CASCADE
Catastrophic shifts in drylands:
How can we prevent ecosystem degradation?

CASCADE REPORT series

A method for resilience assessment

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A method for resilience assessment

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1. Abstract

In this report we present the method for and results of the resilience assessment (named "Resilience Assessment Tool - RAT") that is the objective of task 7.2.

Based upon the information gathered through the inventory of land management practice (task 7.1), and extensive work in the field in contact with land users and other stakeholders, the RAT was designed to be applicable on a variety of socio-ecological systems, from mainly natural ones to those heavily modified by human activities. The objective of the assessment is to resume and organize important information to understand the resilience of socio-ecological system at the scale at which management is implemented, highlighting strength 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.

The first step of the evaluation centers on assessing how land users value the provision of ecosystem services and the state of the environment; this allows defining the healthy state of the socio-ecological systems in a participative way. Furthermore, scientific and local knowledge are combined to assess the possible evolution of the socio-ecological system and of the pressure sources that can degrade it, as well as the impact of shocks and disturbances on the socio-ecological system. Moreover, we analyze in detail the contribution of land management practices to the resilience of the socio-ecological systems, together with the resilience of land management practices themselves across time, space and in relation to different disturbances. We will present the results from the first application of the Resilience Assessment Tool in the study sites of the CASCADE project, along with some general conclusions about the most relevant factors playing a role in the resilience of dry Mediterranean socio-ecological systems.

The results of the RAT implementation will serve as base for developing guidelines for best practices that will be part of deliverable 7.3.

Contents

2. Introduction

In this report, first the methodology is presented both in terms of theoretical concepts and in practice, together with the process that lead to the design of the assessment tool. Secondly, the results of the first application of the RAT are presented here for each of the CASCADE study sites. A conclusion and discussion of the methodology constitutes the final section of this report. The complete assessment method, together with the list of variables considered in the analysis of results is found in the annex.

2.1. Resilience and regime shifts

A regime shift is defined as an abrupt change of the way an ecosystem functions and of its internal structure (Andersen, Carstensen, Hernández-García, & Duarte, 2009). Regime shifts are a concern because they are difficult to predict (Guttal & Jayaprakash, 2008): even if a system has remained stable for a long period, a regime shift can occur abruptly and with very limited warning signals (Brock & Carpenter, 2012). Moreover, It can cause a profound change in the provision of ecosystem services and can, e.g. in drylands, lead to desertification (Crépin, Biggs, Polasky, Troell, & de Zeeuw, 2012). Recovery from a regime shift is usually difficult if not impossible: once the system has shifted to a new configuration (called "degraded stable state"), it tends to display hysteresis (Groffman et al., 2006). Thus, it is not sufficient to reduce the pressure on the system for the ecosystem to return to the previous situation.

From a conceptual point of view, a system can undergo a regime shift for two reasons:

1. The external pressure grows beyond a threshold point (Walker & Meyers, 2004). This is normally caused by a change in processes at bigger scale (e.g. climate change causes an increase in fire frequency and intensity), but can be intensified through feedback mechanisms (e.g. the drought degrades the soil, reducing its water holding capacity, which in turn increases the impacts of the drought).
2. The internal capacity of the system to withstand pressure is eroded (Folke, Carpenter, & Walker, 2010). This is normally due to internal changes of the ecosystem (e.g. a deforested slope is much less stable, and will not be able to withstand an intense rainfall event, even if the precipitation regime isn't changed).

In real world ecosystems the two are often mixed, so that an erratic disturbance regime, together with a gradual depletion of the resilience mechanisms (Jucker Riva, Liniger, & Schwilch, 2016) causes a regime shift.

Effectively acting on the disturbance regime is difficult, as it requires acting at large scale on many different processes. While in some cases it is possible to prevent disturbances acting at the local level (e.g. by excluding fire from an area using fuel breaks), this also represents a major change for the ecosystem, and can produce negative consequences and ultimately bring the ecosystem towards another regime shift (e.g. exclusion of fires will increase the risk of pests and diseases, and will also decrease the amount of fire-prone species. This can result in a regime shift when fire eventually returns to the area). Thus, both mathematical modeling (Gunderson 2000) and empirical observations (Reinhardt et al. 2008) suggest that it is much more valuable to increase the ability of the system to withstand pressure, or in other words, to increase the resilience of the ecosystem. This has a beneficial impact on the ecosystem, regardless of the changes that may occur in the disturbance regime or in other external factors.

2.2. The concept of resilience

The concept of resilience, developed in the seventies (Holling, 1973), has since long been used in the ecology field to explain the dynamic of ecosystems. Theoretical elaboration and ecosystem observation have led to the definition of "*Ecological resilience*" as the capacity of a system to maintain its structure and function in the face of a disturbance (Gunderson, 2000). Integrating an increase in resilience into land management objectives, the so called "resilience thinking", is important to avoid regime shifts and to design cost-effective management strategies (Rist & Moen, 2013)

However, there is still a wide gap between ecological knowledge, theoretical elaboration on resilience, and land management practice (Folke et al., 2013).

Recent elaboration on resilience concepts distinguishes two approaches: 1) Resilience as an internal property of the system, and 2) Resilience as a reaction of the system to a specific disturbance (S. Carpenter, Walker, Anderies, & Abel, 2014). Studies that follow the first approach focus on the structure of the system and on the features that have a general positive effect on the resilience of the system, such as the capacity of self-organization, the functional response diversity, the exchanges between different parts of the system and others (Cabell & Oelofse 2012). This approach is virtually more applicable, as it does not relate the property of the system to specific disturbances or to the context in which it is found (Brand & Jax, 2007). However, it doesn't help to identify specific actions that could help the system to recover in the short term. For example, allowing the administrators of a municipality in a forested area to establish their own land use planning (increasing the self-organization capacity of that socio-ecological system), while probably beneficial in the long term, does not guarantee that the forest will recover after fire.

The second approach, often used by natural scientists, implies a closer study of the perturbation and of the specific context in which the system is: "*To assess a system's resilience, one must specify which system configuration and which disturbances are of interest*" (S. Carpenter et al., 2014). It implies studying the reaction of the system (in a specific configuration) to a certain disturbance: E.g., what measures can be taken to increase the probability of the forest stand to recover after fire, given the knowledge and resources available for land management at the moment?

This approach allows identifying specific actions to increase the resilience of the system, and thus was selected for task 7.2.

3. Methodology

3.1. Objectives of the Resilience Assessment Tool

Task 7.2 has the objective to design an accurate but simple method for resilience assessment to improve the land management in the CASCADE study sites. This means that the results should help in the choice of the most appropriate land management practices to maintain the equilibrium between human and environment and prevent regime shifts, in a way that is compatible with land managers needs and perceptions and in agreement with the scientific knowledge. In order to achieve this objective, we have created the Resilience Assessment Tool (RAT).

The RAT is composed of a series of questions that are answered by an expert in contact with land users and land managers, using all available sources of knowledge, including but not limited to scientific studies. It is designed as a tool to organize and merge knowledge, rather than producing new, in coherence with the approach of the WOCAT Framework for Documentation and Evaluation of Sustainable Land Management Technologies (Liniger et al. 2008). Based on a review of the scientific literature on resilience and the information gained during task 7.1, we have identified the most important characteristics that a Resilience Assessment Tool should have:

- Holistic approach: To understand the resilience mechanisms and the response of the system to disturbance an assessment cannot focus only on the part of the system that is mostly affected by disturbances (e.g. vegetation or soil in the case of the CASCADE study sites), as feedback mechanisms and systemic relations play a crucial role in resilience (Walker & Meyers 2004). In particular, it should include human actions, in terms of land use and land management. First because even in natural and semi-natural ecosystems, the role of land use and land management has a crucial impact on its evolution, secondly because they have the power to change how the land is managed beyond the project timeframe.
- Flexibility: Using a rigid set of indicators generally relevant for resilience would limit the contextualization of the assessment, reducing the validity of the results for the particular system analyzed (Wiesmann & Hurni 2011). Moreover, it should be flexible in terms of scale, as the appropriate system to consider for land management may vary greatly depending on historic, socio-economic and natural processes.
- Trans-disciplinarity: Any effective land management strategy has to meet land user’s needs; otherwise the system is at risk of abandonment or change of land use, which can bring the system to a regime shift. Moreover, local knowledge can give important insights on how processes develop in the specific context of the study site (Berkes et al. 1995). In particular, knowledge about how disturbances impact the system and on the effects of land management on these processes are very relevant for scientists.

- Build on existing knowledge: Most often, information to improve the management of the system is available, but scattered in different sources (Liniger et al. 2002). Rather than focusing on investigating a specific knowledge gap, a resilience assessment should support collecting information from different sources, highlighting the knowledge gaps that remain.
- Modularity: Resilience is not the only criteria to follow when identifying the most appropriate land management strategy. In fact, there can be tradeoffs between increasing the provision of the service or increasing resilience to disturbances. The resilience assessment should be a part of a wider land management strategy, thus it should be compatible with other tools and methods for evaluating and improving land management.

Other crucial methodological choices are related to the definition of resilience, the scale and unit of analysis and the combination of different sources of knowledge. These choices are explained in detail in the following paragraphs.

3.1.1. Application of the resilience concept in the CASCADE project

Scientists agree that resilience is an emergent property of an ecosystem, meaning that it is the result of multiple interactions between the elements which constitute that ecosystem, such as soil, plants, human action, and others (Lavorel, 1999), acting at different scales in time and space. This means that to effectively assess the resilience of an ecosystem, we cannot exclude many of the interactions that occur at the local level, especially those between the environment and the land users (Jucker Riva et al., 2016). This is particularly important in the Mediterranean area, where there is a long history of land use that has had a profound influence on the current structure of the ecosystem (Kosmas et al., 2015).
Among the interactions between land users and their environment, land management has the potential to improve the state of the ecosystem and to increase its resilience to disturbances. The impact of land management is dependent upon the specific natural and human environment of the system. Therefore, identifying and studying the land management practices that are already implemented in the field is needed to understand the role of land management regarding resilience and this has to be done in collaboration with land users and managers (Liniger & Schwilch, 2002). Moreover, land management practices are often implemented in combination (e. g. fuel breaks and selective clearing in forests, or controlled grazing and fodder production in dry pastures). Therefore, to study the resilience of a land management practice, we have to first analyze the land use system as a whole.
Many researches investigate resilience only in relation to point disturbances (Buma & Wessman, 2011); (Lewis, Reid, & Clarke, 2010); (Bérard, Bouchet, Sévenier, Pablo, & Gros, 2011). Land users do not perceive a distinction between degradation caused by specific events and degradation caused by long term pressures or unsustainable use, and are rather concerned with the stability of a certain land management system, i.e. that the environment will continue to provide the ecosystem services and benefits they look for.

Thus, in the context of an interdisciplinary and applied use of the resilience concept, the distinction between pressure drivers, and between sharp changes (regime shifts) and slower changes (degradation) are less relevant. To be of practical use, the assessment of resilience was designed to be close to the land users' needs but without disregarding the scientific understanding of resilience and regime shifts.

Often resilience studies are based only on the investigation of past events (Soane, Scolozzi, Gretter, & Hubacek, 2012); while the history of a system can explain much of the current state, it doesn't necessarily allow to forecast its future evolution, due to the fact that pressures drivers and the internal functioning of the system, as well as the demand for ecosystem services, might have changed since the last perturbation (Elmqvist et al., 2003). In the present assessment, we rely mainly on experts' knowledge to forecast future evolution of pressures and important processes.

In this report, by resilience of a land management system we mean the ability of a land management system to remain productive and valuable, according to land users' evaluation, in the face of pressure sources, and to withstand the shocks that affect the area.

Point disturbances like fire or droughts are part of the history and of the evolution of most of the land management systems analyzed here. However, a change in intensity or frequency of disturbances, or a modification in the internal functioning of the land management system, can produce a regime shift. Thus, while the causes of regime shifts are complex and multidimensional, the trigger is often a shock or disturbance event, after which the system changes to a new state. Understanding the impact of disturbances on a land management system is important to forecast its future evolution, and what modifications to the way the land is managed could increase resilience of the system.

It is important to distinguish between disturbances that are “normal” and that might even increase the resilience of the system in the long term (Folke et al., 2010), and those that induce permanent changes to the system. Because of the uncertainty related with the concept of “*permanent changes*”, we have chosen to limit the relevant time span to 30 years. Thus any change to the system that is not likely to recover within 30 years is considered “permanent”. In the text of the RAT, the term “*permanent change*” was used in place of “*regime shift*” because it is easier to understand and carries fewer implications.

Besides the relationship between the system and the disturbance that affect the area, we also consider the internal changes of the system (e. g. the degradation caused by the land use), and we try to take into account processes that occur at a bigger scale.

By evaluating in detail the role of land management in relation to resilience, this assessment helps to identify weaknesses and possibilities for ameliorations in the way the land is managed in order to increase stability in the provision of ecosystem services and to prevent regime shifts.

3.1.2. Land management systems as the unit of analysis

We consider a land management system the object of study, and land management as the main way to increase its resilience. More precisely, among the land use types that are most common in the study sites, we analyze a particular land management system: an area that is managed with a specific set of land management practices for the same purpose.

Normally, a land management system corresponds to one area, with one land use / cover. For example: "*Pinus halepensis afforestation managed with selective clearing and firebreaks for landscape conservation and controlling soil erosion*". However, a land management system can be composed of different land uses / covers if they are all managed by the same actors and with the same objectives. For example: "*Grazing system managed with seasonal grazing management and fodder cultivation for milk and meat production*". If the same management practices are applied on small portions of land within an area, with the same objectives and by the same or comparable actors, they can be considered as one land management system. For examples: "*Riverbank management with multi-specific shrub plantation and dry walls to prevent soil erosion, reduce risk of floods and increase diversity of vegetation*".

3.1.3. Combining scientific and lay knowledge

Integrating lay knowledge in scientific assessments, especially on land management, allows identifying solutions that are closer to land users perception and needs, and is therefore an effective way to ground results in the local context. What has been called "knowledge exchange" (Fazey et al., 2012) or "trans-disciplinary approach" (Wiesmann & Hurni, 2011) has also advantages for the scientific investigation of the ecosystem: Most often, lay knowledge relies on a long term management experience that spans through multiple generations of land users. Information on past events, and in particular on the evolution of the ecosystem is difficult to acquire through conventional scientific data; this is particularly true for remote ecosystems that are not at the center of long-term monitoring activities. Even when data series are available, they rarely include information at the detailed scale that is required for land management studies.

Moreover, land users tend to have an integrated understanding of their land, meaning that they can holistically understand the relation between many different variables and processes, and can recognize patterns in the evolution of the ecosystem. This is particularly difficult to obtain with standard scientific methods that tend to focus on "average situations" and on few variables at a time.

However, local knowledge has its weaknesses, and comes in a form that is difficult to integrate with scientific data. In particular, stakeholder knowledge is based on each individual experience and on the knowledge that he or she has been able to obtain. Moreover, lay knowledge is often descriptive: land users have difficulties in classifying or quantifying information.

