How does land management contribute to the resilience of mediterranean forests and rangelands? A participatory assessment

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Full title:

How does land management contribute to the resilience of Mediterranean forests and rangelands? A participatory assessment

Short title:

PARTICIPATORY ASSESSMENT OF RESILIENCE IN MEDITERRANEAN ECOSYSTEMS

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1. Abstract

In Mediterranean forests and rangelands, the supply of important ecosystem services can decrease or cease as a consequence of disturbances and climatic oscillations. Land managers can sometimes prevent or mitigate the negative effects of disturbances through appropriate land management choices. In this study, we assess the contribution of land management practices (LMPs) to the resilience of 8 Mediterranean forests and rangelands to~~against~~ multiple disturbances. The study uses a transdisciplinary approach, involving scientists, land managers, and local administrators. Data about disturbances, ecosystem services, the role of LMPs, and the resistance of LMPs~~ resistance~~ to disturbances are combined using a semi- quantitative index, and analysed to evaluate how the LMPs implemented are suited to the disturbances affecting each study site. Our results indicate that the practices analysed are particularly effective against wildfires and torrential rainfalls. However, droughts are more difficult to address and the practices were heavily affected by their occurrence. Tree planting appears to be highly affected by disturbances. Practices that selectively reduce the amount of vegetation appear to be beneficial in fostering recovery of ecosystems. Our assessment also suggests that it is particularly difficult to increase resilience to drought~~s~~ and fire~~s~~ simultaneously. Practices that aimed to mitigate the impact of land use did not always prove valuable in terms of resilience. Finally, study sites that included efforts to address disturbances in their management objectives also displayed practices making the biggest contribution to resilience.

2. Introduction

Dry Mediterranean ecosystems have a long history of exposure to climatic oscillations and land use changes (Alados et al., 2011; Blondel, 2006; Zdruli, 2014). However, land degradation caused by disturbances affects the supply of ecosystem services, sometimes irreversibly (Baeza *et al.*, 2007; Mayor *et al.*, 2016; Santana *et al.*, 2014, Bowman *et al.*, 2016), with negative consequences for the well-being of land users and for the socio-ecological system at larger scale. For example, low Mediterranean woodlands can shift to shrublands after repeated or intense fires (Baeza *et al.*, 2007; Lozano *et al.*, 2012; Pausas *et al.*, 2008). Droughts can trigger shrub encroachment in grass-dominated pastures, changing not only the economic value of the land but also the water cycle at a larger scale (Caldeira *et al.*, 2015; Folke *et al.*, 2004).

Resilience (Holling, 1973), defined as the capacity of a system to withstand or recover from disturbances, is an important feature of ecosystems and a highly debated topic in recent ecological and socioecological research (Bérard et al., 2011; Bernués et al., 2011; Elmqvist et al., 2003; Kizos et al., 2014; Knox & Clarke, 2012). Since its first definition, resilience, or lack of, has been related to the inner complexity of systems (Cabel & Oelofse, 2012; Gunderson, 2000; Walker & Meyers, 2004); it is the result of the multiple interactions between different processes, and their feedbacks. Resilience, however, can be significantly modified by human activities and their interactions with disturbance events and natural processes (Sporton, 2007). Current scientific knowledge does not view resilience as a static property; ecosystems can have multiple equilibrium states (or configurations), each of which has its own stability landscape (Gunderson, 2000; Scheffer *et al.*, 2009; Walker *et al.*, 2004). Moreover, according to the panarchy framework (Walker *et al.*, 2004), each system evolves as a result of the interactions occurring at multiple scales (Davoudi *et al.*, 2012; Groffman *et al.*, 2006). Resilience thus contributes to the long-term sustainability of socioecological systems, allowing for recovery, adaptation, and transformation in the face of shocks and sudden changes. (Domptail *et al.*, 2013)

Land management is defined as the specific combination of practices through which land is used (Hurni, 2000). It is different from “land use”, which is the objective or purpose for which land management is implemented (FAO & UNEP, 1999) and refers to broader categories such as cropland, grazing land, or forest land. Land management practices (LMPs) are normally implemented to increase productivity of the land or to reduce degradation associated with human activities. Through land management, humans can also change the resilience of the ecosystems (Alados *et al.*, 2011; Crépin *et al.*, 2012; Folke *et al.*, 2010; Jucker Riva *et al.*, 2016): Successful LMPs can make it more difficult for the ecosystem to reach a critical threshold (e.g. reducing the frequency of fires in a forest area prevents a shift to shrub-dominated vegetation). Further, LMPs can reduce the impact of disturbances (e.g. increasing vegetation reduces water loss during droughts) or directly move the system towards a more stable configuration (e.g. afforestation after a fire in case of failed spontaneous recovery). Adapting LMPs to increase resilience to disturbances – so-called “resilience thinking” (Plummer & Armitage, 2007; Rist & Moen, 2013) – is in most cases preferable to changing the land use as a whole, which would require great efforts and have highly uncertain ecological and socio-economic impacts, possibly affecting the livelihoods of local communities. While a wide set of methods and tools exist to assess how LMPs affect sustainability of land use (Bunning *et al.*, 2011; ELD Initiative, 2015; WOCAT, 2008), there are few studies that focus on how LMPs influence the resilience of ecosystems. The few such studies that exist are very case specific (e.g. valid only for a certain event or area) or context specific (e.g. valid only for a certain type of disturbance). Thus, despite efforts to operationalize the resilience concept (Bergamini *et al.*, 2013; Mitchell *et al.*, 2014; Plummer & Armitage, 2007; Resilience Alliance, 2010), it remains difficult to identify practical solutions for land managers, as the value of a certain LMP may vary greatly if we consider only the degradation caused by land use or if we include increasing resilience to disturbances within the management objectives (Jucker Riva *et al.*, 2016). Therefore, there is a need to increase our understanding of how LMPs can contribute to resilience. There is also a need for practical methodologies to evaluate the role of land management in order to avoid a decrease in resilience, achieve cost-effective management strategies, and thus increase long-term sustainability.

