The use of domestic herbivores for ecosystem management in Mediterranean landscapes

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\textbf{ABSTRACT}

In the Mediterranean basin, the structure and species composition of traditional landscapes have historically been shaped and maintained by human-driven disturbances, such as extensive livestock grazing. The cessation of these activities, which have partially replaced the role of natural disturbances, may lead to vegetation overgrowth and biomass accumulation, with potential adverse impacts on biodiversity, ecosystem functions and services. Recently, the use of livestock for ecosystem management, with the purpose of maintaining grazing disturbance and the associated ecosystem processes, has been gaining traction. Nevertheless, there is still limited evidence on the performance of such grazing interventions. This review assesses the state of the art regarding the use of livestock for ecosystem management in Mediterranean landscapes. It examines the association between the regime and duration of grazing interventions and their reported effects on ecosystems. The list of reviewed interventions (68 interventions, retrieved from 47 studies) covered a diverse range of landcover systems (from grasslands to forests), of grazing regimes (characterized by different levels of grazing intensity and livestock species), and of duration of grazing (from short-term, $< 5$ years to long-term grazing, $> 20$ years). Wildfire prevention and biomass control, biodiversity and habitat conservation and the regulation of soil quality are the main reasons for the use of grazing interventions. The results of this review suggest that the use of domestic herbivores in ecosystem management can contribute to wildfire prevention and biomass control, with these positive effects fading away in long-term grazing interventions. Goats seem to perform better than cattle for biomass control. The effects on biodiversity and habitat conservation depend on the grazing regime, with intensive grazing showing negative results, while the effects on soil quality are generally negative but require further assessment, due to data limitations.

\textbf{1. Introduction}

Human activities have historically influenced ecosystem functioning, namely by replacing natural disturbance factors with human induced disturbances. In particular, over much of Europe, wild large herbivores and the natural disturbance exerted by them have been replaced by livestock, which, to some extent, may mimic the formers’ functional role that maintained the spatial and temporal heterogeneity and structural complexity of habitats (Navarro et al., 2015; Smit and Putman, 2011; Teillard et al., 2016). However, the

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The combination of land-use change and loss of herbivory-related disturbances affects ecosystem structure and composition (Sutcliffe et al., 2015), leading to impacts on ecological processes that sustain ecosystem function, such as fire regimes and trophic dynamics (Ripple et al., 2015; Smit and Putman, 2011). This has implications for the delivery of critical ecosystem services, such as those associated with carbon and nutrient flows or the regulation of extreme events (Manzano-baena and Salguero-herrera, 2018; Morais et al., 2018).

Recently, there have been calls to use livestock to maintain herbivory related functions in marginal farmland (Barry and Hunsinger, 2021; Gordon et al., 2021; Pérez-Barbería et al., 2023). Although commonly criticized for causing damage to ecosystems (Apollonio et al., 2017; Steinfeld and Gerber, 2010), when appropriately managed, domestic livestock have the potential to play an important role in close to nature ecosystem management, promoting restoration and enhancing biodiversity (Bermejo et al., 2012; Proença and Teixeira, 2019; Teague and Kreuter, 2020). Moreover, the use of livestock to maintain grazing and associated ecosystem functions (i.e., in “grazing interventions”), with the aim of maintaining or restoring healthier and more resilient systems, has been gaining attention (Buison et al., 2021; Godde et al., 2018; Rouet-Leduc et al., 2021; Teague and Kreuter, 2020). Nonetheless, there is still limited information about how to design such grazing interventions, given the variety of factors that influence them, such as the characteristics of the grazing regime or the environmental conditions (Apollonio et al., 2017; Germano et al., 2012; Maestre et al., 2022; Teague, 2015). A systematic literature review is needed to collate and assess existing data about these grazing interventions.

This review compiles and assesses published studies of grazing interventions for ecosystem management, specifically in the Mediterranean biome regions. While this review is motivated by the current changes to land use-land cover systems in the Mediterranean basin, the search was expanded to all Mediterranean regions to gather as many examples as possible and examine how livestock grazing has been utilized for ecosystem management in landscapes with a Mediterranean climate. Specifically, we aim to understand where (i.e., location and land cover system) these grazing interventions are being applied, the features of the grazing regimes implemented, the main management goals of such interventions, how they are being monitored and the outcomes in relation to their intended purpose.