In the RAT, we aim at combining scientific knowledge about the system with the experience of land users and local administrators. This aspect is crucial to ensure that the assessment is compatible with the views of local actors, who are the ones that actively manage the system and can affect its evolution (Liniger, Lynden, & Schwilch, 2002).

We have taken several steps to ensure an effective integration between scientific and lay knowledge:

- Repeated and extended field visits: During the course of WP7 we have performed several field visits in all the study sites. This allowed meeting stakeholders and creating a stakeholder group for each study site. We have taken care to contact different categories of stakeholders including land owners, land users, advisors and local experts (forestry service, fire protection, public or private advisory), local administrators.
- Flexible design of the Resilience Assessment Tool; we designed the RAT to include a wide range of information, from quantitative to descriptive. Thus, depending on the source available, all type of information, be it from studies and scientific publications or from exchanges with land users, can be used and combined to complete the assessment. In particular, the use of semi-quantitative indicators and a "*Comment /specify*" section next to each question allowed flexibility in the assessment and simplified interpretation of results.
- Simple language: throughout the tool specific terms like "regime shift" were avoided and we have taken care of simplifying all questions as much as possible, even if a link with scientific concepts and definitions was maintained.
- Testing of the tool: We have tested the questionnaire in a wide range of situations and with different stakeholders to ensure that all parts are understandable and could be answered by scientists, local administrators and land users.

3.2. Design of the Resilience Assessment Tool

The process that lead to the Resilience Assessment Tool stemmed from the information gathered through task 7.1, and involved several phases of testing and reviewing that are resumed in Figure 1 and explained in detailed in the following paragraphs.

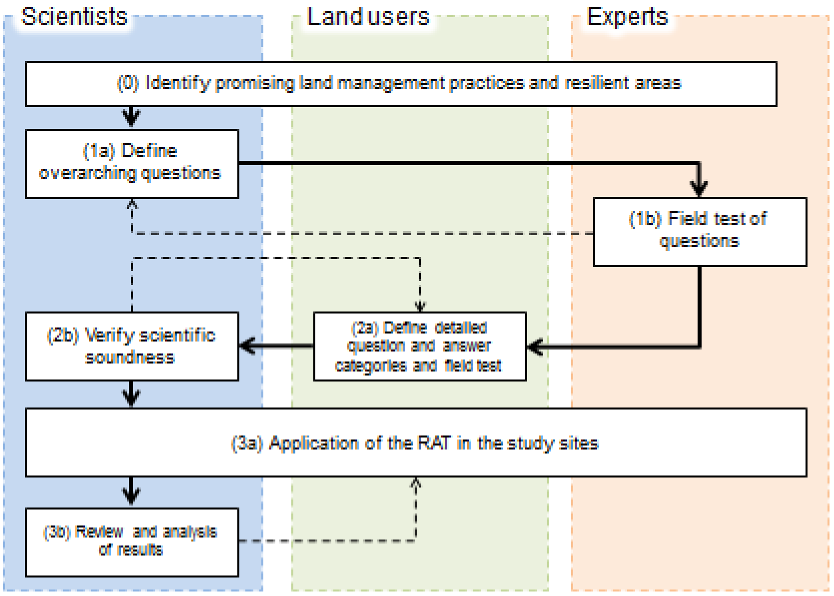


Figure 1. Design phases of the Resilience Assessment Tool and interactions with different stakeholder groups. Scientists refer to project partners other than University of Bern; experts refers to local experts or advisors. Dashed lines represent review after testing phases.

3.2.1. Identification of the main scientific questions for assessing resilience

During the field visits and the contacts with stakeholders for performing task 7.1, we have acquired information on the processes that are relevant for the evolution of the land management system: In a first stakeholder meeting in the study sites, that served as an introduction and presentation of the project, we asked the help of stakeholders in identifying "healthy" and "degraded" areas for the most common land use types. Follow up questions during field visits with land users and managers, and semi-structured interviews with local experts and administrators, allowed us to identify relevant processes that could play a role in the resilience of the study areas (See table 1).

On healthy areas:	On degraded areas:
· What are the environmental processes that make the area	· Why is the land degraded? · Was the land healthy in the past?

more resilient? · What socio-economic factors and institutions support the land management? · What could degrade it beyond recovery potential?	If yes, how long ago? · Why is the land not managed as in the healthy areas? · What could be done to improve it?

Table 1. Introductory questions for land users/managers during the first visits in the study sites

The answers given by stakeholders were crosschecked with local experts, using remote sensing, and compared to various sources of scientific knowledge such as data collected on the field by project partners and previous studies on the study site areas. This work, coupled with the "Inventory of Land Management Practices" (del. 7.1) allowed us to identify the most relevant processes in the study sites, and lead to the main scientific questions that are at the base of the RAT (see Figure 1 phase 1a).

We have tested the main questions in October 2014 in Spain, during field work across a variety of different land management systems to verify the relevance of the questions and the possibility to answer them using local and expert knowledge (Fig. 1 phase 1b). These main scientific questions and their relation with the sections in the RAT are presented in Table 2.

Is the present area healthy or degraded? What are the services that it provides?	→	Section 2: Scope of the land management system
How is the area most likely to evolve?	→	Section 3: Evolution of the land management system
What disturbances could degrade the system? What permanent changes could they induce?	↘	Section 4: Influence of external shocks and disturbances
Is the land management beneficial in preventing or reducing degradation or in fostering recovery after a disturbance?	↗	
Is the land management adapted to the different situations and environmental conditions?	→	Section 5. Details about the land management system

Table 2. Main scientific questions and relation with sections of the questionnaire

3.2.2. Design and testing of the Resilience Assessment Tool

Once the relevance of the main scientific questions was verified on the ground, we proceeded in the structuring of the assessment tool, according to the principles outlined in section 3.1.

A draft of the RAT was tested in April 2015 in Greece with land users and local administrators, focusing on the land management practices identified in task 7.1 (see Fig. 1, phase 2a). All the questions were submitted to interviewees as open questions; particular attention was given to verifying the understandability of the question and the validity of the categories proposed as answers.

After the testing with land users, and the consequent changes to the RAT, the tool was submitted to the scientists participating at the 2015 CASCADE project meeting (Fig. 1, phase 2b). This phase served as final testing of the RAT and as training for the study-site partners. During this phase particular attention was given to ensuring that the questions were scientifically sound. Feedback from project partners was integrated in the final version of the RAT.

3.2.3.. Structure of the Resilience Assessment Tool

The Resilience Assessment Tool is structured in 5 sections: section 1 allows identifying the land management system, locating it, and sketching its major features. Section 2 focuses on the state of the system and the claims the land users have on the system, it includes a specific questionnaire, called “Environmental Perception Questionnaire”, that is submitted directly to land users. Section 3 focuses on the foreseen evolution of the system in the next 10 years, by analyzing the factors that might increase pressure, or affect management. In this section point disturbances (such as fires, floods and others, called shocks and disturbances in the RAT) are not considered. Section 4 then focuses on the role of shocks and disturbances, first analyzing their impact on the system, especially in relation to regime shifts, secondly by evaluating the role of land management with respect to these disturbances. Section 5 resumes important information about the system and details about the land management practices (see the full RAT questionnaire in Annex 1).

Moreover, the Resilience Assessment Tool is designed to be compatible with the WOCAT assessment method for land management technologies, both in terms of the approach to assessment and of the terminology.

The resulting type of data collected through the RAT implementation includes the following:

1. Scoring/importance evaluation: Used to identify and rank the elements (e.g. demanded ecosystem services, most important environmental properties, most impacting disturbances) that are relevant to each land management system. The scoring is from 1 to 4 (less important to very important)
2. Evaluation of state: the experts are asked, in consultation with stakeholders, to categorize the provision of ecosystem services and the state of different environmental properties. They can

choose between "to maintain" (thus considered healthy) or "to improve" (thus considered degraded).

3. Semi quantitative evaluation of land management effectiveness: The RAT asks to evaluate benefits of land management on a scale between -4 and 4. Values below zero indicate negative impacts (i.e. decrease in resilience, increase in degradation), values above 0 a positive impact.
4. Open questions: wherever possible, open questions in the form of “Specify/comment” were added to facilitate interpretation of quantitative results and to capture information that could not be categorized or quantified.

3.2.4. First application of the RAT in the CASCADE study sites

The present version of the RAT was submitted to the project partners in summer 2015, who proceeded to apply it in the study sites in autumn 2015 (see Fig 1, phase 3a). The choice of the land management system to be assessed was made by study-site partners’ team in dialogue with the WP7 leaders.

The main criteria to select the land management systems to be assessed were:

- The land use of the system is similar with the dominant land use of the study site.
- The land management system is a promising or a commonly used combination of land management practices.

The gathering of information to complete the assessment included at least one stakeholder meeting per study site, during which the EPQ (“Environmental Perception Questionnaire”, see Annex 2) was completed and, when necessary, follow up interviews with local administrators or experts were held.

The RAT was completed using a form in MS Word and a first round of data collection underwent a review to improve coherence, completeness and clarity of the information collected (Fig. 1, phase 3b). For the present analysis, the final assessments from all 8 study sites were subsequently uploaded in a dedicated database on Google Drive. Results were analyzed using a spreadsheet program. The spreadsheet allows the automatic creation of a summary result page to facilitate dissemination of results and further discussion among practitioners, as shown in annex 5.

The focus of the data analysis was to summarize the most relevant information in a semi-quantitative way, without disregarding the qualitative information. For this purpose we used the data type 1 and 2, while for the interpretation of results we relied on the open questions.

In particular, to evaluate the state of the system, the provision of ecosystem services (section 2) and the future evolution of the land management system we combined the scoring (data type 1) with the state evaluation (data type 2) using the following formula:

$$\sum\left(\frac{n_{h*I_h}}{n_T * I_T}\right)$$

Where n_h refers to the number of elements considered “healthy” (provision of ecosystem services, state of environmental properties) or “improving” (when analyzing the future evolution of the system). I_h is the importance score of the healthy/improving elements; n_T is the total number of elements considered, and I_T is the sum of the importance scoring given to the elements considered. This allows condensing aspects like provision of ecosystem services and the state of the environment in a single number.

4. Results

4.1. RAT Section 1: General information on the land management system

4.1.1. Identification of the assessed land management systems

General information on the land management systems assessed was collected through the first part of the RAT. In particular, the name of the land management system (Table 3, column 3) had to reflect the environment, but also the main objective of land management.

Study Site Name	*Country*	*Name of the Land Management System*	*Unique Code*	*Main Author and Affiliation*
Varzea	Portugal	Recently burnt maritime pine plantation subjected to logging, with withdrawing of forest slash residues and conditioning machinery movement to minimize impacts on pine recruitment	Por_1	Keizer Jan Jacob, University of Aveiro (Portugal)
Varzea	Portugal	Recently burnt maritime pine plantation subjected to traditional logging following the fire, with extraction of all the woody material and use of heavy machinery	Por_2	Keizer Jan Jacob, University of Aveiro (Portugal)
Ayora	Spain	Pinus halepensis afforestation managed with selective clearing and firebreaks for landscape conservation and controlling soil erosion	Spa_2	Baeza Jaime, CEAM Foundation (Spain)
Ayora	Spain	Shrubland under selective clearing and planting for fire risk reduction and resilience increase	Spa_3	Baeza Jaime, CEAM Foundation (Spain)
Messara	Greece	Carob afforestation on grazing land for land restoration and income diversification	Gre_1	Panagea Ioanna, Technical University of Crete (Greece)
Randi	Cyprus	Extensive grazing system with carob and tree protection and fodder provision	Cyp_1	Christoforou Michalakis, Cyprus University of Technology (Cyprus)
Castel Saraceno	Italy	Seasonal high altitude cow pastures managed with metallic fences to regulate grazing	Ita_1	Quaranta Giovanni, University of Basilicata (Italy)
Albatera	Spain	Spatially diverse multi-specific plantation to restore degraded shrubland and combat desertification	Spa_1	Bautista Aguilar Susana, University of Alicante (Spain)

Table 3. Identification of the land management systems analyzed with the Resilience Assessment Tool. Variables considered are 11a, 11b, 11d, 11e, 13a, 121a (see Annex 3)

Table 3 shows the list of land management systems assessed using the RATS. The first four land management systems are located in forest areas where the main driver of land degradation is fire. The land management systems located in Greece and Cyprus are similar in terms of land use (animal farming) which is also the main pressure driver. Also the Italian study site's main land use is grazing, but overgrazing is not a problem there, as the climate is much more humid than in Greece and Cyprus (see Table 4). The last site is Albatera, where the degradation is mostly due to previous agricultural use of the land. The study sites will be presented throughout this report in the same order used for Table 3, in order to facilitate comparison. The most relevant question answered in Table 3 is: "*What is the name of the land management system?*" (variable 13a, see Annex 3.)

4.1.2. Description of the system

Table 4 shows the information, collected through the RAT that characterizes the natural and human environment of the land management system. The categories and definitions used are coherent with the WOCAT indicators and are derived from questions in section 5 of the RAT. The main questions are: "*5.1.2 Agro-climatic zone","5.1.3 Landforms","5.1.4. Which land use type constitutes the land management system?", "5.1.5. Previous land use type(s) in the last 100 years", "5.1.7. Who is managing the land management system?"*(see Annex 1).

The land use in the study site has been categorized adopting the WOCAT classification as shown in Figure 2.

Land use type	*Subcategory of land use type*
Cropland: Land used for cultivation of crops (field crops, orchards).	***Ca: Annual cropping:*** *land under temporary / annual crops usually harvested within one, maximally within two years (eg maize, paddy rice, wheat, vegetables, fodder crops)* • ***Cp: Perennial (non-woody) cropping****: land under permanent (not woody) crops that may be harvested after 2 or more years, or only part of the plants are harvested (eg sugar cane, banana, sisal, pineapple)* • ***Ct: Tree and shrub cropping****: permanent woody plants with crops harvested more than once after planting and usually lasting for more than 5 years (eg orchards / fruit trees, coffee, tea, grapevines, oil palm, cacao, coconut, fodder trees)*
Grazing land: Land used for animal production	• ***Ge: Extensive grazing land:*** *grazing on natural or semi-natural grasslands, grasslands with trees / shrubs or open woodlands for livestock and wildlife* • ***Gi: Intensive grazing/ fodder production:*** *improved or planted pastures for grazing/production of fodder (for cutting and carrying: hay, leguminous species, silage etc) notincluding fodder crops such as maize, cereals. These are classified as annual crops (see above*
Forests / woodlands: land used mainly for wood production, other forest products, recreation, protection.	•***Fn: Natural forests:*** *composed of indigenous trees, not planted by man* • ***Fp: Plantations****, afforestations: forest stands established by planting or/and seeding in the process of afforestation or reforestation* • ***Fo: Other****: eg selective cutting of natural forests and incorporating planted species*
Mixed: mixture of land use types within the same land unit.	• ***Mf: Agroforestry****: cropland and trees* • ***Mp: Agro-pastoralism****: cropland and grazing land (including seasonal change between crops and livestock)* • ***Ma: Agro-silvopastoralism****: cropland, grazing land and trees (including seasonal change between crops and livestock)* • ***Ms: Silvo-pastoralism****: forest and grazing land* • ***Mo: Other****: other mixed land*
Other:	• ***Oi:*** *Mines and extractive industries* • ***Os:*** *Settlements, infrastructure networks: roads, railways, pipe lines, power lines* • ***Ow:*** *Waterways, drainage lines, ponds, dams* • ***Oo:*** *Other: wastelands, deserts, glaciers, swamps, recreation areas, etc*

Figure 2. Land use type classification according to the WOCAT Technology questionnaire and used in the Resilience Assessment Tool.

