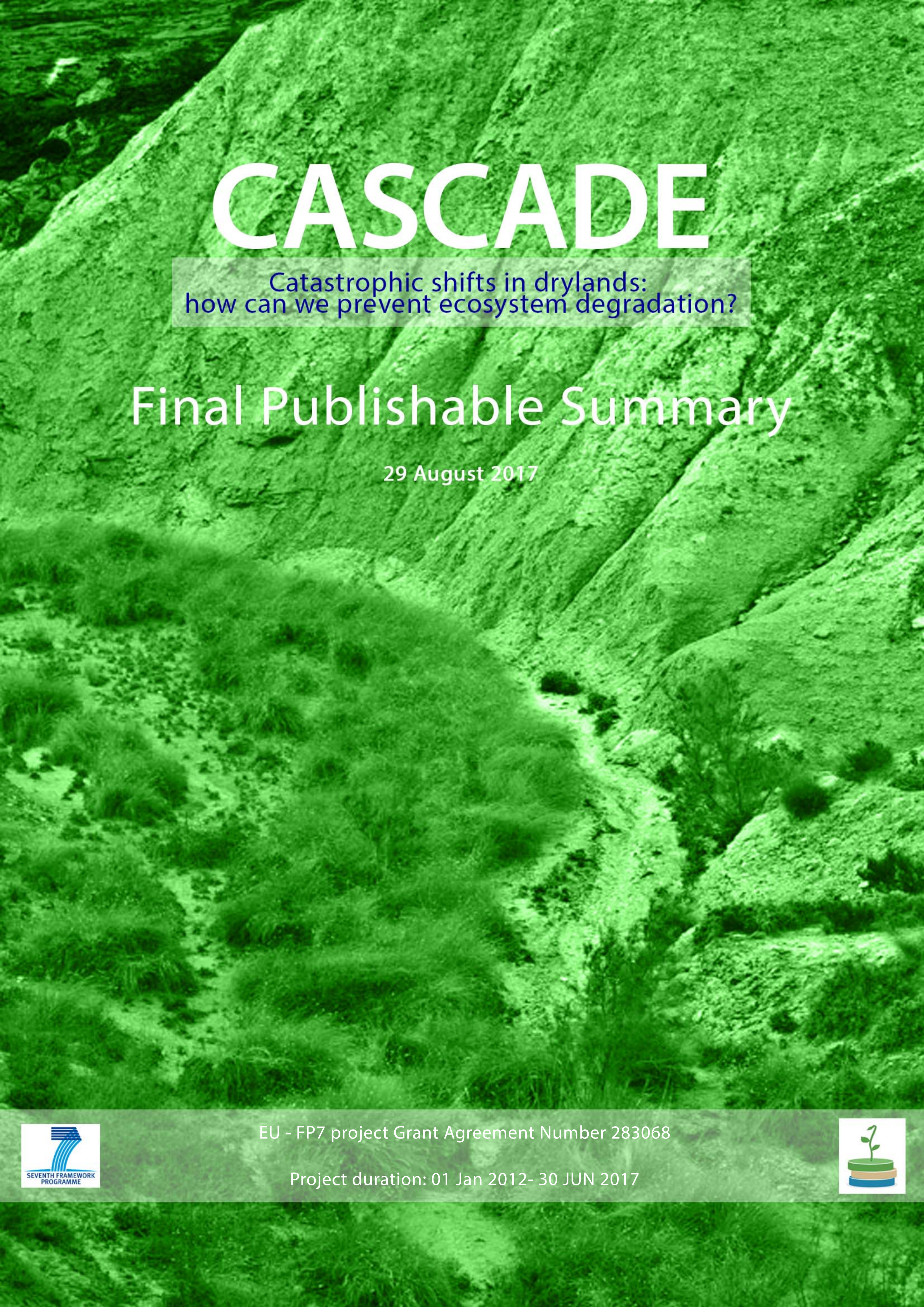


CASCADE

Catastrophic shifts in drylands: how can we prevent ecosystem degradation?

Final Publishable Summary

29 August 2017

EU - FP7 project Grant Agreement Number 283068

Project duration: 01 Jan 2012- 30 JUN 2017

Final Publishable Summary

1.1 Executive summary

One of the most challenging themes in ecology to date has been to understand discontinuous changes or sudden shifts in ecosystems. In the era of the 2030 Sustainable Development Goals, which encompass ideas around Land Degradation Neutrality, advancing this understanding becomes even more critical. Better identification of early warning signals for such changes can help us to develop better-timed and more cost-effective solutions, allowing anticipation of, adaptation to, or even prevention of, undesirable ecosystem shifts. The aim of the CASCADE project was to advance understanding of sudden ecosystem shifts in Mediterranean ecosystems. It takes an integrative, multidisciplinary approach to deliver conceptual, methodological and empirical advances in understanding ecosystem change.

The project linked applied and theoretical ecology at multiple scales with analyses of human-environment-climate relations and stakeholder engagement in Mediterranean drylands to address three key questions: i) What are sudden ecosystem shifts in drylands and how do different pressures lead to such shifts? ii) What processes happen in the soil and vegetation during a sudden shift? iii) How can we manage vulnerable ecosystems better?

In answering these questions, six study sites were selected in Portugal, Spain(2), Italy, Crete and Cyprus, in a West-East transect. In these study sites, various ecosystem service changes were analysed using Landscape and Function Analysis (LFA), in order to detect more subtle changes of possible upcoming ecosystem shifts, and to see which ecosystem services are decreasing and to what extent; this showed that degradation pressures severely impact ecosystem properties and services of the selected ecosystems along the Mediterranean basin in a wide range of ecological, biogeographical and historical characteristics. In field experiments, trends towards soil fertility loss with increasing fire recurrence (one, two, three or four fires in 37 years) were observed at both the short- and the long-term following fire. Labile organic matter fractions were more sensitive than total amounts to fire impact, suggesting their high indicatory value for this type of disturbance, therefore they might serve as potential early warning indicators for changes in soil functioning in response to both fire and overgrazing. Computer modelling suggests that plant patterns in a degrading landscape are also good indicators of upcoming tipping points, these conclusions are reinforced by field observations. More useful knowledge about dryland ecosystems and tipping points was discovered.

In order to prevent tipping points from taking place, cost-effective management interventions, acceptable to stakeholders, should be applied before thresholds are reached. Cooperation with local stakeholders and making use of their knowledge is vital, since they have knowledge of their land and of effective technologies. Selection of the right measures, as well as the right timing for implementation are vital for success, which implies that if the shift has already occurred, measures should be implemented during windows of opportunity when conditions are at their most favourable. Interventions should include bundles of different practices used in combination to both mitigate the pressure and reduce vulnerability, and be supported by policy.

Restoration of ecosystems that are already degraded is extremely difficult due to probable loss of mainly soil resources, but is not impossible. Successful restoration is enhanced by using multispecies in big patches, yet minimizing intraspecific competition by reducing the number of individuals per species within the same patch and combining species in the plant patches with plant traits that maximize the capture and deep infiltration of runoff water.

1.2 Summary of project context and objectives

Knowledge needed to understand and predict thresholds for catastrophic shifts in dryland ecosystems is still limited. The challenge is to improve the understanding of the underlying processes in the soil-water- plant system, as well as of socio-economic drivers and land use management that might move dryland ecosystems towards thresholds, to be able to define threshold values for tipping points and to find ways to prevent such shifts from occurring. When tipping points are being approached, action is urgently needed to avoid catastrophic shifts in the dryland ecosystem. Based on the generated knowledge we can create decision making tools to find suitable management options that help prevent shifts and promote sustainable land management.

Better integration of existing monitoring information across a range of spatial and temporal scales is needed to detect potential thresholds, and research needs to focus on ecosystems undergoing a threshold shift to better understand the underlying processes. CASCADE is exactly addressing these issues in an integrated and holistic way in order to advance the state of knowledge in the research field of ecosystem behaviour, thresholds and tipping-points. To ensure that in-depth knowledge will be gained about regulating processes and mechanisms, CASCADE will focus explicitly on dryland systems as being one of the most fragile and threatened ecosystems in Europe.

The specific aims and objectives of the CASCADE project are to obtain a better understanding of sudden shifts in drylands that may lead to major losses in biodiversity and concomitant ecosystem services. By focusing on vulnerable drylands as our target ecosystems, we build further on existing knowledge regarding shifts in these ecosystems. CASCADE will improve our understanding of the biogeochemical mechanisms underlying sudden and catastrophic shifts, and of the key biotic and abiotic factors influencing these processes. Based on these analyses, CASCADE will develop ways to predict the proximity of the CASCADE's dryland ecosystems to thresholds in such a way that these predictions can be used by policymakers and land users for more sustainable management of drylands worldwide.

The specific objectives of CASCADE, subdivided by WP are:

- WP1: Management of the project.
- WP2: To analyse the historical and current state of a series of selected dryland ecosystems in southern Europe in relation to climate and human activities, and the role of thresholds and tipping point in the land degradation processes in these sites,
- WP3: To experimentally assess on a field micro plot scale the interplay between biogeochemical processes, especially the spatial and temporal variation in water and nutrients and how that affects facilitation and competition, underlying tipping points and sudden regime shifts in vegetation structure and composition in the study sites,
- WP4: To experimentally assess on a field mesocosm scale the interplay between vegetation structures (spatial patterns and composition), hydrology, land use, and sudden regime shifts,
- WP5: To experimentally assess on a landscape scale the vegetation structure (composition, cover, spatial patterns) and ecosystem services before and after regime shifts, as well as the potential of restoration of degraded systems,
- WP6: To develop a spatially explicit model that links the empirical observations on the various scales in WP3, WP4 and WP5 to come up with reliable and empirically based indicators of the proximity of the ecosystems to thresholds and sudden shifts,
- WP7: To design management strategies to deal with tipping points and thresholds in the studied dryland ecosystems and their resilience towards change; these management strategies will be formulated in terms of comprehensive guidelines including principles, best practices, implementation approaches and recommendations,

- WP8: To integrate socio-economic factors into the ecological model and undertake scenario analyses of land management strategies, including their multi-scale evaluation with policy makers to enable formulation of policy recommendations for preventive and restorative dryland management,
- WP9: To make the results accessible to the scientific community by means of scientific papers and to local policy makers and land users by means of popular papers and reports; these reports will especially describe the outcome of the integrated modelling, indicators of sudden shifts, and adaptation strategies of local land users in the study sites and to develop a multi-media communication strategy, including a manual on knowledge transfer and dissemination, a training event for project partners on knowledge transfer and dissemination, a CASCADE website, including an information system to be known as CASCADIS, and a video/film presentations of scientific issues underlying shifts in dryland ecosystems and the management of land degradation.

