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Research article

Targeting best agricultural practices to enhance ecosystem services in European mountains

A. Bernués [a,b], A. Tenza-Peral [a,b], E. Gómez-Baggethun [c,d,*], M. Clemetsen [c], L.O. Eik [c], D. Martín-Collado [a,b]

[a] Departamento de Ciencia Animal, Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Zaragoza, Spain
[b] Instituto Agroalimentario de Aragón – IA2 (CITA-Universidad de Zaragoza), Zaragoza, Spain
[c] Faculty of Landscape and Society, Norwegian University of Life Sciences, P.O. Box 5003, Ås, N-1432, Norway
[d] Norwegian Institute for Nature Research (NINA), Sognsveien 68, 0855, Oslo, 0349, Norway

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ABSTRACT

Agri-environmental policies in Europe are failing to sufficiently address ongoing environmental degradation, biodiversity decline, climate impacts, and societal demands for sustainability. To reverse this, policymakers, practitioners, and farmers need better guidance on which specific agricultural practice/s should be promoted and how to adapt current practices to reach the desired objectives. Here we use social valuation tools to elucidate the relationship between agricultural practices and the provision of key ecosystem services in mountains, including maintenance of scenery from agricultural landscapes, conservation of biodiversity, regulation of climate change through carbon sequestration, production of local quality products, maintenance of soil fertility, and prevention of forest wildfires. We use as case studies two contrasting but representative mountain agroecosystems in the Mediterranean and Nordic regions of Europe. We analyze the best agricultural practices in both agroecosystems to reach the targeted environmental outcomes under three plausible policy scenarios. We find significant differences in the average contribution of agricultural practices to ecosystem services provision, which suggest the need for regionalizing the research efforts and, consequently, the design of agri-environmental policies. However, we also identify practices for ecosystem service delivery across policy scenarios and agroecosystems. Among these, grazing and silviculture practices such as extending the grazing period, grazing in semi-natural habitats, grazing in remote and abandoned areas, adapting stocking rate to the carrying capacity, and moving flocks seasonally, stand out for their relevance in all policy scenarios. These results highlight the potential of adequate grazing and silviculture practices to deliver bundles of ecosystem services. Our study provides guidance to design agri-environmental policies in Europe that focus on rewarding farmers for their sustainable management of natural resources, climate change mitigation and adaption and biodiversity conservation.

1. Introduction

Worldwide, agricultural support policies are failing to provide environmental outcomes aligned with global sustainability targets (FAO, UNDP and UNEP, 2021). Intensive agriculture with large negative externalities receives direct and indirect public support though price incentives and subsidies. By contrast, marginal rural areas of high nature value (HNV) and ecosystem services provision are largely neglected and left to abandonment (Navarro and López-Bao, 2019; Scown et al., 2020). In Europe, agri-environmental policies now aim at addressing ongoing environmental degradation, biodiversity decline, climate action, and societal demands for sustainability, but have so far had limited success (Pe'er et al., 2019; European Court of Auditors, 2020). Despite agri-environmental schemes are solidly established in the European Union (EU) since 1985 and cover 44 million ha, only a few schemes such as the Burren Programe for improving the natural and cultural heritage of the Burren in Ireland (Moran et al., 2021) or the Ecological Compensation Area scheme for biodiversity protection in the Swiss Alps (Kampmann et al., 2012), are reported as being successful for biodiversity, maintenance of cultural landscapes and achieving environment

* Corresponding author. Faculty of Landscape and Society, Norwegian University of Life Sciences, P.O. Box 5003, Ås, N-1432, Norway.
E-mail addresses: abernues@cita-aragon.es (A. Bernués), atenza@cita-aragon.es (A. Tenza-Peral), erik.gomez@nmbu.no (E. Gómez-Baggethun), morten.clemetsen@nmbu.no (M. Clemetsen), lars.eik@nmbu.no (L.O. Eik), dmartin@cita-aragon.es (D. Martín-Collado).

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sustainability (Tyllianakis and Martin-Ortega, 2021).

Among the potential solutions to overcome the lack of consistency between agricultural policy, environmental policies (e.g. EU Natura, 2000, HNV farmland areas), and the Sustainable Development Goals (Scown et al., 2020), various studies point at the need to set target-oriented policies (Pe'er et al., 2019; Navarro and López-Bao, 2019). Target-oriented agri-environmental policies aim to replace direct income support farm premiums linked to hectares of land by farm payments based on the delivery of public goods (Grethe et al., 2018; 'Pe'er et al., 2020), favoring a green subsidy reform (Cassou, 2018).

Here we propose a novel methodological framework for targeted design and implementation of agri-environmental policies in European mountains. Based on social valuation tools, we determine the potential of a wide portfolio of real agricultural practices to provide key ecosystem services under different policy scenarios. Particularly, we aim to understand what is the contribution of different agricultural practices to deliver key ecosystem services at the farm level, and what are the agricultural practices that should be rewarded for the conservation of mountain agroecosystems.

Payments for ecosystem services (PES) have been long proposed as an effective instrument to promote synergies between agriculture development and nature conservation objectives (Engel and Muller, 2016). Depending on the policy's objective, PES schemes can be designed based on results or on management practices (Reed et al., 2014). The case has been made that results-based PES could be unfair because ecosystem services delivery is a multifactorial process where not all influencing factors are under farmers' control. On the other hand, management-based PES are sitting on moving sand because knowledge on the link between agricultural practices and ecosystem services is still scarce (Rodríguez-Ortega et al., 2014). To develop sound PES schemes, policymakers and farmers need clearer guidance on which agricultural management should be promoted and how to adapt their current practices to reach the desired objectives. In this study, we provide this guidance by identifying the specific agricultural practices that help obtaining key ecosystem services in two contrasting but representative mountain agroecosystems in the Mediterranean and Nordic regions of Europe.