LMPs are often difficult to assess, as the impact of practices can be extremely diverse even within the same area, depending on the timing, location, and conditions of the environment in which they are implemented (Liniger *et al.*, 2017; Schwilch *et al.*, 2011). Systematic information on the application and impacts of practices is~~are~~ often lacking and difficult to compare. Moreover, the value of LMPs also depends on their economic sustainability and cultural acceptability (Hurni, 2000); thus, the perception of different actors is extremely relevant. Co-creation of knowledge, also known as transdisciplinary research (Hadorn *et al.*, 2006; Mauser *et al.*, 2013; Pohl & Hirsch Hadorn, 2007; Regeer & Bunders, 2009), is an innovative approach to address complex environmental issues that stems from the idea that multiple types of knowledge exist beyond conventional science, and that they can be combined (Reed *et al.*, 2008; Regeer & Bunders, 2009; Tàbara & Chabay, 2013). It consists of a process in which scientists from different disciplines and stakeholders actively exchange and combine information on a certain topic. This approach has been applied successfully to the assessment of LMPs in multiple ecosystems around the globe (Liniger *et al.*, 2013; Liniger & Schwilch, 2002; Pohl *et al.*, 2010; Schneider & Rist, 2014; Schwilch *et al.*, 2009, 2012, 2013). Not only is the perception of stakeholders considered in the assessment, but also their knowledge and experience about the land is used to contextualize data and fill information gaps that may arise during the assessment. This knowledge co-creation approach is coherent with recent approaches to resilience studies (Bergamini *et al.*, 2013; O’Connell *et al.*, ~~D., Abel,~~

~~N., Grigg~~
~~, N.,~~

Maru, Y., Butler, J., Cowie, A., Stone-Jovicich, S., Walker, B., Wise & Ruhweza, A., Pearson, L., Ryan, P., Stafford Smith, 2016; Plummer & Armitage, 2007; Rist & Moen, 2013; Sporton, 2007; Walker *et al.*, 2010): the focus is on gathering and combining existing knowledge (Resilience Alliance, 2010), using methodologies based on self-evaluation (Choptiany *et al.*, 2016), participation (Cumming *et al.*, 2005; Dixon & Stringer, 2015), and/or active exchange between scientists and land managers (Domptail *et al.*, 2013; Mitchell *et al.*, 2014). Finally, the approach is often integrative and interdisciplinary (Cabel & Oelofse, 2012; Sporton, 2007).

Our study evaluates the contribution of LMPs to the resilience of six Mediterranean rangelands and forests affected by disturbances, using as input information gathered through a knowledge co-creation process. Results are analysed to evaluate whether the combination of LMPs implemented in each study site is appropriate to coherent with the disturbances affecting the each system, and to obtain a general indication on how different types of practices can contribute to the resilience of natural and semi-natural ecosystems.

3. Methodology

In this study, we focus on the resilience of semi-natural Mediterranean ecosystems in relation to multiple disturbances that can reduce the provision of ecosystem services, the so-called "specified resilience" (Folke *et al.*, 2010) or "resilience of what to what" (Carpenter *et al.*, 2001). Each study site presents a different combination of LMPs and disturbances. Furthermore the amount/type of available scientific knowledge (e.g. literature or measurements) versus stakeholder knowledge varied. This means that we could not define in advance specific indicators to assess the contribution of LMPs to the resilience of the ecosystem. In order to have a systematic and reproducible methodology that could be implemented across different study sites, we chose to define a series of questions to be answered by a team of researchers, by consulting available scientific knowledge, -and by discussionng with stakeholders. Results concerning the role of LMPs were then translated into a semi-quantitative evaluation and combined in a single evaluation using a mathematical index.

In a preliminary phase of the research, we described a list of promising and common LMPs in the different study sites using the WOCAT technology questionnaire (WOCAT, 2008), and identified the respective land management systems, i.e. the land managed through a specific set of LMPs, by the same group of actors for a specific purpose. This allowed us to unambiguously identify the area of interest, the set of management practices, and the actors involved in the management that constituted the pool of stakeholders that were invited to participate in the assessment. Moreover, we proceeded to design the questionnaire using an iterative and participatory process (Method S1). The questionnaire (named Resilience Assessment Tool, Method S2) includes a characterization of the state of the system (e.g. state of most important ecosystem services and ecological features), type of disturbances and their impact on ecosystem services, role of land management in modulating the negative impact of disturbances, and external factors that could influence the dynamic of the land management system (e.g. policies, socio-economic context, climatic trends). Answers are provided by choosing an option on a pre-defined list and adding details and comments in free text.

The first step of the implementation phase centred on engaging a comprehensive pool of stakeholders in participating in the assessment. To do so, we proceeded in a cascade way from the stakeholders that were land managers, and local administrators directly involved in the land management. Overall, 57 already in contact with the researchers, from the preliminary phase of the research, to all the land users, land managers, and local administrators directly involved in the land management. Overall, 57 stakeholders (between three and 12 stakeholders per site) agreed to participate in workshops together with one or two researchers per study site. Information resulting from the first workshop was complemented and crosschecked with data obtained from local monitoring programmes, scientific literature, and direct observation by participating scientists. Inconsistencies and knowledge gaps were addressed by again consulting the stakeholders and local experts. Results were subsequently reviewed by an external group of researchers to ensure that complete and systematic answers were provided to each question. A complete list of sources used is presented in table S3.

After completing and reviewing all the questionnaires, we ranked the answers to questions closely related to the contribution of LMPs to the resilience of the land management systems we studied. These questions related to~~were~~: (1) the impact of disturbances on important ecosystem services; (2) the influence of LMPs~~land management~~ in preventing a disturbance, mitigating its negative effect, or fostering recovery; and (3) the resistance of a LMP ~~land management practice~~ to a disturbance, i.e. the extent to which ~~if~~ the effectiveness of a LMP~~land management practice~~ changes after the occurrence of a disturbance. For each question, answers were provided in the form of a selection from a pre-defined, pre-ranked list of possibilities ~~to choose from~~, and an open answer to justify the choice and provide further details for interpretation. These three evaluations were merged into a single resilience index as explained in detail in the following paragraphs. The values obtained refer to the contribution of each LMP to the resilience of the land management system to~~against~~ a specific disturbance. ~~These values are presented hereafter averaged per land management system, to evaluate the suitability of the land management to the disturbances occurring in the area, or per type of practice to gain cross-site indications on the role of different practices with regards to resilience.~~

3.1. Impact of disturbances

To assess the impact of disturbances on ecosystem services, we first identified which ecosystem services are considered important by land managers. We relied upon the perception of stakeholders participating in the assessment, using a predefined list of ecosystem services derived from the WOCAT Technology questionnaire (WOCAT, 2008) and widely used for this kind of participatory assessment. Then, using both scientific and lay knowledge, we identified the ecosystem services that are likely to be degraded by each disturbance. The impact of each disturbance D_j was quantified through equation 1:

$$D_j = ES_j/ES \qquad \text{(Eq. 1)}$$

where ES is the number of ecosystems services identified as important by stakeholders, and ES_j is the number of ecosystem services affected by the j^{th} disturbance (among those services considered important). Equation 1 gives a number between 0 (no impact on important services) to 1 (all important services are affected).