1.3 Description of the main science and technology results

1 Introduction

One of the most challenging themes in ecology to date has been to understand discontinuous changes or sudden shifts in ecosystems. Recognition and documentation of sudden changes in ecosystem structure and function have become a major research focus during the past 10 to 20 years. Discontinuous changes have been observed and analysed for a wide variety of ecological systems, including lakes, peatlands, marine systems, forests and also drylands and rangelands. As an example, an increase in grazing may seem to lead to only a marginal decrease in vegetation cover, until a critical threshold is passed (also termed 'tipping-point'). At this point the ecosystem shifts to an alternative stable state, characterized by a different structure, species composition and/or functioning, which may, for example, no longer be able to provide sufficient food for herbivores. Thus, the relationship between increasing pressure and observed ecosystem state (e.g. vegetation cover) is described as non-linear or discontinuous. This phenomenon qualifies as a "catastrophic shift" (according to the mathematician René Thom's catastrophe theory), an abrupt change in the state of a system that is difficult or impossible to revert. One of the reasons a system can undergo a regime shift is because the external pressure grows beyond a threshold point. This is normally caused by a change in processes at larger scale (e.g. climate change induces an increase in fire frequency and intensity), but can be intensified through a cascading series of events (e.g. the drought degrades the soil, reducing its water holding capacity, which in turn increases the impacts of the drought). If thresholds or tipping points are passed, the ecosystem may change state, either positively or negatively, and sometimes irreversibly (in terms of species composition and relative abundances, species richness, and total vegetation cover), as illustrated in Figure 3A. Sudden transitions have been shown to occur under continuous external stress, such as decreased water availability or increased grazing. When an external pressure is an event that occurs at discrete points in time such as wildfires, sudden shifts can be anticipated and thresholds relevant to event frequency and intensity are possible key indicators.

Transitions to a degraded state can, in drylands, cause a profound change in the provision of ecosystem services and can lead to desertification, thereby greatly reducing human benefit, affecting livelihoods and possibly inducing land abandonment. Critical thresholds, at which dryland ecosystems degrade from a desired to an undesired state, with bare ground or undesired plant composition, imply major losses of biological diversity, ecosystem functioning and resilience. Regime shifts are difficult to predict: even if a system has remained stable for a long period, a regime shift can occur abruptly and with very limited warning signals. However, certain features of spatial vegetation patterns may provide indicators of the proximity to thresholds in dryland areas. In particular, in dryland areas vegetation often occurs in patches separated by bare soil (inter-patch) and the pattern of these patches changes when a threshold is approaching. Hence, the use of such indicators is a first approach to predict occurrence of shifts. A second approach consists of looking at the occurrence and strength of the environmental drivers that may push an ecosystem from a healthy to a degraded state. Kéfi et al. (2007) showed, both empirically and by modelling, that grazing intensity and/or resource availability may force a system towards such a catastrophic shift so that the levels of strengths of these drivers can serve as indicators of where the shifts are likely to occur. Also modelling studies by other researchers of shallow lakes have successfully adopted this driver approach, identifying critical levels of phosphate loading for ecosystem shifts. The third and most recent approach to better understand and predict shifts in ecosystem states involves a system approach. This approach takes into account as many ecosystem properties as possible, as well as the interplay between these properties.

Recovery of a degraded ecosystem into a previous healthy state is usually difficult if not impossible: once the system has shifted to a new configuration (called "degraded stable state"), return to the stable healthy state tends to display hysteresis (see figure 3A), meaning that the path to degradation differs from the path to recovery. Thus, it is not sufficient to reduce the pressure on the system for the ecosystem to return to the healthy situation, since necessary resources to return to that state could have been lost.

The challenge is to understand the thresholds that may lead to shifts more clearly, to provide early warning of impending issues, so that strategies can be put in place to use environmental resources more sustainably. In the era of the 2030 Sustainable Development Goals (SDGs), which encompass ideas around Land Degradation Neutrality (LDN), advancing this understanding becomes even more critical. It is very important for global sustainability to understand how drylands respond to ongoing environmental change, as drylands form a significant part of the Earth's surface. Better identification of early warning signals for such changes can help us to develop better-timed and more cost-effective solutions, allowing anticipation of, adaptation to, or even prevention of, undesirable ecosystem shifts (Sietz el al, 2017). Both continuous and discontinuous transitions result especially from human activities and changing climate, and may be prevented by proper management. Therefore, management decisions at individual, institutional and policy levels are critical to prevent the downward spiral of degradation and desertification.

The CASCADE (Catastrophic shifts in drylands: how can we prevent ecosystem degradation?) Project has taken an ambitious approach to examining critical thresholds in European dryland landscapes. CASCADE was financed by the European Commission and consisted of a multi-disciplinary team from 15 institutes contributing expertise in: plant ecology at a range of spatial scales; soil science; modelling grazing, fire and land abandonment; economy; land management in drylands; and the formulation of effective policies to promote sustainable land use and LDN. One of the main objectives of CASCADE was to assess whether there are losses of important environmental ecosystem services resulting from the pressures on ecosystems, and from associated sudden shifts, 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. As vegetation patterns are considered one of the main indicators for imminent shifts in drylands, CASCADE focused on those ecosystems in which vegetation patterns can be expected, namely grasslands, shrublands and forests. Within these systems, research was conducted on a range of scales, from detailed studies of plant and soil characteristics at patch scale and plant – soil interactions, to modelling management options at regional level. Finally, practical management guidelines were erected to prevent tipping points from occurring, and also socio-economic consequences and optimal timing opportunities was investigated.

Since current understanding about the causes and characteristics of catastrophic ecosystem shifts in Mediterranean drylands is limited, the CASCADE Project addressed the following three key research questions within the context of Mediterranean drylands :

- What are sudden ecosystem shifts (Q1)?
- What processes happen in the soil and plants during a shift (Q2)?
- How can we manage vulnerable ecosystems better (Q3)?

By answering these questions this paper also aims to provide a synthesis of the CASCADE project.

2 Study Sites

CASCADE had six study sites spread across the entire Euro-Mediterranean (Figure 1). The main characteristics of these sites are given in Table 1. As can be seen from Figure 1 and Table 1, the sites cover several ranges, such as a West-East range (Varzea to Randi), and a range in amount of precipitation and aridity index (Albatera to Castelsaraceno). Together the study sites cover conditions typical for the Mediterranean. Different types of land degradation and desertification are found across the study sites. While forested areas (Ayora and Varzea) are susceptible to repeated wildfires, rangelands face soil erosion owing to poor vegetation cover (Albatera, Messara and Randi) or shrub encroachment (Castelsaraceno), due to overgrazing and insufficient grazing management (leading to undergrazing in Castelsaraceno). Both forest and rangelands are affected by drought and abandonment. The main causes of degradation for each CASCADE study site are also different, but they are always associated with the accumulated impact of a driver: forest fires, marginal agriculture and grazing, and long-term poor land management. Less often, the causes are related to climate, which nevertheless acts as a catalyst by making the system more vulnerable to disturbance. This accumulated impact might cause sudden ecosystem shifts, which may be one of the factors that causes abandonment. [EE1] In the Mediterranean, land abandonment is a widespread and increasing issue (Bielsa et al., 2005; Duarte et al., 2008; Sluiter and de Jong, 2007), also in the CASCADE study sites. After abandonment, the land might not supply the same ecosystem services as before. All study sites are affected by droughts in summer. The historical development and land use are described in Daliakopoulos and Tsanis (2013), and has resulted in current land use being either wood production or marginal grazing.

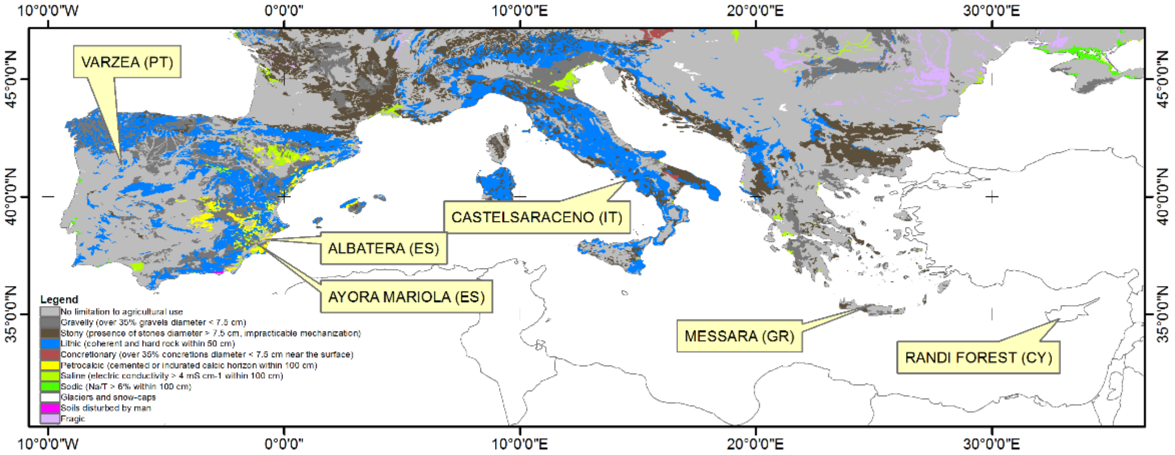


Figure 1: The CASCADE Study Sites

Table 1: Main characteristics of the CASCADE study sites, partly after Tsanis and Daliakopoulos (2015)

	Várzea	**Albatera**	**Ayora**	**Castelsaraceno**	**Messara**	**Randi**
Altitude [m]	450-600	225-310	20-1,200	972-1,284	100-230	90-230
Land use*	F	CS	F	CPF	CS	CF
Current main use	Wood production	Recreation, limited grazing	Livestock (low density)	Livestock (low profitability)	Marginal grazing	Marginal grazing
Mean annual temperature [ºC]	13.4	18	14.6	9.1	17.9	19.5
Mean annual precipitation [mm]	1,170	268	385	1,290	504	489
Mean annual PET [mm]	1,417	1,630	1,479	1,230	1,632	1,698
Aridity Index	0.84	0.16	0.26	1.05	0.31	0.29
Climate classification	H[+]	Sa[+]	Sa[+]	H[+]	D-Sh[+]	D-Sh[+]
Aspect	SSW	NE	NW	E/NE	N	NE/W
Elevation (m.a.s.l.)	468 - 530	180 – 270	763 - 1041	1764 - 1861	435	140
Stress factor	Fire	Multifactor	Fire	Grazing	Grazing	Grazing
Reference ecosystem	*Pinus pinaster* forest	Semi-steppe dry shrubland	Unburned *Pinus pinaster* and *P. halepensis* forest	Productive pastureland	Shrubland	Shrubland
Degraded ecosystem	4-times burned areas (2-years after last fire)	Dwarf shrubland	Shrubland. Areas burned in 1979	1.Overgrazed lands 2. Undergrazed lands	Unpalatable community	Unpalatable community
Soil type & bedrock	Umbrisols; Cambisols over schists	Calcisols; Cambisols over marls	Regosols over marls/ limestone	Regosols over limestone/ dolomite	Cambisols; Luvisols over marls/limestone	Calcaric Regosols over marls
Plant community; target species	Pine woodland; *Pterospartum tridentatum*	Open shrubland; *Anthyllis cytisoides, Calicotome villosa*	Pine woodland; *Rosmarinus officinalis*	Grassland; *Brachypodium rupestre,Stipa austroitalica*	Open shrubland; *Hyparrhenia hirta*	Open; shrubland *Calicotome villosa*

[*]: C (Croplands), S (Scrublands), P (Pasturelands), and F (Forests); [+]: D (Dry), Sa (Semi-arid), H (Humid), and Sh (Sub-humid); [$]: climate, historical use and mismanagement)

3 Methods

The methodology used in CASCADE to answer the 3 research questions Q1-Q3 is summarized in Figure 2. The first step was to select reference ecosystems within the 6 study sites. Within these ecosystems, drivers (Tsanis and Daliakopoulos, 2014) and stress levels were identified, and it was determined who were the stakeholders and which were the relevant policies. Regarding stress levels, 4 levels were identified as shown in Figure 2. Different kinds of experiments were used to research these different levels; each using its own methods and each focusing on one or more of the research questions:

- Stress levels were investigated by monitoring soil and plant characteristics (Mayor, 2015, 2017). The CASCADE project assessed soil improvement as a function of a stress gradient, aiming to identify functional thresholds and processes that might occur after a critical decrease in the soil-in plant system. The CASCADE project carried out various experiments to identify soil- and plant-mediated signals of (imminent) ecosystem shifts soil at patch scale during a shift. In the first, so-called ‘stress- gradient’ experiment, we compared soil quality and performance of targeted plant species at three levels of stress as they occurred under field conditions. In this observational approach we measured soil properties within plant patches and outside plant patches (inter-patches), measuring canopy cover, basal diameter, soil organic carbon and other plant and soil characteristics (Mayor 2015).