The findings delivered by this review will ultimately be valuable to inform the use of grazing as a tool for ecosystem management. Namely, the data and insights here presented are intended to contribute to the implementation of evidence-based approaches, thereby fostering enhanced management practices, in Mediterranean ecosystems.

2. Methods

2.1. Literature review

We surveyed the scientific literature, identifying the studies that report and assess the use of livestock grazing as a tool or approach to manage ecosystem composition, structure, and functioning. Only peer-reviewed publications were included in the review. The literature search was limited to studies published between 2000 and 2020 (Fig. S1), with the aim of covering recent literature ensuring that the studies were up to date and therefore more relevant to guide future interventions and their assessment.

For the literature review we used a keyword-based search on the Scopus® and Web of Science® databases. For this, we used a search string covering, respectively, the purpose of the intervention, the type of livestock used, and the biome. Concerning the type of livestock, we included the main livestock species present in Mediterranean landscapes. The search was performed on 23rd of February 2021, using the following query: "grazing" AND (“ecosystem management" OR “landscape management”) AND (“horse” OR "cow" OR "sheep" OR "goat" OR "donkey" OR "cattle" OR "livestock" OR “bovine" OR "caprine" OR "equine" OR "ovine") AND "Mediterranean" AND (PUBYEAR > 1999). We constrained the search to papers written in English and excluded papers from non-related research areas (i.e., subject areas other than environmental, agricultural, and biological sciences). The search yielded 1184 studies. We also conducted an additional search, for peer-reviewed studies only, on the first 100 entries of Google Scholar, using the same keywords as above. From this search an additional five studies were added to the original list of 1184. The subsequent selection of relevant papers followed the PRISMA protocol (Selçuk, 2019) (Fig. S2). After duplicate check and removal, 860 studies were scanned by title and abstract. Only studies that were located in Mediterranean regions (including the Mediterranean Basin, California, Central Chile, the Cape Region of South Africa and Southwestern and Southern Australia) were retained, which further reduced the list to 189 papers. Finally, we screened the full text of these 189 papers, keeping only the studies that tested domestic or semi-domestic ungulate herbivores for ecosystem management. After these filtering stages, we retained 47 of the original 1184 papers.

2.2. Data extraction

To compile the information extracted from the papers, we created a database containing information for the following categories:
Study location, land cover system, management goals (i.e., the targeted ecosystem services), measured variables, grazing regime, including grazing intensity and livestock species, grazing history (i.e., years of grazing in the intervention site), and reported outcomes (Table S1).

2.2.1. Studies location and Land cover system
We collected information on the location of the study sites (coordinates and countries) to assess the distribution of the interventions within the Mediterranean biome. Studies were also classified based on the dominant land-use – land-cover (LULC) class, either according to the classification provided by the authors, or, if the paper did not mention the LULC system, according to the described dominant vegetation type and species, or using the study’s location to assess the LULC in Google Earth. We considered five classes of LULC: grassland, shrubland, woodland (also including wooded pastures, such as the dehesas in Spain and montados in Portugal), traditional wood/shrubland (i.e., shrubland with interspersed trees), and landscape mosaic (i.e., coarse grained multiple land cover mosaics), classifying each study accordingly.

2.2.2. Management goals
We screened each paper to gather information on which were the management goals of each intervention, i.e. the reasons motivating the use of grazing (e.g., risk of fire; land abandonment/degradation, habitat and biodiversity loss). Then, the management goals were associated with regulation and maintenance ecosystem services (following the CICES V5.1 classification, Haines-Young and Potschin, 2018) to identify the ecosystem services being targeted by the grazing intervention.

2.2.3. Measured variables
The measured response of the ecosystem to herbivory may depend on choice of the monitored variables. Hence, we reviewed the variables used by each study, to investigate how this feature of the study design affected the reported outcomes. Moreover, this information is also valuable to guide the selection of monitoring variables in future studies. We recorded the main variables monitored and their units of measurement. Then these variables were linked to the various stages of the ecosystem services cascade model and grouped in four main categories, that is, ecosystem properties, functions, benefits or values (Boerema et al., 2017). For our analysis, we concentrated on the variables that were emphasized in the abstract, discussion, or conclusions of each paper, as these are the ones that are anticipated to have the most significance in terms of the ecosystem’s response.