Advancing our understanding of the links between farming practices and ecosystem services delivery is crucial to inform sound decision-making (Dale and Polasky, 2007). However, several factors have so far limited the applicability of ecosystem service considerations in agro-environmental policy design. For example, it is difficult to segregate the effects of individual practices on one or multiple ecosystem services (Power, 2010; Rodríguez-Ortega et al., 2014). Similarly, ecosystem services are provided in bundles (Raudsepp-Hearne et al., 2010; Martín-López et al., 2012), often interconnected to additional sustainability criteria (Bernués et al., 2016), with multiple trade-offs and synergies between them (Turkelboom et al., 2018). In addition, the effect of agricultural practices on ecosystem services provision varies across agroecosystems, and temporal and spatial scales, making it difficult to establish general recipes (Dale and Polasky, 2007). For example, the positive effects of organic farming on biodiversity expand beyond the local scale, making it difficult to isolate neighboring conventional farms' effects at the landscape scale (Rundlöf et al., 2008, 2010; Schmidt et al., 2005). Finally, many ecosystem services are difficult to measure, particularly cultural ones, which are of great importance in many mountain and other HNV agro-ecosystems (Chan et al., 2012; Kaltenborn et al., 2020). Therefore, the integration of such ecosystem services in research and policy remains a major challenge (Daniel et al., 2012).

We reviewed the existing literature about the links between farming practices and ecosystem services using the following query in SCOPUS: *"(TITLE ("agricultural practices" OR "farming practices") AND TITLE-ABS-KEY ("ecosystem services"))"*. We obtained 37 documents but discarded nine that did not relate to the topic. Most empirical studies focused on the effect of one or few agricultural practices on one or few ecosystem services (e.g. Rodríguez-Ortega et al., 2014; Piastrellini et al., 2015; Souty-Grosset and Faberi, 2018). There were, however, some exceptions. Lee et al. (2019) carried out a meta-analysis of agricultural conservation practices on provisioning, regulating and supporting ecosystem services in different agricultural and silvopastoral systems. Shackelford et al. (2019), based on a synthesis of evidence, explored the relationship between nutrient management, conservation agriculture, habitat management, and grazing management practices with provisioning, regulating and supporting ecosystem services in California. Meta-analyses or evidence-based reviews like these provide a broader insight, but are often constrained by research gaps concerning, for example, effects of agricultural practices on neglected or difficult-to-measure ecosystem services (Shackelford et al., 2019).

Various studies examined ecosystem services provided by agricultural cultural landscapes (Gómez-Baggethun et al., 2011; Gaitán-Cremaschi et al., 2017). Challenges involved in these exercises, such as the complexity of setting up empirical experiments at the landscape scale and of measuring intangible ecosystems services and values, fostered the use of participatory social and cultural valuation tools (Oteros-Rozas et al., 2014). Such valuation methods often rely on deliberative processes, expert knowledge, or the preferences and values of local stakeholders to value non-marketed ecosystem services (Rodríguez-Ortega et al., 2014; Bernués et al., 2016; Cheng et al., 2019). Applying the landscape scale perspective on the multiple dimensions of natural and cultural ecosystems, opens the way for seeing rural areas as shared arenas for the co-production of cultural values and ecosystem services provided by farming and agricultural practices (Selman, 2012; Stenseke, 2016).

Despite the advances in methodological approaches and in the theoretical and empirical understanding of the relationship between agricultural practices and ecosystem services provision, some important issues remain unresolved. In the first place, little research has been done on how agricultural practices at the farm level affect ecosystem services that are relevant in and across particular biophysical, socioeconomic, and policy contexts (Seppelt et al., 2011; Rodríguez-Ortega et al., 2014). Secondly, studies analyzing a wide range of practices on both easy and difficult to measure ecosystems services using the same methodological approach are scarce. In addition, most of the scientific knowledge on ecosystem services has not extended beyond academia. It is therefore critical that scientific research results better respond to the demands and needs of decision-makers and practitioners (Haida et al., 2016; Olander et al., 2017).

We fill these research gaps using a novel methodological framework based on social valuation tools to determine the potential of a wide portfolio of regional agricultural practices to provide key ecosystem services under different target-oriented agri-environmental policy scenarios. The specific objectives are: i) to assess the contribution of different agricultural practices to deliver key ecosystem services at the farm level, and ii) to identify best agricultural practices for each agroecosystem under different agri-environmental policy scenarios. Our methodological framework can help policymakers and practitioners to operationalize agricultural policies based on environmental objectives, as discussed below.

2. Methodology

2.1. Study areas

The two areas under study correspond to HNV agro-ecosystems in Atlantic/Alpine Norwegian mountains (hereafter Nordic agro-ecosystem) and in Mediterranean Spanish mountains (hereafter Mediterranean agroecosystem) (Fig. 1). Both agroecosystems are of relevance for the purposes of this research because of: i) decreasing economic importance of the agricultural sector, grazing livestock in particular; ii) being biodiversity-rich areas of high natural and cultural values which constitute strong tourism assets, and iii) being subject to intense

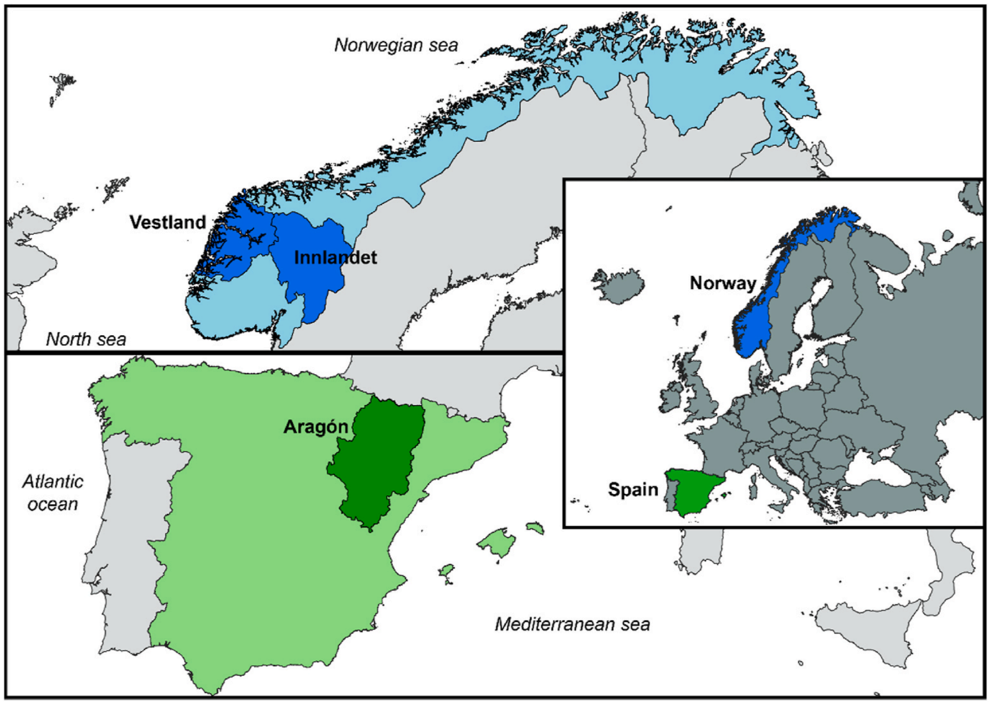

Fig. 1. Location of study areas.

landscape change, mainly due to vegetation encroachment.