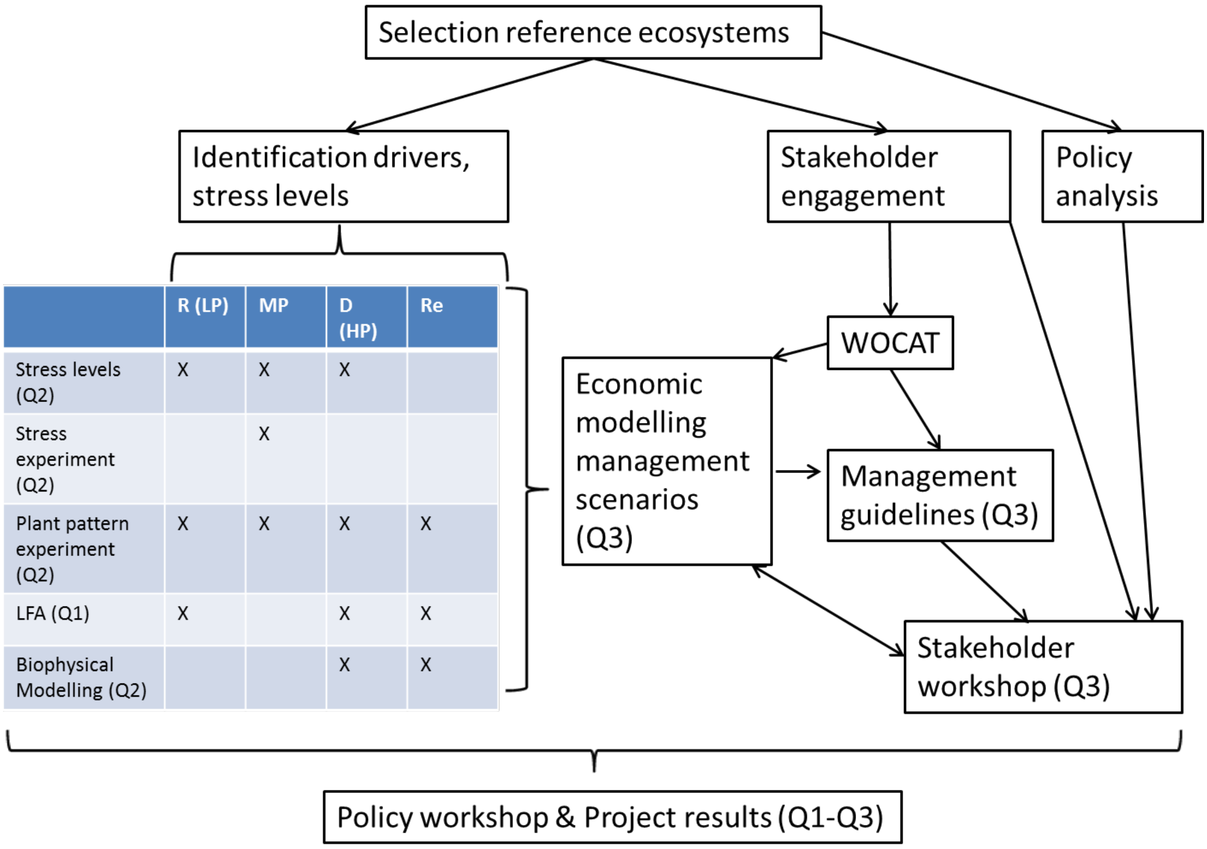
- Following the stress level investigation, a stress experiment was conducted in which roofs were used for different duration to mimic the effect of drought (Mayor, 2017). In this so-called ‘drought-stress’ experiment, we again performed the same set of soil and plant measurements, but now comparing different manipulative treatments at a the MP stress level. This level was chosen because the HP level is already degraded (past the tipping point), while for the LP level it is unlikely that shifts can be reached by manipulating the system. By means of translucent roofs, we excluded rainfall from the vegetation patch to enhance drought conditions. As control, we used roofs that let the rain fall through as well as vegetation patches without roofs.
- Manipulative plant pattern experiments where conducted to study effect of vegetation pattern on resource loss, and on restoration potential (Bautista et al, 2015, 2017). The effect of plant cover and pattern on resource conservation was studied on experimental plots and natural slopes. Degradation reversal potential was assessed as a function of plant colonization pattern and diversity and the hypothesized eco-hydrological feedbacks that modulate dryland dynamics. At the patch scale, we compared the performance of (1) multispecies versus monospecific patches, and (2) patches with singe individuals versus patches with increasing number of individuals and or species.
- Landscape and Function Analysis (LFA) was used to study ecosystem services provided by systems at different levels of degradation (Valdecantos and Vallejo, 2015). CASCADE studied the key properties of the ecosystems (and derived services) and assessed the degree to which they have been affected by the degradation drivers. The three aspects of the evaluation process carried out were: 1) determination of plant composition of the ecosystem, 2) quantification of standing plant biomass, litter and belowground biomass, and 3) application of the methodology of LFA that combines spatial distribution of vegetation and the assessment of soil surface properties. The selection of these key common indicators and assessment methods has been based on the work developed by the EU-funded PRACTICE project (Bautista and Mayor, 2010). They represent few essential indicators that can characterize ecosystem functioning for a majority of drylands worldwide, mostly focusing on five ecosystem services: water and soil conservation, nutrient cycling, carbon sequestration, and diversity of vascular plants. Most provisioning and cultural services are considered to be very much context dependent. 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). The methodology has been applied in all CASCADE field sites in at least two ecosystems representative of a healthy reference and a degraded state, and where available also in a restored site (Table 1).
- Bio-physical modelling was done to understand and predict sudden shifts (Kefi et al, 2016). Models focused on two axes of improvement of current dryland models relevant to study dryland resilience: i) the way external pressures are incorporated in dryland models; we focused on three types of external pressures: grazing, fire and drought; ii) the way vegetation (the ‘biotic component’) is modelled; we incorporated species, functional groups and species-species interactions in dryland vegetation models. We investigated how the additional

ecological mechanisms included affected the response of the ecosystem to stress. We especially looked for shift behaviours and identified the conditions that favoured the emergence of catastrophic shifts at the ecosystem scale.

-

Stakeholders were engaged at the beginning of the project, and perceived current and future changes in environmental conditions and adaptations to those conditions were explored through stakeholder focus groups early on in the project. The existing land management practices were subsequently assessed using the standard WOCAT technology questionnaire (WOCAT, 2008) with stakeholder involvement. Those results formed the basis of an in-depth study on sustainability and resilience of land management practices vis-à-vis ecosystem thresholds and disturbances (Jucker et al, under review).

Results of experiments and well as the WOCAT questionnaires were used to model the economic effects of different management scenarios (De Ita et al, 2017), following the rationale described in Sietz et al (2017). Further, we evaluated the socio-ecological effectiveness of land management by linking non-linear ecosystem behaviour to an economic evaluation of land management options providing essential insights into appropriate timings, climate-induced windows of opportunity and risk and financial viability of investments (Sietz et al., 2017). These considerations informed an integrated modelling assessment in which the effects of a set of management scenarios were evaluated regarding their ecological impact, i.e. the likelihood that vegetation cover remains above a critical threshold, as well as their economic impact, i.e. net present value over a period of 10 years. Stakeholder engagement formed a fundamental part of our integrated assessment. Future changes and expectations expressed by stakeholders make management scenarios more realistic and coherent with their willingness to act. Economic modelling results, WOCAT information and information on relevant policies were combined to formulate management guidelines, which were discussed with stakeholders in workshops held in each of the 6 study sites. Key questions on the role of land management practices during extreme events were assessed together with stakeholders. Feedback from stakeholders was used to fine-tune the scenarios. Finally, project results were presented to, and discussed with, policy stakeholders from all sites in a ‘policy workshop’.



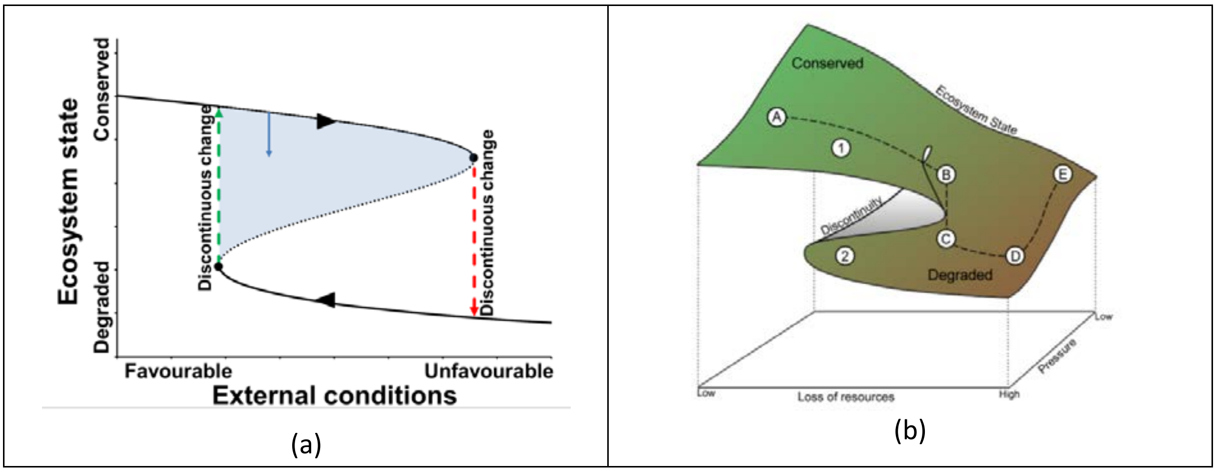
	R (LP)	MP	D (HP)	Re
Stress levels (Q2)	X	X	X	
Stress experiment (Q2)		X		
Plant pattern experiment (Q2)	X	X	X	X
LFA (Q1)	X		X	X
Biophysical Modelling (Q2)			X	X

Figure 2: : Methodological approach of CASCADE. Q indicates which questions were addressed by which research. The different levels of stress/degradation are as follows: R (LP) = Reference (Low Pressure); MP = Medium pressure; D (HP) = Degraded (High Pressure) and Re = Restored.

4 Q1 What are sudden ecosystem shifts?

Introduction Q1

A generally accepted framework for the description of catastrophic shifts is that of the fold catastrophe (Figure 3), introduced in section 1. In this framework, certain disturbances caused by unfavourable external conditions can cause the system to shift towards a degraded state. The maximum disturbance that can be absorbed by the system is the system's resilience. As long as the disturbance stays within the resilience, the system has the capacity to return to its previous conserved state when the disturbance ceases. As the figure shows, resilience decreases when the system approaches the tipping point. Knowing the exact magnitude of the system's resilience a priori is rather challenging, as it usually depends on feedback loops between biotic and abiotic components of the ecosystem.