Unique Code	*Climate*	*Land forms*	*Present land use(s)*	*Past land uses (date of change in years from present)*	*Land managers*
Por_1	sub humid	· Hill slopes	· Fp: Plantations;	· Ge: Extensive grazing land; (50)	· Employee, small scale land users, · Leaders / privileged, · Mainly men
Por_2	sub humid	· Hill slopes	· Fp: Plantations;	· Ge: Extensive grazing land; (50)	· Employee, Small scale land users, · Leaders / privileged, · Mainly men
Spa_2	sub humid	· Plateau / plains, Mountain slopes, · Valley floors	· Fo: Other; · Fn: Natural forests; · Fp: Plantations	· Ma: Agro-silvopastoralism; (60) · Mf: Agroforestry;	· Employee, Small scale land users · Mainly men
Spa_3	sub humid	· Plateau / plains, · Valley floors	· Fo: Other; · Fp: Plantations;	· Ca: Annual cropping; (60) · Fn: Natural forests; · Ca: Annual cropping	· Employee
Gre_1	sub humid	· Hill slopes	· Fp: Plantations; · Ms: Silvo-pastoralism;	· Gi: Intensive grazing/ fodder production; (15) · Mp: Agro-pastoralism;	· Individual/household, · Leaders / privileged · Mainly men
Cyp_1	semi-arid	· Plateau / plains, · Hill slopes	· Ge: Extensive grazing land; · Gi: Intensive grazing/ fodder production;	· Ct: Tree and shrub cropping; (20) · Gi: Intensive grazing/ fodder production;	· Individual/household, · Small scale land users, · Common / average land users, · Mainly men
Ita_1	sub humid	· Mountain slopes	· Ms: Silvo-pastoralism;	· Ca: Annual cropping; (50) · Ms: Silvo-pastoralism;	· Individual/household, · Medium scale land users, · Mainly men
Spa_1	semi-arid	· Ridges, · Mountain slopes, · Hill slopes	· Fp: Plantations; · Fn: Natural forests;	· Ge: Extensive grazing land; (Unknown) · Ct: Tree and shrub cropping;	· Employee, · Mainly men

Table 4. Description of the natural and human environment of the land management systems analyzed with the Resilience Assessment Tool. Variables used are: 11e,121b, 512a,513a,514a,514b,514c,515a,515c,515d,517a, 517b,517c,517d (see annex 3)

Details about climate together with trends and past changes have been presented in detail in Del. 2.1. To that we can add an observation from the RAT implementation: In the last 2 years, climatic extremes have characterized the majority of the study areas; the driest ones (Randi, Albatera and Ayora) have experienced droughts, while Castelsaraceno and Varzea have experienced higher rainfall than normal.

The CASCADE project studies natural and semi-natural ecosystems; it comes to no surprise that most of the land management systems analyzed are located outside the plains, in hilly or mountainous areas (Table

4, column 3). From the categorization of present land uses we can immediately identify a difference between forest systems and grazing systems: the former (Por_1, Por_2. Spa_2, Spa_3) are rather homogeneous; the latter, despite having a clearly dominant land use, are more heterogeneous. During meetings, the farmers interviewed have repeatedly stressed the importance of having multiple land uses and vegetation types to increase quality of fodder and reduce production failure risks: this is particularly important in drier areas (Gre_1 and Cyp_1) where one single land use / vegetation type cannot support the animal farming all year round. The 5th column of Table 4 shows that all the land management systems analyzed have had a major land use change in the last 60 years. This is coherent with the general pattern of the Mediterranean countryside: during the industrial boom of the 1950s and 60s there has been a massive change in the way natural and semi-natural ecosystems were used, the old localized and self-sufficient land use mosaic changed towards a more industrialized and homogeneous land use (Cyp_1, Por_1, Por_2) or towards land abandonment when the land was not productive enough anymore or the attraction of nearby cities was higher.

Most land management systems analyzed fall in the second category. This is particularly important for the system Ita_1, where a change in the economic system completely changed the dominant land use, almost abandoning the farming practices in the area and caused what could be identified as a regime shift in the environment.

Moreover, the impacts of past land uses is not only still visible today, but has direct implication on the resilience of the environment to disturbances and on the effectiveness of land management practices. (c.f.. A prominent example is Spa_1, where the terraces created during the agricultural exploitation of the area influence the infiltration capacity of the soil, and thus the ability of the natural vegetation to colonize the area. Also in the forest areas of Ayora (Spa_2) the agricultural activities of more than 50 years ago still have an impact on the type of vegetation, on its flammability and ability to recover after a fire. The last column of Table 7 shows the actors who are in charge of the land management.

The management is mainly performed by private companies or government agencies in forest and natural areas (Portugal and Spain), while individuals are in charge of land management in grazing areas.

Table 5 shows the most important land management practices implemented in each land management system. Among them there are practices that are considered particularly promising by land managers or researchers in increasing the resilience of the land management system (Por_2, Spa_1, Spa_3, and Gre_1). Others can be considered "traditional" or of wide-spread use (Por_2, Ita_1, Spa_2, and Cyp_1). A more complete description of each land management practice is provided in Annex 4.

Unique Code	*Land Management practice*	*WOCAT identifier (if present)*
Por_1 (Varzea)	Post-fire conservation logging	
Por_2 (Varzea)	Post-fire traditional logging	
Spa_2 (Ayora)	Selective forest clearing to prevent large forest fires Cleared strip network system (firebreaks) for fire prevention Afforestation with Pinus halepensis after fire	SPA010 SPA009 SPA012
Spa_3 (Ayora)	Clearing of fire-prone seeder species. Planting of fire resistant resprouter species	SPA011 SPA011
Gre_1 (Messara)	Graze land forestation with Ceratonia siliqua (carob trees) in the Mediterranean Controlled grazing in spring months and tree protection	GRE008
Cyp_1 (Randi)	Fodder provision to goats and sheep to reduce grazing pressure on natural vegetation Planting Carob and olive trees to prevent erosion Carob tree protection from rats	CYP001 CYP002
Ita_1 (Castel Saraceno)	Metallic fences to regulate grazing	
Spa_1 (Albatera)	Multi-specific plantation of semiarid woody species on slopes Spatially-diverse multi-specific plantation Multi-specific plantation of semiarid woody species on terraces with stone walls in ravines and gullies	SPA013 SPA015 SPA016

Table 5. Land management practices in the study sites and relation with the WOCAT database. Variables considered are 131a-131f (see annex 3)

4.2. RAT Section 2: Perception and claims of land users

Section 2 of the RAT is functional to evaluating the perception of land users of their land. This is important not only because effective land management practices have to be compatible with the livelihood strategies of the land users and with their perception of the environment, but also because the identification of what is to be considered "healthy" and what is considered “degraded" is context- and culture- dependent and can be very different between scientists and land users. The understanding of which changes are desirable and which not has to be defined in a participatory manner. A major example of how differently scientists and land users can perceive the state of the land is presented in Figure 3.

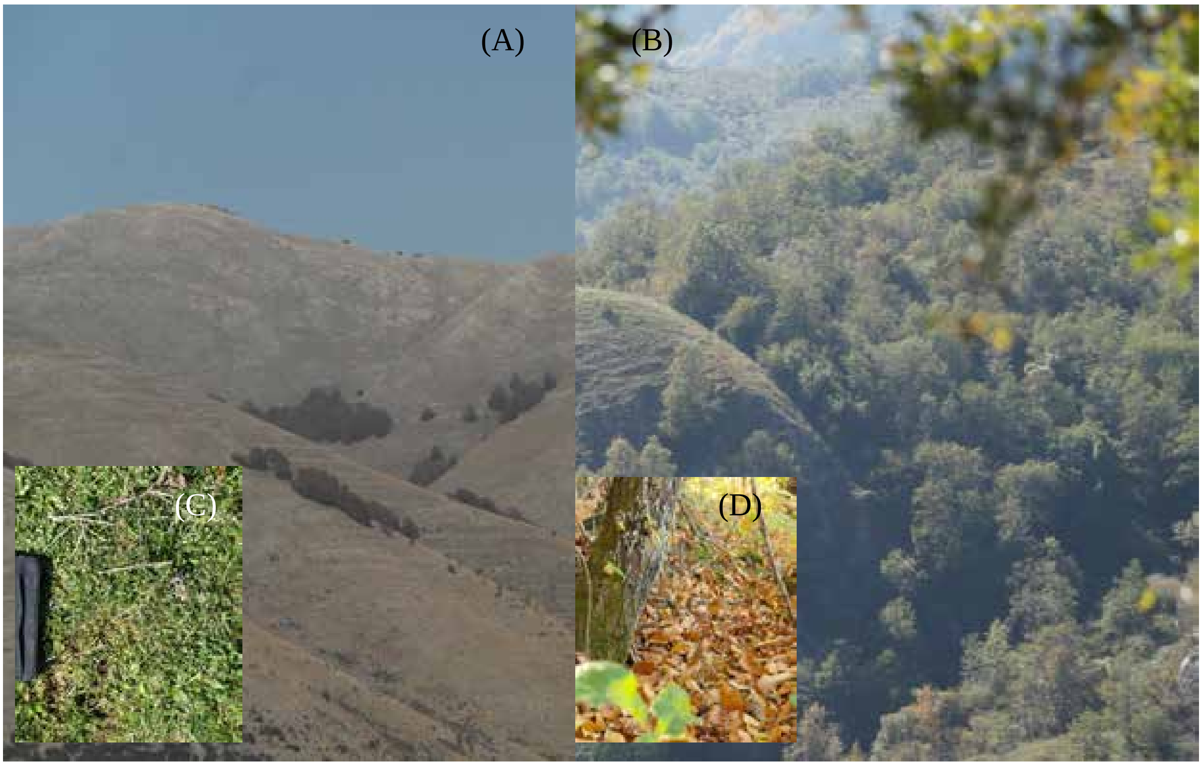


Figure 3. Two very different areas in the Castelsaraceno study site. Contrary to common ecological understanding, land users have identified zone (A) as "healthy", and zone (B) as “degraded”. This is related to the cultural and economic importance of pastures in the area. While the mountain top (A) is dominated by palatable grasses (C), the forested slope (B) hosts very few palatable species at ground level (D). Photos by Matteo Jucker Riva.

The data that composes Table 7 has been collected in two different ways.

Firstly by asking stakeholders the following question (2.1.): “*What are the functions or services the land management system should provide?*” according to a list of ecosystem services selected from the WOCAT questionnaire to meet the specifics of the CASCADE study sites (c.f. Table 6).

P Productive Services:	*E Ecological services :*	*S Socio cultural services:*
· (P1) Animal and plant productivity (quantity and quality), including timber and biomass for energy · (P2) water (quantity and quality) for human, animal and plant consumption · (P3) land available for production (area of land for production per person) · (P4) Others	· (E1) regulation of excessive water (e.g. water logging) · (E2) regulation of scarce water and its availability e.g. during dry seasons · (E3) reduced erosion · (E4) soil formation · (E5) above ground biodiversity · (E6) greenhouse gas absorption (CO_2, methane, etc.) · (E7) micro-climate regulation (wind, shade, temperature, humidity) · (E8) Protection from extreme events (fires, drought, floods, etc.) · (E9) Others	· (S1) Recreation(e.g. tourism, sports) · (S2) Cultural services(e.g. maintaining traditional landscape) · (S3) Conflict mitigation · (S4) Others

Table 6.Classification used in the RAT for the services / functions that the land management system should provide. Selected from the WOCAT Technology questionnaire.

Secondly, by submitting a small questionnaire directly to land users and managers. This questionnaire, called Environmental Perception Questionnaire (EPQ), once translated in all the study sites' languages, has been submitted to a group of stakeholders as diverse as possible, during stakeholder meetings or one- to-one interviews. For each "*environmental property*", responders were asked to value the importance on a scale from 1 to 4 and to assess the state of degradation: either "*to maintain*" (healthy) or "*to improve*" (degraded). The results detail the perception of the state of degradation of the land management system, as well as the demand for ecosystem services. (cf. Annex 2 for the complete Environmental Perception Questionnaire). The number of responders varies greatly (see Table 7, because we selected only those stakeholders with a direct relationship with the land management system analyzed: land owners/users, advisors (e.g. forestry service, fire protection, public or private advisory), administrators in charge of the area (municipality, regional government). We present the results of the evaluation of the ecosystem services in Figure 4 and in Table 8 column 2, while the results of the EPQ are presented in Table 8 columns 3, 4 and 5, in Figure 5 and in Table 9.

Study site	Por_1 (Varzea)	Por_2 (Varzea)	Spa_2 (Ayora)	Spa_3 (Ayora)	Gre_1 (Messara)	Cyp_1 (Randi)	Ita_1 (C. Saraceno)	Spa_1 (Albatera)
Number of responders	1	4	10	12	10	9	8	3

Table 7. Number of responders to the Environmental Perception Questionnaire per land management system

4.2.1. Relative importance of different ecosystem services categories

The graphs shown in Figure 4 are computed based on the answer to question 2.1.1 "*Importance of services and functions*", in which the expert performing the assessment was asked to rank the different categories of ecosystem services according to their importance, integrating the opinions of relevant stakeholders. The results show the demand for ecosystem services in the land management systems.

