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Review

Grazing as a Management Tool in Mediterranean Pastures: A Meta-Analysis Based on A Literature Review

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Abstract: The present study reviews the impact of mechanical interventions, and controlled burning combined with grazing in the Mediterranean-climate regions (MCRs) of the world. Relevant studies were searched for in the Web of Science database. Additional studies were located in the citations of these publications, and in a local database. Finally, 26 studies were included in this review. Since 1978, several other relevant studies have emerged at a rate of 24% in a 5-year time step. The studies have focused on the effects of combined grazing with other management tools on vegetation structure (18 publications), biomass productivity (16 publications), and floristic diversity (12 publications). The results were analyzed for (a) sites and treatments and (b) effects on plant structure, productivity and floristic diversity. Herbaceous forage increased after a reduction in shrub cover. Shrubs tended to recover in the grazed pastures. Vegetation height was reduced in almost in all cases according to available data. Despite its potential recovery, shrub biomass was affected by grazing in most cases. The impact of subsequent grazing was mixed regarding floristic diversity. Grazing is a useful tool for landscape management in MCRs, but the proper way to combine it with other interventions depends on the management goals.

Keywords: Mediterranean-climate regions; grazing; clearing; controlled burning; cutting; thinning; vegetation structure; productivity; floristic diversity

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1. Introduction

Animal husbandry is one of the most important activities in human history. While it has become more intensive in recent years, keeping animals in closed spaces, even today, a large part of livestock is raised extensively or semi-extensively. These two breeding systems are largely based on the use of pastures, often originating from past human interventions in forest landscapes. Therefore, grazing has to be regulated so that the natural elements of the landscape can be maintained [1]. Mediterranean-climate regions (MCRs) are not an exception to this situation. The Mediterranean Basin is a region where the history of disturbance is critical for its ecosystem functions [2,3], while other MCRs, such as those in California and Chile, share quite common land use patterns with it [4]. Nevertheless, the environmental history of MCRs is highly complicated and comparisons among them reveal differences and similarities in environmental indicators [4,5].

An unequivocally negative role is often attributed to grazing, with grazing exclusion policies as a typical measure serving that perspective [6]. It is well-documented, though, that the reduced intensity or complete abandonment of grazing has negative consequences for Mediterranean ecosystems [7,8]. The depopulation processes, that have been taking place in the rural areas of the Mediterranean for more than 60 years, underpin the significant

reduction in livestock. Grazing abandonment or undergrazing favors ecological succession, i.e., the expansion of shrubs into grasslands (shrub encroachment) [3,5]. Such natural processes happen at the expense of the floristic physiognomy and diversity of grasslands and often affect several parameters that determine the pastoral value of these lands [9]. It has been pointed out that the prevention of shrub encroachment is important both for the economy and the environment [7]. To halt this process, controlled fires and interventions with mechanical means are often suggested to take place [8].

In most cases, management interventions aim to maintain a landscape mosaic that is considered to be capable of serving multiple objectives simultaneously. Objectives include the balance between human activities and nature, the protection of biodiversity, fire prevention, and the accessibility of various forage resources for grazing animals [10–14]. In Mediterranean ecosystems, disturbances, such as fires and various types of cutting and mechanical treatments for the improvement of forage availability or for cultivation purposes, have played a significant role in the retention of landscape diversity [15–17]. These disturbances are considered episodic, while the opposite is true for grazing, which is considered a chronic disturbance. The combination of these two types of disturbance is common in the Mediterranean region and therefore responsible for the typical formation of vegetation [18].

Natural or anthropogenic fires are considered one of the basic factors shaping Mediterranean landscapes. However, when fires occur near zones of the interface with human activities, they pose a direct risk to ecosystem services, properties, cultural values, and often human lives [19,20]. As an effort to mitigate the phenomenon of fires in MCRs, but also to manage grazing and maintain biodiversity, controlled (or prescribed) burning has been developed gradually since the 1960s [21]. Fire management usually enters public dialogue with an emphasis on fire suppression, including a continuous increase in firefighting resources. Fire prevention, as a rule receives less attention with prescribed burning being a prohibited practice or one with very limited use in most Mediterranean countries. This is in contrast to its extensive application in other countries such as the USA or Australia [20,22,23]. Currently, the use of prescribed burning has gradually started being considered more broadly in MCRs against the common perception and generalization of the solely negative consequences of wildfire.