(a)

(b)

Figure 3: catastrophic shifts: In panel (a) the drawn lines represent the stable equilibrium values for the system and the dotted line the unstable equilibrium (which serves as the boundary between the basins of attraction of the stable equilibria. Between the two grey vertical arrows (denoting "sudden shifts") the system can be in two alternative stable states. The blue area represents resilience, the blue arrow a disturbance, and the black dots tipping points. The red and green dotted arrows indicate degradation path and restoration path respectively. In panel (b) the situation is more complex because the dynamics of the system is not driven by one but two stressors.

When the system's resilience is exceeded, the system jumps to a new state through a sudden shift when the tipping point is passed. Note that the term 'sudden' can be misleading as humans have the tendency to relate human timescales to their perception, thereby relating sudden ecosystem shifts to perhaps weeks or months. However, the term 'sudden' can have a much broader time range. For example, de Menocal found in 2000, that the transition of the Saharan region from annual grasses and shrubs to desert conditions took around 500-600 years, while Scheffer et al. (1993) recorded that transitions between two stable states in shallow lakes can take between 1 and 5 years. The range in duration of an ecosystem shift, depends on the size and nature of the ecosystem. 'Sudden' should also be interpreted in relation to the rate of change of the main driver the ecosystem responds to (such as change in rainfall). Shifts can take place over different timescales ranging from days to years, and, for example, a slow ecological change may precipitate an abrupt economic change.

The degraded state may be stable in the sense that it also presents a new resilience against external conditions. If the ecosystem is governed by one important external variable, then restoration via this variable ultimately leads to a recovery of the system via another path (see figure 3, 'D' to 'E').

In practice however, the system may not return to the initial state but will instead lead to an alternative situation. The reason is that the shift from the original state to the degraded state is often accompanied by a loss of other resources, and that the restoration attempt does not affect these resources in such a way that a shift back to the original desirable state happens. Especially for dryland systems, the absence of a resource may prevent transition to a conserved state. This alternative situation is not always desirable as it may hold inferior ecosystem value than the initial system. This can be illustrated as a cusp catastrophe (Figure 2B), which is a 3-D version of Figure 3A, and in which separate axes are used for pressure and loss of resources.

In Figure 3B, (A) represents an area where a driver is causing pressure to the ecosystem which nevertheless retains a good status and high resources. Here the system is in stable state 1, and can maintain this state regardless of pressure (e.g. grazing) due to its resilience. As resources become depleted the system reaches a region where two alternative stable states (1 and 2) coexist. When the resource depletion has brought the system to the tipping point (B), it shifts to state (C). An example is a grazing system where the rate of consumption gradually grows and at a certain moment exceeds the rate of biomass production leading to a collapse. If resources are depleted further (D), transition back to (C) may require some kind of effort with respect to the lost resources. Going back to state (B) is even more difficult (as explained for Figure 3A). More importantly, eliminating the exerted pressure drives the system to an alternative state (E) rather than back to its pristine condition, because the depletion of resources and not the (grazing) pressure was driving the collapse. Therefore, it is possible that the system becomes "trapped" in this alternative state, especially if resources at hand are non-renewable (e.g. soil) and their loss cannot be amended within a reasonable timeframe (e.g. the human lifespan).

The cusp catastrophe concept and variations can be adopted for different ecosystems or selected ecosystem health indicators. For example, similar transitions can take place between different states of a forest where the combined high fire frequency and loss of resources (e.g. seed bank or soil) can lead to changes in the phenology of the vegetation and ultimately to a stable shrub land. As long as resources do not recover the system would remain locked in this state. However, when resources start to recover, a gradual improvement of the ecosystem would occur according to Figure 3B. Comparable to grazing, at higher fire frequencies the cusp model predicts hysteresis.

CASCADE results Q1

Although CASCADE's field sites include different Mediterranean ecosystems, in general the plant communities in the degraded situations are very different from the respective healthy references both in composition and abundance (Valdecantos and Vallejo 2015, Valdecantos et al 2016). Pressure resulted in more homogeneous communities than in undisturbed states, except in Randi and Castelsaraceno, with little variations within degradation levels. The field sites affected by grazing showed a general decrease in plant diversity with grazing pressure and, hence, can be described as overgrazed. In addition to these change in diversity, we observed a profound change in species composition in all grazed sites, more modest in Castelsaraceno. Aboveground biomass was reduced in two out of three grazed sites (Castelsaraceno overgrazed and Randi) but increased in Messara. Plant spatial pattern and distribution in the grazed states is markedly different than in the un-grazed ones, with higher cover of open areas 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 and, hence, resource conservation. Similarly, LFA derived indices (infiltration, stability and nutrient cycling) are lower in all degraded sites than in their respective references suggesting a degradation of soil surface conditions and, thus, soil, water and nutrient conservation in the system. On the other hand, grazing, especially when intense, represents an important tool to reduce fire risk in areas with prolonged drought periods by reducing the amount of fuel available. In these cases, grazing systems provide another service to people as they reduce the fire hazard.

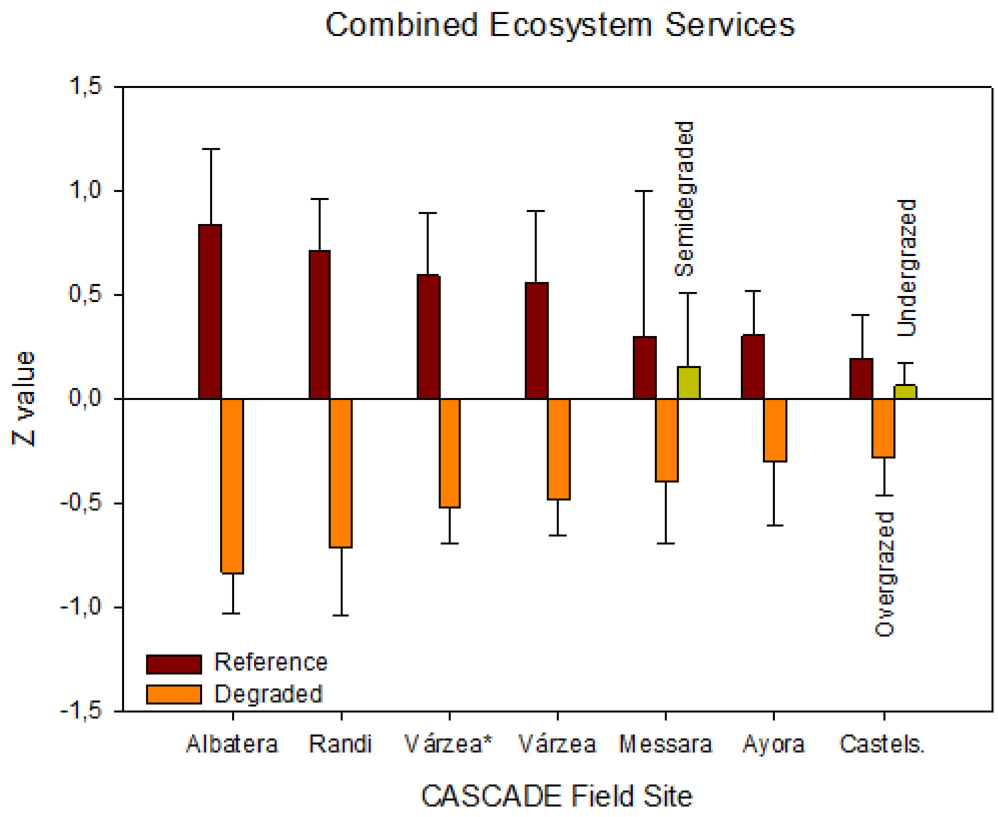


Figure 4: Summary of the loss of standardized ecosystem services due to the local degradation pressure in all CASCADE field sites . Bars represent an average of all five environmental services evaluated. Várzea refers to the C sequestration service including estimated biomass of the overstory with bibliographic data.*

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. These result in an overall significant loss of ecosystem services (Figure 3). But this maritime pine forest ecosystem 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. Pine regeneration after fire, and hence catastrophic shifts, 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. 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 and is likely to occur in the very high fire recurrence of the Degraded plots in Várzea. 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. This imbalance between fire regime and dominant plant species' life histories or unfavourable post-fire conditions may result in a failure to recover pre-fire carbon stocks and hence C sequestration service. 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).

Albatera showed the highest relative losses of all individual ecosystem services of all CASCADE field sites (Fig. 4). It is the most stressed site as reflected by the very low aridity index (0.16; Table 1) and multiple diffuse pressures that 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) that finally determine the conservation of resources. 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).

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). The stability index showed the lowest loss in the Degraded as compared to the Reference state. Previous works in semiarid Mediterranean areas have shown 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). 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 passed a threshold of irreversibility.

Ecosystem services have shown important losses due to grazing in the order Randi > Messara > Castelsaraceno (Fig. 4) following a decreasing order of aridity. 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 around this threshold (Table 1).

Discussion and Conclusions Q1

Results showed that 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. Sudden ecosystem shifts in Mediterranean ecosystems are therefore transitions that result in decreased plant cover and diversity, accompanied by increased loss of resources and reduced delivery of ecosystem services.

5 Q2 Ecological mechanisms underlying catastrophic shifts (WHAT PROCESSES HAPPEN IN THE SOIL AND PLANTS DURING A SHIFT?)

Introduction Q2

In the case of dry Mediterranean ecosystems, one key mechanism is the interplay between plant-plant interactions at small and large spatial scale. At small spatial scales, local facilitation occurs when neighbouring plants “help” each other, by means of shading, the improvement of local soil quality through the build-up of soil organic matter, and/or the conservation and acquisition of water and nutrients. At large spatial scales, the plants compete for the same limited resources which constrain the growth of the population. This effect is especially pronounced under relatively harsh environmental conditions, where the contrast between bare ground and the ameliorated conditions in the direct vicinity of a plant is strongest, and were the overall scarcity of resources drives global competition. Facilitation is exerted through multiple mechanisms that, in general, imply improved soil conditions underneath and near plant patches, particularly higher water infiltration capacity (Mayor et al., 2009) and nutrient cycling (Mayor et al., 2016).

The interplay between local facilitation and global competition results in vegetation forming patterns, as plants in a patch with other plants will be better able to survive harsh conditions than alone (facilitation) while, at the same time, patches compete with each other (competition). Patterns that result from facilitation and competition can take several forms, for example gaps of bare soil surrounded by vegetation and labyrinths of vegetation and bare soil (Rietkerk et al., 2004). With decreasing overall vegetation cover, the occurrence of a catastrophic shift becomes more likely (Rietkerk et al., 2004).

Furthermore, while passing the critical threshold means that, even together, plants are not able anymore to survive, recovery through the establishment of single plants will require higher levels of resource availability, precisely due to the absence of facilitation, at least during the initial stage of re-establishment. For this reason, the avoidance of catastrophic shifts is to be preferred over rehabilitation as recovery can be ecologically difficult and economically expensive.

To understand ecosystem behaviour under stress, not only interaction between plants and plant species, but also interaction between plants and their direct environment, including soils, are important. A number of research efforts have tried to predict ecosystem shifts, using plant and soil indicators. The focus of the indicators has varied depending on the site study and main variable.

Kéfi et al. (2007) analysed spatial vegetation patterns in terms of the frequency distribution of vegetation patch sizes in three arid Mediterranean ecosystems in Spain, Greece and Morocco. They showed that the patch-size distributions away from tipping points follow a power law, while those approaching a tipping point deviate from a power-law distribution. These deviations correspond to a disproportionate high frequency of relatively small vegetation patches. The mechanism behind this is that the patches shrink to the minimum size at which they can survive through facilitation. In this way, spatial vegetation patterning can serve as an early-warning signal for the proximity of tipping points and unwanted, sudden catastrophic shifts.

