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Disentangling the role of management practices on ecosystem services delivery in Mediterranean silvopastoral systems: Synergies and trade-offs through expert-based assessment

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ABSTRACT

Silvopastoral systems (SPS) emerge with a renewal interest in the Mediterranean for their promotion of multifunctionality through a variety of ecosystem services (ES). However, the understanding of how combined forestry and pastoral practices affect the ES delivery as well as the synergies and trade-off dynamics amongst them is still very limited. We applied the structured expert consultation Delphi method to assess the medium-term effect of relevant silvopastoral management practices (SMP) on the delivery of provision, regulation and maintenance and cultural ES in Mediterranean mid-mountain SPS in Spain. The deliberation process entailed two rounds and the Delphi panel was finally formed by 69 experts covering a broad spectrum of background and expertise. Results show that some practices, such as silvicultural treatments (e.g., thinning or coppice selection), play a multifunctional role contributing to ES delivery in bundles while some trade-offs are also identified between SMP, such as free animal grazing, and the provision of some ES. Synergies are also found between ES, such as livestock production and recreational hunting and between timber production and carbon sequestration, whereas possible trade-offs were particularly relevant between wildfire prevention and carbon sequestration. These findings can support decision-making processes towards sustainable and multifunctional silvopastoral management in the northern Mediterranean basin.

1. Introduction

Livestock agroforestry systems are by far the most widespread agroforestry land–use type in Europe, covering 15.1 million ha, 3.5% of European land area (den Herder et al., 2017). Among these, silvopastoral systems (SPS) combining woodlands, forage, and livestock in the same land (Mosquera-Losada et al., 2009) dominate, with their largest area found in Spain (3.5 million ha; den Herder et al., 2017).

SPS are conceived as multifunctional and dynamic Socio-Ecological Systems resulting from the historical co-evolution (i.e. relationships, feedbacks, and dependencies) between local communities and their environment (Berkes et al., 2003; Plieninger and Huntsinger, 2018), shaping a diversified landscape structure and configuration which fosters Ecosystem Services' (ES) supply to society (Torralba et al., 2016; Fischer and Eastwood, 2016). Furthermore, SPS are recognised as High Natural Value (HNV) farmland since they host rich biodiversity associated with human culture and activity (IEEP and EFNCP, 2014; Moreno et al., 2018). Moreover, they play a central role in wildfire prevention (Robles et al., 2008), erosion control, hydrological regulation, and carbon storage (Kay et al., 2019) while providing resources and supporting landscapes and communities associated with cultural, historical, aesthetic, and recreational values and heritage (Jose et al., 2019; Moreno et al., 2018).

Despite the interest in SPS is growing due to the significant role it may play in balancing productivity and environmental protection (Smith et al., 2013) while promoting sustainable rural development (Primdahl et al., 2013), traditional silvopastoral management is under decline in the Mediterranean. This is mainly linked to the rural abandonment process threatening the continuity of SPS that require low-intensity human use (Bugalho et al., 2011; Plieninger et al., 2015),

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and leading to changes in ecosystem processes and functions, that modify the pool of ES provided to society (Felipe-Lucia et al., 2018).

ES' flows in SPS are driven by many factors, such as vegetation attributes or soil properties, but also by the legacy effect of historical disturbances on them (Palomo et al., 2016). Since forestry and pastoral management practices induce spatial–temporal changes in the components of the silvopastoral ecosystem, influence the delivery of ES (Felipe-Lucia et al., 2018; Jose et al., 2019).

Recent studies have contributed to assess the influence of forest and pastoral management on the dynamics of ES and biodiversity (Biber et al., 2015; Pang et al., 2017; Schwaiger et al., 2019, Roces-Díaz et al., 2021). However, the effect of forestry and pastoral management practices on the provision of ES is usually dealt with separately and their combined knowledge is still very limited. Accordingly, a better understanding on the relationships between management practices and ES dynamics in Mediterranean SPS may provide further insights to improve the synergic provision of ES bundles while minimizing their trade-offs.

The valuation of the goods and services delivered by ecosystems can adopt biophysical, socio-cultural, or economic perspectives either if it focuses on field measurements, the relevance for society, or the contribution to societal welfare of ES, respectively. While economic valuation is considered controversial for the idea of the commodification of nature and the difficulties to assess cultural ES (Bernués et al., 2014), socio-cultural valuation of ES linked to European agroforestry in scientific literature is hoarded by Spanish "dehesas" and Portuguese "montados" (Moreno et al., 2018). Comparatively, little is known about livestock grazing in forest understory (Ruiz-Mirazo and Robles, 2012), that hinders the development of management guidelines, incentives and practices since empirical studies often involve a large number of contextual factors and are hampered by the long temporal scales involved (Duncker et al., 2012; Rodríguez-Ortega et al., 2014). Furthermore, there is a scarcity of studies focusing on several ES categories and management alternatives (Torralba et al., 2016) that would allow to disentangle trade-offs and synergies across them.

This study aims to assess the contribution of silvopastoral management practices (SMP) potentially beneficial for the provision of multiple ES in Spanish Mediterranean mid-mountain SPS. To tackle such a complex task, we applied the Delphi expert elicitation technique that enabled gathering deep knowledge based on experience while spanning across several disciplines and aiming for the widest possible consensus.

2. Materials and methods

2.1. Study area/geographical context

This study focuses on Mediterranean mid-mountain SPS in Spain. These areas are characterized by holding a heterogeneous agro-silvo-pastoral mosaic landscape of woodland, scrubland, and farmland that has been shaped by human activity for centuries (Blondel, 2006). The long history of land use and culture along with the rough topography (from 800 to 1500 m altitude) and Mediterranean climate have favored biodiversity and a high number of endemisms (Fabbio et al., 2003; Lomba et al., 2015). Dominant tree species at lowest elevations (<1000 m) comprise *Pinus halepensis*, *P. pinaster*, *Quercus ilex,* and *Q.suber,* whereas at altitudes ranging from 800 to 1500 m the most common species are *P. sylvestris, P. nigra* and *Q. pubescens*.