On the other hand, the most usual practices when it comes to the creation of open spaces, as well as diverse habitats, are the use of intensive mechanical or manual treatments. Mechanical treatments of shrub vegetation may include cutting coarse wood, slashing coarse and fine wood debris, pruning standing branches or resprouts, trimming woody biomass to a lower level, and thinning by removing entire standing shrubs. Some authors suggest that mechanical treatments are safer for the environment or more effective at preventing shrub encroachment than controlled burning is [9,24,25]. On the other hand, controlled burning in a *Pinus canariensis* forest is more beneficial than clearing is when important factors, such as fire intensity, are properly adjusted [26]. There may also be differences in shrub resprouting between sites that have experienced burning and mechanical or manual treatments [27], though, after some years, the effects of these two types of treatments may start being similar [28,29]. Mechanical and manual treatments are the most suitable option in cases when biomass reduction must be applied in strict areas. The interference of private properties in land management plans is a typical example of that [30]. While land clearings and shrub cuttings can be quite beneficial for Mediterranean ecosystems, careless use of these tools can also be harmful, if the intensity or seasonality of the mechanical treatments [31] or their spatial scale are not considered carefully [32–34]. Additionally, the high costs of mechanical and manual treatments could be prohibitive of the continuous use of this practice. In contrast, a combination of them with utilization methods would be more viable. Animal husbandry can play this role, as grazing is a major utilization activity that can be developed in natural ecosystems apart from timber harvesting [30].

Previous review studies have highlighted the importance of management interventions in improving the rangeland value of Mediterranean shrublands [35], and to prevent land abandonment [7,25]. The importance of grazing, even in large numbers, was also noted for several Mediterranean ecosystems [36]. The Rouet-Ledouc et al. [37] study can also be considered relevant to this topic, as they investigated the effectiveness of grazing at fire prevention for a wider range of ecosystems. However, there is no research primarily targeted at deriving conclusions from existing scientific studies that have combined grazing with other management interventions in Mediterranean ecosystems. Such a collective approach will facilitate decisions to draw on land management, especially on the restoration of grasslands that are invaded by shrubs. The aim of this study was to review the scientific literature related to (a) the underlying reasons and the techniques used for the removal of shrubs before grazing as applied in Mediterranean ecosystems, (b) the effects of grazing, introduced after the removal of shrubs or the implementation of other previous management interventions, on the basic characteristics of the vegetation (structure, productivity, and floristic diversity), and (c) the management implications regarding the future use of such interventions in Mediterranean shrublands.

2. Materials and Methods

The search for studies was carried out using a combination of different tools. Initially, the search engine of the Web of Science (WoS) website was used, with the following conditions:

((graz * OR brows * OR sheep OR goat * OR cattle OR hors * OR livestock OR herbivore * OR donk * OR deer *) AND (mediterranean OR (dry AND hot AND summer) OR maquis OR garrigue * OR chaparral OR matorral OR fynbos OR mallee OR phrygana) AND (shrub * OR scrub * OR brush * OR understor * OR bush *) AND (clear * OR cut * OR thin * OR mechanic * OR masticat * OR prunn * OR mow * OR slash * OR trim * OR (prescribed AND burn *) OR (control * AND burn *)).

From the above search, 198 records were found, fourteen of which were considered suitable to be included in the present study, because this number of records focused on the combined effects of grazing, after the implementation of several management treatments. In a second phase, a literature review based on the bibliography of the aforementioned studies was conducted. This included both the studies cited by these fourteen publications and the follow-up studies in which they were referenced. In order to find these follow-up studies, Google Scholar was used. Through this, the number of studies increased to 23. Finally, three more studies were included, by searching the bibliographic base (in paper format) of the Laboratory of Rangeland Science and Protected Areas Management, of the University of Thessaly. Thus, the total number of studies reached 26, referring to a total number of twenty sites (Table 1. The studies included in this review cover a period from 1978 [38] to 2022 [39] (Table 2).

Table 1. Research purposes and management implications of the studies presented.

Authors	Research Topic	Management Implications
Poissonet et al. (1978)	Impact of land management treatments in a *Quercus coccifera* (controlled burning and clearing + grazing simulation with or without fertilization).	Moderate fertilization levels and mowing at a relatively low frequency (simulated grazing systems) achieve better floristic diversity results than pure controlled burnings do, despite the frequency of the latter. Remarkable variations were observed throughout the years. Controlled burning did not achieve the desirable formation, while simulated grazing resulted in a grassland formation.
Green et al. (1979)	Utilization of chaparral shrubs by goats in fenced and non-fenced sites, cleared or non-cleared.	Shepherd guidance is enough for goats to graze young shoots, but fencing is required if an older woody component is present. Grazing without fencing limitations is more environmentally feasible.