2.2.4. Grazing regime: grazing intensity and livestock species
A grazing regime is defined by three main components (Sumson and Pollock, 2005): timing of grazing (the time of the year when grazing occurs); grazing intensity; and livestock species (species present, single or mixed herds). We extracted data on the three components (Table S1) to characterize the regime of grazing interventions. However, because the availability and quality of the information on the timing of grazing was fragmented and highly variable among the reviewed studies, we decided to not include it in the analysis, and work only with the remaining two components: grazing intensity and livestock species.

Regarding grazing intensity, most reviewed studies provided quantitative or qualitative information on this variable. However, we found that the criteria used to characterize the grazing intensity was variable and dependent on local conditions (e.g., carrying capacity). For instance, we found that similar stocking densities could be associated with different levels of grazing intensity in different studies (Numa et al., 2012; Zaady et al., 2001) (Table S1). For that reason, we opted to follow a qualitative approach and consider the level of grazing intensity reported by the authors of each paper in relation to their specific interventions. The same limitation and approach has been reported and applied by Rouet-Leduc et al. (2021). We thus considered three levels of grazing intensity: extensive, moderate and intensive grazing. All the studies that reported “low-intensity grazing” or “traditional grazing” were classified as “extensive grazing” regimes. Moreover, if a paper assessed or compared two or three grazing regimes, they were considered as distinct grazing interventions.

2.2.5. Grazing history
Grazing history was assessed as the duration of grazing at each site. Each study was classified in one of the following classes: “Short-term”, when grazing had been introduced in the study area for less than 5 years; “Medium-term”, when the study area had been grazed between 5 and 20 years; and “Long-term”, when grazing occurred in the area for more than 20 years, which was considered as “historical” grazing (Fernández-Lugo et al., 2013; Ljubčič et al., 2014; Tardella and Catorci, 2015).

2.2.6. Reported outcomes
The results of each grazing intervention were classified as “positive”, “negative”, and “no effects”, depending on whether grazing contributed or not to achieving the proposed management goals. Additionally, when studies evaluated the contribution of grazing to more than one ecosystem service, we identified the co-benefits and trade-offs regarding ecosystem service provision.

2.3. Data analysis
First, we conducted a descriptive data analysis to summarize the main features of the selected studies and of the reported grazing interventions. Second, we examined the main management goals of the grazing interventions and summarized them into ecosystem services categories. Third, we listed the variables that were most frequently measured to monitor the outcomes of the intervention with respect the main targeted ecosystem services. Finally, we used cross-tabulations (contingency tables) and Fisher’s exact test of
independence (McDonald, 2014) to determine if the outcomes for each targeted ecosystem service were influenced by the grazing intensity, the livestock species, or the grazing history. This test was selected because it is robust to low sample sizes. If a significant association was found (p-value < 0.05), the odds ratio was computed to measure the strength and direction of the association. These analyses were conducted using the MASS and stats packages in R (Venables and Ripley, 2002).

3. Results

3.1. Main features of the reviewed studies

The final list of 47 studies (Table S2) was distributed across three of the five global Mediterranean zones (Fig. 1), with 39 in the Mediterranean basin across seven countries (Croatia, France, Greece, Israel, Italy, Portugal and Spain), 7 in the USA, and one in Australia. Our systematic literature search did not yield any studies in Chile or South Africa.

The studies reported 68 grazing interventions, which covered a diverse range of LULC categories: 22 interventions focused on shrubland systems, 10 interventions on woodlands, 17 on grasslands, 13 on Mediterranean landscape mosaic systems and six on traditional wood/shrubland systems (Fig. S3). Grazing intensities were reported for a total of 58 interventions (extensive grazing, n = 22; moderate grazing, n = 19 studies; intensive grazing, n = 17 studies). The remaining ten interventions did not report grazing intensities, but rather compared grazed vs. non-grazed (control) plots (e.g. Carrol et al., 2007; Kelt et al., 2005), or compared the use of different livestock species (e.g. Glasser and Hadar, 2014; Jáuregui et al., 2009) without mentioning grazing intensity. These ten grazing interventions were not considered when assessing the outcomes by intensity level.

Regarding the different livestock species, cattle was used in 38% of the cases (28% in single-species herds and 10% in mixed herds). Additionally, 51% of the interventions assessed the effects of sheep (18% as a single species and 33% in mixed herds), while goats were used in 47% of the cases (16% in single-species herds and 31% in mixed herds) (Fig. S4).