CASCADE results Q2

Stress-level experiment

At four CASCADE sites, we assessed changes in soil quality and plant performance as a function of a grazing-stress gradient, with the aim to identify possible functional thresholds controlling critical shifts in the soil-plant systems.

In the Castelsaraceno and Santomera sites, soil quality parameters did not vary significantly between grazing-stress levels. These two sites represented the wettest and the driest CASCADE sites, respectively, and were subjected to grazing pressures that were, overall, low to moderate. These relatively low grazing intensities were the most plausible cause for the lack of effect of the stress gradient in both sites. A possible explanation for this lack of grazing impacts in these two sites might involve an interactive effect of climatic conditions, with the role of grazing being reduced under the most extreme, driest as well as wettest experimental conditions. The relative wet climate of Castelsaraceno, together with its high vegetation cover, might make its soil-plant system robust enough to deal with the current grazing levels. In the case of Santomera with its very dry conditions and reduced overall vegetation cover, one might expect that soil conditions are mainly affected by water availability, being the limiting factor for vegetation cover and growth and, ultimately, soil quality. Conversely, the remaining two sites, Messara and Randi, showed noticeable effects of grazing-stress levels on several of the measured soil quality indicators. At the same time, however, no clear pattern emerged as to how grazing-stress levels were linked to threshold values of soil quality indicators. However, overgrazing generally reduces the vegetation cover, which increases soil erosion and leads to a reduction in soil fertility and thus productivity. CASCADE studies have shown that if surface cover falls below 30-40%, soil erosion increases sharply because of the high connectivity of bare patches (Mayor et al 2016).

The comparison of the soil quality indicators of vegetation patches and inter-patches provided more consistent information. Topsoil organic matter and nutrient contents were clearly higher in vegetation patches than in inter-patches in two of the three study sites where the vegetation revealed a well-defined patchy pattern, i.e. in Santomera and Randi as opposed to in Messara.

The effects of the different grazing-stress levels on the performance of the targeted plant species differed markedly between the four study sites. In Santomera, canopy cover and basal twig diameter of Anthyllis cytisoides did not vary noticeably with grazing-stress level, although there was a tendency for twig growth to be higher at the high-stress plots, probably due to compensatory growth. In Randi, canopy cover and branch basal diameter of Calicotome villosa showed higher values for the low and intermediate stress levels than for the high stress level. In Castelsaraceno and Messara, neither plant cover nor biomass of the two target species Brachypodium rupestre and Hyparrhenia hirta, respectively, showed clear differences among the three grazing-stress levels.

A possible explanation for these findings follows a similar kind of reasoning as presented earlier, on the observed effects on soil quality. Grazing impacts are reduced not only in marginal ecosystems that are essentially controlled by lack of water availability (Santomera) but also in productive ecosystems without lack of water availability and high vegetation cover (Castelsaraceno), except perhaps if grazing pressures become much higher than at present. From the two sites with less extreme conditions Messara showed a noticeable impact of grazing-stress level on soil quality but not on plant performance, while Randi revealed a consistent grazing effect on both soil quality and plant performance.

Stress experiment

No consistent effects of the enhanced drought periods on the measured indicators of soil quality and plant performance were found. For the driest sites, Randi and Santomera, we found increased nutrient availability and, to a lesser extent, higher carbon contents with increased drought stress. This is probably due to an increased amount of litter and dead roots being degraded (López-Poma and Bautista, 2014). Similarly, for Randi and Santomera we found a decreasing trend in plant performance with increasing drought stress, but not for the other two sites. These results indicate an extraordinary capacity of the plant-soil systems of these very dry areas to cope with drought, as only the combined effect of a severe natural drought plus the additional experimentally-induced drought finally produced a decrease in plant performance.

Plant pattern experiments

Our findings (Bautista et al 2015) have demonstrated that both plant cover and plant pattern exert a critical role in controlling water and soil conservation in patchy ecosystems. This role mainly relies on the sink capacity of the soils underneath the plant patches, rather than on the capacity of the patches for rainfall interception and physical obstruction to overland flow, but both these phenomenon enhance water storage below a plant patch. The connectivity of bare-soil emerged as the most critical pattern attribute for explaining the hydrological behaviour of patchy ecosystems, as it reflects and depends on both cover and pattern. Larger bare-soil connectivity implies larger water and sediment losses from semiarid slopes, but it also implies larger inter-patch areas, which is beneficial for the performance of the downslope patch. Although plant cover and biomass are the most common vegetation properties used for hydrological modelling, our results suggest that other patch metrics like patch number and/or size distribution could be better hydrological indicators than patch cover. Integrated indexes based on capturing the connectivity of the bare-soil matrix in patchy ecosystems, such as Flow length index, have great potential as surrogates for the hydrologic functioning in semiarid landscapes. These indices can be easily obtained from aerial photographs and incorporated into hydrologic and erosion models at the hillslope and catchment scales.

Bautista et al (2017) showed that, at the patch scale, the effect of patch diversity and size on plant performance depended on the plant functional types considered and the environmental conditions, yet some common pattern was found for a large variety of dryland species tested.

At early stages of the restoration trajectory (first 1-2 years after planting), with all plant seedlings sharing similar rooting space, there was no evidence of complementarity between species that may have resulted in higher productivity in multispecies patches as compared with monospecific patches. However, there was no evidence either of detrimental effects of interspecific competition, as compared with intraspecific competition in monospecific patches. Big diverse patches benefited better from the higher capacity for trapping water and other resources from runoff than big monospecific patches. Under stressful conditions, facing both intra-specific and interspecific competition within the plant patch is more challenging for the species than interacting only with conspecific individuals.

Figure 5: Global plant survival (all species together) in plant patches as a function of patch size (number of individuals in the patch; 1, 2, 4 or 8) and diversity (number of the species; 1, 2, 4 or 8). Labels in X axis represent the patch treatments, with first number representing the number of individuals and second number representing the number of species. Number of functional groups for treatments 1_1 and 2_2 is one, while for the rest of treatments number of functional groups is four. Bars represent mean values and standard error from replicated plots.

Compared with patches with a single plant, individual biomass was not significantly reduced by increasing the number of accompanying species in the same patch (figure 5). Increasing patch size and diversity may reduce to some extent the probability of sapling survival in the restored patch. However, in general, the reduction in survival with increasing diversity is minor suggesting a positive net outcome from the trade-off between a relatively low risk of decreasing survival and the benefits derived from increasing diversity. Functional diversity did not appear to be more relevant than species diversity for plant patch performance at early stages of the restoration trajectory.

At the community scale, low initial plant cover did not constrain the potential for restoration success, which could be explained by the positive effect of water and sediment transfer from large bare soil areas to few existent plant patches. Our findings have demonstrated that eco-hydrological feedbacks between resource redistribution and vegetation dynamics that are mediated by bare-soil connectivity exert an important role in modulating the restoration potential of dryland ecosystems. Larger bare-soil connectivity implies larger water and sediment losses from semiarid slopes, but it also implies larger inter-patch areas and associated larger run-on inputs to existent plant patches, which is beneficial for the performance of the vegetation in the patch. This local feedback, if strong enough, increases the range of conditions (external stress, minimum initial cover) that allow the recovery of the system.

From an applied perspective, in a context of dryland restoration, a number of recommendations can be derived from our results, including (1) using (creating) multispecies big patches, yet minimizing intraspecific competition by reducing the number of individuals per species within the same patch; (2) spatially arranging plant patches on slopes in a way that maximizes the capture of runoff water by plant patches; (3) combining species in the plant patches with plant traits that maximize the capture and deep infiltration of runoff water.

Modelling

All the models developed in CASCADE confirm the importance of positive feedbacks in driving the emergence of catastrophic responses at the ecosystem scale as a response to increasing stress. We showed that incorporating a realistic aspect of grazing, which is that grazers tend to eat more at the borders of vegetation patches in a patchy landscape, decreased dryland resilience by increasing the size and the probability of catastrophic shifts under increasing stress (drought or grazing intensity) (Schneider & Kéfi 2016). We also found that incorporating a feedback between fire occurrence and vegetation composition promoted, in combination with drought, the emergence of alternative stable states and therefore of possible catastrophic transitions between those states (Baudena et al. In preparation). The connectivity-mediated feedback (i.e. the feedback between vegetation pattern, resource redistribution and productivity) decreased the amount of pressure required to cause a critical shift to a degraded state (Mayor et al. 2013). Not including these feedbacks into dryland ecological models may lead to an overestimation of ecosystem resilience and therefore failures in the prediction of catastrophic shifts.

Furthermore, the model results suggest that the upcoming climate change predicted for Mediterranean drylands, and in particular the rainfall patterns, could induce and enhance the occurrence of catastrophic shifts in those ecosystems.

The fire models suggest that the oak forests are very resilient and that in this case, catastrophic shifts may actually be less common than previously thought (Baudena et al. In preparation; Vasques et al. In preparation) (although alternative states emerge when a positive feedback between vegetation composition and fire occurrence is introduced in the model ; Baudena et al. In preparation).

The models developed contribute to the fundamental understanding of what determines the species composition of a given dryland and how that drivers the response of the ecosystem to increasing stress, in particular: why and how alternative stable states, and therefore catastrophic shifts, occur in drylands. This fundamental understanding provides some keys for 1) preventing dryland degradation and 2) restoring degraded ecosystems (see section 5).

The grazing model (Schneider & Kéfi 2016) suggests that vegetation patterns provide early warning signals of approaching desertification (i.e. the spatial structure itself). However, spatially heterogeneous grazing does not only altered ecosystem stability (by increasing the probability of catastrophic shift) but could also blur the early warning signals at high grazing pressure. This suggests that we need to be cautious regarding the use of early warning signals of ecosystem degradation when the pressure at play has a spatially-explicit component. It also suggests that additional indicators of degradation need to be developed taking into account the spatial component of the stressor.

Furthermore, model simulations suggest that using a bare-soil connectivity index (Flow length; Mayor et al. 2013), in addition to vegetation cover and pattern, may provide more informative early-warning indicators of dryland degradation. Mayor et al. (2013) concluded that bare-soil connectivity and vegetation patterns both form important early-warning indicators for dryland degradation, Verwijmeren et al. (2014) found that the aspect of hillslopes has the largest influence on vegetation cover and soil functioning, furthermore they found species association strength to be an important factor at both species pair level and community level for maintaining ecosystem functioning. Tirabassi et al. (2014) found that certain vegetation pattern metrics may offer possibilities in identifying an upcoming critical transition in semi-arid ecosystems. They also introduced new measures to assess the quality of these indicators, and found new early warning measures to be of higher quality than classical indicators. Mayor et al. (2016), researched the quantity and quality of soil organic matter in forest areas with different fire frequency regimes, and found that a year after a fire, the amount of soil organic matter increased, while its quality was lower (expressed as the ratio of labile and total organic) and areas undergoing repeated fires decreased their likelihood of recovery due to the high loss in resources. The researchers concluded that the labile organic matter fractions in the soil might be used as an early-warning indicator for shifts in soil fertility in response to fire recurrence.

Eventually, quantifying those indicators derived from model studies on field data may help identify field sites that are at the higher risk of irreversible degradation and prioritize those for conservation measures.