Silvopastoral management in Mediterranean mid-mountain was traditionally multipurpose providing wood (timber, firewood, charcoal), non-wood products (nuts, berries, mushrooms, aromatic plants, cork, resins), and grazing and resting area for livestock. Forest fodder resource is usually embedded in the extensive livestock management of farms along with pastures and forage crops (Baiges et al., 2007; Casals et al., 2009). A range of livestock including cattle, sheep, goats and horses, mainly specialized in meat production, obtain shelter and strategic forage in form of woody and herbaceous vegetation, leaves, branches, and fruits that compensates the fodder shortage in winter and summer that characterizes Mediterranean grasslands (San Miguel-Ayanz, 2001).

The forests in Spanish Mediterranean mid-mountain areas are characterised by low economic profitability associated with slow growth rates, low timber yields, and high cost of forestry operations due to the relief and the wildfire hazard (González-Olabarria and Pukkala, 2011). Simultaneously, extensive livestock farming lost prominence, decreasing the number of farms and increasing their herd size, or replacing sheep flocks by cattle driven by global change (Bernués et al., 2011; Plieninger et al., 2015). While the intensification process of extensive livestock systems also affects mid Mediterranean mountain farming, the abandonment is threatening silvopastoral management (Varela et al., 2022).

2.2. Selection of ecosystem services (ES) and silvopastoral management practices (SMP)

Following the Common International Classification of Ecosystem Services (CICES V5.1; Haines-Young and Potschin, 2018) and after a careful literature review (e.g. Torralba et al., 2016; Fagerholm et al., 2016; Kay et al., 2019), we selected eight relevant ES provided by SPS, covering provisioning, regulating and maintenance, and cultural ES categories (Table 1). The provisioning service dimension was addressed through the production of livestock and timber (wood and biomass) products since these are still the main marketable goods from SPS in the Mediterranean, providing commodities that support the economic yield for both forest owners and livestock farmers (Moreno et al., 2018; Kay et al., 2019). For regulating and maintenance services, we considered the provision of habitats for biodiversity and carbon sequestration (related with climate stability) as key ecological functions and life support systems that ultimately give rise to ES (Torralba et al., 2016). We also addressed the regulation services provided by SPS to deal with perturbations by means of erosion control and wildfire prevention services respectively, both of which provide the insurance value to face the uncertainty in the provision of ES (Baumgartner, 2007; Torralba et al., 2016). Finally, hiking and hunting represent two important cultural services capturing the recreational value of Mediterranean SPS that have been comparatively less addressed in the literature (Fagerholm et al., 2016). Moreover, hunting of big and small game often represents the major source of income (San Miguel-Ayanz, 2005) or provides non-commercial benefits for forest owners (Campos et al., 2021) while supporting the local rural economy in some Mediterranean regions.

We considered 18 Silvopastoral Management Practices (SMP) commonly adopted in Mediterranean SPS. These were compiled from literature review, interviews with researchers and information obtained from surveys carried out with forest owners and livestock farmers in Catalonia and Aragón, two representative sites of north-eastern Mediterranean mid-mountain SPS in Spain (Varela et al., 2022; see **Table A1** in **Appendix A**). SMP were grouped in four core domains according to the component of the SPS targeted: shrub and herbaceous treatments, silvicultural treatments (tree layer), grazing practices, and transversal practices (Table 2).

With the aim of addressing the benefits from SMP on ES provision and avoiding cognitive burden in experts from information overload (Winkler and Moser, 2016), we selected 118 relevant combinations of SMP and ES for which a positive contribution can be expected. Combinations with expected negative effect (e.g., prescribed burning and erosion control or targeted grazing and livestock production), or negligible effect (e.g., rotation of resting areas and livestock production), and those with confusing interpretation (e.g., grazing with different species and livestock production) were removed to reduce the volume and complexity of information and to facilitate the assessment. Nevertheless, we allowed experts to signal possible negative effects in their assessments (see Section 2.3).

Table 1
Ecosystem services addressed in this study grouped according to the Common International Classification of Ecosystem Services (CICES v5.1: Haines-Young and Potschin, 2018).

Section CICES	Group CICES	ES indicator	Description
Provisioning	Reared animals for nutrition, materials, or energy	Production of livestock products	Forest contribution to the rearing of domesticated animals and their outputs
	Wild plants for nutrition, materials, or energy	Production of timber products	The harvestable volume of wood for material and energy use
Regulation & Maintenance	Regulation of baseline flows and extreme events	Erosion control	Control and prevention of soil loss and flood regulation
	Regulation of baseline flows and extreme events	Reduction of wildfire hazard	Reduction of vegetation vulnerability to ignition and spread of fire
	Lifecycle maintenance, habitat and gene pool protection	Provision of habitat for biodiversity	Conservation and maintenance of habitats and biological diversity for species
	Atmospheric composition and conditions	Carbon sequestration	Amount of carbon sequestered in soil and biomass over time
Cultural	Physical and experiential interactions with the natural environment	Provision of spaces for recreational activities: hiking	Potential for sport, recreation, provide certain characteristics (i.e., naturalness, aesthetics) and accessibility
		Provision of spaces for recreational activities: hunting game	Potential to provide opportunities for hunting of big and small game

Table 2
Relevant combinations of silvopastoral management practices and ecosystem services evaluated (x).

			Ecosystem Services (ES)								Total SMP-ES assessed
Silvopastoral management practices (SMP)			Provision		Maintenance and regulation				Cultural		
Group	N°	Description	Livestock	Timber	Erosion	Wildfires	Biodiversity	Carbon	Hiking	Hunting	
Shrub and herbaceous treatments	1	Seeding understorey herbaceous species	x	–	x	x	x	x	x	x	7
	2	Selective clearing	x	x	x	x	x	x	x	x	8
	3	Prescribed burning	x	x	–	x	x	–	x	x	6
	4	Coppice selection	x	x	–	x	x	x	x	x	7
Silvicultural treatments	5	Thinning	x	x	–	x	x	x	x	x	7
	6	Shelterwood cutting	x	x	x	x	x	x	x	x	8
	7	Reducing stand density	x	x	x	x	x	x	x	x	8
Transversal practices	8	Shredding of residues	x	x	x	x	x	x	x	x	8
	9	Conservation of water bodies and sources	x	–	x	–	x	–	x	x	5
	10	Conservation of forest roads and paths	x	–	–	–	x	–	x	x	4
	11	Fencing to favour tree regeneration	x	x	x	x	x	x	x	–	7
	12	Extending stand rotation	–	x	x	x	x	x	x	x	7
	13	Rotation of livestock resting areas	–	x	x	x	x	–	x	–	5
	14	Extending the forest grazing period	x	x	–	x	x	x	x	x	7
Grazing practices	15	Grazing with different livestock species	–	x	–	x	x	x	–	–	4
	16	Free animal grazing in the forest area	x	x	x	x	x	x	x	x	8
	17	Rotational grazing with forest compartmentalization	x	x	x	x	x	x	x	x	8
	18	Targeted grazing for biomass reduction purposes	–	–	–	x	x	x	–	x	4
		Total combinations SMP-ES assessed	**14**	**14**	**11**	**16**	**18**	**14**	**16**	**15**	**118**