3.2. Influence ~~Role~~ of L~~l~~and M~~m~~anagement Practices

By combining the information provided by the stakeholders with the scientific data available, we evaluated the influence of each land management practice in (a) preventing a disturbance; (b) mitigating the negative impacts of a disturbance on the land management system, or; (c) fostering recovery. This evaluation was conducted by answering the following questions: “*Does the LMP~~land management~~ reduce*
“*Does the land management help recover/ restore the system after a disturbance?”*. The answers were

the occurrence of disturbances?"; "*Does the LMP ~~land management~~ mitigate the negative effect of disturbances?";*

"*Does the land management help recover/ restore the system after a disturbance?".* The answers were transformed into values, derived from the pre-ranked list of five possibilities, ranging between -2 (degradation is heavily increased or recovery is prevented) and 2 (degradation is minimal or recovery is ensured). We combined the values related to prevention, mitigation, and recovery to obtain a single number indicating the direct influence of a LMP~~land management~~ on resilience of the system. Considering that prevention, mitigation, and restoration strategies are equally weighted, the influence of a LMP~~land management practice~~ *(I)* on the disturbance is calculated as per equation 2:

$$I_{i,j} = p_{i,j} + m_{i,j} + v_{i,j} \qquad \text{(Eq. 2)}$$

where $I_{i,j}$ is the influence of the ith LMP on the jth disturbance identified for the land management system, and $p_{i,j}$, $m_{i,j}$ and v~~r~~$_{i,j}$ are, respectively, the influence of the ith LMP in preventing, mitigating, or assisting recovery from the jth disturbance. Equation 2 results in a numerical value between -6 to 6, where negative values correspond to net negative effects of land management in relation to a disturbance (increase in occurrence or in the related degradation), 0 corresponds to a negligible effect or a balanced effect of positive and negative effects, and positive values indicate a beneficial net effect of the practice.

We also investigated the resistance of ~~how~~ LMPs ~~resist~~ to ~~a~~ disturbance, i.e. any change in ~~if~~ their effectiveness following the ~~decreases after a~~ disturbance, using both scientific knowledge and stakeholder perception. This is an important and often overlooked aspect of resilience, ~~.~~particularly ~~Even more so~~ for semi-natural ecosystems that are often of low economic value: in such cases, investments in land management are limited, especially in maintaining a practice.
The resistance $r_{i,j}$ of a practice *i* to a disturbance *j* was assessed as a penalty to the influence *I* on a point scale from 0 (the practice is as effective after as before the disturbance) to 3 (the effectiveness of the practice is negatively affected by the disturbance, leading to increased degradation).

3.3. Overall resilience assessment

Finally, we combined the impact of disturbances ~~D~~,D_j~~,~~ the influence of LMPs~~land management~~ $I_{i,j}$, and the reaction of practices $r_{i,j}$ in an index using Equation 3, considering that $I_{i,j}$ cannot be below the maximum negative effect of the influence of land management:

$$R_{i,j} = D_j(I_{i,j} - r_{i,j})/k \qquad (3)$$

Where the value of *k* is 6, when $-6 \leq (I_{i,j} - r_{i,j}) \leq 6$, or 9 when $-6 > (I_{i,j} - r_{i,j}) > 6$. Eq. 3 results in a value between -1 and 1, where ~~all~~ negative values indicate that the practice has a detrimental effect on resilience, 0 indicates ~~to~~ a null or balanced effect, and ~~all~~ positive values indicate a positive contribution of the LMP~~land management~~ to resilience. ~~These values were calculated for each practice separately, considering only the effects of that specific practice on the ecosystems in relation to the environment.~~

3.4. Study sites

Our study focuses on eight sites in five countries in southern Europe (figure 1), where regime shifts have occurred or are likely to occur in the near future, due to anthropogenic or climate pressure. They are semi-natural ecosystems, dominated by Mediterranean forests and shrublands, but with a long history of land animal farming in the shrub-dominated areas (Ita_1, Gre_1, and Cyp_1), and wood production in the use that includes cropping. They are characterized by a variety of climatic conditions, from humid (Por_1 and Por_2) to sub-humid (Spa_2, Spa_3, Ita_1, Gre_1) and semi-arid (Spa_1, Cyp_2). All study sites except Spa_1 (Restored shrubland) and Spa_3 (Diversified shrubland) are still used for production:

animal farming in the shrub-dominated areas (Ita_1, Gre_1, and Cyp_1), and wood production in the others (Por_1 and Por_2, and Spa_2 to lesser degree). All the study sites are affected by disturbances that have generated or are likely to generate long-term changes in the ecosystem, decreasing the supply of ecosystem services. All LMPs identified had been implemented for a minimum of 10 years before this study began.

Insert table 1

Insert figure 1

Another difference among the study sites is related to the respective main objectives of land management. These range from maximizing productivity (Por_2 *Traditional logging*) to reducing the impact of land use (Por_1 *Conservation logging*, Cyp_1 *Extensive grazing*) or restoring the ecological or productive value of the land (Spa_1 *Restored shrubland*, Spa_2 *Restored forest*, Gre_1 *Silvopastoral system*). Among their management objectives, three of the land management systems specifically include dealing with disturbances: Spa_3 *Diversified shrubland*, Ita_1 *Seasonal pasture* and, at least in part, Spa_2 *Restored forest*.

4. Results

Throughout the eight study sites we identified a total of 16 LMPs (table 2) that were implemented prior to our study, either in combination (five study sites) or alone (three study sites). To extrapolate general indications and compare the contribution of LMPs to resilience across the sites, we grouped them according to the type of practical actions involved in each practice (table 2). Detailed description of land management practices is presented in table S4.

Insert table 2

Clearing of vegetation is aimed at reducing the biomass in fire prone areas. When implemented in forests, the wood extracted can be used for production. *Grazing management* focuses on regulating the access of animals that graze in a certain area throughout the year (Ita_1) or in particularly vulnerable periods (Gre_1). *Planting of shrubs* is a restoration practice for degraded areas, aimed at increasing vegetation cover and thereby reducing soil erosion, increasing fertility, and triggering the natural evolution of the ecosystem. *Planting of trees* is used both in forest areas (Spa_2) and in rangelands (Gre_1, Cyp_1) as a restoration measure. Finally, under *Other,* we classified two practices used in Cyprus, *Carob tree protection from rats* and *Fodder provision to animals during summer*, to mitigate degradation caused by grazing and pests.

4.1. Disturbances and impact on the supply of ecosystem services

The first step ~~of the analysis, functional to~~in evaluating the impact of disturbances in a way compatible with the perception of stakeholders~~,~~ focused on identifying the most important ecosystem services (table 3).)