The Nordic agroecosystem covers the counties of Vestland and Innlandet in South-West Norway. Central farming systems in this area are pasture-based meat sheep, dairy goats, dairy cows, and beef cattle farms. Managed land is primarily devoted to natural grasslands, forests and cultivated fodder, fruits, and berries in the lowlands. The use of grazing resources varies according to a seasonal and altitudinal gradient. The substantial decline of agricultural activities in the area, especially since the 1970s, has been a significant driver of biodiversity loss in the traditional pastures and meadow habitats located in lowlands (Nybø et al., 2011). In parallel, there is also a strong continuing process of vegetation encroachment and landscape closure, which however has not stopped these cultural landscapes from being a major tourism attraction in Norway due to their scenery.

The Mediterranean agroecosystem covers the region of Aragón, in northeast Spain, where landscapes are the result of long-term human-nature co-evolution processes (Butzer, 2005; Blondel, 2006). Millennia of agro-silvo-pastoral ways of life have shaped these cultural landscapes, where a global biodiversity hotspot co-exist with highly humanized multifunctional landscapes (Grove and Rackham, 2003; Oteros-Rozas et al., 2013). Due to these heterogeneous environmental characteristics, a wide variety of farming systems exist, from specialized grazing systems in the mountains to mixed animal-crop systems with a considerable variation in intensity (Rodríguez-Ortega et al., 2016). The traditional Mediterranean agroecosystem is characterized by extensive, low-input/low-output farming, with some arable land -mostly forages, permanent crops (mainly olive groves and vineyards), and cereals- and a large reliance on natural pastures, are also in decline.

2.2. Expert-based survey and questionnaire

We carried out expert consultation processes through an on-line questionnaire to assess the effect of agricultural practices in ecosystems services at each study area. Experts were selected to cover different types of knowledge and disciplinary backgrounds: (i) researchers with expertise on agriculture-environment relationships, and (ii) technicians/managers from governmental agencies and Non-Governmental Organizations related to agriculture and environmental conservation, as well as from agricultural and natural heritage associations, local agribusiness, and cooperatives. Experts were invited to participate in the study via telephone and/or e-mail. In total, 93 experts participated in the process, including 61 experts in Spain (29 researchers and 32 technicians) and 32 in Norway (21 researchers and 11 technicians).

The surveys were conducted in November–December 2015 in Spain, and in March–April 2019 in Norway. The questionnaire consisted of three parts. First, respondents were introduced into the objectives and the funders of the study and were informed about their rights in terms of data protection and project participation. The questionnaire then proceeded with a brief description of the Nordic and Mediterranean mountain agroecosystems under study. We then collected professional data of respondents, including occupation and working place. Next, respondents were asked to rate the influence of each agricultural practice on each ecosystem service on a six-point rating scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). To allow flexibility and minimize biases, we also included the option "I don't know".

2.3. Assessment of links between agricultural practices and ecosystem services

We assessed the average contribution of each agricultural practice to a given ecosystem service as the sum of the 'experts' scores for that agricultural practice divided by the number of experts that had provided an answer, after removing the answers where the option "I 'don't know" had been selected. Observed differences between agroecosystems (Nordic vs Mediterranean) and expert categories (researchers vs technicians) on the contribution of agricultural practices to ecosystem services were analyzed using a Mann-Whitney test.

2.4. Selection and grouping of agricultural practices

An initial list of agricultural practices with a documented positive effect on ecosystem services was compiled from the report by Cooper et al. (2009). This report identifies agricultural practices contributing to the production of ecosystem services with public good character from a comprehensive review of scientific and grey literature, agri-environment schemes, and 'experts' opinions in different European regions. Following the methodology described in Rodríguez-Ortega et al. (2018), who monitored the management and functioning of representative sheep-crop farms in the Mediterranean agroecosystem, 36 relevant practices were selected. The list was then adapted to the Nordic agro-ecosystems. Out of the 36 practices in the initial list, ten were discarded because they did not apply to the Nordic agroecosystem; for example, "maintaining fallows in rotation" or "carcasses left in situ". Another two, "optimizing soil drainage (non-organic soils)" and "biogas production from animal waste", were added because they were relevant in this region. In total, 36 agricultural practices were evaluated for the Mediterranean agroecosystem and for in the Nordic agroecosystem, 26 practices being common to both agroecosystems (Table 1). Following Rodríguez-Ortega el al. (2018), the farming practices of both agro-ecosystems were then grouped into five categories of related practices, labelled i) semi-natural vegetation and landscape elements (vegetation and elements), ii) croplands (crop and species), iii) inputs, iv) grazing and silviculture activities, and v) other.

2.5. Identification of ecosystem services

To keep the complexity of the study at a manageable level, we focused on the most important ecosystem services provided by the two mountain agroecosystems, as identified in previous socio-cultural and economic valuation studies (Bernués et al., 2014, 2015). Most relevant ecosystem services were identified using a combination of deliberative (focus groups) and survey-based stated-preference methods (choice modelling) to determine the perceptions of farmers as well as other citizens, and to value them in economic terms according to the willingness to pay by concerned populations. In total, we analyzed six ecosystem services covering all major categories in established international classifications (provisioning, supporting, regulating and cultural ecosystem services) (e.g. TEEB, 2010). Four ecosystem services were common to both study areas, including maintenance of scenery from agricultural landscapes (cultural); conservation of biodiversity (supporting); the regulation of climate change through carbon sequestration (regulating); and production of local quality products (provisioning). In addition, we analyzed maintenance of soil fertility (regulating) in the Nordic agroecosystem; and prevention of forest wildfires (regulating) in the Mediterranean agroecosystem.