3.2. Management goals of the grazing interventions

We identified five main regulation and maintenance ecosystem services (Haines-Young and Potschin, 2018) linked to the use of livestock for ecosystem management (Table 1). Thirty-five papers assessed the contribution of livestock grazing to services related to “biodiversity and habitat conservation”. In this group we identified services such as the prevention of habitat or biodiversity loss (Leal et al., 2019; Numa et al., 2012), the maintenance of floral resources (habitat) for pollinators (Henkin et al., 2016; Shapira et al., 2020), and the preservation of ecosystem functioning, such as promoting plant regeneration and seedling survival (Abraham et al., 2018; Cierjacks and Hensen, 2004). In addition, 23 papers targeted “wildfire prevention and biomass regulation” services, such as the control of shrub encroachment through regulation of vegetation biomass and structure (e.g. Alcaniz et al., 2020; Schoenbaum et al., 2018; Silva et al., 2019). The “regulation of soil quality” was the third most frequent regulation ecosystem service, being assessed in 12 studies focused on improving or preserving soil quality and preventing erosion (e.g. Golodets and Boeken, 2006; Tardella and Catorci, 2015). Finally, four studies assessed the contribution of livestock grazing to the “Control of invasive plant species” (DiTomaso et al., 2008; Germano et al., 2012; Gornish et al., 2018; Skaer et al., 2013) and two studies assessed the effects of grazing on “Carbon
Although this review focuses on the use of grazing for regulation and maintenance functions, studies also reported the impact of grazing on provisioning and cultural services: 37 of 47 papers addressed provisioning services, mostly livestock or dairy production (Glasser et al., 2012; López-Sánchez et al., 2016; Merriam et al., 2016), while five studies were interested in the cultural benefits of grazing interventions, mainly for tourism and the recreational value of Mediterranean landscapes (Bartolome et al., 2000; Jouven et al., 2016) (Table 1).

3.3. Measured variables

Variables related to the biophysical properties of the ecosystem (e.g., vegetation structure or cover and plant species richness) were used in over 50% of the grazing interventions, for all the ecosystem services (Fig. 2). All three classes of outcomes were reported for biodiversity and habitat conservation when using this type of variables, while for wildfire prevention and biomass control, interventions reported positive outcomes and no effects of grazing (Table 2). Regarding the regulation of soil quality, most interventions measured variables associated with ground-level vegetation cover and reported negative outcomes (Table 2).

Variables associated with ecosystem functions (e.g., tree growth rate, reproductive or regeneration potential, soil water content) were measured in 30% of the interventions assessing biodiversity and habitat conservation, and regulation of soil quality. These variables were also used in 20% of the interventions assessing wildfire regulation and biomass regulation (Fig. 2). All three classes of outcomes were reported when using variables of ecosystem function (Table 2). Variables associated with benefits and values were the least used, also with diverse outcomes for the assessed ecosystem services (Fig. 2; Table 2).

3.4. Outcomes of the grazing interventions

This section addresses the main outcomes of grazing interventions for the three most targeted regulation and maintenance ecosystem services: biodiversity and habitat conservation (n = 48); wildfire prevention and biomass regulation (n = 30) and regulation of soil quality (n = 19) (Table 1). We test the influence of grazing intensity, livestock species and grazing history on the reported outcomes.

3.4.1. Influence of grazing intensity

We found a significant association between grazing intensity and the outcomes for biodiversity and habitat conservation (Fisher's
The estimation of the odds ratio demonstrated a negative correlation between intensive grazing and the occurrence of positive effects ($p = 0.001$). Specifically, 70% of the intensive grazing interventions reported negative effects for this ecosystem service. In contrast, no significant associations were found between extensive and moderate grazing and the reported outcomes, suggesting that outcomes tend to be more variable and may depend on other factors. Nevertheless, both regimes showed overall positive effects for biodiversity and habitat conservation (66% and 69% respectively; Table 3; Fig. 3a and b). Regarding wildfire prevention and biomass regulation, no significant associations were observed between grazing intensity and the reported outcomes. However, positive outcomes were reported in over 60% of all grazing interventions targeting this ecosystem service (Table 3). Conversely, none of the studies assessing the effects on the regulation of soil quality reported positive effects, with approximately 80%, reporting negative effects (Fig. 3). Also, no significant association with grazing intensity was found in this regard. Moreover, regardless of the grazing intensity, all the six interventions testing livestock grazing for the control of invasive species reported positive outcomes. In the three interventions focusing on carbon sequestration, moderate grazing showed no effects, whereas intensive grazing resulted in a negative outcome (Table 3).