Table 1. *Cont.*

Authors	Research Topic	Management Implications
Godron et al. (1981)	Site cover and botanical diversity effects of grazing simulation in a *Quercus coccifera* garrigue.	Mediterranean ecosystems are pretty sensitive to soil erosion; thus, forests have to be re-established. However, some parts of them should be used as pastures, where fertility should be maintained.
Poissonet et al. (1981)	Botanical diversity effects of grazing simulation in a *Quercus coccifera* garrigue.	After clearing and continuous mowing (grazing simulation), the created plant community was very different, more balanced and richer in herbaceous vegetation, although it did not have a typical vigorous grassland structure. The increase in pastural value and changes in composition occurred more directly with fertilization. Severe drought can wipe out some species families (e.g., grass-like species, such as Cyperaceae). High levels of fertilization can make the plant community more exposed to climate change.
Étienne et al. (1991)	Biomass and volume growth models in grazed maquis vegetation of pine and oak forest areas that are partially fertilized.	Shrub growth models after disturbance should be considered in fuel management. There are differences between major Mediterranean maquis shrubs in the development of volume, biomass, and growth rate.
Papanastasis et al. (1991)	Yields of shrubs and herbs in a bladed (partially seeded) or slashed kermes oak shrubland.	Seeding after clearing is the method that increases yields of herbaceous vegetation the most. On the other hand, it is the most expensive method. Clearing without seeding is less effective for yields of herbaceous vegetation. Slashing is the least expensive and the best method ecologically; however, it results in a rapid restoration of shrubby vegetation over that of herbaceous vegetation.
Perevolotsky et al. (1992)	*Quercus calliprinos* and *Phillyrea latifollia* response after thinning and pruning, followed by goat grazing.	Thinning + grazing combined favors open spaces, mostly affecting the cover of low trees in comparison to that of dwarf and medium shrubs. *Q. calliprinos* was affected only by thinning, while subsequent grazing had an impact on *P. latifolia*. Thinning + grazing can develop rich pastures with low fire risk, though well-established spatial plans are required.
Papachristou et al. (1997)	Effects on vegetation structure and productivity and grazing response of sheep and goats in a slashed or cleared kermes oak shrubland.	The existence of a greater amount of herbaceous biomass results in the existence of feed of a higher nutritional value. Via the maintenance of a low cover, the movement of animals in the pasture is facilitated. These interventions are also beneficial for biodiversity and act against fire hazard.
Yiakoulaki et al. (1998)	Effects on biomass and dietary preferences of goat grazing in a *Pinus* forest fuel treatment dominated by kermes oak in the understory.	Grazing management systems do not affect the forage utilization preferences of goats. Nevertheless, low forage availability can affect animal welfare and productivity. Intensive grazing by goats can reduce fuel amounts in a pine forest's understory.
Hadar et al. (1999)	Clearing and/or heavy cattle grazing effects on botanical composition and functional groups in garrigue.	Heavy grazing tends to homogenize the height of the plants to the horizontal level, with certain plant species being affected. Grazing during the growth period of plants is a useful tool for fire prevention. It seems that clearing can cause an increase in species diversity, while intensive grazing decreases it. A combination of them can transform a garrigue formation, from a shrub-dominated to a geophyte-rich herbaceous community, dominated by early flowering plants.