Table 1
Agricultural practices evaluated for each ecosystem services in Nordic (N) and Mediterranean (M) mountains.

Group	Agricultural practice	Ecosystem service									
		Landscape		Biodiversity conservation		Soil fertility	Forest wildfires	Carbon sequestration		Quality products	
Vegetation and elements	1. Maintaining semi-natural vegetation (trees and shrubs) characteristic of each area	N	M	N	M	N	M	N	M	N	M
	2. Maintaining grasslands	N	M	N	M	N	M	N	M	N	M
	3. Managing land in small plots	N	M	N	M		M				
	4. Retention of hedges, shrubs and trees among arable fields	N	M	N	M	N	M	N	M		
	5. Retention terraces		M		M				M		
	6. Retention traditional buildings and field boundaries	N	M	N	M						
	7. Retention of water points	N	M	N	M		M				
	8. Retention of drove roads and tracks	N	M	N	M		M				
Crops and species	9. Crop diversification	N	M	N	M	N		N	M		
	10. Growing locally adapted crop varieties and breeds	N	M	N	M	N		N	M	N	M
	11. Growing crop varieties with lower requirements		M		M				M		M
	12. Genetic selection for high productivity			N	M					N	M
	13. Retention of high proportion of semi-natural meadows and pluri-annual crops	N	M	N	M	N		N	M		
	14. Utilizing nectar source crops for pollinators		M		M						
	15. Utilizing cover crops		M		M				M		
	16. Utilizing crop rotations, including legumes		M		M				M		M
	17. Maintaining fallows in rotation		M		M		M		M		
	18. Substituting bare fallow for green/seeding fallow		M		M				M		
Inputs	19. Reducing use of machinery	N	M	N	M	N	M	N	M		
	20. Reducing ploughing/tilling								M		
	21. Reducing chemical fertilizers			N	M	N		N	M	N	M
	22. Utilizing manure correctly	N	M	N	M	N		N	M	N	M
	23. Reducing pesticide use			N	M	N				N	M
	24. Reducing herbicide use		M								
	25. Reducing animal drugs			N	M	N				N	M
	26. Reducing proportion of animal concentrates			N	M			N	M	N	M
	27. Reducing off-farm dependency	N	M	N	M	N		N	M	N	M
Grazing and silviculture	28. Extend grazing annual period	N	M	N	M	N	M	N	M	N	M
	29. Grazing in semi-natural habitats	N	M	N	M	N	M	N	M	N	M
	30. Grazing in remote and abandoned areas	N	M	N	M	N	M	N	M		
	31. Grazing with several species	N	M	N	M	N	M	N	M		
	32. Moving flocks seasonally	N	M	N	M	N	M	N	M	N	M
	33. Maintaining meadow mowing	N	M	N	M	N	M	N	M		
	34. Carcasses left in situ				M						
	35. Adapting stocking rate to the carrying capacity of agroecosystem	N	M	N	M	N	M	N	M		
	36. Active management of forest (forestry/silviculture)	N	M	N	M	N	M	N	M	N	M
Other	37. Optimizing soil drainage (non-organic soils)	N		N		N		N			
	38. Biogas production from animal waste							N			
	Total	22	29	27	34	21	16	21	26	14	16

2.6. Prioritization of agricultural practices for agri-environmental policy scenarios

We analyzed and ranked best agricultural practices under three hypothetical agri-environmental policy scenarios that determine the relative importance of different ecosystem services.

The first scenario reflected the (1) *social demand* for ecosystem services from mountain agroecosystems as identified in previous studies in the same Nordic and Mediterranean agro-ecosystems (Bernués et al., 2014, 2015). The relative importance was obtained using individuals' stated behavior in hypothetical choice settings. Specifically, we used a survey-based choice experiment, where individuals were asked to choose between a series of combinations of attributes (ecosystem services under study) and levels (defined in biophysical terms). Each choice set included three alternative levels of delivery of the ecosystem services. When individuals made their choice, they traded off between the levels of the attributes. The relative importance that the population gave to ecosystem services provision depended on the region as consequently did the resulting policy scenarios. In the Nordic agroecosystem, the relative of importance (willingness to pay for a given ecosystem service over the total willingness to pay) of ecosystems were: 0.266 for the conservation of the agricultural landscape, 0.204 for biodiversity conservation, 0.255 for the maintenance of soil fertility and 0.276 for production of quality products linked to the territory. In the Mediterranean agroecosystem, these results were: 0.082 for the conservation of the agricultural landscape, 0.184 for biodiversity conservation, 0.532 for the prevention of wildfires and 0.202 for production of quality products linked to the territory.

The second scenario (2) *biodiversity conservation and climate change mitigation* corresponds to a policy that gives equal importance (0.5) to biodiversity and carbon sequestration. The third scenario (3) *biodiversity conservation* corresponds to a policy focusing only on biodiversity (relative importance = 1). These scenarios are plausible within the current agri-environmental policies in Europe, in particular the eco-schemes of the new CAP 2023–2027 and the European Green Deal.

To establish the most important agricultural practices to target the different policy scenarios, we defined the importance that each practice have on the compliance of each policy scenario as follows:

$$IP_iS_j = \sum_{k=1}^{6} CP_iES_k \times rIES_kS_j$$

where IP_iS_j is the importance of practice i on policy scenario j, CP_iES_k is the average contribution of practice i to ecosystem service k *(calculated as described in section 2.4)*, and $rIES_kS_j$ is the relative importance of ecosystem service k to the policy scenario j.

3. Results

3.1. Importance of agricultural practices for delivering ecosystem services

Figs. 2 and 3 show, for each agroecosystem, the average contribution (and standard deviation) of different agricultural practices to the provision of ecosystem services. Practices where significant differences between agroecosystems were observed are highlighted. There were no statistically significant differences between expert categories, and therefore they are not presented.