From a perspective of trade-offs, the effects on the regulation of soil quality were generally associated to trade-offs with the other two services, at any grazing intensity, whereas the negative relation between biodiversity and habitat conservation and wildfire prevention and biomass regulation was associated with intensive grazing regimes. Co-benefits were reported between the control of invasive plant species and biodiversity and habitat conservation, regardless of the grazing regime. Moreover, co-benefits between wildfire prevention and biomass regulation and biodiversity and habitat conservation, were also found in extensive and moderate regimes.

### Table 2

Variables measured to monitor the outcomes of the interventions regarding the three main ecosystem services, in the reviewed papers. EP – Ecosystem properties; EF – Ecosystem functions; B – Benefits. Green circles represent Positive outcomes; Yellow circles represent No effects; and red circles represent Negative outcomes. The size of the circles represents the number of studies reporting each result.
Table 3
Effects of the grazing interventions on ecosystem services (B&H: Biodiversity and Habitat conservation, WFP: Wildfire prevention and biomass regulation, SQ: Regulation of soil quality, IC: Control of invasive plant species, CS: Carbon sequestration; “+”: Positive effects; “−”: negative effects; “o”: No effects). Grazing interventions are arranged by grazing intensity, livestock species and land cover system (WS mosaic: wood-shrubland mosaic; L mosaic: landscape mosaic).

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<tr>
<th>Grazing Interventions</th>
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<td>Cattle</td>
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<td>Sheep &amp; Goat</td>
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grazing regimes (Table 3).

3.4.2. Influence of livestock species

Results from the cross-tabulation analysis suggested a significant association between the reported outcomes for wildfire prevention and biomass accumulation and the type of livestock species (Fisher’s exact test, \( p = 0.043 \)). However, the odds ratio estimation did not confirm this result, revealing only a marginal association (\( p = 0.06 \)) between using goats and the occurrence of positive

![Fig. 3. Relative frequency of reported outcomes for the three grazing intensities, per assessed ecosystem service (only the services with sufficient data were analysed).](image)

![Fig. 4. Total number of grazing interventions and reported outcomes for each type of assessed livestock species and reported outcomes, for the three grazing intensities, per assessed ecosystem service (only the services with sufficient data were analysed). Mixed – grazing intervention assessing the effects of mixed species herds, including sheep and goat, sheep and cattle and cattle and goat.](image)
outcomes (Table S7). Moreover, despite not showing a significant association, interventions using cattle in extensive and moderate grazing regimes mostly reported positive results for biodiversity and habitat conservation (≈66%) (Table 3; Fig. 4b), whereas for intensive grazing results were variable.

Sheep and goats were tested in 51% (n = 35) and 47% (n = 32) of the interventions, respectively, and showed similar results whether they were used separately or in mixed herds (Fig. S4). Although not significant, sheep and goats in intensive grazing regimes, showed a lower proportion of positive outcomes for biodiversity and habitat conservation, in woodland and wood-shrubland systems, compared to cattle (Table 3; Fig. 4c) (Celaya et al., 2010; Fernández-Lugo et al., 2009; Lázaro et al., 2016). Finally, regardless of the grazing intensity and species considered, most of the reported outcomes for the regulation of soil quality were negative.

### 3.4.3. Influence of grazing history

We found a significant association between grazing history and the outcomes reported for wildfire prevention and biomass accumulation (Fisher’s exact test, \( p = 0.03 \)). In this case, after estimating the odds ratio, long-term grazing showed a significant negative association with positive results (\( p = 0.027 \)), i.e., the probability of positive outcomes occurring in long-term grazing interventions is significantly lower than in short-term grazing (Table S10). On the other hand, regardless of grazing intensity, all the interventions with short-term grazing, report positive outcomes for this ecosystem service (e.g., Glasser et al., 2012; Ruiz-Mirazo and Robles, 2012; Silva et al., 2019) (Fig. 5), describing the rapid decline in biomass accumulation due to grazing. No significant associations were found for biodiversity and habitat conservation, and regulation of soil quality (Fig. 5b). In extensive and moderate grazing regimes, long-term grazing reported more positive outcomes for biodiversity and habitat conservation (Lázaro et al., 2016; Leal et al., 2019; Papanastasis et al., 2017), and the only negative outcome (in extensive grazing) was linked with the long term use of veterinary substances (Numa et al., 2012). Moreover, five out of six studies with long-term intensive grazing reported negative outcomes for biodiversity and habitat conservation (e.g., Fernández-Lugo et al., 2013; Saiz and Alados, 2012).