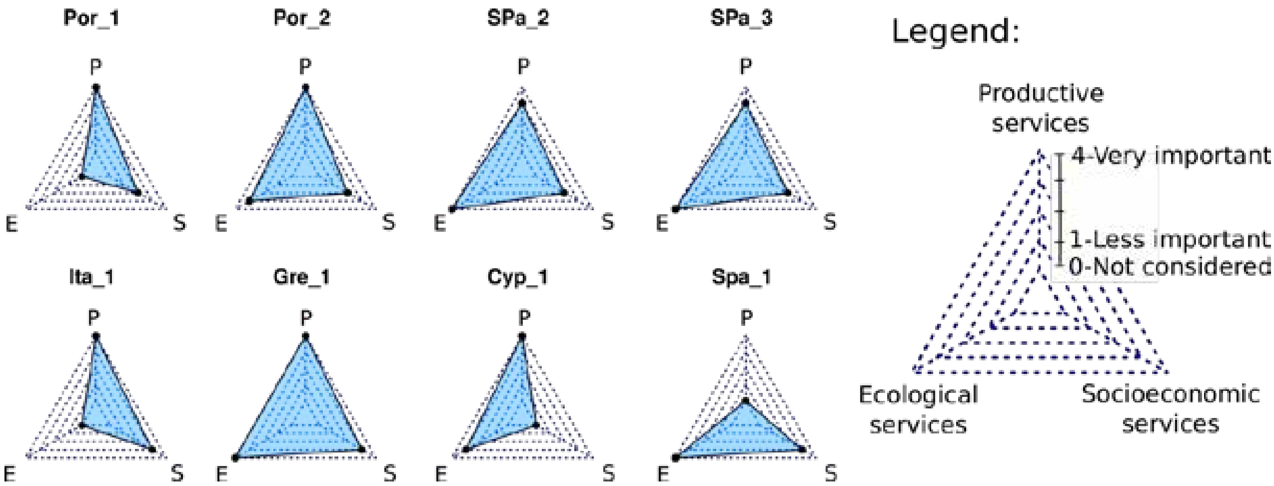


Figure 4. Relative importance of different categories of ecosystem services, as assessed by land users and experts on scale from 1(less important) to 4. (Very important).Value 0 indicates that the ecosystem service category was not considered. The variable considered are: 11e, 121b, 211a, 211b, 211c, 211d (see annex 3)

Productive services are indicated as "very important" in most of the study sites (Por_1, Por_2, Gre_1, Cyp_1, Ita_1), while ecological services are the most important only in areas that are not used intensively for production (Spa_1, Spa_2).

Socio-cultural services are generally more important in grazing areas compared to forests, probably due to the personal attachment and the long tradition of animal farming that is related with pastures, while forest areas are more considered for their ecological value. Obviously these results are largely influenced by the composition of the stakeholder group. However, by selecting only stakeholders that have a direct relationship with the area, as well as aiming at a highly diverse group of responders in terms of profession, age and relation to the area, we feel that the RAT evaluation is reliable for the land management system assessed.

4.2.2. Assessment of healthy and current state

By enquiring about the current provision of ecosystem services and on the stae of the environment, we are able to compare the current situation to the healthy one, and also to relate the state of the environment with the provision of ecosystem services. Table 8 allows comparing the most relevant information from both section 2.1 of the RAT and the Environmental Perception Questionnaire. The second and fifth column of Table8 show the provision of services as assessed by experts (c.f. previous paragraph), while column 3, 4 and 6 show the evaluation resulting from the Environmental Perception Questionnaire.

Study site identifier	*Most important ecosystem services*	*Most important "healthy" environmental features*	*Most important "degraded" environmental features*	*services provided at a satisfactory level*	*Env. properties considered healthy* [b ‡]
Por_1 (Varzea)	· (P1) Animal and plant productivity (-) · (P2) water (quantity and quality) for human, animal and plant consumption (+)	-- [†]	-- [†]	44.40%	-- [†]
Por_2 (Varzea)	· (P1) Animal and plant productivity (-)	· High soil organic matter · High number of wild grazers · Low number of wild / domestic grazers	· Presence of a mixture of grasses, shrubs and trees · High number of different species · Presence of a specific plant or group	0%	24.30%
Spa_2 (Ayora)	· (E3) reduced erosion (+) · (E5) above ground biodiversity (-) · (E6) greenhouse gas absorption (+) · (E8) Protection from extreme events (+)	· Low surface runoff · Good soil drainage/infiltration · Continuity of vegetation canopy/cover	· Soil erosion · Presence of a mixture of grasses, shrubs and trees · Number of different species	88.90%	40.20%
Spa_3 (Ayora)	· (E6) greenhouse gas absorption (-) · (E8) Protection from extreme events (-)	· High soil moisture · Presence of different landscape elements and vegetation patterns · Good soil drainage/infiltration	· Presence of a mixture of grasses, shrubs and trees · High number of birds · Discontinuity of vegetation canopy or low biomass density	0%	51.40%
Gre_1 (Messara)	· (P1) Animal and plant productivity (+) · (P3) land available for production (-)	· Presence of different landscape elements and vegetation patterns · Presence of a mixture of grasses, shrubs and trees · Low soil erosion	· Low number of wild / domestic grazers · Favorable soil structure · Connectivity between healthy areas	71.40%	64.90%

Study site identifier	*Most important ecosystem services and evaluation of provision*	*Most important "healthy" environmental features*	*Most important "degraded" environmental features*	*Current provision of ecosystem services*[a]	*Current state of the environment* [b ‡]
Cyp_1 (Randi)	· (P1) Animal and plant productivity (-)	· High number of domestic grazers · Presence of one specific habitat/land use/land cover · Discontinuity of vegetation	· Good soil drainage/infiltration · High number of predators · High number of different species	16.70%	32.60%
Ita_1 (Castel Saraceno)	(P1) Animal and plant productivity (-)	· Presence of a mixture of grasses, shrubs and trees · Presence of a specific plant or group · Continuity of vegetation canopy/cover	· Low presence of alien/ dangerous species · Availability/ protection of springs / water sources	0%	73.80%
Spa_1 (Albatera)	· (E3) reduced erosion (-) · (E5) above ground biodiversity (+) · (E8) Protection from extreme events (-)	-- [†]	-- [†]	61.90%	-- [†]

Table 8. Evaluation of the healthy and current state of the land management system. Column 2 and 4 are based on the question: "What are the functions or services the land management system should provide?" of the RAT, column 3, 4 and 6 on the question: "Which properties of the environment are to be maintained or improved?"asked directly to stakeholders through the Environmental Perception Questionnaire. Values in column 5 and 6 range between 0 (completely degraded) and 100% (completely healthy). If the value is above 50%, the system is considered healthy. The values in column 5 and 6 have been calculated using the formula presented in section 3.2.4.

[a] *Weighted percentage of ecosystem services that are considered healthy /sufficiently provided*

[b] *Weighted percentage of environmental properties considered healthy*

[†] *Not enough responses to the Environmental Perception Questionnaire were collected*

Considering the current state of the environment , most of the land management systems analyzed are considered degraded, with Por_2 being the most degraded, while Ita-1 is considered the healthiest.

It is interesting to notice how the evaluation through the Environmental Perception Questionnaire (column 6) does not necessarily correspond to the assessment of the most important ecosystem services (column 5). Ita_1 that was considered healthy by the stakeholders in all the categories of environmental properties, while the provision of services was considered highly unsatisfactory. The reason of this difference probably lies in the fact that land use productivity in the Italian study site is hindered by the economic system and regulatory restrictions, rather than environmental constraints. Thus, stakeholders perceive a problem in the provision of services but not in the state of the environment.

Por_2, that was considered the traditional, less sustainable land management system in the Varzea study site, is evaluated as providing less services than Por_1, where a more sustainable management practice for post-fire logging was adopted. Also, in the Ayora study-site, Spa_2, which is a semi-natural forest, is considered degraded, while Spa_3, that is located near a shrubland area (in ecological terms this is the "degraded" state of the forest present in the study site) is considered "healthy". If we look at the evaluation of the provision of ecosystem services, the relation between the two land management systems analyzed in the Ayora study site is the opposite. This might be related to the fact that while Spa_2 is a forest with environmental properties that are similar to the other forest stands in the area, thus providing several ecosystem services, Spa_3 is a shrubland that does not provide important ecosystem services. But due to the particular land management that changed vegetation composition, it is considered healthier than most other shrubland formations in the area and more resistant to fire.

Gre_1, where pastures were restored using Carob trees and managed grazing is considered healthy, is in agreement with the evaluation of ecosystem services provision. Cyp_1 which is a traditional pasture in a very dry area is considered degraded despite the number of land management practices implemented, probably because the overall productivity remains low, despite the land management which is mostly focused on mitigating degradation.

4.2.3. Relative importance of different environmental properties

Beyond the evaluation of the state of the system, the results of the Environmental Perception Questionnaire provide a more detailed description of the relationship between land users and their environment. A detailed analysis of the EPQ results is presented in the following figures. Firstly how land users have judged the importance of different environmental properties, and secondly how they have assessed the state of the environment.

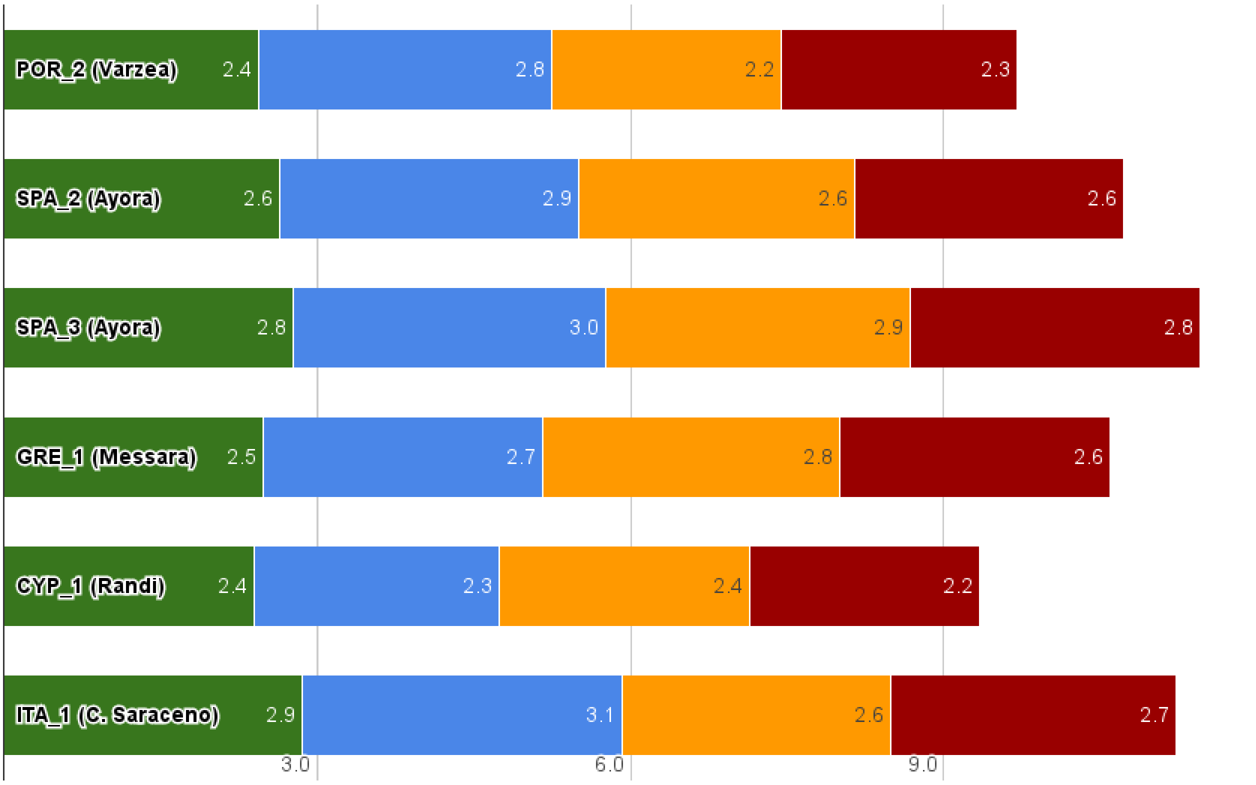


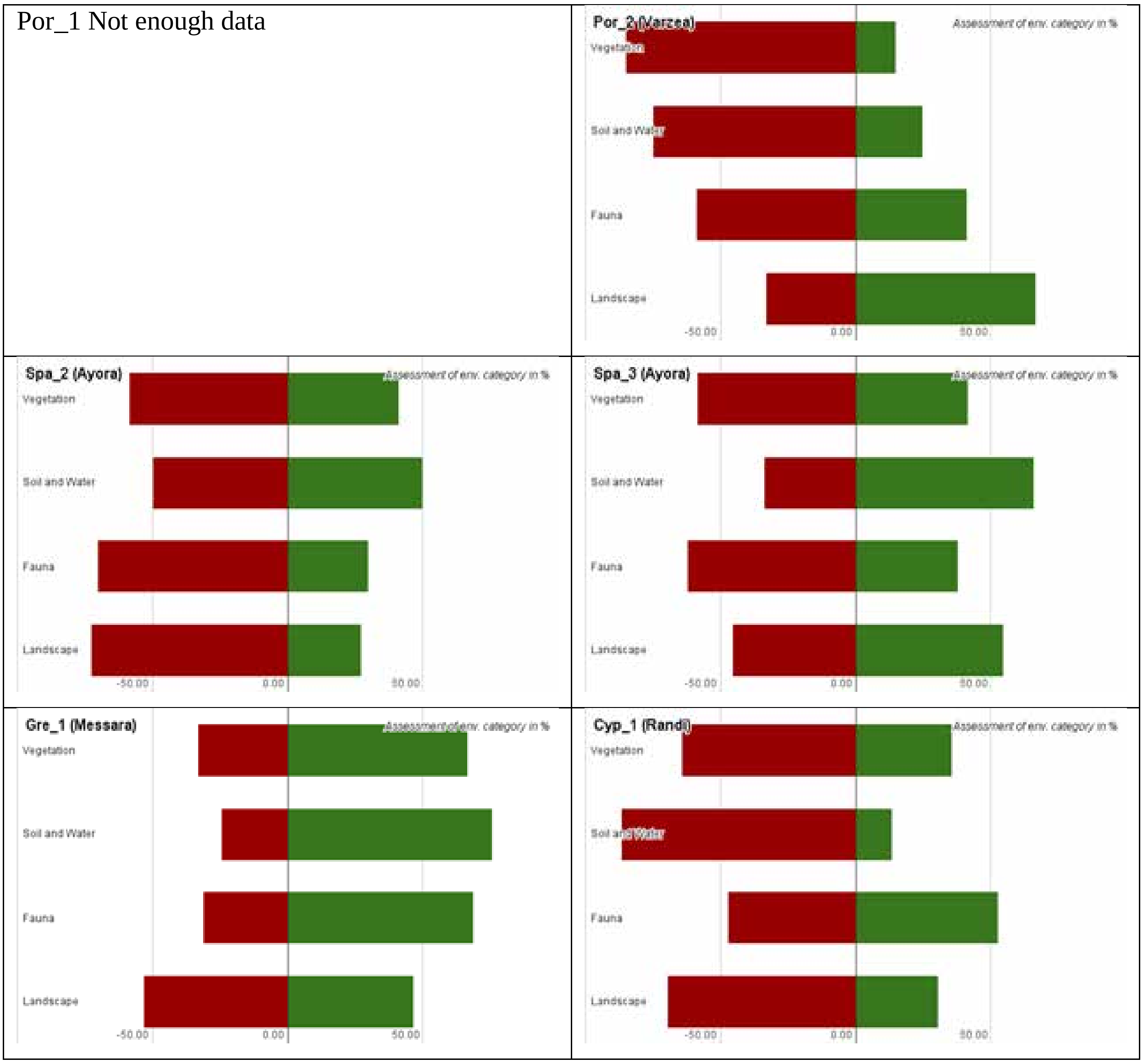
Figure 5. Importance of different categories of environmental properties based on the response to the Environmental Perception Questionnaire. Results correspond to average evaluation of importance per each category and range between 1(less important) and 4(very important)
Legend:
Green = Vegetation;
Blue = Soil and Water;
Yellow = Fauna;
Red = Landscape
Variables considered are q11 to q24 (see annex 3)

Figure 5 shows the relative importance of the different categories of environmental properties analyzed in the Environmental Perception Questionnaire. In most of the land management systems the "*Soil and Water"* category is considered the most important. It is also the category that "drives" the evaluation: all the land management systems that are considered healthy overall, the "*Soil and Water*" category is considered "*healthy*" as well (see Fig. 5). Among the most important environmental properties within the "*Soil and Water*" category, "*soil erosion*" is considered the most important one, especially in the forest management systems (Por_1, Por_2, Spa_2, Spa_3, see table 8).