2.3. *The Delphi method*

The Delphi method is a structured and individual expert-elicitation technique consisting of an iterative process where a group of experts is consulted on a series of rounds to arrive at a certain degree of consensus on the issues raised (Landeta, 2006). The technique is a recognised group communication process, based on the judgment of experts, to deal with uncertainty in complex and multifaceted issues where the available information is limited, conflicting, or unsuited to empirical modelling (Martin et al., 2012).

It is characterized by the anonymity of participants, the repetition or interaction with controlled feedback and the group statistical response (Rowe and Wright, 2001; Landeta, 2006).

The Delphi technique is also a useful socio-cultural method to evaluate ES (Rodríguez-Ortega et al., 2018). It has been previously applied for addressing the geographical distribution of ES based on land use (Geneletti, 2007; Scolozzi et al. 2012; Shipley et al., 2020), public preferences for recreational use of forest (Edwards et al., 2012) and the effect of land use on ES and biodiversity (Waldron et al., 2016; Filyushkina et al., 2018; Rodríguez-Ortega et al., 2018).

2.3.1. *Selection of experts*

We selected 316 well-known experts with diverse backgrounds and knowledge on ES and the different components of Mediterranean SPS in Spain. The expert group involved researchers and technicians working in the public administration at different levels (county-level, provincial, regional, and national), private sector, and NGOs while looking for a well-spread geographically represented sample and balance of professional and academic disciplines related to livestock farming, forestry, and environmental conservation. Experts were self-assigned in the forestry, livestock and silvopastoral sector according to their specific or transdisciplinary experience on SPS.

2.3.2. *Questionnaires and data collection*

The questionnaire started with an illustrated description of SPS in Mediterranean mid-mountain areas in Spain. Secondly, we collected information on experts' workplace and types of forest and livestock systems they were more experienced with. Third, participants were asked to assess the positive mid-term (five-ten years) and mid-intensity effect of each SMP over each ES at stand level in the selected combinations through a six-point Likert type scale: none (0), very low positive (1), low positive (2), intermediate positive (3), high positive (4), and very high positive (5) contribution. In spite of our focus on the benefits of SMP, and given the large number of SMP and ES, the possible negative contribution option was allowed to be signalled by the experts in their assessment, as well as the "don't know/no answer" option. The order of appearance of each ES was randomized to avoid order bias in the evaluation. A pilot questionnaire administered to ten professional colleagues with a similar profile to the potential participants allowed to test and fine-tune the final questionnaire.

The Delphi survey entailed two rounds and was carried out online between February and September 2020. From the total 316 experts contacted, the first round collected 100 responses, 51% researchers and 49% technicians, specialized in the forest (34%), livestock (50%) and silvopastoral (16%) sectors, respectively. The response ratio obtained was 32.8%, which is in line with other studies (Rodríguez-Ortega et al., 2018). The second-round questionnaire included a summarized numerical and graphical report with both individual and global responses from the first round and invited experts to revise their initial valuation. Finally, the second round collected responses of 69 experts who comprised the Delphi panel. While the optimal panel size for a representative pooling has not been determined (Akins et al., 2014), our panel exceeds the range of participants commonly observed in Delphi studies (Mukherjee et al., 2018).

Furthermore, since the response ratio decreases with the number of rounds (Novakowski and Wellar, 2008), most Delphi studies comprise two rounds (Edwards et al., 2012, Rodríguez-Ortega et al., 2018). In our study we tested the stability (consistency) in individual and global answers and the agreement among experts to decide the appropriate number of rounds (Rowe and Wright, 2001). Although most participants (75%) reconsidered at least one initial answer after looking at the group's overall responses in the second round, the maximum of answers modified by a participant represented 5% from the 118 combinations addressed. Global stability was also achieved since none of the combinations showed a statistically significant different mean value according to nonparametric Mann-Whitney U tests. (Beiderbeck et al., 2021). A greater convergence of the answers was found by the reduction of variability (coefficient of variation) in experts' opinion in 65.2% of the combinations (coefficient of variation decreased in 97.7% of the combinations when considering only the responses of experts that answered both rounds). Therefore, we assumed that stability and an acceptable agreement among experts was attained in these two rounds and finalised the Delphi process (Rowe and Wright, 2001). The Delphi panel comprised 52% researchers and 48% technicians, belonging 49%, 32%, and 20% of them to the forest, livestock and silvopastoral sector, respectively and covering 90% of Spanish regions.

2.4. *Data analysis*

We focused on the positive valuations by means of the contribution of each SMP to the ES categories. For each combination, the contribution was estimated as the scores given by experts multiplied by a correction factor of one minus the ratio of negative and positive number of responses. Therefore, the factor considered the negative scores and neutralized the effects of "don't know/no answer".

In order to seek for differences in the assessment among experts according to category (researchers and technicians) and expertise background (forestry sector, livestock sector and silvopastoral), we applied the non-parametric Mann-Whitney and Kruskal-Wallis tests, respectively.

We carried out a Kruskal-Wallis test followed by the post hoc Dunn's multiple comparison to identify subsets of SMP with a homogeneous contribution on each ES and to compare SMP across ESs to identify ES bundles.

Pearson's Chi-square test was used to explore the potential negative contribution of SMP to ES supply and hence the possible disservices or trade-offs among practices. Thus, we compared the percentage of negative and positive & neutral (grouping from none (0) to very high positive (5)) responses on the contribution of SMP to ES provision.

Finally, we applied Spearman rank correlations to explore overall synergies and trade-offs, i.e. the increase of some ES may cause a decline in other ES (Blanco et al., 2019), among ES (Roces-Díaz et al., 2020; Morán-Ordóñez et al., 2020).

All analyses were performed with SPSS 23.0 software.