### 4. Discussion

#### 4.1. Overview of the use of grazing interventions

Scientific research on the use of livestock grazing for ecosystem management in Mediterranean landscapes has increased over the past decade (Fig. S1). However, despite growing interest, only a limited number of studies were found focusing on this subject, indicating a scarcity of published research documenting the outcomes of the use of domestic herbivores for managing ecosystem function, structure, and composition. In the Mediterranean basin, where most of the studies meeting our search criteria were concentrated, human induced changes, such as traditional livestock production and intentional fire, have historically played a significant role in shaping various ecosystems (Pereira et al., 2012) and maintaining diverse landscapes (Blondel, 2006). Therefore, interventions were largely motivated to preserve these landscapes and their associated high levels of biodiversity (Casasús et al., 2007;
Grazing interventions have been gaining popularity as a potential way for ecosystem management. However, despite their increased use, this review showed that grazing interventions often yield variable outcomes (Fig. 3; Table 3). Despite the observed positive results, grazing was not always effective, and the results of the interventions included a significant proportion of negligible (no effects) or even negative effects.

4.2.1. Positive outcomes
Positive effects on biodiversity and habitat conservation were observed when extensive or moderate grazing was implemented (Fig. 3; Table 3). In shrubland habitats in Portugal, this led to an increase in grasses and shrub diversity (Silva et al., 2019), while in Italy, it enhanced plant functional diversity of grasslands (Tardella and Catorci, 2015). While not statistically significant, intensive grazing regimes generally yielded positive results for wildfire prevention and biomass regulation, as authors confirmed the rapid grazing control of vegetation encroachment (Bashan and Bar-Massada, 2017; Celaya et al., 2010; Ruiz-Mirazo et al., 2011).

4.2.2. Negative outcomes
Intensive grazing regimes, on the other hand, had a significantly higher proportion of negative outcomes for biodiversity and habitat conservation. For example, these regimes drastically reduced palatable species of endemic shrubs (Fernández-Lugo et al., 2013), and decreased forage potential for honeybees in grasslands (Henkin et al., 2016). Furthermore, negative effects for the regulation of soil quality were observed regardless of grazing regime. These findings, although lacking statistical significance, were in great part associated with an increase in bare soil when livestock was present (e.g., Papanastasis et al., 2017; Saiz and Alados, 2012). Finally, one study reported negative outcomes for biodiversity and habitat conservation due to the use of veterinary substances, which affected dung quality, thereby impacting the abundance of dung beetles in an extensive long-term grazing regime (Numa et al., 2012).

4.2.3. Trade-offs
Trade-offs (i.e., both positive and negative outcomes), were primarily observed between the regulation of soil quality (e.g., Celaya et al., 2010; Delattre et al., 2020; Skaer et al., 2013) and the other evaluated ecosystem services. For example, the use of mixed herds of...
sheep and goats can successfully remove shrub biomass, but lead to an increase in bare soil and erosion susceptibility (Ruiz-Mirazo and Robles, 2012). Moreover, a trade-off was reported between biodiversity and habitat conservation and wildfire prevention and biomass regulation, when intensive goat grazing controlled high amounts of shrub cover, but hindered the availability of green foliage of heather plants and therefore the sustainability of shrubland systems (Celaya et al., 2010).

4.2.5. Co-benefits

Eight interventions reported co-benefits (i.e., positive effects for multiple ecosystem services), identifying positive effects for biodiversity and habitat conservation coupled with positive effects for wildfire prevention and biomass regulation and for control of invasive plant species. Shrubland systems benefited from extensive to moderate grazing, leading to positive changes in vegetation cover, directly reducing fire hazard and allowing higher light irradiation in the lower vegetation layers. This indirectly contributed to the increase of plant species richness and diversity (Table 3) (Mendes et al., 2015; Moinardeau et al., 2019). Co-benefits were also observed in grassland systems where the control of non-native plants allowed the colonization of native grasses and the increase in small mammals abundance, including two endangered species (Germano et al., 2012; Gornish et al., 2018).