Maintenance of scenery in agricultural landscapes. Twenty-two and twenty-nine agricultural practices were assessed as having a positive effect on maintaining the agricultural landscape in Nordic and Mediterranean agro-ecosystems. The most important practices were grouped around "vegetation and elements" and "grazing and silviculture". These

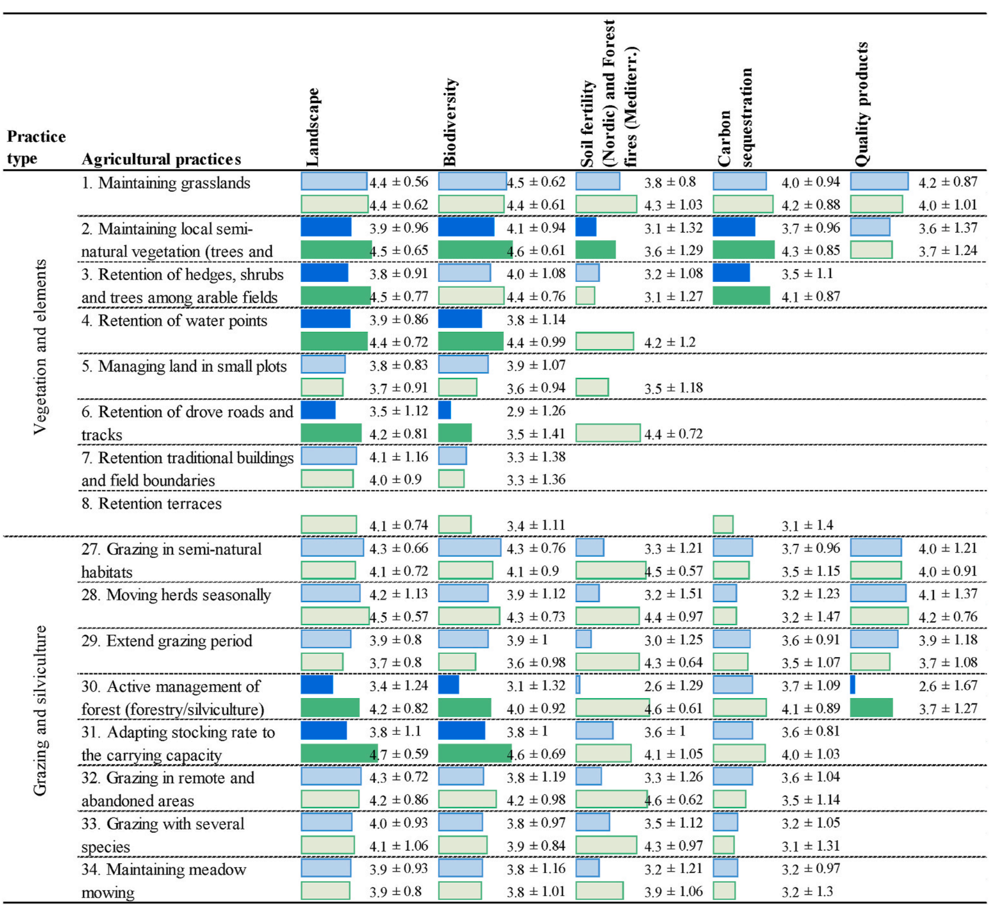

Fig. 2. Contribution of agricultural practices related to "Vegetation and elements" and "Grazing and silviculture" on ecosystem services in Nordic (blue bars) and Mediterranean mountains (green bars). Average and standart deviation of expert scores. Values of the rating scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). Bars with dark colors refer to statistical differences (Mann-Whitney U test, $p < 0.01$) between regions on the contribution of agricultural practices to ecosystem services.. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

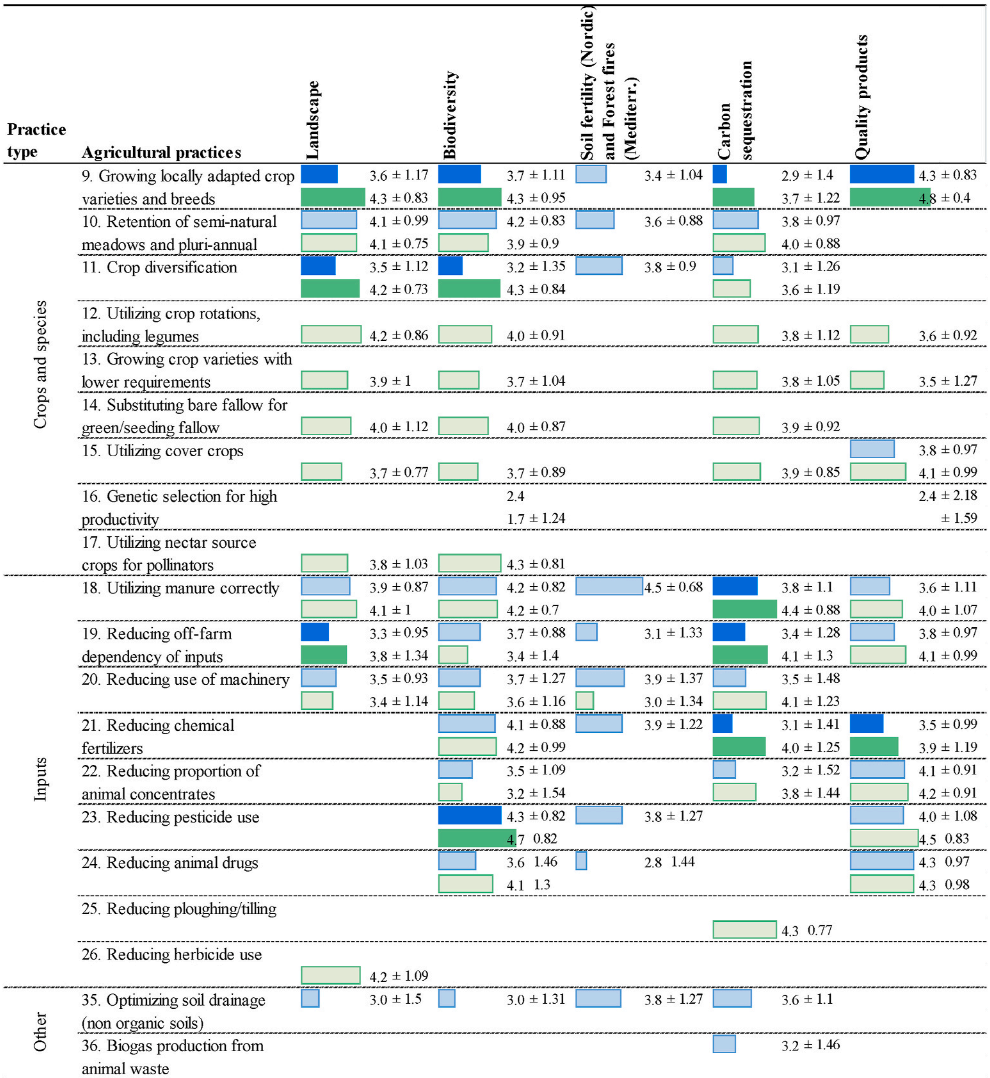

Fig. 3. Contribution of agricultural practices related to "Crops and species", "Inputs" and "Other" on ecosystem services in Nordic (blue bars) and Mediterranean mountains (green bars). Average and standart deviation of expert scores. Values of the rating scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). Bars with dark colors refer to statistical differences (Mann-Whitney *U* test, $p < 0.01$) between regions on the contribution of agricultural practices to ecosystem services.. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

types of practices include some agricultural practices linked to traditional farming systems such as maintaining local semi-natural vegetation, retaining hedges shrubs and trees among arable fields, grazing in semi-natural habitats, and moving herds seasonally.