3. Results

3.1. *Delphi panel*

Among the experts that comprised the Delphi panel, we found differences in expert assessment in 11 combinations (SMP-ES) (9.3% of the total evaluated) when comparing by expert categories (Fig. 1). Technicians valued higher the contribution of some silvicultural treatments (P4, P5 and P6) and shredding of residues (P8) on wildfire prevention, and the conservation of water bodies (P9) and reduction of stand density (P7) on hiking and on recreational hunting, respectively. In contrast, researchers scored higher the contribution of fencing to favour tree regeneration (P11) on carbon sequestration and of free animal grazing in the forest area (P16) on the erosion control and biodiversity.

When grouping experts by background, we found significant differences in the evaluation of 12 combinations (10.2% of the total; Fig. 2). Experts from the livestock sector scored higher the effect of transversal practices (P8 and P10) and two grazing practices (P15 and P17) on livestock and timber production, respectively. They also scored higher the contribution of shredding of residues, grazing with different livestock species, and reducing stand density on biodiversity, and of thinning on carbon sequestration.

3.2. *Contribution of SMP to ES delivery*

The contribution of SMP to the ES supply in Spanish mid-mountain SPS is provided in Fig. 3 while the statistical results and homogeneous subsets of practices on each ES appear in **Appendix A. Table A2.**

SMP with the highest contribution to livestock production were reducing stand density (P7), the conservation of water bodies sources (P9), and the conservation of forest roads (P10) while silvicultural treatments and shrub and herb treatments together with, rotational grazing (P17) also contributed importantly. As expected, silvicultural treatments showed the highest contribution to timber production.

The best-valued practices for erosion control were fencing to favour tree regeneration, rotation of livestock resting areas and seeding understorey herbaceous species. Silvicultural practices (P4, P5) and two transversal practices (P11 and P12) provided the highest contribution to carbon sequestration. In contrast, fencing and extending stand rotation practices obtained the lowest values in wildfire prevention. Silvicultural treatment and most grazing practices were the best valued for wildfire prevention. Transversal practices, such as conservation of water bodies, were by far the most positive for biodiversity conservation, followed by grazing with different livestock species and some silvicultural treatments, whereas free animal grazing and prescribed burning showed a

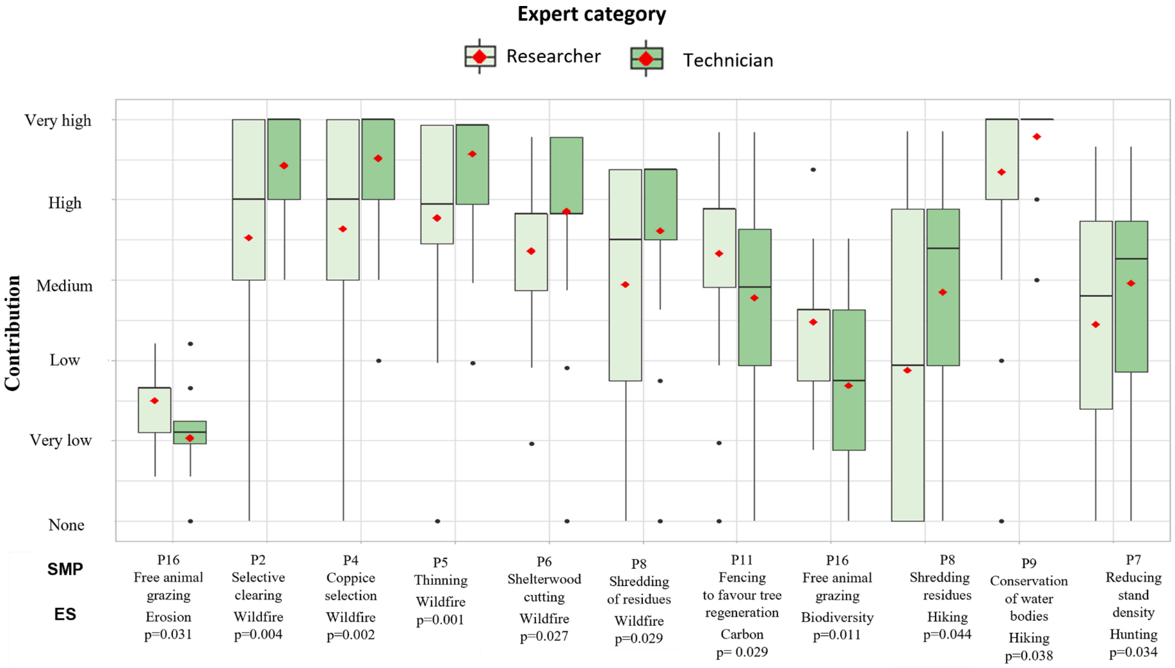

Fig. 1. Differences between expert category valuation of SMP over ES (U Mann-Whitney test, p < 0,05). Boxplot shows average (red dot), median and interquartile range. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