Insert table 3

In half of the study sites, both “productive” and “ecological” services were indicated as valuable, while in only two of them no productive services were deemed valuable. Among the ecological services, “reduced erosion” is the most frequently indicated (six out of eight study sites), followed by “above-ground biodiversity" (four out of eight) and "protection from extreme events". Sociocultural services are the ones least considered, with no study site indicating both recreational and cultural services.

Having identified the most important ecosystem services, we evaluated how each disturbance could affect them using eq. 1 (table 4).

Insert table 4

In seven out of eight study sites, more than one disturbance was reported as likely to decrease the provision of important ecosystem services. The disturbances most commonly reported being also the most impacting: droughts and wildfires. *Wildfire* affects not only the forest systems but also the pastoral ones. Exceptions include *Restored shrubland* (Spa_1) and *Seasonal pasture* (Ita_1). The second most commonly reported disturbance is *drought*, affecting five of the eight land management systems. Third are outbreaks of *pests and diseases*, including plant diseases (e.g. nematodes and Tomicus beetles in forests), animal diseases (in grazing systems), but also animal pests: Ita_1 pastures are affected by wild boar that disrupt the grass layer, Cyp_1 shrublands are affected by brown rats, which attack the carob trees, increasing their mortality.

4.2. Influence ~~Role~~ of L~~l~~and M~~m~~anagement P~~p~~ractices on disturbances

The second step in assessing ~~functional to assess~~ the contribution of LMPs to the resilience of forest and rangeland consists in evaluating the influence of LMPs on the system when a disturbance occurs, and how the LMPs are affected by the disturbance. The results of both evaluations are presented in figure 2.

Insert figure 2

Most LMPs assessed have a positive influence on the disturbances studied (i.e. they reduce the land degradation caused by the disturbance), with the exception of *Grazing management,* which was the only one assessed to have a negative influence on resilience (to drought). All the practices appear to have very different levels of influence and resistance depending on the disturbance considered. In particular, *grazing management ~~type practices~~* practices were considered *positive and resistant* only in relation to pests and diseases, *negative but resistant* in relation to droughts, and *positive but not resistant* in relation to fires. *Clearing of vegetation* was judged to be positive not only against wildfires and pests and diseases but also in relation to droughts. *Planting of trees* was judged *positive and resistant* in relation to floods, but *not resistant* in relation to droughts and scarcely resistant to fires. Similarly, *shrub planting* was assessed ~~evaluated~~ to have a positive effect on the ecosystem's resilience to fire~~s,~~ and, to a lesser degree, torrential rainfall, but negative effects on resilience to ~~affected heavily by~~ drought~~s~~ and~~,~~ flood~~s~~. ~~and to a lesser degree by torrential rainfalls.~~

Our interpretation of the negative influence scored by ~~the~~ *grazing management* ~~types of~~ practices is that these increase grazing pressure on some areas, reducing the vegetation cover and thus amplifying the effects of drought. The highly variable scores obtained by the same type of practice in relation to different disturbances suggests that a combination of different practices is needed to tackle the full spectrum of disturbances that can harm an ecosystem. Practices belonging to the *planting of trees* type were considered *not resistant* to droughts and fires. This casts doubt over the long-term effectiveness of this type of practice when implemented in drylands that are frequently affected by those disturbances. *Clearing of vegetation* scored high values against multiple disturbances. This is related to the fact that a selective and partial clearing of vegetation favours the growth of the remaining plants and reduces the competition for water among individuals, which are factors that favour recovery of ecosystems in a wide variety of situations. If we consider the values in figure 2 by disturbance type (colour), our data suggests that impacts of drought are very difficult to reduce (average influence of all practices against drought is close to 0). By contrast, the practices assessed seem to have a rather positive influence on reducing the degradation related with wildfires and torrential rainfalls (average influence close to 3).

4.3. Overall contribution of land management practices (LMPs) to the resilience to disturbances

Having assessed the impact of disturbances on the land management system and the influence~~role~~ of LMPs when a disturbance strikes, we can now evaluate the overall contribution of LMPs to the resilience of the land management system using eq. 3 (table 5 and figure 3.)

Insert table 5

Insert figure 3

Almost all the practices assessed had an overall positive impact on the resilience of the land management systems in which they were implemented. However, in six out of eight study sites, some LMPs had a ~~the land management~~ ~~showed some~~ negative impact~~s~~ on resilience. Among the forest systems, it appears that the LMPs of the *Restored forest* (Spa_2) contribute the most to the resilience of the system. However, the *Afforestation with P. halepensis* (resilience contribution value -0.33 against fire and -0.11 against drought~~s~~) appears to have a negative role. The removal of the vegetation under *Traditional logging* has a ~~positive~~ neutral effect in relation to ~~these disturbances~~fire, ~~especially if~~ compared to the negative effect of *Conservation logging*. In rangeland systems, the *Fences* adopted in the Italian study site appear to be very effective in increasing resilience. In terms of resilience against fire, *Diversified shrubland* in Spain, where selective cutting and planting of fire resilient species was applied, scores highest in the study. However, it scores lowest if we consider only the contribution of land management to resilience against drought.

In our interpretation, the high scores of the *Restored forest* (Spa_2) and *Seasonal pastures* (Ita_1) is related to the fact that the practices implemented aim directly at reducing the impact of the most relevant disturbances; in other words, the land management strategy addresses the disturbance directly. The detrimental influence of the *Conservation logging* is particularly interesting: the dead woody material left on the ground reduces soil erosion by rain, but it also increases the chances of both fire and disease outbreaks, reducing the resilience of the system. *Carrob afforestation* scores a higher value in the *Sylvopastoral system* (Gre_1) compared to *Extensive grazing (Cyp_1).* This is related to a different evaluation with regards to its contribution to resilience against fire: in Cyprus, the average biomass density of the shrublands is much lower, and so planting carob could increase the amount and continuity of fuel present; in Greece, the fuel amount and connectivity of vegetation are higher, and so the presence of carob does not further increase the risk of fire. If we consider the average value per land management system (figure 3), our analysis appears to indicate that the higher the number of disturbances affecting a system, the less positive the contribution of LMPs to resilience.