Table 1. *Cont.*

Authors	Research Topic	Management Implications
Gutman et al. (2000)	Herbage biomass, small tree and dwarf shrub cover effects on thinned + grazed garrigue (mainly *Quercus calliprinos* woodland, partially batha vegetation). Forage utilization and beef cattle herd performance was also measured.	Intensive grazing by cattle can create an open park-like landscape, similarly to known goat grazing practices. Herbage is increased as a result of the phosphate fertilization caused by cattle feces, which is relevant to their supplementary feed, mainly poultry litter. Coupled with this kind of feed, the grazing management system of the current study can lead to a high herd beef performance. However, additional feed costs could create feasibility difficulties. Control of undesirable batha vegetation is difficult even via herbicide.
Étienne et al. (2001)	Impact of different management interventions on vegetation structure and floristic diversity of maquis ecosystems where fuel management was performed.	Livestock herds are able to promote ecosystems with rich biodiversity, while they are also used for fuel management, contributing to the carbon cycle and the aesthetic value of the landscape. However, even a 20-year period is small for biodiversity monitoring. An important reason for that is the frequent catastrophic fire events in that kind of ecosystem.
Delgado et al. (2004)	Shrub structure and forage productivity in a *Genista scorpius* shrubland, grazed by cattle or sheep.	Land clearings can increase grass forage production, but this is dependent on annual rainfall and location conditions. It could require some years for fertilization to show its effects on productivity. After clearings, *G. scorpius* individuals grow slowly, although cattle or sheep grazing does not seem to have an effect on them.
Lécrivain et al. (2004)	Description of a clearing technique executed by shepherds for the creation of pasture paths and open areas in a holm oak (*Quercus ilex*) stand. Measurements took place for three years.	Shepherds should be involved in clearing plans, since they are able to create openings in shrublands based on the needs of the herds. Via the creation of a network of patches and considering the capabilities of the flocks to maintain an open vegetation structure, an alteration in the vegetation could be achieved. Thus, the grazing period in a year can be increased.
Potts et al. (2010)	Ecological effects of deer grazing on chaparral (*Adenostoma fasciculatum*), previously prescribed burning or masticated. Effects of the treatments and their applying season in the recruitment of *Ceanothus cuneatus*.	Spring-controlled burning results in greater *C. cuneatus* mortality because seedlings have less time to recover from summer drought. Controlled burning treatments are more effective for wildlife conservation, but less effective for fire prevention compared to mastication in the medium term. However, fire risk is likely to be higher in mastication areas compared to those treated with controlled burning in the short term, because areas that have been recently masticated have more fine dead fuel and grass on the ground. Deer grazing only reduces shrub height and does not affect other characteristics (cover and seedlings).
Alvarez-Martinez et al. (2013)	Structure and productivity effects in pasture restoration of intensive goat grazing (clearing, trimming, or slashing treatments applied previously).	Grazing following other interventions can contribute to a conversion of shrubland into grassland (clearing or controlled burning prior to grazing), or limit shrub growth (trimming prior to grazing).
Masson et al. (2015)	Structure and botanical diversity effects in different treatments applied for the control of the invasion of brambles in grassland. Grazing was performed by goats.	Yearly land clearings followed by grazing can reduce brambles and increase herbaceous diversity, but they are not enough for complete dry grassland restoration. Water infiltration can favor competitive plant species. Dry grassland restoration can be obtained via a combination of interventions for several years, including clearing + grazing but also the restraint of water infiltration.