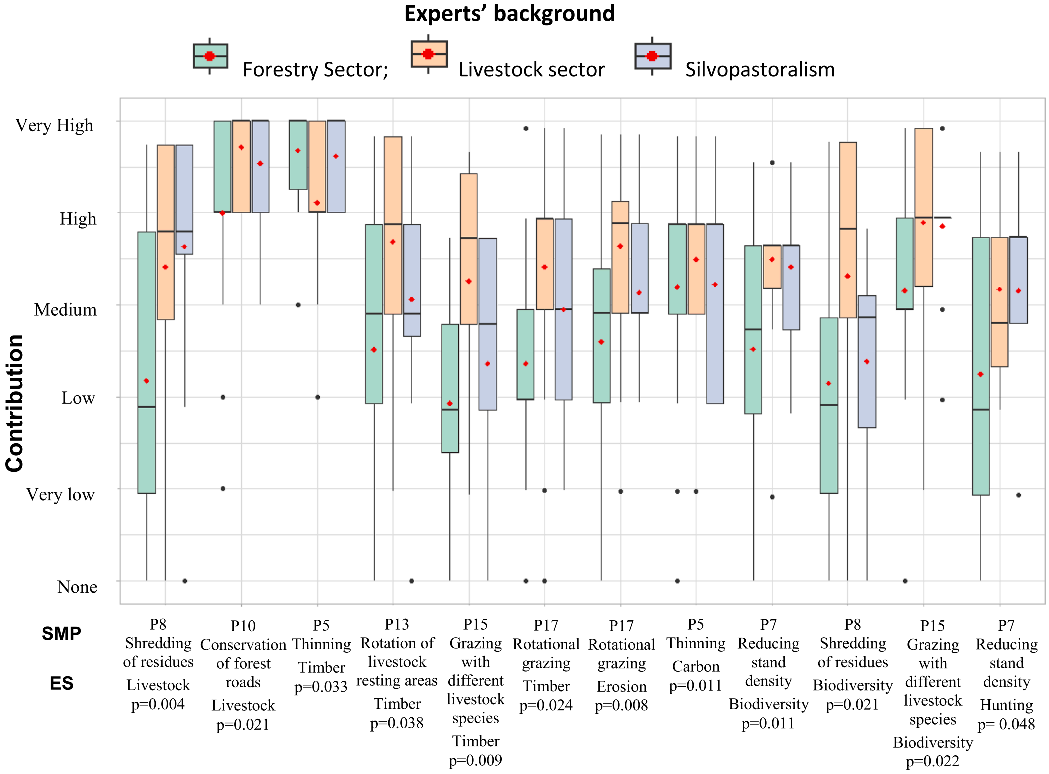

Fig. 2. Differences between expert background valuation of SMP over ES (Kruskal-Wallis test p < 0,05). Boxplot shows average (red dot), median and interquartile range. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

lower contribution.

The contribution of SMP to the provision of both cultural ES, i.e., the creation of spaces for recreational activities of hiking and hunting, showed the greatest dispersion according to the standard error (**Table A2**). Transversal practices such as conservation of forest roads and water bodies followed by silvicultural treatments such as coppice selection and thinning as well as selective clearing scored the highest for both cultural ES. Those practices along with rotation of livestock resting areas and grazing with different livestock species also showed a high contribution to multiple ES. In contrast, extending the forest grazing period and free animal grazing in the forest area gathered the lowest contributions to multiple ES.

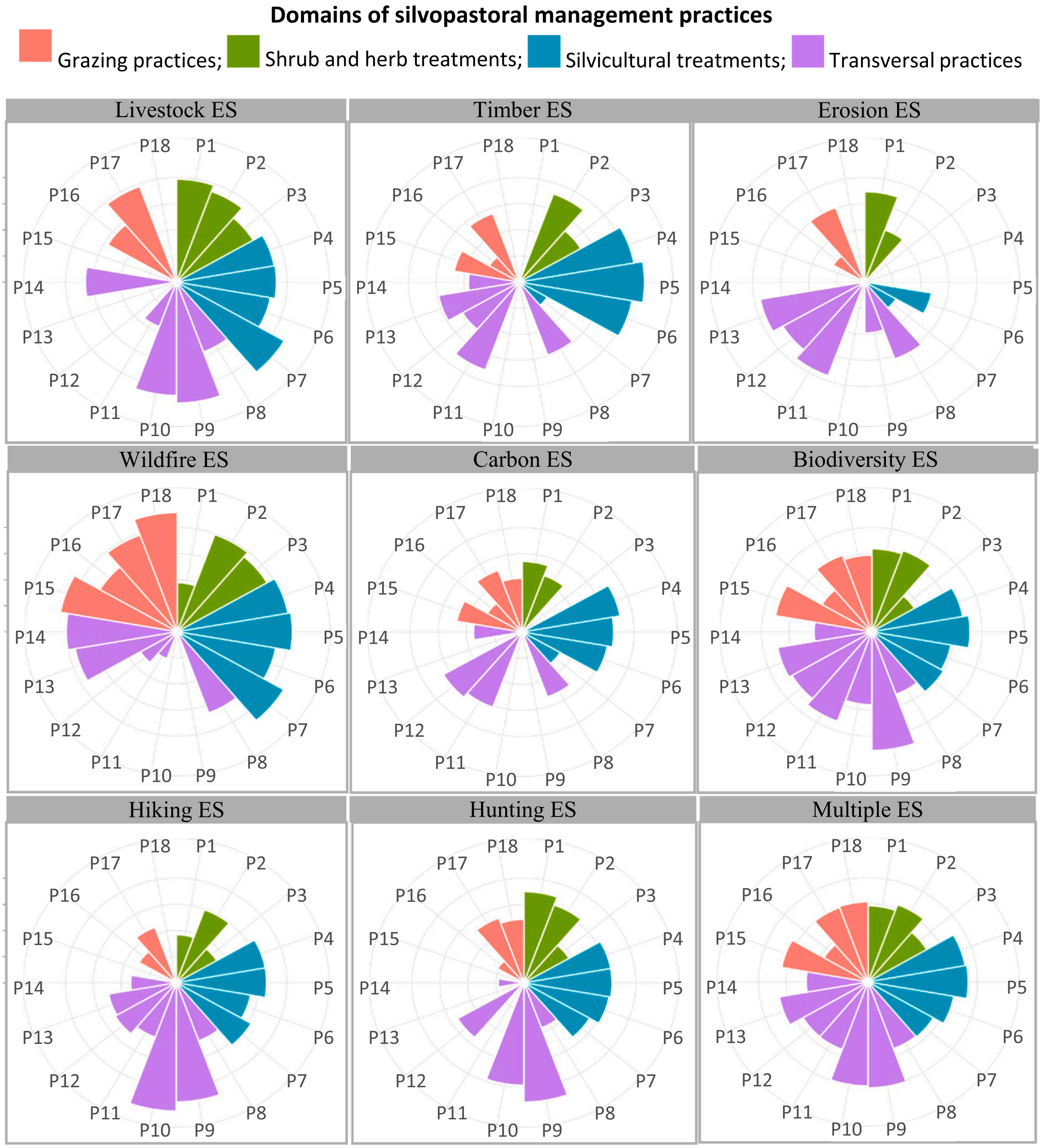

Fig. 3. Rose diagram illustrating the contribution of SMP to individual and multiple ES. Each petal of the rose represents the contribution (from 0 or null to 5 or very positive) of the practice on the ES while the colour refers to the management practice domain. The detailed descriptive statistics are found in Appendix A.

3.2.1. *Identification of multifunctional SMP and ES bundles*

When comparing the effects of practices across ES (**Table A3**), silvicultural treatments such as coppice selection, thinning and shelterwood cutting supplied bundles of ES as shown by their significant contribution to timber production and wildfire prevention, followed by livestock, hiking and carbon sequestration. Additionally, other SMP (prescribed burning and rotational grazing) also generated bundles of ES but with lower extent. In contrast, fencing and seeding understorey herbaceous species did not provide ES bundles, showing a low multi-functional role.