For a given ecosystem studied, the models developed allow reaching a better understanding of how different interactions and drivers control the composition of dryland communities and their changes through time. Such a knowledge can be extremely useful in terms of management, e.g. to foster one given community over another (or to prevent being trapped in an undesired community). For example, the model results underline the importance of the practice of planting seedlings from late successional, resprouting species to increase the resistance and resilience to forest fires (Valdecantos et al 2016). The modelling approach reinforces such practices as it underlines the importance and the resilience of late successional resprouter species on the time scale of a few generations of these plants, which is well beyond human observation.

Moreover, the essential role of facilitation for both species coexistence and ecosystem resilience highlighted by the models suggests that it may provide a good opportunity for ecosystem restoration. In a degraded dryland, remaining adults individuals can be used as nurses to increase the recruitment probability of seedlings planted below or close to their canopies. In degraded grazed drylands, the same strategy can be applied using preferentially nurse species adapted against grazing, to improve the early survival of the planted seedlings.

Discussion and conclusions Q2

Most of the empirical results obtained by CASCADE showed that increased stress through grazing (stress-gradient experiment) or drought (drought-experiment) deteriorated the plant-soil ecosystem, probably moving it to critical points for catastrophic shifts to happen. Since we did not actually observe such a catastrophic shift taking place in any manipulative rainfall-exclusion experiments, we cannot say where these tipping points lie. However, in the case of the Randi site on Cyprus, the increasing contrast in soil conditions between patches and inter-patches with increasing level of grazing pressure pointed to the proximity of a critical shift into a degraded state. Results also indicated positive feed-backs and local facilitation, as most of the statistically significant differences in soil quality and plant performance corresponded to better values for vegetation patches than for inter-patches. These results suggests that shifts would involve changes in both vegetation and soil, and that indicators reflecting both vegetation pattern and soil quality could provide early warning signals of shifts. Understanding of plant-soil and plant-plant interactions is also crucial to understand shifts in Mediterranean dryland ecosystems. Such understanding can improve predictions of shifts, but can also be used to increase the chance of success of restoration efforts.

This kind of summary/synthesis is vital. I wonder in the next draft if we need to start with the key findings (increased stress through grazing and drought caused ecosystem deterioration, moving it towards tipping points) and then draw out aspects from each of the experiments to exemplify that. What do you think? It should work if much of the theory comes earlier on in the paper.

6 Q3 HOW CAN WE MANAGE VULNERABLE ECOSYSTEMS BETTER?

Introduction Q3

Whether an ecosystem moves towards a shift is determined by its ecological dynamics in interaction with the management of the land. The previous sections of this paper have shown how we can assess ecosystem shifts and which soil characteristics and plant processes facilitate or prevent such shifts. When it comes to the question on how to change the management in order to prevent a shift, mitigate or rehabilitate land degradation, we thus need to understand this interaction of management and ecology. The social-ecological systems and their spatial and temporal dynamics determine the demand for ecosystem services, which again determine how the land is managed. This requires the integration of users' perspectives. In CASCADE, stakeholders such as land users, land planners and policy makers were engaged in the research right from the beginning in order to better understand how vulnerable ecosystems can be managed. Although generalizing impacts of land management remains challenging, as practices can be extremely diverse depending on the area, actors and timing (Schwilch et al. 2014), with CASCADE we were able to advance by elaborating some principles for three typical Mediterranean dryland drivers of degradation: forest fire, overgrazing and land abandonment.

CASCADE work Q3 (- forest fire context)

Almost all the practices assessed (Table 2) have an overall positive impact on the resilience of the land management systems in which they are implemented. However, three quarters have at least some negative impacts (Jucker et al – under review). In general, the higher the number of disturbances affecting a system, the less positive the contribution of land management practices to resilience. With the exception of the clearing of fire-prone species in Ayora, no other technology has an all-round positive effect. Thus, combining different land management practices appears to be the best strategy to consistently increase resilience against all disturbances.

Table 2: Land management practices identified in the study sites grouped by type of intervention.

Type of land management	Land management practice	Study site
Clearing of vegetation	Post-fire conservation logging	Várzea
	Post-fire traditional logging	Várzea
	Selective forest clearing	Ayora
	Cleared strip network system (firebreaks)	Ayora
	Clearing of fire-prone seeder species.	Ayora
Grazing management	Metallic fences to regulate grazing	Castelsaraceno
	Controlled grazing in spring months	Messara
Planting of shrubs	Plantation of semiarid woody species with micro-catchments	Albatera
	Spatially diverse plantation of diverse semiarid woody species	Albatera
	Plantation of semiarid woody species on terraces	Albatera
	Planting of resprouter shrubs and trees	Ayora
Planting of trees	Afforestation with Pinus halepensis after fire	Ayora
	Grazing land afforestation with carob trees	Messara
	Planting carob and olive trees to prevent erosion	Randi
Other	Carob-tree protection from rats	Randi forest
	Fodder provision to animals during summer	Randi forest

Table 3: Scenarios of adaptive land management.

Management scenario		Description	Start conditions	
			Degraded sites	Restored sites
Baseline scenario	Least risk aversion	If vegetation cover smaller 30% → reduce number of animals grazed on pasture to half	X	X
Scenario 1 (S1)	Higher risk aversion	If vegetation cover smaller 40% → reduce number of animals grazed on pasture to half	X	X
Scenario 2 (S2)	Resting in wet years and extreme risk aversion	In wet years and if vegetation cover smaller 60% → reduce number of animals grazed on pasture to half	---	X

Forest fire context

Our results stress the importance of preventive actions before a fire event (Jucker et al 2016). Among the land management practices that can be implemented before the fire, fuel management appeared to increase forest resilience the most. Fuel management means minimizing fuel load and connectivity in order to reduce fire risk (e.g. by reducing highly flammable biomass and creating bare strips). Management of forest regeneration (after fire) and reforestations should promote a low density, spatially differentiated and species-diverse canopy, which also reduces outbreaks of pests. While forest regeneration from seed banks is only possible with long time intervals between fires, regeneration from resprouting individuals fosters a quick recovery, especially under beneficial conditions such as north-facing and rather gentle slopes (Jucker et al. 2016). CASCADE studies have also highlighted that establishing a vegetation cover immediately after fire has an important role in preventing soil erosion and thus retaining nutrients and maintaining soil fertility (Mayor et al 2016). Mulching has been shown to be an effective practice to prevent soil erosion when there is lack of spontaneous cover, also in fire breaks. To control the fuel load and the risk of spreading pests and diseases, a vegetation cover of 50-60% has been shown to be most effective.

In Várzea, restoration actions (post-fire logging) improved ecosystem services at the very short term (< 2 years) after their implementation although the dynamics of the plant communities were slowed down, probably due to the impact of the heavy machinery on the earliest regenerated plants. In Ayora, where the ecosystem service assessment was conducted more than ten years after the application of restoration actions, positive impacts on most properties and services were observed, especially on biodiversity and fire risk reduction. Only C sequestration was negatively affected by restoration as actions included the removal of seeder fire-prone vegetation and hence the aboveground biomass.

Overgrazing context

Promising management practices to control vegetation cover include rotational grazing, fodder provision and area closure. In Randi and in the overgrazed state in Castelsaraceno we observed a general improvement of ecosystem services by grazing exclusion, especially in Randi where plant cover, litter accumulation and aboveground biomass recovered to similar levels found in the undisturbed reference areas. However, grazing exclusion, if economically possible at all, can also lead to shrub encroachment, increased fire hazard and reduced fodder value, as found in Castelsaraceno, implying that management during recovery is necessary.

Restoration in Messara aimed to transform land use from grazing to carob tree orchards as a silvo-pastoral system rather than to recover the pre-disturbance state of the ecosystem. This practice has proved to provide multiple benefits such as additional fodder and shade for animals, decreased soil erosion, improved soil fertility and additional income through olive and carob products. The grazing systems in Randi and Castelsaraceno are affected by animal pests (rats, boars), which are mitigated by short term management options like tree protection and pasture fencing, but would require an integrated ecosystem approach to promote natural predators. Another problem is pasture degradation by more perennial, invasive and/or unpalatable species or thorny shrubs, influenced by grazing intensity, animal types and herd composition. Beside diversifying herds, options include manuring pastures, seeding fodder species and mechanically removing thorny shrubs. Controlled grazing as well as avoiding abandonment also reduces risk of fires. Once a fire has occurred on grazing land, it is important to allow a minimum of 2 years for resting (while providing supplementary fodder) or actively revegetate, in order to prevent a regime shift. Remaining plant individuals can be used as nurses to increase the recruitment of seedlings planted below.

Land abandonment context

In the Mediterranean, land abandonment is widespread. Land management options for abandoned land include revegetation, rotational grazing or alternative uses of land, such as bee-keeping, biodiversity management, tourism or wind / solar energy production. It also needs to be considered that land, which is not used economically at present, can become valuable in future and thus knowledge and infrastructure might need to be maintained. Cooperation and new forms of management (e.g. silvi-culture) help to overcome labour availability constraints.

Act in time: Guiding land managers and policy implications

Looking at stakeholders' perception of the past activities in response to regime changes, environmental management adaptation measures were the main interventions across all study sites (67% of measures across sites). Socio-political measures formed the next largest set of actions (15%) and consisted of improving land use and environmental management through cross-sector organization, advancing or creating policies for land use, and patrolling to prevent illegal practices. Under socio-economic measures, stakeholders mentioned economic support, subsidies, and migration.

By complementing the ecological assessment of the rangeland resilience model with insights on investment costs (e.g. costs to purchase supplementary fodder) and income through livestock production we assessed scenarios of adaptive land management representing varying levels of risk aversion and resting periods as a conservational strategy (Tab. 3). In this modelling approach, we distinguished degraded and restored starting conditions and particularly considered the emergence of windows of opportunities and risks to capture critical land management timings that realize ecological benefits at minimum risk and cost (Sietz et al. 2017). Our findings show that the socio-ecological effectiveness of these management scenarios differed largely according to windows of opportunities and risks, starting conditions and investment and capital costs (e.g. for supplementary fodder and hired labour). For example, the higher risk aversion and resting in wet years/extreme risk aversion scenarios (see S1 and S2; Tab. 3) implied a significant increase in the likelihood of maintaining a vegetation cover above 40%, though only at restored sites. Yet although the conservational scenario S2 effectively prevented degradation, the economic loss was greater (-370Euro/ha) than in S1 (-140Euro/ha). This indicated that policy incentives such as subsidies would be useful to increase land users' motivation to implement this type of management.

Besides scenario analysis, monitoring of key processes and adaptive management are essential for decision making and inherently linked to resilience thinking. In particular, increased response diversity is crucial to better manage critical dynamics and emerging opportunities and risks and thus build resilience to future socio-ecological disturbances. The variety of promising measures within the CASCADE study sites and the information about their sustainability and resilience was used as the basis for guiding natural resource managers in improving the management of dryland ecosystems, in particular with regards to preventing disturbances, mitigating their negative impact and ensuring recovery. With this, land management takes an important role in avoiding ecosystem shifts to degraded states. Three booklets on the three above-mentioned prevailing Mediterranean dryland drivers were produced (see Schwilch et al, 2016). Each booklet has a number of ecological principles and related land management recommendations, each taking into account that ecosystems are also affected by the occurrence of droughts, as the impact of the driver may vary depending on drought conditions.