Table 1. *Cont.*

Authors	Research Topic	Management Implications
Lasanta et al. (2016)	Changes in the landscape structure and livestock numbers after the execution of a plan of clearings to promote grazing in La Rioja, Spain.	Spatial dynamics can be changed by land clearings, as is shown in the case of La Rioja. Pastures were developed in contrast to shrublands, while livestock numbers also increased.
Bashan et al. (2017)	Spatiotemporal dynamics of garrigue vegetation in different treatments. Grazing was performed by goats (high intensity) or cattle (low intensity).	Measures for fire prevention can be different from those developed for biodiversity conservation. Goats with high stocking rates can be quite effective at the control of woody vegetation. In contrast, low-stocking-rate cattle grazing is not effective. A strategy to achieve different targets should be promoted at a landscape level.
Lasanta et al. (2018)	Analysis of the changes in forest fires in La Rioja region before and after the land clearing plan.	When it comes to fire management, a large focus on suppression is ineffective. Grazing can contribute to fuel management, but livestock should exist in high numbers. Land clearing should be combined with cooperation with local livestock breeders. With the combination of clearing and grazing, environmental, economic and social goals can be simultaneously achieved in the Mediterranean.
Lasanta et al. (2019)	Changes in average pasture production before and after the implementation of the land clearing plan in the La Rioja region.	Seasonality in pasture productivity in Mediterranean mountain regions is an important issue in livestock management. Land clearings promote ease of movement through the pasture. Effective breed sizes and the manpower of young people are significant factors for the maintenance of extensive livestock systems.
Moinardeau et al. (2020)	Impact of clearing and/or goat grazing on the restoration of an artificial embankment understory invaded by brambles	The combination of clearing and grazing can have a positive impact on the heterogeneity and diversity of herbaceous vegetation. Shepherd supervision can be helpful in bramble invasion control. The location of sheds is important in such a situation, along with the application of proper stocking rates, animal training, and contacts between managers and shepherds. A supplementary feed should be avoided. When tall brambles are present, clearing is proposed, but costs should be considered.
Grupenhoff et al. (2021)	Ecological changes in goat grazing in a fuel treatment in Californian chaparral, with a sporadically present oak overstory. Cutting, pile burning and herbicide were previously applied.	Interventions before grazing were beneficial for the reduction in the fuel hazard and the diversification of the pasture. Goat grazing affected only herbaceous vegetation. The seasonality and duration of grazing and botanical composition are important factors when goat grazing is applied for fuel management.
Lasanta et al. (2022)	Landscape impact of the land clearing plan in La Rioja.	A mosaic landscape can be achieved via land clearings and grazing, that is rich in biodiversity and has a low fire risk.
Bicho et al. (2022)	Productivity and resilience to drought of an improved pasture grazed by cattle a pasture improved by cattle grazing (clearing + seeding + ploughing), compared to that of the natural understory (cork oak woodland).	Although the improved pasture was far more productive, the natural understory showed better drought resilience. Climate change impacts on production can be mitigated via the promotion of forage plants resistant to drought. The management strategies that need to be developed should not be very offensive against the natural vegetation. Such a direction would also promote biodiversity and ecosystem balance.
Castro et al. (2022)	Evaluation of ecological changes in a shrubby understory, cleared then grazed by sheep of a mixed sclerophyllous forest, treated for fuel reduction purposes.	In order to keep fuels in a low amount in the understory, grazing is required after clearing. Fire prevention and biodiversity targets have to be met, especially in Natura 2000 sites.

Table 2. Present effects (indicated by X) of the interventions examined in each study, sorted into three categories (structure, productivity, and floristic diversity). Experimental years are also included.

	Effects on Structure	Effects on Productivity	Effects on Floristic Diversity	Duration of Experiment (Years)
Poissonet et al. (1978)			X	9
Green et al. (1979)		X		6
Godron et al. (1981)	X	X	X	9
Poissonet et al. (1981)	X		X	9
Étienne et al. (1991)		X		6
Papanastasis et al. (1991)		X		2
Perevolotsky et al. (1992)	X			2
Papachristou et al. (1997)	X	X		3
Yiakoulaki et al. (1998)		X		1
Hadar et al. (1999)	X		X	5
Gutman et al. (2000)	X	X		10
Étienne et al. (2001)	X		X	10 and 15
Delgado et al. (2004)	X	X		3 and 4
Lécrivain et al. (2004)	X			3
Potts et al. (2010)	X		X	3
Alvarez-Martinez et al. (2013)	X	X		3
Masson et al. (2015)	X		X	3
Lasanta et al. (2016)	X		X	11
Bashan et al. (2017)	X			11
Lasanta et al. (2018)		X		12
Lasanta et al. (2019)		X		31
Moinardeau et al. (2020)	X	X	X	3
Grupenhoff et al. (2021)	X	X	X	3
Lasanta et al. (2022)	X	X	X	3 and 6
Bicho et al. (2022)		X		10
Castro et al. (2022)	X	X	X	2

The reviewed studies concern changes regarding the structure, productivity and diversity of the vegetation. A group of these studies does not involve true grazing by a specific herbivore, but refers to the application of mowing of shoots at standard frequencies as an imperfect way to simulate grazing in a cleared kermes oak (*Quercus coccifera*) shrubland [38,40,41]. However, we included this group of studies in our review, since the simulation of grazing via mowing or clipping is often achieved in the relevant literature. In Esterel hills, France, the clearing of the understory took place simultaneously with the thinning of trees in the overstory, which consisted of individuals of *Pinus pinea*, *P. halepensis* and *Quercus suber* [42]. This study was included in the present review since it included comparisons between grazing and no grazing after the interventions. It is also worth noting that the present review includes two studies on the mechanical thinning of low trees. One study was conducted in a Mediterranean oak scrubland where the initial thinning of the woody vegetation was followed by beef cattle grazing [43] and another study included additional management with the pruning of *Quercus calliprinos* [44]. As this particular species often takes a shrub-like form, the impact of these disturbances was considered interesting for the

present review. In contrast, the impact of grazing following wildfires or burnings that were not applied under a strict protocol, such as pastoral fires, was not considered.