5. Discussion

5.1. Methodology

A synthetic assessment of resilience is challenging because resilience is an emergent property, therefore it is influenced by multiple processes that are difficult to capture in a single evaluation (Domptail *et al.*, 2013; Gunderson, 2000). Furthermore, different perceptions are involved in land management assessments, adding to the complexity of understanding resilience. Complex evaluations are however difficult to communicate and use, and reliance on simplified indices is a widely acknowledged technique in applied research projects (Costantini *et al.*, 2016; Helldén & Tottrup, 2008; Mcdonagh *et al.*, (n.d.); Mumby *et al.*, 2014; Pyke *et al.*, 2013). Throughout our study we had to necessarily navigate between opposite needs: to generalize to obtain a usable methodology and results that would be relevant beyond the specific case, to contextualize in order to have a meaningful assessment. Generalization was obtained by framing common questions and pre-defined answers, that could be answered through both scientific and stakeholder knowledge, by cross-site comparison of results and by grouping the LMPs by type. Contextualization was obtained by considering the land management system, including stakeholder perception and knowledge, and focusing on specific ecosystem services.

A crucial methodological choice was to restrict the number of stakeholders to those with a tangible influence on the land management of each study site. In some cases, this meant that the number of people consulted in one study site (Por_2, *Traditional logging*) was limited to four. With such a low number of stakeholders the results may not be representative for the greater area, but they accurately reflect the views of those most directly involved with the land. In order to ensure a diversity of perspective within the stakeholder pool, we would ideally recommend including at least 10 stakeholders belonging to at least 3 different categories (e.g. land managers, land users, local administrators, experts/consultants). This was not always possible in our study because many of the study sites are located in areas subject to land abandonment and outmigration.

The first step of our analysis focused on identifying which ecosystem services are to be maintained or restored. This was essential to define the scope of our investigation, and was fundamental~~functional~~ to the evaluation of the impact of disturbances. However, this approach to resilience does not integrate all the possible ways a system can cope with disturbances (Briske *et al.*, 2010; Gunderson, 2000; Mumby *et al.*, 2014). Rather than focusing on resisting, recovering, or adapting the land management, in certain cases it may be worthwhile transforming (O'Connell *et al.*~~, D., Abel, N.,Grigg, N., Maru, Y., Butler, J., Cowie, A., Stone- Jovicich, S., Walker, B., Wise & Ruhweza, A., Pearson, L., Ryan, P., Stafford Smith~~, 2016; Walker *et al.*, 2004), i.e. changing the land use entirely in order to make use of a different set of ecosystem services, which may arise after a disturbance or may turn out to be more stable. A separate study should be carried out to evaluate the possibilities, advantages, and disadvantages of transforming the land use system to one that is less affected by disturbances, involving different stakeholders, processes, and scales.

We evaluated the influence of LMPs (eq. 2) by taking an integrative approach (Mauser *et al.*, 2013), i.e. by assessing the combined outcome of a certain practice implemented in a certain context in relation to a disturbance, without analysing separately each variable that contributes to the resilience of a land since there is some indication that the effects of practices may depend on the conditions of the system management system. This may have led to a difference in the assessment across different study sites, since there is some indication that the effects of practices may depend on the conditions of the system itself before the disturbance (Walker *et al.*, 2010) and other contextual factors such as the landscape (Jucker Riva *et al.*, 2017) and time of implementation (Jucker Riva *et al.*, 2016). An example was the different evaluation of *Carob plantation* with regards to fire in Cyprus and Greece. The contextual information about the land management systems collected through the questionnaire enabled us to explain differences not captured through the numerical evaluation.

In order to obtain more generally valid conclusions, we chose to analyse the role of the different LMPs separately, and to classify them by type. This was essential to draw general conclusions about similar land practices implemented in different study sites (e.g. tree planting in Spain and Cyprus), even if the practice is usually implemented in combination with another (e.g. tree planting + vegetation removal in Spain vs. tree planting + controlled grazing in Greece). With the exception the *Restored shrubland* (Spa_1), the practices implemented over the same study site are very different, making it possible to distinguish the effects of one from the other. The notion of adaptive management suggests that LMPs should change after a disturbance, adapting to the new conditions. In the land management systems studied, however, we did not detect changes in management. Such changes appear more likely to occur depending on subsidies, the economic context, and other actor decisions not directly related to the occurrence of a disturbance.

The way the index is structured involved different methodological choices. First, we considered prevention, mitigation, and recovery as equal. This differs from the usual approach to land degradation, which considers prevention to be more important. We chose not to consider prevention as more important because some disturbances cannot be prevented through land management (e.g. droughts, floods). Moreover, some resilience studies suggest that preventing the occurrence of a disturbance may in the long run make the ecosystem less resilient. Second, we had to weigh~~t~~ the resistance of a LMP~~land management practice~~ (*r*) against its influence (*I*). We thus modified the output of equation 2~~calibrated the equation~~ so that a small beneficial influence in preventing, mitigating, and fostering recovery the first time a disturbance strikes could be offset by~~equilibrates~~ a negative effect on that LMP ~~of the technology~~ of the disturbance itself~~after the occurrence of a disturbance~~. This choice was based on the fact that, in most cases, one or two disturbances have occurred since the implementation of the land management practice. This might not be appropriate~~fit~~ for studies involving~~that consider a~~ much longer timespans or disturbances with more frequent occurrence~~regime~~.

5.2. Results

Our results show how double-edged the contribution of LMPs to resilience can be, depending on the disturbance type. In particular, practices to manage fire~~s~~ appear to conflict with those to manage drought. *Carob plantations* can increase the resilience to ~~occurrence of~~ fires but reduce resilience to ~~the impact of~~ drought~~s~~ (Gre_1). *Planting resprouter shrubs* has a ~~very~~ positive effect on resilience to ~~with regard to~~ fire, but reduces resilience to drought (Spa_3)~~is detrimental to resilience when a drought occurs~~. This is very relevant because the two disturbances are often linked, and one tends to reinforce the other (Bigler *et al.*, 2005). Scientists have previously stressed the importance of considering multiple disturbances at once (Buma & Wessman, 2011; Turner, 2010), but it is difficult to find studies that propose practical solutions. *Selective clearing* ~~appears to have positive effects~~increases resilience to ~~for both~~ fire~~s~~ and drought~~s~~, respectively,~~,~~ by reducing flammable biomass and increasing the water available per individual plant (Spa_2).~~ allowing each individual plant to receive more water per surface unit while reducing the flammable biomass.~~ In grazing areas, *Fodder provision* appears to have positive impacts on resilience~~the recovery of the system,~~ regardless of the disturbance affecting the system.

When considering the combination of LMPs implemented in each study site in relation to multiple disturbances, management strategies addressed at improving the environment do not necessarily prove valuable for increasing resilience. Restoration practices such as planting trees and shrubs appear to be particularly vulnerable to disturbances, and are thus more at risk of failing in the future. Furthermore, no single practice was able to increase resilience to~~of~~ all disturbances while maintaining its effectiveness. This suggests that to effectively increase resilience against several disturbances, multiple practices should be combined. In particular, simultaneously increasing resilience to both droughts and wildfires appears to be challenging. Our results thus stress the importance of considering the full spectrum of disturbances that affect an ecosystem, when designing an effective land management strategy.