When grouping practices in domains (Fig. 4), silvicultural treatments showed the highest contribution for each ES (except for erosion control) and, also for the joint supply of multiple ES, although differences were rather small. The contribution of grazing practices scored the highest on wildfire prevention and on the creation of habitats for biodiversity, but lower than other practices in these domains.

3.2.2. *The potential negative contribution of SMP on ES delivery*

As expected, most of the practices were positively scored by the experts across the ES categories, although some SMP showed likely negative contributions. These SMP with a higher percentage of negative responses in various ES are summarized in Fig. 5 while the statistical information is provided in **Table A.4.**

Free animal grazing in the forest area was the practice that hoarded the highest percentages of negative responses on hunting, erosion control and timber production. More than 40% of the experts identified a potential negative effect of reducing stand density on timber production, erosion control, and carbon sequestration. Similar results were obtained

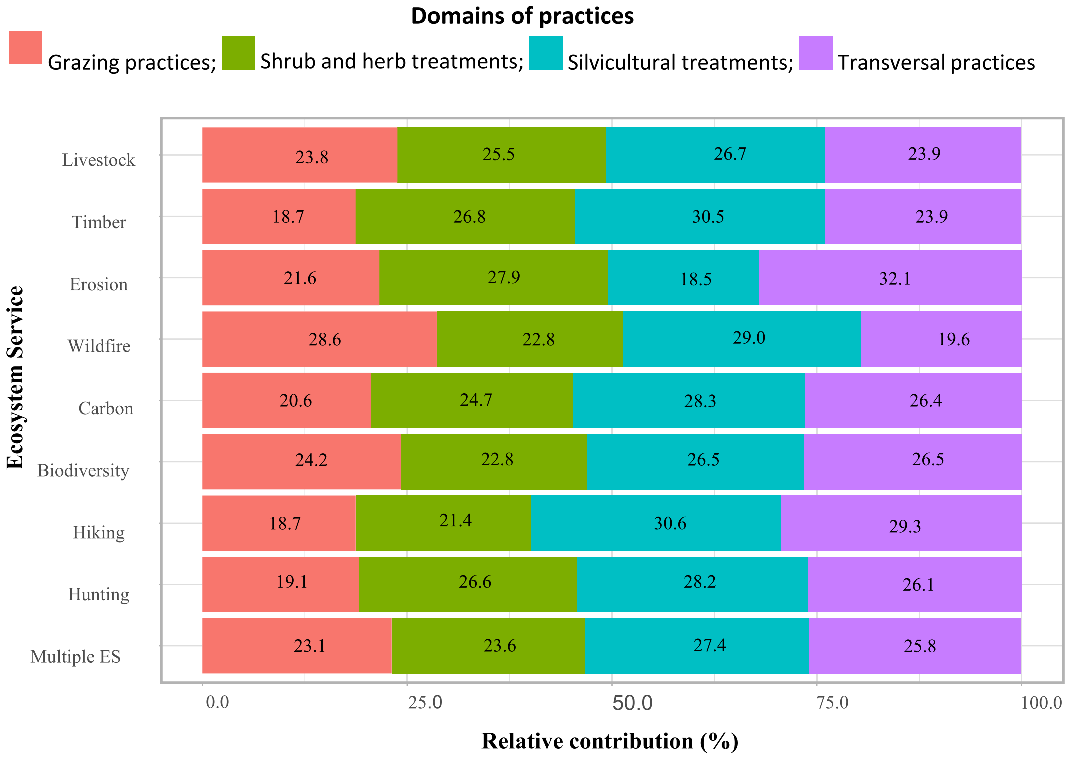

Fig. 4. Relative contribution (%) of SMP grouped in domains to the provision of individual and multiple ES.

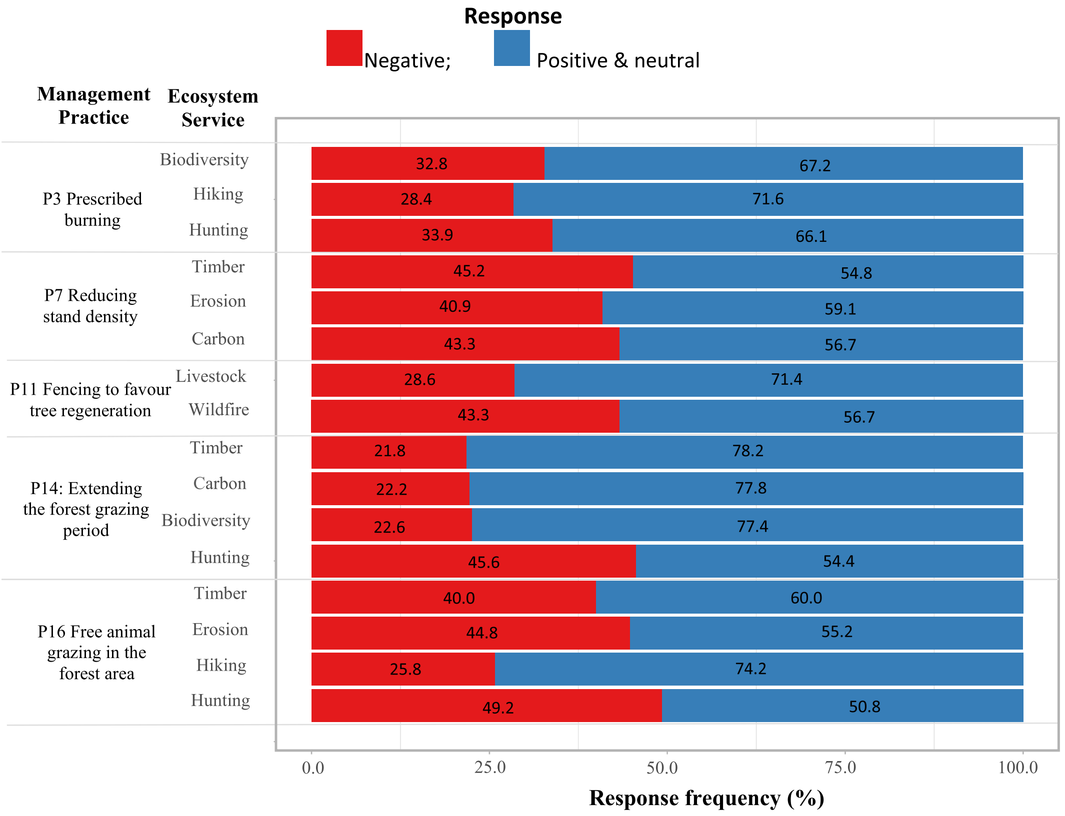

Fig. 5. Frequencies (%) of the negative and positive &neutral (grouping from none to very high positive) responses on the contribution of SMP to ES (p-value associated to Chi-squared < 0.05).

for fencing to favour tree regeneration on wildfire prevention. Extending the forest grazing period also gathered a negative percentage of responses, mainly on hunting.