The Second most important category is the vegetation in all but Gre_1 and Cyp_1, where the fauna is most important. This is related with the main purpose of the land management system: animal farming.

In general, the vegetation is the environmental category to which land users have the most relation and knowledge, and within the vegetation two of the most important properties concern the vegetation diversity: "*Presence of a mixture of grasses, shrubs and trees (complex vegetation structure)*" and "*High number of different species (vegetation diversity)*" (cf. Annex 2).

The categories "*Soil and Water*" and "*Vegetation*" are the most harmonized, in the sense that they are considered either healthy or degraded by a vast majority of stakeholders (cf. Figure 6). "*Fauna*" and "*Landscape*" are the categories that are less clear, in terms of degradation assessment. Overall, "*Landscape*" is the least important category, with the exception of Ita_1. This is probably related with the complexity of landscape processes and the difficulties in relating a specific landscape property to a certain ecosystem services or benefits.



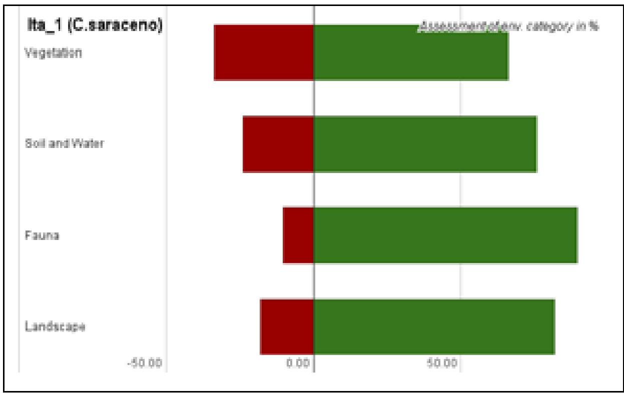
	Spa_1. Not enough data

Figure 6. Assessment of the state of different categories of environmental properties from the Environmental Perception Questionnaire. The bars indicate the ratio between environmental properties considered degraded and healthy in each category (in percentage), without considering the importance evaluation. See annex 2 for the complete list of environmental properties.
Legend:
(Red)= Degraded
(Green)= Healthy

4.3. RAT Section 3: evolution of the system

Like any other system, the land management systems analyzed here change following external disturbances such as fires, drought and economic shocks. However, more subtle and slow changes can happen due to changes in the local context, changes in neighboring areas or caused by internal drivers.

In the context of this resilience assessment, we have considered two aspects that are crucial for the resilience of the systems being analyzed:

1) Pressure factors can slowly degrade the land management system and its ability to recover after a disturbance. E.g. grazing reduces vegetation density which reduces the stability of soil during heavy rains.
2) Economic, administrative and social factors that enable land users to implement sustainable land management may vary in the future and drastically modify the resilience of the land management system.

It would not be cost/effective to identify solutions to increase the resilience to external disturbances, only to have the benefits undermined by slow changes in the environment or by changes in the socio-economic system that could prevent the implementation. Moreover, the resilience to external shocks could be deeply modified by the factors analyzed in this section: urbanization as well as over abstraction of water increase the impacts of droughts or intense rainfall, while a drop in subsidies could prevent land users from restoring their land after a fire.

This type of information is very difficult to find through scientific sources, and in most cases has to be asked to experts or stakeholders. Thus we have limited the forecasting of future trends to the next 10 years, as the level of uncertainty for any further forecasting is very high.

Section 3 of the RAT is dedicated to capturing the evolution of the system through several questions:

"*3.1. What pressures can have a negative impact on the system?*" aims at capturing the pressure drivers that could bring the system to degradation or even a regime shift. First the experts value the importance of each pressure factor today, and then they estimate the evolution in the next 10 years (possible choices are *"Increasing", "Stable"* or "*Decreasing*").

Question 3.2: "*What external factors enable land management?"* is directed to investigate those factors that allow or favor sustainable land management practices to be implemented in the land management system (e.g. subsidies, infrastructure).

Question 3.3: "*How do you foresee the evolution of the land management system in the next 10 years?*" is dedicated to the "internal" evolution of the system in terms of provision of ecosystem services, and of "*Effectiveness of management*". This allows to integrate the fact that land management practices are found at different levels of implementation, and their effectiveness (especially for the land management practices that rely on vegetation) might vary depending on the state of development (e.g. newly planted trees have a limited beneficial impact, but in 10 years will be fully grown).

Furthermore, two open questions allow better understanding what could be done to prevent degradation and further enhance the benefits provided by the land management system. In answering all these questions, experts were asked not to take into account external disturbances and shocks.

4.3.1. Internal evolution of the land management systems, most important external factors and future trends

Table 9 shows the aggregated results of the application of Section 3 of the RAT in the CASCADE study sites. The second and third columns are related with question 3.3, while the last two show the dominant trends of external pressure (question 3.1) and enabling factor (question 3.2) indicators weighted on their importance following the formula presented in section 3.2.4

Study site	*Provision of services/functions*	*Effectiveness of management*	*Combined trend of pressures*	*Combined trend of enabling factors*
Por_1 (Varzea)	(+)	(=)	Increasing	Stable
Por_2 (Varzea)	(+)	(=)	Increasing	Stable
Spa_2 (Ayora)	(+)	(=)	Decreasing	Stable
Spa_3 (Ayora)	(=)	(-)	Decreasing	Stable
Gre_1 (Messara)	(+)	(+)	Decreasing	Increasing
Cyp_1 (Randi)	(+)	(=)	Decreasing	Stable
Ita_1 (Castel Saraceno)	(-)	(=)	Stable	Stable
Spa_1 (Albatera)	(+)	(=)	Increasing	Increasing

Table 9. Evolution of ecosystem service provision, management effectiveness and external factors in the next 10 years. Information in column 4 and 5 is based on the sum of the importance values assigned to "increasing", "stable" and "decreasing" indicators.
Color legend:
(Green) = Positive evolution
(Yellow) = Stable
(Red) = Negative evolution
Variables considered are 33a, 33b, 33c, 33d, 31, 32, 31a-31s, 32a-32s c.f. annex 3

While most of the management systems were considered degraded in the evaluation through the Environmental Perception Questionnaire, the provision of ecosystem services is forecasted to increase in the next 10 years in almost all study sites. One exception being Spa_3, where the vegetation has already reached a stable state after the implementation of the land management practice, thus provision of ecosystem services is not expected to increase. Benefits provided by land management practices are forecasted to remain stable in almost all the land management systems. The two exceptions are Spa_3, where maintenance of the land management practice is not performed, and thus benefits are expected to diminish. For Gre_1, where the most relevant management practice involves planting of Carob trees, the benefits (both productive and ecological) are expected to increase with the size of the trees. For what concerns pressure factors, the Portuguese land management systems forecast an increase in pressure mainly due to the impact of logging activities on soil. In Spa_1 pressures is also thought to be increasing due to urbanization. External factors vary among the different study sites, and only in Ita_1 are expected to remain stable overall.

Table 9 shows the most important external pressures and enabling factors, together with their trends as assessed in each land management system Overall the most frequently considered external pressure that could degrade the system is "*Deforestation / removal of natural vegetation*" (all the study sites except Ita_1). This indicator includes both grazing and fire, thus is relevant in all the study sites that are degrading or affected by desertification.

Study site	*Most important external pressures with future trends*	*Most important enabling factors for land management with future trends*
Por_1 (Varzea)	· Removal of natural vegetation (+) · Unsustainable soil management(+) · disturbance of water cycle (+)	· Market prices of goods produced from the land (-) · Land tenure (=) · Presence of infrastructures (+)
Por_2 (Varzea)	· Removal of natural vegetation (+) · Unsustainable soil management(+) · Disturbance of water cycle (+)	· Subsidies for land management or nature (=) · Conservation (=) · Market prices of goods produced from the land (+) · Land tenure (=)
Spa_2 (Ayora)	· Removal of natural vegetation (-)	· Subsidies for land management or nature conservation(=) · A specific land use activity (+) · Land tenure (=)
Spa_3 (Ayora)	· Removal of natural vegetation (-)	· Subsidies for land use activity (-) · Land tenure (=) · Laws and regulations prescribing land management (=)
Gre_1 (Messara)	· Overgrazing (-) · Urbanization and infrastructure development (=)	· Subsidies for land use activity (-) · Subsidies for land management or nature conservation(=) · Affordable energy price (-)

	· Over abstraction of water (+)	
Cyp_1 (Randi)	· Unsustainable soil management(=) · Disturbance of water cycle (=)	· Subsidies for land use activity (-) · Affordable energy price (=) · Market prices of goods produced from the land (-)
Ita_1 (Castel Saraceno)	· Industrial activities and mining (=) · Urbanization and infrastructure development (+) · Over abstraction of water (+)	· Subsidies for land management or nature conservation (-) · Laws and regulations prescribing land management (+) · Cooperation and community organization (+)
Spa_1 (Albatera)	· Removal of natural vegetation (+) · Unsustainable soil management(+) · Disturbance of water cycle (+)	· Market prices of goods produced from the land (-) · Land tenure (=) · Presence of infrastructures (+)

Table 8. The 3 most important external pressures and enabling factors per study site and their evolution in the next 10 years (in order of importance).
Legend:
(-) Decreasing enabling factor or external pressure;
(=) Stable;
(+) Increasing enabling factor or external pressure.
Variables considered are 33a, 33b, 33c, 33d, 31, 32, 31a-31s, 32a-32s c.f. annex 3

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Among the enabling factors "*Laws and regulations prescribing land management*" is by far the most common, and is forecasted to remain stable in all the study sites except Spa_3 (increasing). This shows the importance of national and regional policies and the impact they have on the land. Moreover, it is interesting to see that subsidies, both directed towards the implementation of land management practices ("*Subsidies for land management or nature conservation*") and towards a land use activity ("*Subsidies for land use activity (agriculture, farming, tourism and others)*") are considered to have an important impact on land management systems. Moreover, they are forecasted to remain stable or to decrease. Nevertheless "*Market prices of goods produced from the land*" is also considered an important enabling factor, showing how the link between productivity and sustainable land management is still very important. Land users in livestock management systems depend on the market prices of milk and cheese to invest in their land. Also in forest areas where the main land managers are government organizations, selling the wood after the logging (Por_1, Por_2) or fuel reduction management practices (Spa_1) allows to integrate the public funding for nature conservation and to increase the number of interventions.

4.4. RAT section 4: shocks and disturbances

Section 4 of the RAT is dedicated to understanding the relation between the land management system and the shocks and disturbances that occur in the region in which the land management system is located (i.e. with the same natural and human environment) and that could affect the land management system in a negative way. Question 4.1 "*Type and frequency of shocks and disturbances affecting the land management system*" allows to identify all the disturbances that affect the land management system, without considering the permanent changes. Information about the frequency of return of the disturbance and the date of the last event is included.

Question 4.1.1 **“***Can the shock or disturbance cause permanent change in the land management system?”* focuses on the disturbances that could bring the system to a regime shift, and question 4.1.2 “*Under what conditions does the shock or disturbance cause permanent change?*” asks on what aspect of the environment the disturbance will have permanent impact.

Furthermore, question 4.1.3 *“Describe the impact of permanent change on the provision of services/functions”* tries to outline the actual impact of a regime shift on the provision of ecosystem services.

Section 4.2 “*Effectiveness of land management in preventing, mitigating or restoring the land management system after a shock”* investigates the positive or negative role of each of the land management practices implemented on the disturbance. Finally, question 4.3.2 “*What additional land management practices could be used to prevent, mitigate or restore the land management system?”* allows to indicate further management practices that could help reduce the impact of regime shifts and disturbances in general, using the WOCAT database as a main reference.

4.4.1. Most important shocks and disturbances affecting the system

To understand the resilience of a land management system it is important to identify the disturbances that can have an impact on the system. On this topic, merging scientific understanding with the knowledge of land managers is critical, because the latter can benefit from years of experience on disturbances events. More importantly, they can identify those disturbances that have a relevant impact on the system and can trigger a regime shift.

Table 12 shows the most relevant disturbances (in terms of negative impacts) for each land management system, together with the frequency and the last event that occurred in the region where the land management system is located.

Study site	*Most important shocks and disturbances*	*Frequency*	*Last event*
Por_1 (Varzea)	· Fires · Pests / disease	· Between 5 and 10 years · Once per year or less	· 2012 · 2015
Por_2 (Varzea)	· Fires · Pests / diseases	· Between 5 and 10 years · Once per year or less	· 2012 · 2015
SPa_2 (Ayora)	· Fires · Droughts	· Between 1 and 5 years · Between 5 and 10 years	· 2013 · 2014
SPa_3 (Ayora)	· Fires · Droughts	· Between 1 and 5 years · Between 5 and 10 years	· 2013 · 2014
Gre_1 (Messara)	· Fires · Droughts · Pests / diseases	· Between 5 and 10 years · Between 5 and 10 years · No information	· No information
Cyp_1 (Randi)	· Fires · Droughts · Torrential rainfall	· Between 5 and 10 years · Once per year or less · No information	· 2013 · 2015 · 2015
Ita_1 (Castel Saraceno)	· Drop in value of production and subsidies for production · Pests / diseases	· Between 5 and 10 years · Once per year or less	· 2003 · 2015
Spa_1 (Albatera)	· Droughts · Floods · Torrential rainfall	· Between 5 and 10 years · Once per year or less · No information	· 2014 · 2009 · 1982

Table 9. Most important shocks and disturbances per land management system. Frequency (column 3) and last event (column 4) refer to events occurring not only in the land management system but also in the surrounding area. The variables considered are 41a-41z (see annex 3)

All of the land management systems analyzed report more than one disturbance having a relevant impact.

In the land management systems analyzed fire is by far the most common, and it affects not only the forest systems but also the others, with the exception of Spa_1, where the vegetation density is too low for a fire to spread and of Ita_1, where the humid climate reduces the risk of fires. The second most common disturbance is drought that affects 5 out of the 8 land management systems, followed by pest and disease, that include both animal (relevant only for the pastoralist systems) and plants (relevant for all the system). In particular Ita_1 pastures are affected by wild boars that represent a major problem because they disrupt the grass layer in the pastures and damage the infrastructures; Cyp_1 is affected by brown rats, which attack the Carob trees and increase their mortality, contributing to land degradation and desertification. Ita_1 indicates "*drop in value of production and of subsides for production*" as the most impacting disturbance. Indeed the changes in the subsidies system and in the cheese market prices have had a profound effect on the land use and thus the environment of the land management system. Abrupt changes in the economic system as the one presented for Ita_1, are rarely considered in environmental studies on resilience; however they have an important effect on the land use and the land management, and thus indirectly on the environment.