The results of our assessment are consistent~~coherent~~ with a separate study (Valdecantos *et al.*, 2016) based on the Landscape Function Analysis procedure of ~~(~~Tongway & Hindley~~,~~ (2004). The assessment was carried out in all study sites comparing an undisturbed area, a degraded area and an area that had been managed or restored. Consistent with the present results, this study found that ~~(Valdecantos *et al.*, 2016) and yielded the following results coherent with our study:~~ *Traditional logging* in Portugal appeared~~s~~ to improve ecosystem services supply more than *Conservation logging, Tree planting* in Cyprus and Greece improved~~s~~ water infiltration and ~~,~~ nutrient cycling and reduced~~s~~ erosion, and *Selective clearing and planting* in shrubland in~~(~~Spain~~)~~ improved~~s~~ biodiversity and permanently reduced~~s~~ fuel load. The systems that scored the highest values from our assessment are indeed those that explicitly include resilience among their management objectives: *Seasonal pasture* in Italy; *Diversified shrubland* and *Restored forest* in Spain.

Our study also shows how the effectiveness of LMPs can change as a consequence of the disturbance itself. Identifying such feedbacks is extremely important to understand resilience (Carpenter *et al.*, 2009; Folke *et al.*, 2004; Mitchell *et al.*, 2014). From our study, revegetation practices such as shrub and tree planting are more at risk of collapsing after a disturbance: *Afforestation with pines* and *shrub planting* were assessed to be particularly vulnerable to both droughts and fires. The value of these practices is highly discussed among scientists (Maestre & Cortina, 2004; Pausas *et al.*, 2004; Vallejo *et al.*, 2012), especially if they are not combined with other practices that focus on increasing resilience (Seidl *et al.*, 2016).

Resilience is considered by scientists to be part of sustainability (Hurni, 2000). In practice, however, we have detected a conflict between reducing land degradation and managing for resilience: *Conservation logging* applied in Portugal to reduce the impacts of logging on soil was revealed to be far less beneficial to resilience than *Traditional logging.* This, together with the shortcomings identified for *tree* and *shrub planting,* highlights the risks and uncertainties associated~~related~~ with strong interventions aimed at controlling or modifying specific aspects of the ecosystem (Domptail *et al.*, 2013; Hilderbrand *et al.*, 2005). In accordance with recent research, it appears that allowing for self-organization (Bergamini *et al.*, 2013; Choptiany *et al.*, 2016; Peterson, 2000), e.g. through selective vegetation removal, is far more beneficial. Diversity, often associated ~~related~~ with increased resilience ~~increase~~ in scientific literature (Acácio & Holmgren, 2014; Bennett *et al.*, 2015; Elmqvist *et al.*, 2003; Lavorel, 1999) appears to be relevant for our study: increasing species diversity was considered a benefit of ~~positive factor for~~ *shrub planting* in Spa_1 and Spa_3; since few LMPs proved beneficial against multiple disturbances, an increase in resilience could be achieved by diversifying the management. Finally, land management systems that include increasing resilience among their management objectives proved to be more successful, supporting the concepts of the "adaptive management" (Plummer & Armitage, 2007; Rist & Moen, 2013) and the "resilience thinking" (Folke *et al.*, 2010; Mitchell *et al.*, 2014; Rist & Moen, 2013; Walker & Salt, 2012) approaches.

6. Conclusion

Our study focuses on the role of land management practices (LMPs) in relation to the disturbances that affect several Mediterranean ecosystems, using information collected through a knowledge co-creation approach evaluated through a synthetic, semi-quantitative index. By evaluating in detail the land management options, we are able to highlight important practical information for land managers. Our spatially explicit definition of land management systems allowed us to study both the natural environment and human actions, and is flexible enough to be adapted to a wide variety of areas. Involving stakeholders allowed us to not only include different perspectives, but also to overcome knowledge gaps and missing information that would have required extensive monitoring and field observations.

The results of our assessment revealed that the practices analysed are particularly effective against wildfires and torrential rainfalls. By contrast, droughts are more difficult to counter and the LMPs were heavily affected by their occurrence. The effectiveness of LMPs belonging to *tree planting* group appears highly sensitive to disturbances, calling into question their value in areas that are frequently affected by disturbances. By contrast, LMPs that selectively reduce the amount of vegetation appear to be beneficial in fostering recovery of ecosystems. Furthermore, our assessment suggests that there are potential conflicts among~~between~~ land management objectives: increasing resilience to~~against~~ drought~~s~~, for example, appears to reduce resilience to~~against~~ fire~~s~~ and reducing the impact of logging in forests appears to reduce resilience to~~against~~ fire~~s~~ and pest outbreaks.

The methodology used in this study allowed us to synthetically evaluate the combined effect of different LMPs in relation to several disturbances. Furthermore, the methodology could be integrated into sustainability assessments and land management planning tools to facilitate “resilience thinking”. If future studies include specific indicators ~~on~~ for ecological processes that influence resilience to different disturbances, this could enhance the quality of results and their applicability across different ecosystems.

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8. Supporting information:

Method S1. Design process of the Resilience Assessment Tool and interactions with different stakeholder groups

Appendix S2. Resilience assessment Tool

Table S3. Sources used to assess the contribution of land management to resilience of mediterranean forests and rangelands

Table S4. Detailed description of land management practices assessed

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Table 1. Main features of the land management systems studied.

Study site	Environment	Land management objective	Land management practices	Main land managers
Conservation logging (Por_1)	Sub-humid pine forest	Recently burnt pine plantation logged limiting withdrawal of wood and reducing machinery movement to minimize impacts on pine recruitment	Post-fire conservation logging	Company/ Government employees
Traditional logging (Por_2)	Sub-humid pine forest	Recently burnt pine plantation logged with extraction of all the woody material and heavy machinery to maximize productivity	Post-fire traditional logging	Company/ Government employees
Restored shrubland (Spa_1)	Arid shrub-land	Spatially diverse multi-specific plantation to restore degraded shrubland and combat desertification	Plantation of semi-arid woody species with micro-catchments Plantation of diverse semi-arid woody species Plantation of semi-arid woody species on terraces	Company/ Government employees
Restored forest (Spa_2)	Semi-arid pine forest	Pine afforestation managed with selective clearing and firebreaks to control soil erosion and restore landscape	Selective forest clearing Cleared strip network system (firebreaks) Afforestation with Pinus halepensis after fire	Small-scale land users
Diversified shrubland (Spa_3)	Semi-arid shrub-land	Shrubland under selective clearing and planting for fire risk reduction and resilience increase	Clearing of fire-prone seeder species. Planting of resprouter shrubs and trees	Company/ Government employees
Seasonal pasture (Ita_1)	Humid grassland with shrubs	Seasonal cow pastures managed with metallic fences to regulate grazing and prevent damage from boars	Metallic fences to regulate grazing	Small-scale land users
Silvo-pastoral system (Gre_1)	Semi-arid shrubland	Carob afforestation on grazing land (goats and sheep) for land restoration and income diversification	Grazing land afforestation with carob trees	Small-scale land users
Extensive grazing (Cyp_1)	Arid Shrub-land	Extensive grazing (mostly goats) with carobs, tree protection and fodder provision to reduce degradation from	Planting carob and olive trees to prevent erosion	Small-scale land users

59

overgrazing

Table 2. Land management practices identified grouped by type.