Conservation of biodiversity. Twenty-seven and thirty-four agricultural practices were assessed as having a positive effect on biodiversity in Nordic and Mediterranean agro-ecosystems. The most important practices were grouped around "vegetation and elements", "grazing and silviculture" and "inputs". Among them, we highlight the positive effects of maintaining grasslands, grazing in semi-natural habitats, reducing pesticides and chemical fertilizers, and using manure correctly.

Carbon sequestration. Twenty-one and twenty-six agricultural practices were assessed to have a positive impact on carbon sequestration in Nordic and Mediterranean agro-ecosystems, respectively. The most important practices were grouped around "crops and species" and "inputs". We distinguish especially the positive effects of retaining a high proportion of semi-natural meadows and perennial crops and using manure correctly.

Production of local quality products. Fourteen and sixteen agricultural practices were identified to positively affect the provision of quality products linked to the territory in Nordic and Mediterranean agro-ecosystems. The most important practices were grouped around "inputs", emphasizing the positive effects of reducing animal drugs, and the use of pesticides and concentrates.

Soil fertility. Twenty-one agricultural practices were identified as having a positive effect on soil fertility in the Nordic agroecosystem. The most important practices were grouped around "crops and species" and "inputs"; for example, retaining a high proportion of semi-natural meadows and perennial crops, crop diversification, using manure correctly and reducing machinery use.

Prevention of forest wildfires. Sixteen agricultural practices were identified as having a positive effect on the prevention of forest fires in the Mediterranean agroecosystem. The most essential practices were grouped around "vegetation and elements". We found especially positive effects for "grazing and silviculture", standing out the effects of maintaining grasslands, retaining water points, grazing in remote and abandoned areas, and managing actively forests through forestry silviculture activities.

The standard deviation of expert scores on the effect of agricultural practices on ecosystems services was relatively low (the average across practices of the ratio SD/average contribution was 0.31 and 0.23 for Norwegian and Spanish experts, respectively), which shows a generally high level of agreement across experts in their valuation (Figs. 2 and 3). Agreement was consistently higher for practices with high contribution to ecosystem services provision (correlations between average contribution and the ratio SD/average contribution were −0.89 and −0.93 for Norwegian and Spanish expert valuation, respectively).

Still, significant differences between agroecosystems were observed for some agricultural practices contributing to the maintenance of agricultural landscapes (nine agricultural practices), biodiversity protection (eight), carbon sequestration (nine), and quality products (three), with higher values obtained for the Mediterranean agro-ecosystem in all cases.

3.2. Prioritized agricultural practices for each agri-environmental policy scenario

Fig. 4 lists the 12 most important agricultural practices for the compliance of each of the three agri-environmental policy scenarios explored.

Social demand scenario. The relative importance of ecosystem services under this policy scenario was different in the Mediterranean and Nordic agro-ecosystems due to the different importance given to ecosystem services. In the Nordic agroecosystem agricultural practices of highest priority were mainly related to farm management, especially the reduction of agrochemicals and animal drugs due to its negative impact on biodiversity. In the Mediterranean agroecosystem, where a high socio-cultural preference for the prevention of forest wildfires was found, priority agricultural practices focused on "grazing and silviculture", and on "vegetation and elements". Despite these differences between the two agroecosystems, the social-demand scenario prioritizes maintaining semi-natural vegetation and grasslands, grazing in natural areas and forests, and the extensification of farming.

Biodiversity and climate change mitigation. The main agricultural practices that were identified as a deserving priority in this scenario were related to the maintenance of grassland and semi-natural vegetation, meadows and pluri-annual crops, and manure management and fostering grazing practice without exceeding the carrying capacity of the ecosystems. Reducing the use of machinery was identified as a key practice in this scenario, due to its effect in reducing carbon emissions.

Biodiversity conservation. Most practices identified as important for this scenario were common to both agroecosystems. Like in the previous scenario, high importance was given to practices aimed at maintaining semi-natural vegetation and grasslands, promote grazing activity (e.g., adapting stocking rate to the carrying capacity, grazing in remote and abandoned areas, moving herds seasonally), and adequate use of manure. By contrast, we found some particularities. Under this agri-environmental policy scenario, reducing agrochemicals (i.e., pesticides and fertilizers) was identified as a relevant practice in both agro-ecosystems. In the Mediterranean agroecosystem, the retention of water points, the use of locally adapted crops and breeds, and the protection of pollinators were also highlighted among the most important practices. Meanwhile, in the Nordic agroecosystem, consulted experts emphasized the importance of managing land in small plots.

4. Discussion

This study is novel in operationalizing the ecosystem services framework for decision making needs in current mountain agro-ecosystems. The methodological approach is able to attend the social demands on the provision of ecosystem services in different biophysical, socioeconomic, and policy contexts. Also, it covers a wide diversity of key ecosystem services, previously valued and prioritized, and the current agricultural practices applied at the farm level needed to ensure their provision. The established relationships between agricultural practices and ecosystems services can help designing policies that make sense at both the institutional and practitioner levels.