The disturbances are indicated to be relatively frequent and occurred recently. It is surprising that relatively common disturbances, to which the systems must have adapted, can nonetheless trigger a regime shift. This seems to validate the hypothesis of the depletion of internal resilience mechanisms as the cause of regime shifts.

4.4.2. Threshold conditions and consequences of regime shifts.

Thresholds conditions are particularly important to understand the evolution of a system (Briske & Fuhlendorf 2013): If a disturbance passes a threshold, the land management system is likely to undergo a regime shift and to be changed permanently. They depend on physical and biological processes, the state at which the system is found, and the several contextual factors. The topic of threshold is at the center of many recent studies (Briske & Fuhlendorf 2013; Briske et al. 2010; Mumby et al. 2014) but it remains very difficult to quantify thresholds for a specific situation.

Moreover, the impact of the permanent changes on the provision of ESS has to be investigated, together with the possibility that some new ecosystem services might be provided by the changed environment, and that could be the base for an adaptation strategy. Table 11 presents the description of thresholds grouped by disturbances and in relation to the disturbance regime, the state of the environment and the land use and management.

Disturbance type	*Disturbance regime (frequency and intensity)*	*State of the environment*	*Land use/management*
Fire	If recurrent fires occur before the pine stand has been able to create a viable seed bank (typically 10-15 years) (Por_1, Por_2) If more than 2 fires occur within 20 years (Spa_2, Spa_3) If the fire is intense enough to burn the canopy of Carob trees (Cyp_1)	If the influx of pine seeds from neighboring unburnt areas is limited (Por_1, Por_2)	If post-fire logging produces massive mortality of the pine seedlings (Por_1, Por_2) If there is no restriction of grazing after the fire (Gre_1, Cyp_1)
Drought	If multiple periods of drought occur in a short time in combination with fire (Spa_2) If severity of drought is higher than tolerance limit for most shrub species established in the area (Spa_1, Spa_3)	If the trees are young (less than 3-5 years) (Gre_1)	If there is not sufficient irrigation (Gre_1)
Pests / diseases:	If there is more than 1 boar in 40 ha damages are very relevant on pasture and other domestic species (cows, sheep and goats) (Ita_1)		
Torrential rainfall:		If vegetation cover and pattern cannot hold the soil (Spa_1)	If the plants were planted too recently and are not developed enough (Spa_1)
Floods		If riparian vegetation is not continuous (Spa_1)	
Drop in value of production:	If gross margin is lower than variable costs for more than five years (Ita_1)		If subsidies are not related to production (Ita_1)

Table 10. Description of thresholds for disturbances in response to the question "Under what conditions does the disturbance cause permanent change?" in relation to the disturbance regime, the state of the environment, and the land use/management.

Wildfire has a clear and quantifiable threshold related to the frequency of disturbances: Por_1, Por_2, Spa_2 and Spa_3 indicate that 2 fires within less than 10 (Por_1 and Por_2) or 20 years (Spa_2, Spa_3) can entail permanent changes. This is related to the time needed for the plants to reach sexual maturity and produce seeds between fires (Paula et al. 2009; Jucker Riva et al. 2016).

Gre_1, Cyp_1, Por_1 and Por_2 indicate also that the way the land is used after a wildfire (for grazing or for harvesting the wood) can provoke permanent changes in the land management system: this activity adds pressure on the vegetation in the moment it is more vulnerable and can easily bring the plants to die, preventing recovery.

The threshold for drought is related to individual plant resistance; however, there are no quantitative indications in terms of duration or intensity of the drought. In Gre_1, a relation is made between the drought and the stage of development of the plants: at the juvenile stage, after germination, plants go through a period of high vulnerability, which is generally considered to last three years. During this time, they are highly vulnerable to scarcity of water, nutrients, and light.

The term permanent change was used to refer to the changes caused by disturbances, which are likely to last more than 30 years. In the RAT we investigate both the permanent changes in the environment and in the provision of ecosystem services. The results are presented in Table 12, arranged by type of disturbance.

Study site identifier	*Disturbance*	*Permanent changes to the environment*					*Decrease in the provision of ecosystem services*		
		Veget.	*Soil*	*Water*	*Fauna*	*Landsc.*	*Prod.*	*Ecol.*	*Sociocult.*
Por_1 (Varzea)	fires	1.0	0.0	0.0	1.0	1.0	0.5	1.0	1.0
	pests / diseases	1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Por_2 (Varzea)	fires	1.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0
	pests / diseases	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0
Spa_2 (Ayora)	fires	1.0	0.0	0.0	1.0	1.0	1.0	0.5	1.0
	droughts	0.0	0.0	0.0	0.0	0.0	1.0	0.3	1.0
Spa_3 (Ayora)	fires	1.0	0.0	0.0	1.0	1.0	0.0	0.5	0.0
	droughts	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Gre_1 (Messara)	fires	1.0	0.0	0.0	0.0	1.0	0.5	1.0	0.0
	droughts	1.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
	pests / diseases	1.0	0.0	0.0	0.0	0.0	1.0	0.3	0.0
Cyp_1	droughts	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

(Randi)	fires	1.0	0.0	0.0	0.0	0.0	1.0	0.3	0.0
	torrential rainfall	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
Ita_1 (Castel Saraceno)	Economic shock	1.0	0.0	0.0	1.0	1.0	0.5	0.0	1.0
	pests / diseases	1.0	0.0	0.0	0.0	0.0	0.5	0.5	1.0
Spa_1 (Albatera)	droughts	1.0	0.0	1.0	1.0	0.0	0.0	0.7	1.0
	floods	1.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	torrential rainfall	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0

Table 11. Permanent impact of disturbances on the environment and important ecosystem services from answers to the question "Can the shock or disturbance cause permanent change in the land management system?" (Permanent changes to the environment) and "Describe the impact of permanent change on the provision of services/functions" (Important ecosystem services).
Legend:
(green) no permanent change or impact
(yellow) some ecosystem services are impacted
(red) permanent change of the environment or decrease in ecosystem service provision
(grey) there is no demand for the category of ecosystem service

Table 12 shows the negative impact of an above-threshold disturbance on the provision of ecosystem services. Vegetation seems the part of the environment most affected by permanent changes, while soil and water seems to be less concerned. Drought is the only disturbance that is considered not to bring about major changes on in the environment in several land management systems

Most disturbances seem to affect a wide variety of ecosystem services. The specific ecosystem service that is affected depends on the system and it has been related to the demand of services (cf. section 4.2). However, the provision of ecosystem services belonging to all categories (productive, ecological and socio-cultural) seems to be impacted by the disturbances that affect the system, in coherence with the concept of catastrophic shift: a regime shift in the environment induces a vast decrease in the provision of ecosystem services. One of the most threatened ecosystem services is "*(E8) Protection from extreme events*", meaning that if an important disturbance occurs in the land management system, this will become less resilient also to other disturbances. This is a typical form of hysteresis, where feedback between degradation and disturbance prevent the system from recovering and can even lead to further degradation (Carpenter et al., 2009).

On the opposite, the land management systems assessed appear to be resilient to drought. As the description of thresholds for drought suggests (see Table 11), the occurrence of permanent changes is strictly related to the type of vegetation, thus the effects are very variable across different land management systems. The two land management systems that were assessed as less resilient to droughts (Spa_1 and Gre_1) are both characterized by a low scrubland vegetation that is severely limited in its development by reduced water availability (Spa_1 in particular) and low soil fertility (Gre_1). The other sites that generally have more diverse vegetation appear to have a more resilient environment. Productive ecosystem services, where important, do not appear to be hindered by droughts. This is probably due to the adaptation of the land use to the dry climatic conditions.

Pest and disease seem to induce permanent changes only in the vegetation. However they have a noticeable effect on productive services.

The RAT includes a question on what ecosystem services could increase after a regime shift. In effect, a change in the functioning of the system does not necessarily involve a decrease in the provision of ecosystem services. The services that could increase with a regime shift can constitute the base for an adaptation to the new conditions. The most striking example is that of unproductive shrublands that would be replaced by more palatable vegetation formations after a fire (Cyp_1) or the new land uses that would become possible if a forest is turned into a shrubland (Spa_2).

4.4.3. Does management increase resilience?

Land management practices are normally implemented to increase productivity of the land or to reduce degradation associated with land use. But their role regarding resilience depends on how they interact with the specific processes that regulate the occurrence of a disturbance, its impact on the environment and the post-disturbance recovery.

The last part of section 4 of the RAT is focused on analyzing the role of land management practices in preventing or mitigating disturbances or fostering the recovery of the land management system. Due to the variety of land management systems and of disturbances, no specific indicators were used to facilitate the evaluation.

Main questions related to this topic are:

"4.2.1. Does the land management prevent shocks or disturbances?" By prevention we mean to evaluate the influence of land management on the probability of shock or disturbance

"*4.2.2. Does the land management mitigate shocks or disturbances?"* that is defined by influence of land management practices on the degradation associated with a shock or disturbance.

"4.2.3. *Does land management help recover/restore the system after a shock?"*

The expert is asked to answer these questions by choosing one of the statements presented in table 13.

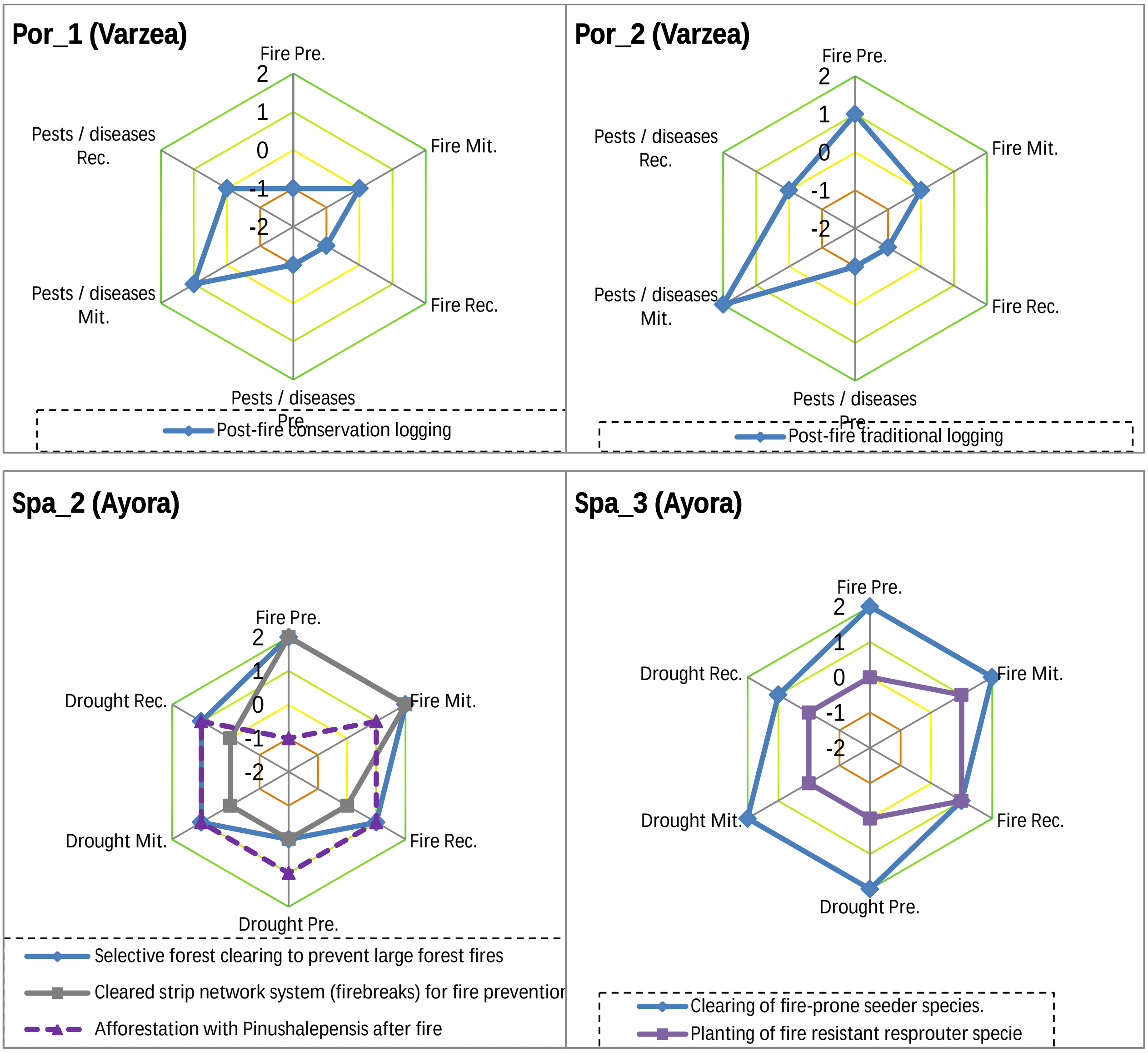
Prevention		*Mitigation*		*Recovery*	
-2	strong increase in probability of a shock	-2	Strong increase of degradation	-2	regeneration prevented
-1	increase	-1	Increased degradation	-1	regeneration decreased or delayed
0	negligible	0	negligible mitigation	0	negligible
1	decrease	1	mitigation	1	increased or faster regeneration
2	strong decrease in probability of a shock	2	strong mitigation	2	full regeneration ensured

Table 12. Possible answers to questions 4.2.1, 4.2.2 and 4.2.3 on the impact of land management on the resilience of land management systems and value used for the quantitative analysis.

Finally, with question 4.3.2 "*What additional land management practices could be used to prevent, mitigate or restore the land management system?*" we ask to describe additional land management practices that could be implemented in the area to increase the resilience of the land use system.

The evaluation was demanded for each individual land management practice in relation to each disturbance identified in question 4.1. The results are reported here first in individual form (Figure 7) and aggregated per each land management system (Figure 8).

From the analysis of the results of the evaluation we do not consider the "*Drop in value of production and subsidies for production*" reported in the assessment of Ita_1, as we cannot directly establish a relationship between the economic disturbances and the land management practice, at least in the terms used here to analyze the environmental disturbances.