3.3. Relationships between ES

Potential dynamics between ES were mostly positive (synergies), meaning that the addressed practices improve them simultaneously (Table 3). Synergies were found between carbon sequestration and timber production, erosion control and creation habitats for biodiversity while the later was also positively correlated with hiking and hunting. Provisioning ES, livestock production and timber production, were correlated with cultural ES, hiking and hunting, which in turn were associated with each other. Negative correlations (trade-offs) were only significant between wildfire prevention and erosion control, mostly because the SMP that contributed to the provision of the former reduced the provision of the latter and vice versa.

4. Discussion

Our study assessed the mid-term contribution at stand scale of relevant SMP on ES, and identified synergies, trade-offs, possible disservices, and bundles of SMP in Mediterranean mid-mountain SPS applying the Delphi method. The panel of experts agreed in most evaluations, but discrepancies arising on cultural ES highlight the need of further investigation (Milcu et al., 2013). Similarly, the disagreement among experts on the contribution of grazing practices to carbon sequestration is consistent with previous studies that observed lower expert knowledge on carbon sequestration dynamics (Rodríguez-Ortega et al., 2018). Recent studies signal the potential of well-managed livestock systems to increase soil carbon storage capacity, but the effects of grazing intensity, regimes, season and species are still understudied (Stanley et al., 2018; Manzano and White, 2019). Likewise, the mismatches in the scoring according to the expert category and specialization claims for a broader transdisciplinary approach.

Agroforestry improves ES provision and biodiversity compared with conventional agriculture or forestry (Torralba et al., 2016). The SMP studied specially enhance livestock production, the provision of habitats for biodiversity and wildfire prevention. Silvicultural treatments and grazing management practices highly contributed to wildfire prevention, in line with the literature (Moreno et al., 2018). Grazing management practices showed their importance in the creation of habitats for biodiversity, confirming their essential role in shaping SPŚ understory and building ecological niches for plants, animals and soil microorganisms (Fonderflick et al., 2010; García-Tejero and Taboada, 2016), while improving wildfire prevention (Riedel et al., 2013) and accessibility for recreational activities. Thus, these results support the role of extensive livestock farming, beyond the provisioning dimensions, as a tool for fire prevention and landscape management in the Mediterranean (Mancilla Leytón and Martín Vicente, 2012). Despite agroforestry can improve erosion control to a higher extent than agriculture (Torralba et al., 2016; Jose, 2009), the contribution of the assessed SMP to this ES was lower compared to other ES evaluated. Erosion control was more influenced by transversal practices, such as extending stand rotation, rotation of livestock resting areas, and fencing tree regeneration areas to avoid soil degradation (Ruiz-Mirazo and Robles, 2012), and also by seeding understorey herbaceous species. In a similar fashion, the contribution of the SMP to the provision of cultural ES was comparatively lower, despite the potential of agroforestry for its enhancement when compared to agricultural or forest land uses (Rolo et al., 2021). While promoting cultural ES is supported by forest managers (Torralba et al., 2020), it is necessary a holistic and multidisciplinary understanding of cultural ES to meet social demands (Milcu et al., 2013).

Regulation services related to water and the hydrological cycle have not been explicitly considered in our study due to the complexity and uncertainties inherent to their assessment (Sabater et al., 2021). Their relevance in Mediterranean environments call for future expansion of our study to explicitly account for this service that we implicitly considered through erosion control, and its relation to water infiltration (Sabater et al., 2021).

Another limitation of our study is that it focused on ES provision, although identification of likely disservices eventually arises (see below). According to Shackleton et al. (2016), ecosystem disservices (EDS) can be described as “the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing”, although an overall consensus on their definition is still pending. While EDS as such were not explicitly addressed in our work, their integration in future assessments of SPS would contribute to increase the understanding of complex social-ecological interactions in these systems (Blanco et al., 2019).

4.0.1. Bundles, synergies and trade-offs of SMP and ES

Despite none of the SMP maximized the contribution across all services, some of them showed high multifunctionality, promoting the joint provision of several ES, i.e., ES bundles. Silvicultural treatments (thinning, coppice selection and selective clearing) exhibited a multifunctional role improving ES in bundles (provisioning and cultural ES and wildfire prevention). These practices contributed simultaneously to obtain forage for livestock production and improved trees for timber production, while increasing carbon sequestration (Ruiz-Peinado et al., 2017), reducing wildfire risk and enabling accessibility for hunting and hiking. Coppice selection has positive effects on timber and livestock production (bioenergy and acorns to feed livestock), carbon sequestration and recreational opportunities (Paletto et al., 2017) while maintaining biodiversity (Torras and Saura, 2008) and improving the resistance to severe drought (Domingo et al., 2020). Similarly, some transversal practices such as shredding of residues, rotation of livestock

Table 3
Spearman correlation matrix among the ES assessed in this study.

-1 -0.75 -0.50 -0.25 0 0.25 0.50 0.75 1

	Livestock	Timber	Erosion	Wildfires	Carbon	Biodiversity	Hiking
Timber	0.05						
Erosion	-0.48	0.33					
Wildfires	0.53	0.00	-0.64 *				
Carbon	-0.10	0.77 **	0.73 **	-0.28			
Biodiversity	0.37	0.43	0.44	0.03	0.61 **		
Hiking	0.62 **	0.57 *	-0.45	0.54 *	0.54 *	0.49 *	
Hunting	0.77 **	0.69 **	0.17	0.00	0.62 **	0.70 **	0.77 **

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.001$. Spearman rank correlation.

resting areas and conservation of water bodies also generated ES in bundles. The availability of infrastructure (i.e., water sources and road networks) is crucial for the implementation or continuation of grazing in forest understorey (Varela et al 2020), as our study also supports.