4.1. Contribution of agricultural practices to ecosystem services

Our results highlight the expected positive contribution of grazing practices and conserving semi-natural vegetation and key landscape elements for maintaining agricultural landscapes, preserve biodiversity, and prevent forest wildfires. In addition, reducing the use of agrochemicals and diversifying crop varieties and livestock breeds (especially locally adapted ones) were identified as key practices for providing quality products, enhance soil fertility, preserve biodiversity, and regulate climate change through carbon sequestration. These findings are consistent with previous empirical research on the effects of farming inputs and landscape elements such as hedgerows and field verges on biodiversity (e.g. Berthet et al., 2012; Andersson et al., 2013), the effects of grazing activity on reducing the risk of wildfires and maintaining landscape heterogeneity (e.g. Ruiz-Mirazo and Robles, 2012), or the effects of farming inputs on soil fertility and carbon sequestration (e.g. Piastrellini et al., 2015; Pathak et al., 2017).

Not all the ecosystem services had the same priority in all regions, nor do common agricultural practices had the same effect on ecosystems services in different agroecosystems. Explanatory factors for these differences arguably include the different biophysical and climatic conditions of these agroecosystems, but also to context-specific social and cultural values. These findings are in line with other studies that suggest the need of redirecting PES schemes to attend the specificities of cases or regions to increase their efficiency and social and environmental benefits (Aguilar-Gómez et al., 2020), and promote targeted spatially explicit agri-environmental policies to avoid misspending efforts and resources (Scown et al., 2020).

4.2. Best practices under different agri-environmental policy scenarios

Several practices were identified as being consistently relevant for ecosystem services delivery across policy scenarios and agroecosystems. Especially, grazing and silviculture practices such as extending the grazing period, grazing in semi-natural habitats, grazing in remote and abandoned areas, adapting stocking rate to the carrying capacity, and moving flocks seasonally, stand out for their relevance in all the studied policy scenarios and agroecosystems. These results highlight the potential of grazing and silviculture practices to deliver key ecosystem services bundles, providing indicative evidence on the importance of promoting these practices in agri-environmental policies (Rodríguez-Ortega et al., 2014).

Our research also suggests that reducing agrochemical inputs positively affect biodiversity conservation and, therefore, is key for greening policies (e.g. the EU Farm to Fork Strategy), regardless of the agro-ecosystem considered. However, we also found that policies addressing social demands in different areas do not imply the same importance of agricultural practices. For example, while using manure correctly and reducing agrochemical use showed to have high social relevance in the Nordic agroecosystem, that was not the case in the Mediterranean ones, where practices related to increasing grazing were found to be more relevant given the higher social demand to controlling forest wildfires.

4.3. Policy implications

Agri-environmental policies in Europe (either the CAP or national policies) are now oriented to foster climate change mitigation and adaption, sustainable and efficient management of natural resources, and biodiversity conservation. These policies are changing from "one-size-fits-all" approaches to results-based schemes, which seek to give greater flexibility to the different regions to define their own environmental and climate priorities, and how to achieve them (Lampkin et al., 2020). The current CAP reform establishes voluntary eco-schemes to address the European Green Deal targets, in particular those stemming from the Farm to Fork Strategy and the Biodiversity Strategy for 2030, and to fulfil the climate and environmental objectives of the CAP. Eco-schemes are linked to specific agricultural practices to address, among others, husbandry and animal welfare (e.g. providing access to pastures and increasing grazing period for grazing animals), agro-forestry (e.g. establishment and maintenance of high-biodiversity silvo-pastoral systems), High Nature Value farming (e.g. shepherding on open spaces and between permanent crops, transhumance and

Practice type	Agricultural practices	Social demand policy		Biodiversity conservation and climate change mitigation policy		Biodiversity policy	
		Nordic	Mediterranean	Nordic	Mediterranean	Nordic	Mediterranean
Vegetation and elements	1. Maintaining grasslands	4,1 ± 0,65	4,3 ± 0,71	3,9 ± 0,99	4,3 ± 0,63	4,5 ± 0,62	4,4 ± 0,62
	2. Maintaining local semi-natural vegetation (trees and shrubs)	3,4 ± 1,09	3,9 ± 0,85	3,7 ± 1,15	4,5 ± 0,64	4,0 ± 1,18	4,6 ± 0,62
	3. Retention of hedges, shrubs and trees among arable fields			3,4 ± 1,15	4,3 ± 0,7	4,0 ± 1,08	4,4 ± 0,77
	4. Retention of water points		3,4 ± 0,73			3,8 ± 1,14	4,4 ± 0,98
	6. Retention of drove roads and tracks		3,3 ± 0,56				
Crops and species	9. Growing locally adapted crop varieties and breeds	3,7 ± 0,82			4,0 ± 0,91		4,3 ± 0,98
	10. Retention of semi-natural meadows and pluri-annual crops	2,7 ± 0,75		3,7 ± 1,13	4,0 ± 0,68	3,9 ± 1,3	0,0 0,0
	11. Crop diversification						4,3 ± 0,85
	12. Utilizing crop rotations, including legumes				3,9 ± 0,8		
	14. Substituting bare fallow for green/seeding fallow				3,9 ± 0,77		
	17. Utilizing nectar source crops for pollinators				2,2 ± 0,41		4,3 ± 0,82
Inputs	18. Utilizing manure correctly	3,9 ± 0,74		3,8 ± 1,03	4,3 ± 0,65	4,2 ± 0,82	
	19. Reducing off-farm dependency of inputs	3,2 ± 0,97					
	22. Reducing use of machinery			3,3 ± 1,45	3,9 ± 0,85		
	21. Reducing chemical fertilizers			3,3 ± 1,13	4,1 ± 0,91	4,0 ± 1,14	4,2 ± 1,01
	23. Reducing pesticide use	2,9 ± 0,67				4,3 ± 0,82	4,7 ± 0,82
Grazing and silviculture	27. Grazing in semi-natural habitats	3,6 ± 1,07	4,3 ± 0,54	3,3 ± 1,26		3,9 ± 1,47	
	28. Moving herds seasonally	3,8 ± 1,09	4,3 ± 0,72	3,2 ± 1,2		3,8 ± 1,31	4,3 ± 0,75
	29. Extend grazing period	3,5 ± 0,85	4,1 ± 0,58	3,3 ± 1,04		3,8 ± 1,2	
	30. Active management of forest (forestry/silviculture)	2,8 ± 1,12	4,3 ± 0,58	2,9 ± 1,32	4,0 ± 0,74	2,9 ± 1,49	
	31. Adapting stocking rate to the carrying capacity		3,4 ± 0,61	3,3 ± 1,05	4,3 ± 0,71	3,7 ± 1,2	4,6 ± 0,7
	32. Grazing in remote and abandoned areas	2,7 ± 0,59	3,5 ± 0,48	3,2 ± 1,24	3,9 ± 0,77	3,6 ± 1,48	4,2 ± 0,82
	33. Grazing with several species		3,4 ± 0,66			3,5 ± 1,32	
	34. Maintaining meadow mowing		3,1 ± 0,71			3,8 ± 1,16	