Type of land management	Land management practice	Study site
Clearing of vegetation	Post-fire conservation logging	Por_1
	Post-fire traditional logging	Por_2
	Selective forest clearing	Spa_2
	Cleared strip network system (firebreaks)	Spa_2
	Clearing of fire-prone seeder species.	Spa_3
Grazing management	Metallic fences to regulate grazing	Ita_1
	Controlled grazing in spring months	Gre_1
Planting of shrubs	Plantation of semi-arid woody species with micro-catchments	Spa_1
	Spatially diverse plantation of diverse semi-arid woody species	Spa_1
	Plantation of semi-arid woody species on terraces	Spa_1
	Planting of resprouter shrubs and trees	Spa_3
Planting of trees	Afforestation with *Pinus halepensis* after fire	Spa_2
	Grazing land afforestation with carob trees	Gre_1
	Planting carob and olive trees to prevent erosion	Cyp_1
Other	Carob-tree protection from rats	Cyp_1
	Fodder provision to animals during summer	Cyp_1

Table 3. Ecosystem services derived from the WOCAT technology questionnaire and indicated as important by stakeholders ~~(D,)~~ for each study site. Selection of ecosystem services was based on a predefined list of services derived from the WOCAT method. However, stakeholders were asked to complete the list with those services they deemed important and which were not on the list. "X" indicates that no ecosystem services were identified as important in that category.

Study site identifier		**Productive Services**	**Ecological services**	**Sociocultural services**
Por_1	Conservation logging	Animal and plant productivity Water (quantity and quality) for human, animal, and plant consumption	Reduced erosion	Recreation (e.g. tourism, sports)
Por_2	Traditional logging	Animal and plant productivity	X	Cultural services (e.g. maintaining traditional landscape)
Spa_1	Restored shrubland	X	Reduced erosion Above ground biodiversity Protection from extreme events	Recreation (e.g. tourism, sports)
Spa_2	Restored forest	Animal and plant productivity	Reduced erosion Above ground biodiversity Greenhouse gas absorption Protection from extreme events	Recreation (e.g. tourism, sports)
Spa_3	Diversified shrubland	X	Greenhouse gas absorption Protection from extreme events	X
Ita_1	Seasonal pasture	Animal and plant productivity	X	Cultural services (e.g. maintaining traditional landscape)
Gre_1	Silvopastoral system	Animal and plant productivity Land available for production	Reduced erosion Above ground biodiversity	Cultural services (e.g. maintaining traditional landscape)
Cyp_1	Extensive grazing	Animal and plant productivity	Reduced erosion Above ground biodiversity Greenhouse gas absorption	X

Table 4. Impact of disturbances measured as the ratio between ecosystem services that can be permanently decreased by a disturbance and the number of ecosystem services considered valuable (eq. 1), grouped by disturbance. Values close to 0 mean no permanent impact on valuable ecosystem services, while close to 1 means all valuable ecosystem services are affected. "n" represents the number of study sites affected by each disturbance (out of8).

Disturbances	Mean impact	Standard deviation	n
Wildfires	0.74	0.23	6
Droughts	0.77	0.22	5
Pests/ Diseases	0.65	0.34	4
Torrential rainfalls	0.63	0.14	2
Floods	0.25	0.00	1

Table 5. Quantitative evaluation of the impact of land management practices (LMPs) on the resilience of the land management systems, by study site. *Impact* refers to the impact of disturbances on the important ecosystem services D_j (eq. 1) which ranges from 0 (no impact) to 1 (all important ecosystem services are affected). The direct influence of LMPs on the resilience of land management systems ($I_{i,j}$, eq. 2) is calculated considering prevention (*p*), mitigation (*m*), and recovery (~~r~~*v*), and ranges from -6 to 6. $r_{i,j}$ refers to the resistance of LMPs~~land management~~ to disturbances; its values can be 0, 1,2, or 3. *Resilience* refers to the overall impact of LMPs on resilience calculated using eq. 3 and can range from -1 to 1.

Land management system		**Disturbance**		**Influence of LM**				**r**	**Resilience**
Code	LMPs	Name	Impact (D_j)	*p*	*m*	*v*	$I_{i,j}$	$r_{i,j}$	$R_{i,j}$
Por_1	Conservation logging	fires	0.75	-1	0	-1	-2	0	-0.25
	Conservation logging	pests / diseases	0.25	-1	1	0	0	0	0.00
Por_2	Traditional logging	fires	1.00	1	0	-1	0	0	0.00
	Traditional logging	pests / diseases	1.00	-1	2	0	1	0	0.17
Spa_1	Shrub plantation with catchments	droughts	1.00	0	1	1	2	3	-0.17
	Diverse shrub plantation			0	1	1	2	3	-0.17
	Shrub plantation with terraces			0	0	0	0	1	-0.17
	Shrub plantation with catchments	torrential rainfalls	0.75	0	2	1	3	2	0.13
	Diverse shrub plantation			0	2	1	3	1	0.25
	Shrub plantation with terraces			0	2	1	3	2	0.13
	Shrub plantation with catchments	floods	0.25	0	1	1	2	3	-0.04
	Diverse shrub plantation			0	2	1	3	3	0.00
	Shrub plantation with terraces			0	2	1	3	3	0.00
Spa_2	Selective clearing	fires	1.00	2	2	1	5	1	0.67
	Fuel breaks			2	2	0	4	2	0.33
	Afforestation			-1	1	1	1	3	-0.33
	Selective clearing	droughts	0.67	0	1	1	2	0	0.22
	Fuel breaks			0	0	0	0	1	-0.11
	Afforestation			0	1	1	2	3	-0.11
Spa_3	Shrub clearing	fires	0.50	2	2	1	5	0	0.42
	Resprouter shrub plantation			0	1	2	3	1	0.17
	Shrub clearing	droughts	1.00	0	2	1	3	0	0.50
	Resprouter shrub plantation			0	0	0	0	2	-0.33
Ita_1	Fences	pests / diseases	1.00	1	1	1	3	1	0.33
Gre_1	Carob plantation	fires	0.80	0	0	2	2	1	0.13
	Controlled grazing			1	2	1	4	2	0.27
	Carob plantation	pests / diseases	0.50	1	1	1	3	2	0.08
	Controlled grazing			1	1	1	3	2	0.08
	Carob plantation	droughts	0.40	0	-1	1	0	2	-0.13
	Controlled grazing			0	-1	0	-1	1	-0.13
Cyp_1	Carob plantation	droughts	0.75	-1	1	1	1	1	0.00
	Tree protection			0	1	1	2	0	0.25
	Fodder provision		0.75	0	2	1	3	1	0.25
	Carob plantation	fires	0.50	-1	0	1	0	1	-0.08
	Tree protection			0	1	1	2	2	0.00
	Fodder provision			0	1	1	2	0	0.17
	Carob plantation	torrential rainfalls	0.50	0	1	1	2	0	0.17
	Tree protection			0	2	1	3	0	0.25
	Fodder provision			0	0	1	1	1	0.00