Decision making regarding SLM and the prioritization of measures requires stakeholder engagement at every stage of the process, as stakeholders have diverse views and hold different priorities. Stakeholders recognize the benefits of strong law enforcement and decision making in SLM, however, different stakeholders mentioned diverse levels of autonomy and state intervention as being desirable. Measures for fire prevention and environmental conservation need to consider short term and long-term consequences for land users, to avoid disengagement and land abandonment. Incentives and strategies to prevent land abandonment need to be in place in order to develop a comprehensive strategy that includes social, cultural and economic considerations. Particular factors that need to be considered include the re-valorisation of rural practices, incentives and support to new generations in the form of education and financing, and the formation of cooperatives and other communal efforts.

Discussion and conclusions Q3

The management of vulnerable ecosystems is a challenging task. This includes maintaining or enhancing the natural resource base as well as sustaining productivity. It requires the maintenance and restoration of vital ecosystem components that provide resilience to climate change, disasters and other threats and risks. In this way, sudden shifts might be prevented. Cost-effective management interventions, acceptable to stakeholders, should thus be applied before thresholds are reached, or when windows of opportunity occur. By considering investment costs together with expected benefits and windows of opportunities and risks, CASCADE findings advance our understanding of socio-ecological determinants of specific land use strategies (Sietz and Van Dijk, 2015) and the evaluation of threshold behaviour. These insights can facilitate land-based management decisions aimed at addressing heterogeneity in global sustainability challenges such as loss of biosphere integrity, livelihood insecurity and vulnerability.

CASCADE provided two key lessons for managing vulnerable ecosystems in cost-effective and efficient ways. These are a) the need for reliably predicting windows of opportunities and risks linked with SLM and restoration advice tailored to land users' needs and b) managerial flexibility enabling continuous and rapid adaptation of management decisions according to emerging opportunities or risks. Interventions should include bundles of different practices used in combination to both mitigate the pressure and reduce vulnerability, and be supported by policy. Only if we manage to effectively **avoid** ecosystem shifts, **reduce** land degradation and **reverse** the negative consequences of both, we will be able to contribute to a land degradation neutral world and as such to SDG 15.3.

7 Discussion and conclusions

This text, in earlier sections, answered the questions 'what are sudden ecosystem shifts in Mediterranean drylands?', 'what processes happen in the soil and plants during such shifts', and 'how can we manage such ecosystems better'. In combination, these answers show that there is degradation in the studied Mediterranean ecosystems, and there are indications that sudden ecosystem shifts occur in these ecosystems, but that hard proof cannot be gathered within a research project of just a few years. Observed changes in vegetation diversity, vegetation composition and soil quality suggest that a point may be reached where ecosystems are no longer able to provide services as they are doing now. Or as they could. Monitoring and modelling provided hints as to which changes in the plant-soil and plant-plant systems might occur during shifts. Some field experiments would benefit from observations over a greater number of seasons, but advances in modelling allowed us to examine the ecosystems, and discover ways to avoid catastrophic shifts, how to make ecosystems more resilient, and how land users could respond to shifts that have already taken place. An understanding of what happens during shifts can thus help define appropriate management strategies that can prevent the occurrence of shifts, or if they have already occurred, can assist in recovery of the ecosystem. Predictions of the proximity of CASCADE's dryland ecosystems to thresholds may be used by policymakers and land users to inform more sustainable management of Mediterranean drylands worldwide, in order to avoid catastrophic.

References to CASCADE papers.

BAUTISTA, S. & LAMB, D. 2013. Ecosystem Services. Encyclopaedia of Environmental Management. DOI: 10.1081/E-EEM-120046612 ed.

BAUTISTA, S. & MAYOR, Á. G. 2010. II. Ground-based Methods and Indicators for the Biophysical Assessment of Desertification Prevention and Restoration Actions. *Deliverable D2. 1 Working papers on Assessment Methods*, 41.

BOESCHOTEN, M. J. C. 2013. *The impact of land degradation on two contrasting dryland ecosystems and the ecosystem services they provide and their potentials for restoration.* Thesis. University of Utrecht.

JUCKER M, LINIGER HP, VALDECANTOS A, SCHWILCH G. 2016. Impacts of land management on the resilience of Mediterranean dry forests to fire. Sustainability 8, 981.

KÉFI, S., RIETKERK, M., ALADOS, C. L., PUEYO, Y., PAPANASTASIS, V. P., ELAICH, A. & DE RUITER, P. C. 2007. Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. *Nature,* 449**,** 213-217.

MAYOR, Á. G. & BAUTISTA, S. 2012. Multi-scale evaluation of soil functional indicators for the assessment of water and soil retention in Mediterranean semiarid landscapes. *Ecological Indicators,* 20**,** 332-336.

MAYOR, Á. G., BAUTISTA, S. & BELLOT, J. 2009. Factors and interactions controlling infiltration, runoff, and soil loss at the microscale in a patchy Mediterranean semiarid landscape. *Earth Surface Processes and Landforms,* 34**,** 1702-1711.

MAYOR, A. G., KÉFI, S., BAUTISTA, S., RODRÍGUEZ, F., CARTENÍ, F. & RIETKERK, M. 2013. Feedbacks between vegetation pattern and resource loss dramatically decrease ecosystem resilience and restoration potential in a simple dryland model. *Landscape ecology,* 28**,** 931-942.

MAYOR, A. G., VALDECANTOS, A., VALLEJO, V., KEIZER, J., BLOEM, J., BAEZA, J., GONZÁLEZ-PELAYO, O., MACHADO, A. & DE RUITER, P. 2016. Fire-induced pine woodland to shrubland transitions in Southern Europe may promote shifts in soil fertility. *Science of The Total Environment,* 573**,** 1232-1241.

SCHWILCH, G., LINIGER, H., AND HURNI, H. 2014. Sustainable land management (SLM) practices in drylands: how do they address desertification threats?, Environ. Manage., 54, 983–1004.

SIETZ, DIANA & DIJK, HAN. 2015. Land-based adaptation to global change: What drives soil and water conservation in western Africa?. Global Environmental Change. 33. 131-141. 10.1016/j.gloenvcha.2015.05.001.

VERWIJMEREN, M., RIETKERK, M., BAUTISTA, S., MAYOR, A. G., WASSEN, M. J. & SMIT, C. 2014. Drought and grazing combined: contrasting shifts in plant interactions at species pair and community level. *Journal of Arid Environments,* 111**,** 53-60.

1.4 Potential impact

The CASCADE project has contributed to answering the many questions that exist regarding tipping points in ecosystems. Although the topic is complex and it will take some time before all the problems surrounding tipping points in ecosystems are understood, the project has brought the understanding of degradation of dryland ecosystems and its restoration a step closer. We have worked on a number of fundamental issues, both in the field with experimental plots, and from behind the desk with computer models. Also we have worked intensively with stakeholders and policymakers in all study sites and tried to figure out how dryland ecosystems can be managed better, and how this improved management can be embedded into policy. We have made use of this knowledge in socio-economic modelling in an attempt to optimize the outcomes and make managing drylands as efficient and thereby as attractive as possible. We have produced leaflets for dryland managers as guidelines bringing all this information together and making it available to the people who work with the land. The three main points of expected impacts, as written in the project proposal of the CASCADE project, were knowledge impact, community impact and policy impact. These three point, and a number of detailed sub-topics, are described in Table 2.

To achieve impact, dissemination is of crucial importance. Therefore, dissemination activities were started early in the project, and have been continued throughout its lifetime, and will continue even after the end of the project.

CASCADiS, the projects dissemination website, is the main source of information coming from the project. We have organised all results from the project on this website in separate sections. An overview of the various sections and their content is given in the table below.

Table 4 Different sections and their content of CASCADiS, the dissemination website of the project.

Sections	**Subsections and content sources**
Key messages Booklets, factsheets and video clips provide information about drylands, ecosystem shifts and the management of vulnerable ecosystems in succinct and easy to read formats.	**Animation**. What is a tipping point? An animation explaining what a tipping points is, using an example of a semi-arid grazing ecosystem. **Video clips** to explain how science is being used to increase our understanding of ecosystem shifts in drylands. **Posters, factsheets and longer booklets** written in non-scientific language of interest to a wide range of stakeholder audiences, from policy makers to school children. **Newsletters** highlighting and illustrating the research being done to understand ecosystem shifts at particular CASCADE study sites.
Study sites CASCADE has investigated six areas (or study sites) in southern Europe where ecosystem shifts have occurred or are likely to occur, with associated consequences for the vegetation, the animals, and the people living there.	D2.1 Study site descriptions D2.2 Drivers of change in the study sites D5.1 Structural and functional changes D8.1 Adaptation strategies for changing conditions D3.1 Critical changes preceding a catastrophic shift D5.2 Restoration potential for preventing and reversing regime shifts D8.3 Stakeholder workshop to evaluate SLM guidelines
What are sudden ecosystem shifts? Like other ecosystems, under certain pressures dryland ecosystems can suddenly shift to a new state	**D2.2 Drivers of change in the study sites:** Natural and human induced drivers of change are analysed in each of the CASCADE study sites. The impact of such changes on potential sudden ecosystem shifts are described in terms of a

characterised by a different structure, species composition and/or functioning. Once an ecosystem has shifted, it is not likely to return to its previous state.	common unifying framework into which instability observed can be fitted. Climate is a governing driver for all Study Sites and land use, land cover, production, consumption and disposal drive the relationship between social and ecological systems. **D5.1 Structural and functional changes associated with regime shifts:** Structural and functional changes in ecosystems affect the services that can be provided. This report details how those changes can be measured and gives results from the CASCADE study sites under pressures from grazing, fire and multiple, diffuse causes. **D7.1 Documented and evaluated natural resource management practices:** Descriptions of the 20 sustainable land management technologies and 3 approaches already in use in the study sites at the start of CASCADE. **D8.1 Adaptation strategies of local land users:** In participatory workshops, stakeholders identified changes in environmental conditions that they have experienced over the last 20 years and discussed how they have adapted to them. They also described the kind of changes they expect to witness in the future and how they might to cope with them too.
What processes happen in the soil and plants during a shift? The key to understanding when and how sudden ecosystem shifts occur lies in knowledge of the detailed processes operating between plants, soil and water.	**D3.1 Critical changes preceding catastrophic shifts:** Observational and manipulative field experiments to investigate changes in the plant-soil system in response to external stress, focussing on stress caused by increasing wild fire recurrence, grazing intensity and severe drought. **D4.1 Potential for sudden shifts in ecosystems:** In order to disentangle the various components of the eco-hydrological feedbacks that relate plant pattern, resource availability and productivity in drylands, as well as the independent role of critical factors that control these feedbacks, CASCADE performed manipulative experiments combined with field observations. **D4.2 The role of increasing environmental pressure in triggering sudden shifts:** Report on manipulative field experiments to assess the occurrence of non-linear, threshold dynamics and tipping points towards a degraded state in response to decreasing plant cover and to gain insights about the mechanisms underlying such dynamics. **D4.3 Dryland restoration dynamics and thresholds as a function of plant pattern and diversity:** Report on the use of manipulative field experiments and modelling to examine the role of patch, size, diversity, spatial pattern and eco-hydrological feedbacks in dryland restoration and degradation reversal. **D6.1 Simulated pressures and ecosystem responses:** Models developed in CASCADE focused on two axes of improvement of current dryland models relevant to studying dryland resilience. Firstly on the way external pressures are incorporated in dryland models (in particular on grazing, fire

	and drought) and secondly on the way vegetation is modelled (incorporating species, functional groups and species-species interactions).
How can we manage vulnerable ecosystems better? Sustainable management of drylands involves recognising signs of impending shifts and adapting land use practices to prevent or mitigate them.	**D6.2 Indicators of critical thresholds:** A tool box of generic early warning indicators to improve degradation monitoring in drylands and thereby help set up effective strategies to prevent desertification before its onset. **D5.2 Restoration potential for preventing and reversing regime shifts:** Different restoration approaches are needed according to the degree of degradation of a site, but little is known about the relationship between the restoration potential and the accumulated loss of ecosystem services. This report focuses on the assessment of some important ecosystem services in CASCADE's degraded and and restored study sites in order to determine their restoration potential. **D7.2 A method for resilience assessment:** The resilience assessment tool is designed to be applicable on a variety of socio-ecological systems, from mainly natural ones to those heavily modified by human activities. The assessment summarises and organises information to understand the resilience of the socio-ecological system at the scale at which management is implemented, highlighting strengths and weaknesses of the land management in coping with the disturbances that occur in the area. The tool's results give important descriptive information on the processes that could modify the socio-ecological system's resilience and the role of land management in it. **D7.3 Comprehensive guidelines for natural resource managers:** Practical guidelines for use by land managers in situations of land abandonment, forest fire and overgrazing. **D8.2 Socio-ecological effectiveness of land management:** The conceptualisation of the socio-ecological effectiveness of land management and a five-step approach to modelling it. **D8.3 Multi-scale evaluation with policy makers:** Feedback from stakeholders and policy makers about the sustainable land management guidelines, scenario analysis and key findings of the CASCADE project.