Furthermore, the studies were sorted into three groups. The first group included the descriptive characteristics of the study itself. Characteristics such as year of publication, geographic referenced area, context of study (experiment or active management), purpose of biomass removal, time of sampling, kind of grazing animals, starting time of grazing, physiognomy of vegetation, overstory layer if any, understory vegetation, and area of interventions (in ha). The second group included information on the treatments applied, such as type of treatments, fencing (if any), treatments before the introduction of grazing, grazing season and duration, and grazing intensity. The third group included the impact on measured parameters, such as the structure of vegetation, productivity, and floristic diversity. For each study, the effects of treatments applied on measured parameters were analyzed and discussed.

3. Results and Discussion

3.1. Characteristics of the Studies

The Mediterranean-climate regions (MCRs) for which the studies met the identified search criteria were represented by the Mediterranean Basin and the State of California in North America. In particular, these studies were found in six countries, namely France, Israel, Spain, Greece, Portugal, and the United States (Figure 1) and they refer to twenty sites in total.

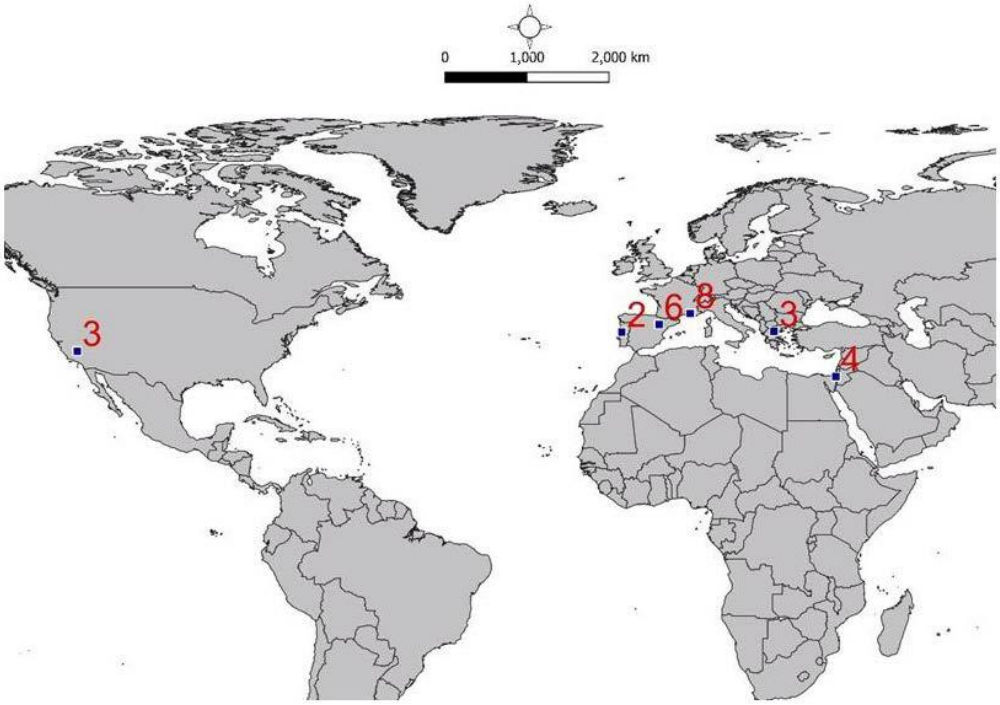

Figure 1. Distribution of the number of studies referring to grazing as a subsequent management intervention in MCRs of the world.

The evolution of the number of studies conducted for the above purposes in a 5-year time step is shown in Figure 2. The linear rate of change in the number of studies is +24%, representing the increasing interest of the scientific community in such studies. The first published work was that of Poissonet et al. [38], related to a clearing + simulated grazing vs. controlled burning experiment in Herault, France. The second one was by Green et al. [45] in California, related to the utilization of shrubs by goats as a management tool to halt the regeneration of vegetation in fuel breaks.