Location of study sites with place names in brackets. Study site countries are depicted in dark grey. Forest sites are marked in green, while rangeland sites are marked in orange

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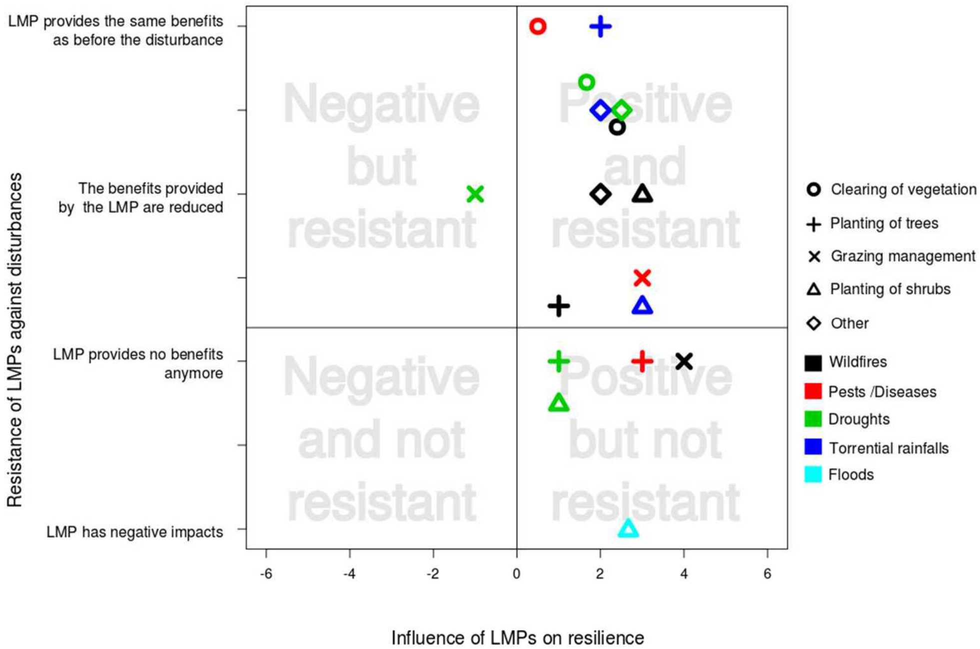

Average influence of land management practices (LMPs) on the disturbance (x axis; relative units) and resistance of LMPs to the disturbance (y axis) by type of practice. The shapes correspond to the different LMP types, the colour indicates the type of disturba[illegible]d lines separate positive from negative evaluations.correspond to the different LMP types, [illegible]our indicates the type of disturbance.

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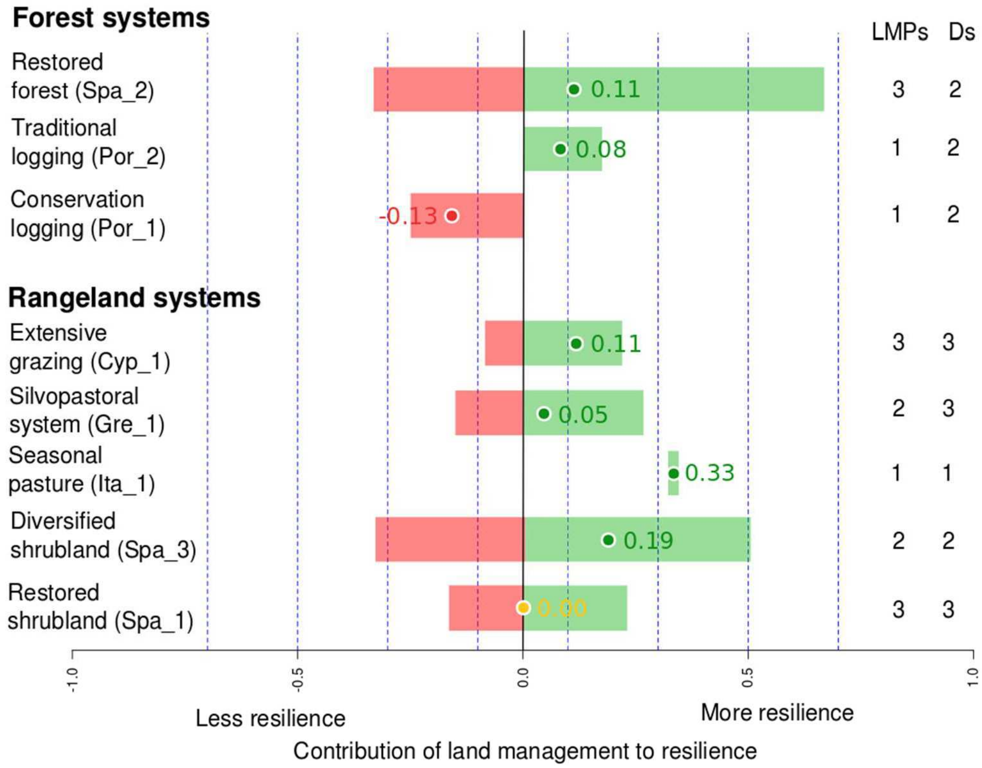

Contribution of land management practices (LMPs) to the resilience of each land management system. The bars range from minimum to maximum resilience values (considering all LMPs in relation to all the disturbances affecting each land management system); the dots indicate the average value. For each land management system, LMPs indicate the number of practices, and Ds indicate the number of different disturbances.

368x287mm (72 x 72 DPI)