A separate description of some of the different dissemination efforts during the lifetime of the project are:

Videos: Short videos are increasingly being used on websites and social media to attract and engage audiences. They can also be useful tools for researchers as they seek to explain the issues they are working on and to present key results. CASCADE made 15 videos and a short film. The film was professionally directed and produced and gives an overview of the objectives and results of the project. The short videos were directed and produced by members of the consortium to introduce CASCADE's main research questions, modelling work and manipulative experiments. An animation describes one example of how a catastrophic shift might occur using a physical analogy. In recorded interviews with 2 people that attended the policy meeting, they describe the importance of CASCADEs results and how they might be used. The film and videos form an important part of the dissemination strategy for the project, have been shown at meetings and stakeholder workshops, and are available on the CASCADE and CASCADiS websites and on the special Vimeo channel https://vimeo.com/channels/drylandshifts .

Publications: Scientists of the CASCADE project were very active in disseminating their findings in scientific papers and speaking about their research on International conferences. A total of 47 publications in refereed journals have been produced by scientists of the project, while 7 are still being reviewed. A total of 22 presentations were given on international conferences, resulting in proceeding contributions. 3 book contributions were produced and a total of 10 oral presentations not resulting in a proceeding contribution were given. In total 4 MSc and/or PHd thesis have been produced within the project.

International arena: Dissemination at international scale took place among scientists through scientific publications, through dissemination to international policy makers, and through dissemination among the general public through the videos.

Policy forum: On Friday, February 24th 2017, the CASCADE Policy Forum was organized in Matera, Italy. The CASCADE Policy Forum was planned to provide discussions between researchers, stakeholders and policymakers at local, municipal, national, EU and UNCCD levels. What do stakeholders find most interesting about CASCADE? How far can CASCADE results contribute to policy making? The results fed into our Deliverable8.3 Report on multi-scale evaluation with policymakers. Various local policy makers were present from regional (Luca Braia, Donato Di Stefano) and national level (Angelica Saggese, member of Italian senate). Also a number of local and regional policy makers from the other partner countries Portugal, Spain, Crete and Cyprus were present. Representatives of UNCCD (Victor Castillo) and FAO (Sergio Zelaya) were present in the round-table discussion where a number of topics around dryland degradation and related problems were discussed. Results and a brief summary of the discussion can be found in Deliverable 8.3.

By combining the dissemination efforts described above, with the project results that were described in earlier sections of this report, CASCADE contributed to impact. The table below describes how the CASCADE contributed to achieve the three main impacts listed above: i) knowledge impact, ii) community impact, and iii) policy impact.

Table 5 Expected impact of the CASCADE project, according to the original impact goals.

Expected impact	**Project realization**	**Assumptions and external success factors / remarks**
Knowledge impact		
Developing theoretical and identifying empirical evidence of regulating mechanisms in dryland ecosystems	In analysing the field results, a number of important conclusions have been drawn and theoretical work has been brought further.	This work, is written down in scientific papers, and is thus available, for other scientists to build on.
Improved process descriptions of ecosystem behaviour accounting for regulating thresholds and sudden regime shifts	Various field experiments have led to increased knowledge and insight in ecosystem behaviour.	Scientific papers have published this knowledge and insights. These can be used to further improve knowledge.
Field evidence of anthropogenic and climate induced shifts in ecosystem state and behaviour	Field work has shown strong clues of shifts having happened using Landscape and Function Analysis (LFA) on ecosystem services.	LFA proved to be a valuable tool in assessing ecosystem behaviour and state, also when comparing different types of ecosystems, since it outputs a single Z-factor.

		Further work needs to be done in assessing the distance to a ecosystem shift.
Integrated modelling linking ecological and socio-economic aspects, combined with participatory information from stakeholders	Grazing and forest fire models have been integrated in socio-economic models in order to optimize management of drylands.	This technique is new and promising. However, further work on these models is necessary, as integrating biophysical and socio-economic models proved challenging.
Scientifically-based land use and management strategies to preserve or restore fragile European dryland systems	Information leaflets were produced for optimized land use and management for dryland areas. Workshops with land managers were organized to get their feedback and to optimize the leaflets with guidelines for optimized management that were produced	Willingness of local stakeholders for adaption and from local policymakers for support is needed for success.
Community Impact		
Developing early warning signals for sudden catastrophic shifts in a range of different dryland ecosystems	A number of potential early warning signals were found; • LFA analysis and Z-value derived from this analysis • Plant-patch patterns give a clue for oncoming ecosystem shift • Inter-patch soil carbon status might be an indicator for an ongoing ecosystem shift	Potential (new) indicators have been found, the validity of these indicators and their use still needs to be developed.
Development of land use and management strategies to preserve or restore biodiversity and ecosystem functioning and services	• A number of land management strategies have been developed and published into information leaflets. • Important findings in the field of co-facilitation of different plant species and spatial organisation.	• Willingness of local stakeholders for adoption and from local policymakers for support is needed for success. • Important findings in the field of restoration can immediately be used in current dryland restoration projects.
Assessing the timing of the measures with regards to their effectiveness towards preventing or reversing catastrophic shifts,	WP8 has successfully applied their socio-economic model to assess the most optimum ‘window of opportunity’ in	The developed technique is promising for further application. Willingness of local stakeholders for

their cost-benefit relations and their acceptability to dryland communities.	applying specific management techniques for optimal efficiency and timing. Information was taken along in information leaflets to land managers.	adaption and (financial) support from policy is necessary for successful implementation.
Policy Impact		
Multi-scale evaluation of scenario analyses with policy makers and land managers.	During the Policy Meeting, organised in the last project year, this topic was discussed. D8.3.	The CASCADE work needs to be taken up by policy makers and put into policy at various levels; international, national and regional. This is a very important key to success but at the same time the most unpredictable one.
Preparation of targeted policy briefs and policy recommendations following the identification of suitable entry points to inform policy.	Direct implementation of management principles into the Sustainable Development Goals and also into e.g. FAO's climate smart agriculture programme. That way, it can be included in the agendas of international policy makers and inform their paradigms and policies directly. See D8.3.	Willingness of these organisations to use CASCADE findings and promote them. Lobbying is necessary.
Specific contributions to achieving the aims of various international organisations (UNCCD, UNCBD, Millennium Development Goals)	Various people within the mentioned organisations are aware of the CASCADE work, and have been sent information during the course of the project.	Willingness of people working in these organisations to spread information and take up recommendations in their work. A number of people working in these organisations received CASCADE newsletters.

To summarize the work done in CASCADE;

1. CASCADE has found a number of indicators or systems to be promising tools for prediction ecosystem shifts. These indicators and systems still need to be fine-tuned.
2. Theoretical understanding and computer modelling has been greatly improved by the work done by CASCADE. A complete comprehension of these complex systems is, however, not yet accomplished and will require additional research.
3. Work on restoration of drylands has provided both theoretical and practical new insights in effectively restoring degraded drylands. These techniques can immediately be used in practice.
4. Together with stakeholders, management guidelines have been made to effectively and economically manage dryland ecosystems being threatened by overgrazing, fire and abandonment. These guidelines have been translated in a number of languages and can immediately be used by land users.

5. During the policy forum, important insights regarding policy making and dissemination of CASCADEs results were shared. To make use of findings in CASCADE effectively, these insights should be implemented (see D8.3).

In general, the CASCADE project has improved insights and knowledge about dryland ecosystems, their degradation and dryland ecosystem tipping points. The people in the project have done their best to disseminate this gained knowledge to the best of their ability, by using internet, scientific channels, video, public journals, etc. to a wide audience. For these results to be taken up and brought further into additional research, i.e. to really achieve impact, application and policymaking is now a task for the people who have taken notice of our work. We sincerely hope this work will be able to improve the quality of dryland ecosystems, prevent their degradation, and also help to sustain the lives of the people within these areas.

1.5 Project website information

CASCADE has two websites, namely the project website (http://www.cascade-project.eu/) and the CASCADIS (CASCADE Information System) website for dissemination (http://www.cascadis-project.eu).
The CASCADE website was established in period 1, and is an important medium to distribute information both within as outside of the project. Deliverable D1.1, that describes the project website, is available from period 1.

Within the project, the partners are being kept up-to-date with various management issues, and they can download information they need for their project work. For visitors outside of the project, the website is a source of information about the project purpose, its goals and the progress that is being made. Also, in the news section, visitors are being informed about relevant activities outside of CASCADE, related to Ecosystem Shifts. The CASCADE website is continuously kept up to date. The CASCADIS website has been established and is continuously being updated with project results as these become available.

What is CASCADE about?

One of the most challenging themes in ecology over the last decades is the quest for the understanding of discontinuous changes in ecosystems. Discontinuous shifts have already been observed and analyzed for a wide variety of ecological systems, including lakes, drylands, peatlands, rangelands, marine systems, and musselbeds.

Some of these discontinuous shifts in ecosystems imply undesired and irreversible changes. For example, shallow lakes can suddenly change into eutrophic systems with a large loss in biological diversity.

CASCADE will investigate and analyze a range of dryland ecosystems in southern Europe to obtain a better understanding of sudden shifts in drylands that may lead to major losses in biodiversity and concomitant ecosystem services.

Based on these analyses, CASCADE will develop ways to

CASCADE 2016 Newsletter issued

Published: Wednesday, 06 July 2016 14:17
Written by Erik van den Elsen

The latest version of the CASCADE newsletter has been issued today

The newsletter reports of a number of subjects and developments within the CASCADE project, amongst others it reports about the last plenary project meeting in Ispra, Italy and also about the progress that the project has made in Workpackage 3 (*Identification of critical changes preceding catastrophic shifts in ecosystems affected by increasing wildfire recurrence*), Workpackage 4 (*The potential for sudden shifts in dryland ecosystems*), Workpackage 5 (*Regime shifts in the CASCADE dryland sites*), Workpackage 7 (*Recommendations for management practices*), and contributions from other workpackages.

The Newsletter can be downloaded **HERE**.

Partner login

Username
elsen029
Password
••••••••
Remember Me ☐

- Forgot your password?
- Forgot your username?