On the contrary, fencing and seeding understory herbaceous species practices presented a low multifunctional role. The creation of fenced areas, mainly to avoid livestock damage in sampling trees, suggests trade-offs between livestock and timber production, especially during the stand regeneration phase, that may also be reduced by promoting facilitation by shrubs to reduce tree consumption by livestock (Boulant et al., 2008). Prescribed burning, beyond its undoubted contribution to wildfire prevention (Piqué and Domènech, 2018), provided ES bundles but to a lower extent (biodiversity and recreational ES). Accordingly, the effects of prescribed burning on these ES can be considerably reduced when combined with grazing practices (Alcañiz et al., 2020).

Among grazing practices, free animal grazing may compromise the provision of ES such as timber production, and cultural ES (mostly, hunting), hence potentially generating several trade-offs between these services and livestock production or even possible disservices (i..e. increasing soil erosion). Therefore, our results indicate that other grazing management systems with more animal control such as rotational grazing or target grazing can be more effective in meeting multiple management objectives. Nevertheless, the increase of labour requirements for farmers is a barrier to promote wood pasture grazing, being more compatible with cattle than sheep farming systems (Varela et al 2022). Thus, free animal grazing management is widely adopted by many farmers in the Mediterranean. Extending the forest grazing period that showed high contribution to livestock production and wildfire prevention, may generate trade-offs with some ES, mainly hunting, but since it may compromise animal performance, it is less interesting for farmers (Teruel-Coll et al., 2019).

The SMP studied revealed multiple synergies on the overall provision of ES, reinforcing the role of SPS to reconcile production and conservation while increasing resilience in the face of climate change to ensure sustainable ES delivery. A strong correlation was found between timber production and carbon sequestration which is consistent with recent studies on forest management in the Mediterranean (Morán-Ordóñez et al., 2020; Roces-Díaz et al., 2021). Provisioning and regulating ES showed synergies with cultural ES. We found a synergistic relationship between hunting and livestock production since both wild and domestic herbivores rely on fodder productivity, although other studies referred possible problems related to health risks (Palomo-Campesino et al., 2018).

Our analysis suggests a potential trade-off between wildfire prevention and erosion control. Previous works indicate that agroforestry improves wildfire prevention and erosion control compared respectively to conventional forestry and agriculture (Jose, 2009; Moreno et al., 2018). However, our results indicate that it is particularly challenging to deal with erosion control and wildfire prevention simultaneously in SPS (Riva et al., 2018). SMP aiming at reducing vegetation cover for wildfire prevention might increase the risk of erosion, especially in steep areas and when the effect of mechanized operations is considered (Edeso et al., 1999). Nevertheless, this trade-off highlights the importance of balancing SMP goals, considering the potential consequences on ES provision to ensure the long-term sustainability of the ecosystem (D'Amato et al., 2011).

4.0.2. *Policy implications*

Despite the multiple ES provided by SPS, this land-use lacks recognition in policies (Mosquera-Losada et al., 2018). In the current Common Agricultural Policy (CAP) (2013–2020), that importantly determines the configuration of European farming systems, the implemented Pasture Eligibility Coefficient (PEC), penalizes SPS since trees result in a reduction in the direct area payments, unless they are considered landscape features (Mosquera-Losada et al., 2018). Furthermore, there is an absence of a common forest policy in the European Union. In this context, the maintenance of multifunctional SPS is hampered by the lack of financial incentives and by environmental regulations (Varela et al., 2020) such as the EU Habitats Directive since many of them are included in the Natura 2000 network and their traditional institutional structures are not easily amenable to the agricultural and conservation policies (Plieninger et al., 2015).

Our results demonstrated that SMP carried out in SPS drive the provision of a high number of ES in a synergic manner, revealing a great potential for Mediterranean forests to improve their multifunctionality and support extensive livestock farming systems through a better integration of both activities. Nevertheless, some SMP had a low multifunctional character (e.g., free animal grazing) despite their wide application and even possible negative contributions to some ES. Hence appropriate measures would be needed to encourage SMP that lead to optimise the provision of ES bundles, or a single ES when needed, accounting for the trade-offs implied. Given that the efficiency and effectiveness of agri-environmental policies implemented through Rural Development Programmes (RDP, CAP Pilar II) to improve nature conservation has not been as expected (Navarro and López-Bao, 2018), the establishment of alternative schemes could be advisable (Rodríguez-Ortega et al., 2018) to complement existing mechanisms and improve the provision of ES. Specifically, these mechanisms should involve stakeholders and consider the contextual heterogeneity of socio-ecological systems in order to increase their success (Aguilar-Gómez et al., 2020) while being tailored to the diversity of farmers and forest owners, their needs and objectives (Varela et al., 2022). As Viaggi et al., (2021) point out, there is a need to investigate further both the micro-mechanisms of decision-making, value creation and coordination among actors, including the micro-level issues in policy design.

5. Conclusions

This study provides an overview of relevant provisioning, regulating-maintenance, and cultural ES dynamics driven in the mid-term by forestry and pastoral practices in Mediterranean mid-mountain SPS. The structured expert-based assessment technique applied depicted the multiple effect of SMP on ES, highlighting synergies and trade-offs among SMP and ES. Our analysis showed that silvopastoral management provide an opportunity to improve the multifunctionality of mid-mountain Mediterranean forests.

Livestock production, habitats for biodiversity and wildfire prevention were the ES provided to a higher extent by the overall SMP evaluated. Neither of the SMP evaluated maximized simultaneously the contribution to all ES. Nevertheless, silvicultural treatments and transversal practices provided multiple ES bundles, suggesting the importance of properly manage tree cover and resources for the delivery of ES. Multiple synergies arose among provisioning, regulating and cultural ES whereas possible trade-offs were especially important between erosion control and wildfire prevention.

Overall, our results reveal complex synergy and trade-off dynamics between ES as mid-term outputs of SMP that should be taken into consideration in decision-making planning of Mediterranean silvopastoral systems. Although silvopastoral management is highly dependent on the environmental and socio-economic context, these findings could help in decision-making processes and policies to foster sustainable management of mid-mountain silvopastoral systems in the northern Mediterranean basin, where the socio-ecological system is similar to the addressed in this study.

CRediT authorship contribution statement

Antonio Lecegui: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Ana M. Olaizola:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Elsa Varela:** Funding acquisition, Investigation, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2022.120273.

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