4.3. Insights on the use of grazing interventions

Grazing intensity was found to be a relevant factor affecting the outcomes of the grazing interventions, depending on the management goals. For example, extensive and moderate grazing regimes performed better than intensive regimes for biodiversity and habitat conservation (see Section 3.4.1; Table 3). However, the low animal density in extensive regimes may not be enough to control shrub encroachment (Bartolome et al., 2000; Calleja et al., 2019). On the other hand, intensive grazing regimes showed a higher potential for shrub removal but also posed higher risks of negative impacts on biodiversity and soil (Fig. 3), particularly in the long-term, with authors highlighting the limited potential of heavy grazing for the preservation of natural resources (Papanastasis et al., 2017; Saiz and Alados, 2012). Meanwhile, moderate grazing regimes also showed positive effects for biomass control. Hence, these findings suggest that moderate grazing might be a preferable approach, when generally considering these two services (Fig. 3), especially in the short-term (Fig. 5).

To ensure that the use of livestock for ecosystem management yields beneficial outcomes, without adding additional pressure (Merriam et al., 2016; Ruiz-Mirazo and Robles, 2012; Skaer et al., 2013), especially regarding biodiversity and habitat conservation, and regulation of soil quality, rotational grazing has been identified as a valuable management tool to create habitat refuges for ground-nesting birds and mitigate soil degradation impacts on grassland systems (Carrol et al., 2007; Roukos et al., 2017). Rotational grazing has also been suggested as an approach to mitigate negative impacts of long-term grazing on biodiversity, particularly at high intensities.

For interventions aimed at regulating plant biomass volume, positive results occur shortly after introducing grazing in the study area (e.g., Glasser et al., 2012; Silva et al., 2019), but these effects seem to fade over time, rendering long-term grazing ineffective for this service. Additionally, it is crucial to consider the specific context and ecological dynamics in which interventions take place, as the adaptation of several plant communities to the long grazing history in some areas of Europe and North America, might be associated with the ineffective outcomes (Fig. 5; Table 3) (Adler et al., 2004; Fortuny et al., 2014), particularly for wildfire prevention and biomass regulation.

The choice of livestock species also played a relevant role in the outcomes for the delivery of wildfire prevention and biomass regulation, with goats in particular showing to be more effective than cattle in removing shrub biomass (Fig. 4) (Bashan and Bar-Massada, 2017). However, we lacked enough statistical power and were not able to identify the direction of this association, likely due to the small sample size. Furthermore, despite the apparent higher performance of goats, one study (Papanastasis et al., 2017) indicated that it may be limited in some contexts. Specifically in Greece, heavy goat grazing was not effective in controlling the expansion of Quercus cocciifera due to dietary preferences. Additionally, careful consideration of the livestock species is necessary to maximize the benefits and minimize potential negative impacts. For example, in highly disturbed areas, using sheep may be preferable to cattle due to associated impacts of the latter on ground cover and soil compaction (Merriam et al., 2016). Previous studies have also proposed the use of mixed herding (Moinardeau et al., 2016) as an alternative to address potential trade-offs. However, two interventions in woodland systems reported negative effects on acorn survival and oak regeneration when using mixed herds of sheep and goats (Cierjacks and Hensen, 2004) (Fig. 4b). Choosing local breeds is another alternative that might enhance the effectiveness of grazing interventions, as they have adapted to the specific ecosystem conditions and benefit from valuable traits such as foraging efficiency, adaptability to local climate and suitability for local vegetation types. For example, Celaya et al. (2010) showed that, by preferring heather plants (Erica sp.), Celtiberic goats caused a higher reduction of shrub biomass than Cashmere goats, resulting in a better balance between woody and herbaceous plants.

The predominantly negative outcomes regarding soil quality regulation are concerning and emphasize the importance of careful monitoring and management when implementing grazing interventions. While bare soil was often measured to assess the impact on soil quality regulation (Alcaniz et al., 2020; Bugalho et al., 2011; Golodets and Boeken, 2006; Ljubicic et al., 2014; Shapira et al., 2020), this variable alone offers only a limited evaluation of soil condition. Therefore, monitoring soil processes, such as decomposition and infiltration rates, could offer a more comprehensive understanding of the effects of grazing. The lack of measures for soil function is likely due to how soil-provided services are generally associated with provisioning services (e.g. provision of raw materials), which compromise the identification of soil-related regulation and maintenance services. Hence, there is the need for guidance on how to address measures of soil function (Baveye et al., 2016; Pereira et al., 2018; Robinson et al., 2014).