Fig. 4. Contribution (%) of top-twelve most important agricultural practices for the compliance of three policy scenarios (i.e. combination of ecosystem services) in Nordic (blue) and Mediterranean (green) mountains. Average and standard deviation of relative importance. Social demand policy scenario corresponds to a relative importance of 0.266 for landscape, 0.204 biodiversity, 0.255 soil fertility and 0.276% quality products in Nordic mountains; and 0.82 landscape, 0.184% biodiversity, 0.532 forest fires and 0.202 quality products in Mediterranean mountains. Biodiversity and climate change mitigation policy scenario corresponds to an equal relative importance of 0.5 for biodiversity and carbon sequestration. Biodiversity conservation policy scenario corresponds to a relative importance of 1 to biodiversity. Agricultural practices not falling within the top-twelve contributing practices to any of the policy scenarios are not shown. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

common grazing), or carbon farming (e.g. extensive use of permanent grassland) (European Commission 2021).

In this context, it is necessary to provide clear guidance and examples of best practices for policymakers and practitioners to address context-specific social demands and climate and environmental priorities (Olander et al., 2017; Pe'er et al., 2020; Lampkin et al., 2020), for example, for the country-specific Strategic Plans of the new CAP. Our study provides a novel and useful methodological framework to design more efficient agrienvironmental policies, including the eco-schemes to be applied in European mountains, by identifying the farming practices that should be promoted under different national contexts and priorities. For example, our framework indicates what specific practices are expected to have a positive impact on two key aspects of the European Green Deal: climate and biodiversity.

For climate change mitigation, payments should reward farms adapting stocking rates to the carrying capacity of pastures and utilizing manure correctly, due to its effect on carbon sequestration (Petersen et al., 2013). To meet biodiversity conservation targets, rewards should be given to farmers maintaining the natural and agricultural plant, crop and livestock biodiversity in their farms, for example through growing locally adapted crops and livestock breeds, conserving semi-natural meadows and perennial crops, diversifying crops, implementing crops rotations, and utilizing nectar sources for pollinators. As discussed above, policies should also target farmers reducing their use of agrochemical inputs, for their direct negative impact on wildlife fauna, not least as a way of compensating the increase of opportunity costs involved in these practices due to the likely reduced output in the short term (Geiger et al., 2010; Brühl and Zaller, 2019).

Redesigning agricultural and food systems to reverse the climate and biodiversity crisis is very urgent. The European Biodiversity and Farm to fork Strategies seem to go in the right direction, however for novel agricultural policies to be effective they need to take into account local farming systems, farmers decision making and management, because policy changes need to be implemented at the farm level. The method we propose is currently operational for real land management in mountains, but it can be adapted to other agricultural regions and policy settings, as it can easily incorporate other relevant farming practices and ecosystems services.

However, it should be noted that the uptake of many farming practices identified in this study to the level required to foster a relevant change in ecosystem service provision at the European scale will face great challenges, related to potential trade-offs among practices, transaction and opportunity costs, and need of technological advice. Many of these practices were common in the past (e.g. retention of hedges shrubs, moving herds seasonally, grazing in remote areas, crop rotations). However, these practices and associated knowledge systems were gradually abandoned in search of increasing productivity in competitive international markets (Gómez-Baggethun et al., 2010). Their recovery and revitalization would mean not only an adequate level of payments for the ecosystem services delivered, but also transformation of farming styles, with a stronger focus on multifunctionality, including climate and landscape farming.

4.4. Limitations of the study

We acknowledge several limitations in this research. First, to overcome the dispersion and gaps of empirical data and the impossibility of qualitatively assess some ecosystem services, we used an expert-based assessment, which qualitatively quantify the benefits of different agricultural practices on ecosystem services. Similarly, practices were identified with a generic name that, although self-explanatory, did not give complete information to assess ecosystem services delivery in biophysical terms. We followed this approach because it would be impossible to offer the information required for each agricultural practice, for each ecosystem service, in each location. For example, defining the "optimal" amount of chemical fertilizer should be determined at the local/farm scale. We assumed that experts could generically judge the relationship between agricultural practice (at the "optimal" level) and ecosystem service provision. This limitation relates to the inherent trade-off between specificity and applicability in research to be useful for policymaking. As suggested by Olander et al. (2017), however, decision makers require cost-effective, straightforward, transferable, scalable, meaningful, and defensible methods that can be readily understood. Second, different sets of ecosystem services implied variation of the weights of a large number of agricultural practices. However, the framework is designed to prioritize the most relevant ones and accommodate diverse policy scenarios under different socioeconomic and environmental contexts with no additional expert-based research. Finally, there are trade-offs and opportunity costs when implementing different practices at the farm level that are not contemplated in the study. Thus, specifications for the optimal management regimes are required at the farm level, as well as advisory services that accompany farmers in the uptake of the agricultural practices, and control systems to ensure the expected outcomes. We hope that further work can build on our research to address these gaps and limitations.

5. Conclusion

Optimizing grazing and silviculture, reducing the use of agrochemicals, and diversifying crop varieties and livestock breeds practices have high potential for delivering climate and biodiversity outcomes, as well as other ecosystem services demanded by society, across different biophysical contexts in European mountains. However, other agricultural practices do not have the same potential for delivering ecosystem services in different agroecosystems, nor is social demand for ecosystem services the same in different countries. Our methodological approach can be regionalized to account for different relationships between agricultural practices and relevant ecosystems services, and therefore, can help policymakers and practitioners operationalizing agricultural policies based on environmental objectives (e.g. CAP eco-schemes).

Credit author statement

Alberto Bernués: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. **Alicia Tenza-Peral:** Writing – original draft, Writing – review & editing. **Erik Gómez-Baggethun:** Methodology, Writing – review & editing. **Lars Olav Eik:** Writing – review & editing. **Morten Clemetsen:** Writing – review & editing. **Daniel Martín-Collado:** Formal analysis, Visualization, 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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