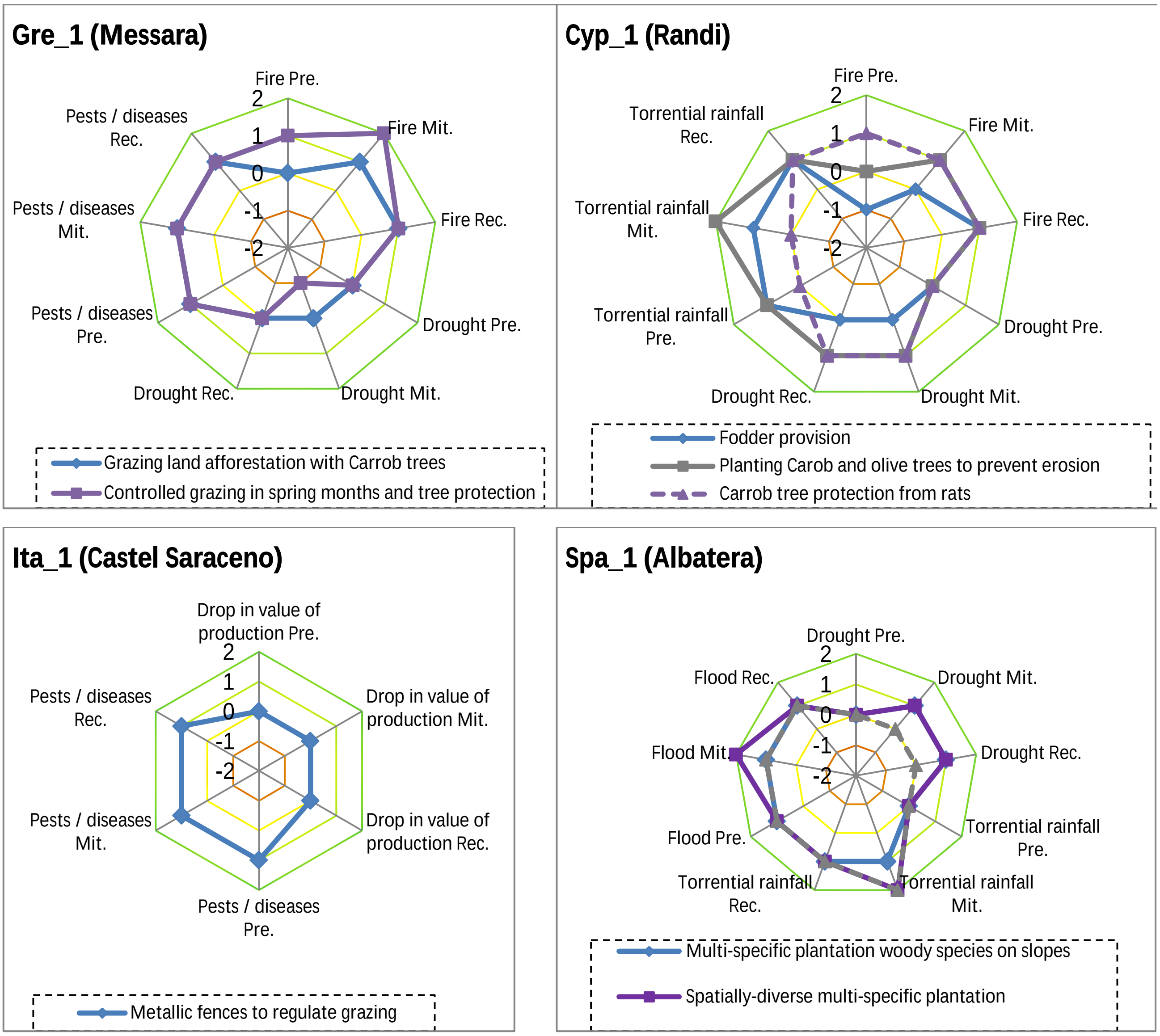


Figure 7. Impact of land management practices on prevention, mitigation and recovery after a shock. Values range from -2 (very negative impact) to 2(very positive impact). The center of the spider-web graph represents the value -2, the internal line correspond to the value 0 (no impact); the external line corresponds to 2(maximum positive impact). The terms "prevention", "mitigation" and "recovery have been shortened in "Pre.", "Mit." and "Rec". Variables considered are 4211, 4212, 4213, 4221, 4222, 4223, 4231, 4232, 4233 (see annex 3)

The graphs in Figure 6 show how diverse the impact of land management can be in preventing, mitigating or fostering recovery. The most striking example is the "traditional logging" in Por_1, that has opposites effect in prevention and mitigation of disturbances. The same can be said for the "*Afforestation with Pinus halepensis*" (Spa_2) and the "*Fodder provision*" (Cyp_1). Most technologies are judged to have a positive effect on mitigation of disturbances, while the prevention is rather difficult. This is related with the very nature of some disturbances like drought and torrential rainfalls that cannot be prevented through land management. Where more than one land management practice is implemented, the negative aspects are compensated by positive ones, with the exception of drought mitigation in Gre_1, for which the two land management practices have a negative or negligible effect. Overall, the negative impact of the land management practices is considered to be low, while almost all of them have a “negligible” impact in some situations, with the exception of the “*clearing of fire prone species*” in Spa_3 that seems to have an overall positive effect.

The aggregated results of the evaluation (Figure 7) show the impact of land management on resilience for each management system, and the values are based on the scoring method presented in Table 13.

	Drought			*fire*			*pests / diseases*			*torrential rainfall*			*flood*		
	Pre v.	*Mit.*	*Rec.*	*Prev*	*Mit.*	*Rec.*	*Prev.*	*Mit.*	*Rec.*	*Prev.*	*Mit.*	*Rec.*	*Prev*	*Mit.*	*Rec.*
Por_1 (Varzea)	--	--	--	-1	0	-1	-1	1	0	--	--	--	--	--	--
Por_2 (Varzea)	--	--	--	1	0	-1	-1	2	0	--	--	--	--	--	--
Spa_2 (Ayora)	1	2	2	3	5	2	--	--	--	--	--	--	--	--	--
Spa_3 (Ayora)	2	2	1	2	3	2	--	--	--	--	--	--	--	--	--
Ita_1 (Castel Saraceno)	--	--	--	--	--	--	1	1	1	--	--	--	--	--	--
Gre_1 (Messara)	0	-1	0	1	3	2	2	2	2	--	--	--	--	--	--
Cyp_1 (Randi)	0	2	2	0	2	3	--	--	--	2	3	3	--	--	--
Spa_1 (Albatera)	0	2	2	--	--	--	--	--	--	0	5	3	3	4	3

Figure 8. Impact of the combination of land management practices of each land management system on prevention, mitigation and recovery after a shock. Color legend:
Dark green = Very positive;
Green = Positive;
Yellow = Negligible;
Red = Negative;
White = the shock does not occur in the land management system.
Variables considered are 4211, 4212, 4213, 4221, 4222, 4223, 4231, 4232, 4233 (see annex 3)

The system where the land management improves the resilience to disturbances the most is Spa_1 where the different re-vegetation methods have a positive impact on both floods and torrential rainfall. Spa_1 and Spa_2 are considered the most effective combinations of management practices to increase resilience toward the disturbances that affect the management system. In both systems three land management practices are implemented, and the combination has a particularly positive effect in mitigating the effects of torrential rain falls (Spa_1) and fires (Spa_2). Interestingly, both systems have a land management practice that increases the amount of vegetation, which has a positive effect on mitigation and also recovery.

The land management practices that are least beneficial are the logging of Por_1 and Por_2. Both land management practice do not aim at improving the environment in any way, but are rather focused on the productive aspects. It has to be noted that the "*conservation logging*", the supposedly more sustainable practice, is assessed to be less beneficial to the resilience of the system, and is the only one that has an overall negative impact, while the effect of "*traditional logging*" is negligible. This is related to the fact that "conservation" logging includes leaving part of the dead material on the ground to reduce soil erosion, but this increases the fuel load and the dead material is a vehicle for spreading diseases (nematodes).

Table 14 shows what additional land management practices could be adopted to increase the resilience of the land management system to disturbances, as suggested by the local experts. While some of them are rather maintenance activities of already implemented land management practices (Spa_1, Spa_2 and Spa_3), others are autonomous land management practices, already implemented in other areas and for which detailed information is available in the WOCAT Technology database (Por_1 and Gre_1). This list of land management practices can serve as a base to improve land management and to engage in discussions with land users on how to improve the management of their land.

Study site name	*Additional management practices that could increase resilience to shocks*	*Described in the WOCAT database*
Por_1 (Varzea)	Prescribed fire Primary Strip Network System for Fuel load Management	yes yes
Por_2 (Varzea)	Prescribed fire Primary Strip Network System for Fuel load Management Post-fire forest residue mulch	yes yes yes
Spa_2 (Ayora)	Control fuel. Reduce pine dead fuel requires recurrent management of the forest Using chipped in-situ (wood and leaves) to cover the soil after a fire to reduce soil erosion	no yes
Spa_3 (Ayora)	Repeated selective clearing sometime after the implementation of the technique (e.g. 10 years)	yes
Gre_1 (Messara)	Terraces for slope and runoff reduction.	yes
Cyp_1 (Randi)	Grazing exclusion Irrigation/ water harvesting Mulching.	yes yes yes
Ita_1 (Castel Saraceno)	Combine sheep, goats and cows in order to both, prevent vegetation degradation and diversify production.	no
Spa_1 (Albatera)	Irrigation in extremely dry periods during the first years after plantation Maintenance work (e.g., of water harvesting structures) while needed	no no

Table 13. Additional land management practices that could increase the resilience of the land management system to disturbances. Variables considered are: 432a, 432b and 432c (See annex 3)

Is management resilient?

Besides the impact of land management on the resilience of the land management system, it is important to evaluate the resilience of land management practices themselves, or in other words if the benefits provided by land management are stable, and how much the effectiveness of land management practices depends on contextual factors.

The most relevant questions for this topic are included in section 4 and section 5 of the RAT. At the end of section 4, with question 4.3.1 "*What is the impact of shocks and disturbances on the effectiveness of land management?*" we investigate how each of the land management practices analyzed will react to a disturbance. In section 5.5, titled "*How does landscape influence the effectiveness of the land management practice?*" we aim to understand what we call *"spatial resilience"* or the ability of a land management practice to be beneficial in different environmental conditions. The categories for the evaluation are the following: "*Land management practice is fully effective*", "*benefits of the LM practice are reduced*", "*LM practice does not provide any benefit*", and "*LM practice has negative impacts*". The spatial resilience is evaluated against aspect /orientation and steepness of slope, as well as previous land use history. Finally we look for other variables that could influence the effectiveness of the land management practice with question 5.5.4: "*Impact of other landscape variable(s)*".

Figure 9 shows how the different land management practices react to the occurrence of a disturbance.

Study sites	*Land management practice*	*Drought*	*Fire*	*Pests/diseases*	*Torrential rainfall*	*Floods*
Por_1 (Varzea)	Post-fire conservation logging		++	++		
Por_2 (Varzea)	Post-fire traditional logging		++	++		
Spa_2 (Ayora)	Selective forest clearing to prevent large forest fires	++	+			
	Cleared strip network system (firebreaks) for fire prevention	0	0			
	Afforestation with Pinus halepensis after fire	-	-			
Spa_3 (Ayora)	Clearing of fire-prone seeder species.	++	++			
	Planting of fire resistant resprouter specie	0	-			
Gre_1 (Messara)	Grazing land afforestation with carob trees	+	+	0	+	
	Controlled grazing in spring months and tree protection	-	+	0		

	Fodder provision	+	++		++	
	Planting Carob and olive trees to prevent erosion	++	+		++	
Cyp_1 (Randi)	Carob tree protection from rats	++	0		++	
Ita_1 (Castel Saraceno)	Metallic fences to regulate grazing			+		
	Multi-specific plantation of semiarid woody species on slopes	-			0	-
	Spatially-diverse multi-specific plantation	-			+	-
Spa_1 (Albatera)	Multi-specific plantation woody species with stone walls	+			0	-

Figure 9. Effectiveness of land management practices after a shock.
Legend:
++ Land management practice is fully effective;
+ Benefits of the LM practice are reduced;
0 LM practice does not provide any benefit;
- LM practice has negative impacts.
Variables considered are 4311, 4312, 4313.

Re-vegetation practices such as "*Afforestation with Pinus halepensis after fire*" (Spa_2), the "*Planting of fire resistant resprouter species*" of Spa_3 and the 3 woody plantations of Spa_1 appear to be the most sensitive ones, probably because they rely directly on the well-being of plants to be effective. An exception is the afforestation with Carob trees (Gre_1) which are very resistant both to fire and to droughts and which will only experience a decrease in effectiveness. To the contrary, land management practices that reduce the vegetation density like logging (Por_1 and Por_2), the "*Selective forest clearing to prevent large forest fires*" and the "*Clearing of fire-prone vegetation*" (Spa_3) display only minor impacts after a disturbance. Overall, drought appears to be the disturbance that has the most impact on land management practices.
For what concerns management practices related to grazing, it appears that "*Controlled grazing in spring months and tree protection*" (Gre_1) is the most vulnerable after a drought.

Figure 10 shows the assessment of the effectiveness of the land management practices under different slope steepness and orientations. Again, the re-vegetation practices seem to be the most delicate: "*Planting Carob and olive trees to prevent erosion*" (Cyp_1), "*Planting of fire resistant resprouter species*" (Spa_3) or "*Fodder provision*" (Gre_1). To this we have to add the practices that use heavy machinery such as "*Selective forest clearing*" (Spa_2) and the "*Clearing of fire-prone seeder species*" (Spa_3), that are strongly limited by steep slopes.

Study sites	*Land management practice*	*North*	*East*	*South*	*West*	*Flat areas (0-8%)*	*Gentle slope (8-15%)*	*Moderate slope (15-30%)*	*Steep slope (> 30%)*
Por_1 (Varzea)	Post-fire conservation logging	4	4	4	4	4	4	4	4
Por_2 (Varzea)	Post-fire traditional logging	4	4	4	4	4	4	4	4
Spa_2 (Ayora)	Selective forest clearing	4	4	4	4	4	3	2	1
	Cleared strip network system	4	4	4	3	4	4	4	4
	Afforestation with Pinus halepensis after fire	4	4	2	3	4	3	2	4
Spa_3 (Ayora)	Clearing of fire-prone seeder species.	4	4	3	3	4	3	1	1
	Planting of fire resistant resprouter specie	4	4	2	3	4	4	2	4
Gre_1 (Messara)	Grazing land afforestation with carob	4	4	4	4	4	4	4	3
	Controlled grazing	4	4	4	4	4	4	4	4
Cyp_1 (Randi)	Fodder provision	4	4	4	4	3	4	2	1
	Planting Carob and olive trees to prevent erosion	4	2	2	4	3	4	2	1
	Carob tree protection from rats	4	4	4	4	4	4	4	4
Ita_1 (Castel	Metallic fences to regulate grazing	4	4	4	4	4	4	4	3
Spa_1 (Albatera)	Multi-specific plantation of s woody species	4	4	2	3	3	4	4	3
	Spatially-diverse multi-specific plantation	4	4	4	4	3	4	4	3
	Multi-specific plantation with stone walls	4	4	4	4	1	3	4	4

Figure 10. Effectiveness of land management across slopes with different orientation and steepness. Legend: (dark green) Land management practice is fully effective; (light green) Benefits of the LM practice are reduced; (yellow) LM practice does not provide any benefit; (orange) LM practice has negative impacts. Variables considered are 5531, 5532, 5533

Finally, the effectiveness of land management practices is compared against different past land uses (Figure 11). As it was said previously, configurations of the land management systems can have an impact on its state today in terms of vegetation type, soil depth and composition and others.