Finally, during our review, we found that the lack of standardized reporting of grazing intensity data posed a challenge in
synthesizing and comparing studies. As the environmental conditions and type of livestock varied across studies, the same stocking density could represent different pressures in different land cover systems. Therefore, this limitation in reporting grazing intensity hindered our ability to draw more robust conclusions. To address this limitation in future research, it is essential that a focus is put on the development of harmonized protocols for defining and reporting grazing pressure that future interventions could follow. Furthermore, it is important to acknowledge that grazing intensity cannot be solely defined based on stocking rates or animal density (Sumson and Pollock, 2005), as the local context plays a significant role in the ecological response to grazing and therefore in determining the appropriate degree of grazing intensity.

5. Conclusions

This review provides an updated summary of the current knowledge regarding the use of livestock grazing for ecosystem management, specifically in Mediterranean landscapes. Despite conducting a global search, the majority of studies and findings focus on the Mediterranean basin, where historical human use and the replacement of wild herbivores by domestic ones increased ecosystems’ dependency on human-driven disturbances. Hence the conclusions drawn can primarily be applied to these regions. The findings of this review demonstrate that the success of grazing interventions is influenced by a variety of factors, such as grazing regimes and the history of grazing. Notably, our findings show that a significant proportion of studies report negative effects or the ineffectiveness of using grazing for ecosystem management, particularly for the delivery of biodiversity and soil related services. This highlights the need for further research to determine the circumstances under which the use of livestock for ecosystem management is a viable alternative that effectively contributes to ecosystem and biodiversity conservation.

Furthermore, although narrowing the search to scientific peer-reviewed studies has the advantage of ensuring higher reliability and robustness of the reviewed literature, it also has the drawback of potentially excluding pertinent data present in the grey literature. For instance, horse grazing has been recommended for the restoration of grazing processes due to their ability to quickly adapt to low herbage availability, and forage efficiency on sparse vegetation when compared to cattle (Fagúndez et al., 2021; Rewilding Europe, 2022; Rewilding Portugal, 2022). However, only two studies in the review assessed the use of this species for ecosystem management. Hence, future studies could consider expanding the search to include grey literature to ensure a more comprehensive analysis of grazing interventions. Additionally, no studies were found that assessed how climate and other environmental factors, such as land morphology or water availability, mediate the effects of grazing. Considering the significant role of these factors, it is crucial to include them in the monitoring schemes of grazing interventions.

Knowledge gaps that still require attention include the selection of appropriate variables to adequately monitor such interventions. For instance, if the goal is not only to manage the ecosystem structure and community composition but also the ecological processes that generate goods and services, monitoring schemes for grazing interventions should consider measurements of both ecological properties and functions. With this in mind, further assessment on soil quality is needed to understand the effects of grazing on soil functions and structure, beyond ground cover, and avoid potential negative impacts. Additionally, adjusting the regime and duration of the interventions to the management goals and the ecosystem condition is also essential to minimize adverse or poor outcomes and to consider potential trade-offs between services.

Overall, the retrieved data revealed heterogenous findings on the use of domestic herbivores for ecosystem management in Mediterranean landscapes. The use of grazing for wildfire prevention and biomass regulation generally yielded positive outcomes, with lower performances observed in longer grazing interventions. On the other hand, using grazing for biodiversity and habitat conservation generated a diversity of outcomes, which were generally positive for extensive and moderate grazing regimes and significantly negative for intensive grazing regimes. Finally, outcomes for the regulation of soil quality were mainly negative, and a common trade-off with other ecosystem services, which calls for dedicated research that contributes to improved livestock management to avoid and mitigate these impacts.

CRediT authorship contribution statement

I.R., T.D., D.M. and V.P. conceived the study; I.R. collected and analysed the data; I.R. prepared the figures; I.R. wrote the text; T.D., D.M. and V.P. supervised the study and assisted in the writing process.

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.

Data Availability

Data will be made available on request.

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