Study Sites	*Land management practice*	*Cropland with terraces*	*Cropland without terraces*	*Grazing land*	*Afforestati on*	*Natural vegetation /non used land*	*Burnt areas*
Por_1 (Varzea)	Post-fire conservation logging	4	4	4	4	4	4
Por_2 (Varzea)	Post-fire traditional logging	4	4	4	4	4	4
Spa_2 (Ayora)	Selective forest clearing	4	4	4	4	4	4
	Cleared strip network system	4	4	4	4	4	4
	Afforestation with Pinus halepensis after fire	4	3	4	4	4	4
Spa_3 (Ayora)	Clearing of fire-prone seeder species.	4	4	4	2	4	4
	Planting of fire resistant resprouter specie	4	4	4	4	4	3
Gre_1 (Messara)	Grazing land afforestation with carob trees	4	4	4	4	4	4
	Controlled grazing	4	4	4	4	4	4
Cyp_1 (Randi)	Fodder	4	2	4	4	4	4
	Planting Carob and olive trees to prevent erosion	4	3	4	2	2	4
	Carob tree protection from rats	4	2	4	4	4	4
Ita_1 (Castel Saraceno)	Metallic fences to regulate grazing	4	4	4	4	4	4
Spa_1 (Albatera)	Multi-specific plantation of s woody species	4	4	4	3	4	4
	Spatially-diverse multi-specific plantation	4	4	4	3	4	4
	Multi-specific plantation with stone walls	4	4	4	3	4	4

Figure 11. Effectiveness of land management across slopes with different orientation and steepness. Legend: (dark green) Land management practice is fully effective; (light green) Benefits of the LM practice are reduced; (yellow) LM practice does not provide any benefit; (orange) LM practice has negative impacts. Variables considered are 5531, 5532, 5533

It seems that most of the land management practices considered for the resilience assessment are not influenced by the land uses examined, with the exception of "*Planting Carob and olive trees to prevent* *erosion"* (Cyp_1) where the land management practice reduces its benefits if new plants have to compete with pre-existing vegetation.

Table 15 summarizes in column 3 the assessment of the spatial resilience of the land management practices, combining in one number the influence of orientation, slope steepness, and previous land use history. The maximum value (1) is obtained by the logging practices of Por_1 and Por_2, as well as by the controlled grazing, which is also independent from all factors considered. Also the clearing of fire–prone species has a low spatial resilience, because its implementation can become more difficult in steep areas or where there is a high presence of stones and outcrops in the soil.

The 4th column in Table 15 shows other factors that could prevent management to be effective. It is clear that soil conditions, and in particular the depth and the stoniness are important factor to consider when implementing a land management practice. Other factors that could reduce the effectiveness of management are related to the vegetation type (Spa_2), and the occurrence of disturbances (Por_1 and Por_2).

Study sites	Land management practice	Resilience of land management practices across different landscapes	Other environmental factors that influence LM effectiveness
Por_1 (Varzea)	Post-fire conservation logging	1.00	Fire intensity
Por_2 (Varzea)	Post-fire traditional logging	1.00	Fire intensity
Spa_2 (Ayora)	Selective forest clearing	0.89	Forest flammability Soil type
	Cleared strip network system	0.98	Forest composition and flammability
	Afforestation with Pinus halepensis after fire	0.88	Soil
Spa_3 (Ayora)	Clearing of fire-prone seeder species.	0.80	Stoniness/Outcrops Grazing
	Planting of fire resistant resprouter specie	0.89	--
Gre_1 (Messara)	Grazing land afforestation with carob trees	0.98	Altitude
	Controlled grazing	1.00	--
Cyp_1 (Randi)	Fodder	0.86	Soil composition
	Planting Carob and olive trees to prevent erosion	0.73	Soil depth
	Carob tree protection from rats	0.96	--
Ita_1 (Castel Saraceno)	Metallic fences to regulate grazing	0.98	Soil depth

Spa_1 (Albatera)	Multi-specific plantation of s woody species	0.89	Soil depth
	Spatially-diverse multi-specific plantation	0.95	Soil depth
	Multi-specific plantation with stone walls	0.91	Soil depth

Table 14. Overall spatial resilience of different land management practices and other factors that could influence the effectiveness of management. Variables considered are 5531, 5532, 5533

5. Discussion and conclusion

5.1. Application of the Resilience Assessment Tool (RAT)

5.1.1. Identification of the land management systems

Resilience can be assessed properly only if we define clearly what the system under investigation is. In the scientific literature, scientists often refer to the resilience of an "ecosystem" (Folke et al., 2004; Kazanis & Arianoutsou, n.d.) or specific elements of the natural environment such as coral reefs (Hughes, Linares, Dakos, van de Leemput, & van Nes, 2013), resprouter shrub communities (J. Keeley, 1986) and others. In practical terms most studies are based on a selection of sampling points within an area of homogeneous features in terms of vegetation, soil or other characteristics (Lavorel, McIntyre, & Grigulis, 1999). In other cases the selection of the area to study is based on natural boundaries like a catchment (Mayor, Bautista, Llovet, & Bellot, 2007) or a forest stand (Moya, De las Heras, López-Serrano, & Leone, 2008).

We think that both approaches, while useful in practice for collecting scientific data, do not fit for a land management study: The approach by sampling points disregards many systemic relationships between parts of the system, and ultimately reduces the usability of the results beyond the sampling points. The use of natural boundaries disregards important factors for management, such as land tenure and regulatory constraints that have an important influence on the applicability of land management practices. Few authors refer to units that integrate human factors such as land parcels (Bestelmeyer, Herrick, Brown, Trujillo, & Havstad, 2004), or households (Choptiany, Graub, Phillips, Colozza, & Dixon, 2015), but they seem to give less importance to the natural environment.

Our definition of "land management systems" as an area that is managed with a specific set of land management practices takes into consideration both the natural and the human environment, and is flexible enough to be adapted to very different situations.

Identifying the boundaries of the land management system, although requiring some preliminary work has been relatively easy in all study sites. However, problems arose in depopulated areas where the land use and the land management is unstable: for example public grazing land near privately owned pastures, used only in summer or in exceptional situations, should it be considered part of the shepherd's land management system? In other cases, some small portions of land within a land management system have a completely different vegetation composition and thus would require to be analyzed on their own. In all the cases, we relied on the criteria of what land management practices were implemented and who are the land managers.

Moreover, the land management is not always easily detectable on the field; it requires repeated exchanges with stakeholders and in-depth investigation. Thanks to the work done for deliverable 7.1, this information was already available for the implementation of the RAT within the CASCADE study sites.

5.1.2. Assessment of the objectives of management and of the state of the land management system

The questions of section 2 of the RAT and in the EPQ aim at understanding what do land users want from a certain area and how they evaluate the provision of ecosystem services and the state of the environment.

Understanding the “scope” of the land management system is essential to provide land management solutions compatible with the land managers livelihood strategies, and the participation of local people in this process is at the center of many recent studies (Dixon & Stringer, 2015; Reed, Dougill, & Baker, 2008; Schwilch et al., 2012). In the RAT we have decided not to discuss only about ecosystem services, but to investigate also the perception of several environmental properties. Besides providing information on the state of the land management system and the perception of land users, it could facilitate drawing links with studies that are being performed within CASCADE, and could serve to orientate future scientific investigation in the study sites on matters that are relevant for local people.

Submitting a questionnaire directly to stakeholders, instead of collecting this information through an expert, allows capturing different perceptions and simplifies the quantification of results. However, in some cases, it was difficult to reach an adequate number of stakeholders having some relation with the studied land management system.

Moreover, the specific state at which the system is found at the moment of responding might have influenced the responses: the evaluation in the Portuguese land management systems (Por_1 and Por_2) was carried out within one year from a wildfire. This has probably influenced the very negative results of the evaluation. Previous studies have shown how perception about land management and the environment changes with time since the fire (Valente et al., 2015). This might not be negative, as the results are closer to the “real” situation at the moment of evaluation, but reduces the validity of the results in the long term played an important role in evolution.

The evaluation of the provision of ecosystem services was overall negative in all the study sites, and was not necessarily in agreement with the evaluation of the environmental properties. The most striking example is Ita_1 that was considered healthy by stakeholders in all the categories of environmental properties, while the provision of ecosystem services was considered "completely degraded". This appears to signal that there is a mismatch between the current configuration of the environment and the desired land uses or that the benefits provided by the environment are hindered by contextual factors (e.g. low market prices of milk and cheese produced on the land management system, for the specific case). The opposite case is Spa_2, where the provision of ecosystem services is considered satisfactory, while the environment is considered degraded. This suggests that the environment of the land management system is in a healthy state, but much degraded and probably close to the tipping point.

Spain 2 and 3 confirm this hypothesis: The vegetation of Spa_2 is an established pine forest, the healthy stable state of the ecosystem in the area, while Spa_3 is the shrubland resulting from failed forest regeneration after fire. Spa_2 provides the demanded ecosystem services such as soil stabilization, wood production and CO2 absorption. It is however at high risk of fire, and regeneration is not certain. Spa_3 does not provide any ecosystem service considered being important; but thanks to the specific management that involved selecting and planting resprouter species is more diverse than other shrubland formation in the area, and regeneration after fire is more likely to occur.

5.1.3. Pressures and factors enabling management

The list of pressures and factors enabling management are adapted from the WOCAT method, based upon the information gathered through the exchanges with stakeholders. There could be some overlapping between pressures and disturbances: e.g. “Deforestation” can be caused by fire, or “Over-abstraction of water” can be driven by drought. However, this is related to the definition of a disturbance. In resilience and regime shift studies, disturbances are considered external from the system and as analyzed as such (David D Briske et al., 2010); however, ecologists agree that small disturbances are to be considered a part of the ecosystem and contribute to its equilibrium and its gradual evolution (Keeley, Pausas, Rundel, Bond, & Bradstock, 2011)

Identifying the factors that can influence management is a key aspect to assess the viability of land management practices, and can provide important information to administrators responsible for land use planning or designing programs to support the sustainability of land uses.

In particular, 4 out of 8 study sites indicate “*market prices of goods produced on the land*” and “*subsidies for nature conservation*” within the 3 most important enabling factors. This suggests that combining public funding for sustainable land management while maintaining the productivity of the land is the best way to improve sustainability and resilience of socio-ecological systems, in accordance with the concept of “*multifunctional agriculture*” (Renting et al., 2009).

Very little quantitative information was available to forecast the future evolution of these factors, and we had to rely for the large part on the opinion of land users. This supports the participatory approach chosen for this study, because the information not available from scientific literature and /or measured data can be presumed from land user and land managers experience.

5.1.4. Disturbances affecting the system and permanent changes

Assessing the disturbances that affect the system, the thresholds and their consequences are a crucial part of studying resilience.

The fact that all assessments indicated more than one disturbance affecting their land management system, and 6 out of 8 more than one potentially inducing permanent changes to the system, shows the importance of not focusing on one single disturbance but of enlarging the scope of the studies that deal with resilience and regime shifts. This is a topic that has been investigated by some researchers (Buma & Wessman, 2011), The description of the thresholds is particularly interesting, as very few information is available in the scientific literature, and even less indications are practically useful, despite recent efforts (D D Briske & Fuhlendorf, 2013; Walker & Meyers, 2004).

We state that on this topic the combination of local and scientific knowledge is particularly interesting, as it can provide information that is important locally and can allow to better understanding the processes and important variables in general terms. For example, the fact that 2 study sites indicated using the land after a disturbance as a factor leading to permanent changes, suggests that scientists should not focus solely on the disturbance, but they should also investigate the state of the system at the moment of disturbance and immediately afterwards. This could increase our ability to forecast regime shifts and to identify new indicators of impending regime shifts that could be practically useful on the ground.

Moreover, identifying probable changes in ecosystem services after an above-threshold disturbance allows to better forecast the impact on the system, and to understand if a regime shift in the environment could turn into a catastrophic shift for the socio-ecological system (Walker & Meyers, 2004).

In particular, 3 out of 8 study sites indicated that a permanent change would lead to “decreased protection from risks”, giving a concrete example of how hysteresis could display in those systems. In general, a permanent change in the vegetation has important consequences for soil erosion. In systems affected by fire, an above threshold fire (in terms of intensity and frequency) would change the composition of vegetation to more fire-prone one, leading to vicious circle of increased disturbances. This phenomenon has been explored in the literature (Knox & Clarke, 2012), and identifying it on the ground could help designing better land management strategies to increase resilience of these land management systems.

5.1.5. Impact of land management on the resilience to disturbances

The evaluation of the impact of land management had to take into account the wide variety of disturbances and land management practices within the CASCADE study sites. Moreover, the information sources on this topic were very different: some systems (e.g. Spa_1) had been previously investigated with scientific means, in others (Cyp_1, Gre_1) we had to rely only on the knowledge of land users and of the expert who compiled the assessment.

Moreover, the existing indicators for resilience assessment (are not flexible enough to be adapted to different contexts, and the general indicators related to regime shifts (Guttal & Jayaprakash, 2008; Scheffer et al., 2009) require a vast amount of data and are too complex to be used in a participatory assessment such as the RAT.

The investigation of the impact of land management practices allows to map the influence of land management on resilience, and has delivered some unexpected results: The land management of Por_1, which was envisaged to contribute particularly to sustainability, was revealed to have rather negative impacts on the resilience of the system.

With the exception of revegetation practices such as "M*ultispecific woody plantation*" (Spa_1) and "*Afforestation with Pinus halepensis*" (Spa_2), no other practice has a positive effect on resilience against droughts. Controlled grazing (Gre_1, Cyp_1), often considered to be the best possible land management practice in pastures, revealed to have some trade-offs, in its impact on resilience to different disturbances.

More in general, only the "*clearing of fire-prone vegetation*" was assessed to have all round positive effects, while all the other land management practices have positive impacts on one disturbance, but negligible or negative effects on others. Thus, combining multiple land management practices seems the most reliable strategy to increase the overall resilience of a system. In general, land management practices are not effective in preventing disturbances.

5.1.6. Resilience of land management practices

Studying the resilience of land management practices allows to understand how much land users can rely on the benefits provided by a certain land management practice (resilience to disturbances) and where the land management practices could be implemented with positive results (spatial resilience). This leads to understand better the potential of each land management practice and could decrease failures in the implementation of these land management practices.

The evaluation of the impact of disturbances proved difficult because in some cases the difference between the impact of the disturbance on the land management practice and on the system was difficult to distinguish, stressing the need to restructure that part of the analysis.

The assessment of the spatial resilience shows how delicate the revegetation practices are, and how much the landscape should be taken into consideration before planning those interventions.
Moreover, all the study sites have reported that soil characteristics (type of soil, rock content, depth) have an important influence on the effectiveness of land management practices.

5.1.7. Conclusions

The Resilience Assessment Tool succeeded in the objective of collecting and organizing relevant information to assess the resilience of the study sites. It served as a platform to combine lay and scientific knowledge in a systematic and standardized way.
The results of the RAT presented here, together with inputs from study site partners, local land managers and the description of the land management practices trough the WOCAT questionnaire (see deliverable 7.1) will constitute the backbone of the guidance for best practices at the center of deliverable 7.3.

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