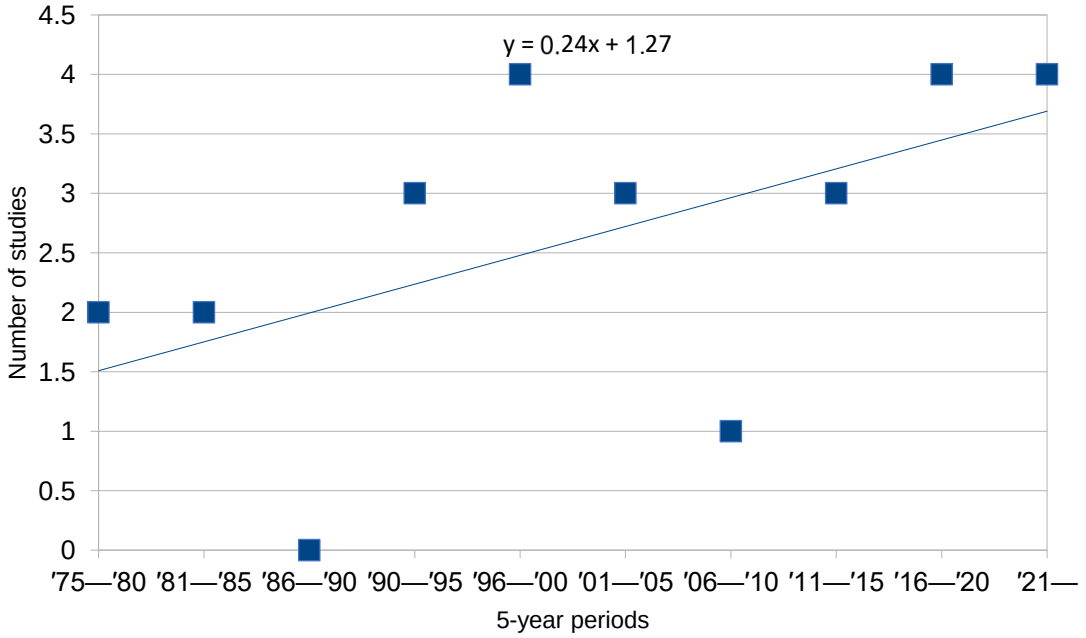

Figure 2. Linear trend line of number of published studies referring to grazing as a subsequent management intervention in MCRs of the world in a 5-year time step.

The management purposes, for which the effectiveness of interventions coupled with grazing was studied, are presented in Figure 3a. All studies were considered to deal with interventions aimed at optimal effectiveness in at least one of the three following issues: fire prevention (FP), the improvement of pastures (PI), and the achievement of a diversified botanical structure (BD) for restoration purposes. Fire prevention and pasture improvement were referenced in the majority of the sites, at 70% and 60%, respectively, while biodiversity was referenced in 40%. The kinds of animals grazing at each site are presented in Figure 3b, with goats being the main grazer (60%), followed by sheep (45%), and cattle (35%). Horses, deer, and grazing simulation (GS) were used in only one site each (5%). In the deer grazing study, other wild herbivores also grazed the area, but some enclosures that were intentionally established to evaluate the lack of grazing prevented deer access [46]. The types of management treatments that preceded grazing are presented in Figure 3c. In the large majority of sites (80%), land clearing (CL) or cutting above the base of the plants (CT) was the only biomass reduction intervention, or was one among other treatments, while in a smaller number of sites other treatments were included, namely slashing (SL), trimming (TR), controlled burning (CB), thinning (TH), pruning (PR), herbicide (H) application, and mastication (M). Subsequent interventions without biomass reduction, namely seeding (SD), fertilizing (F), pile burning (PB), ploughing (PL), herbicide (H) application and draining (D) were applied in 36% of the sites (Figure 3d).

Fire prevention was the main goal of the treatments in all the three studies concerning Californian chaparral. For this purpose, the focus was on domestic or wild animals with browsing habits, namely goats and deer. The improvement of a black-tailed deer habitat was also a purpose of one study [46]. In both the eastern and western Mediterranean Basin, both different purposes of the treatments and grazing animals were mentioned. There was often more than one management purpose for each study in this region. Different kinds of domestic animals were examined, either in terms of grazing in the same treatments or in comparison with each other. Clearing and other interventions of homogenizing vegetation at a horizontal level were performed in all the regions. Thinning vegetation requires the removal of some of the shrubs while trying to give others a tree form. This was performed in two case studies in Israel [43,44], with pruning of the remaining trees also taking place in one of them [44]. Most of the subsequent, improvement interventions such as seeding

and fertilizing were performed in west Mediterranean and Greece. Another improvement intervention was pile burning, which is sometimes applied in Californian pastures.

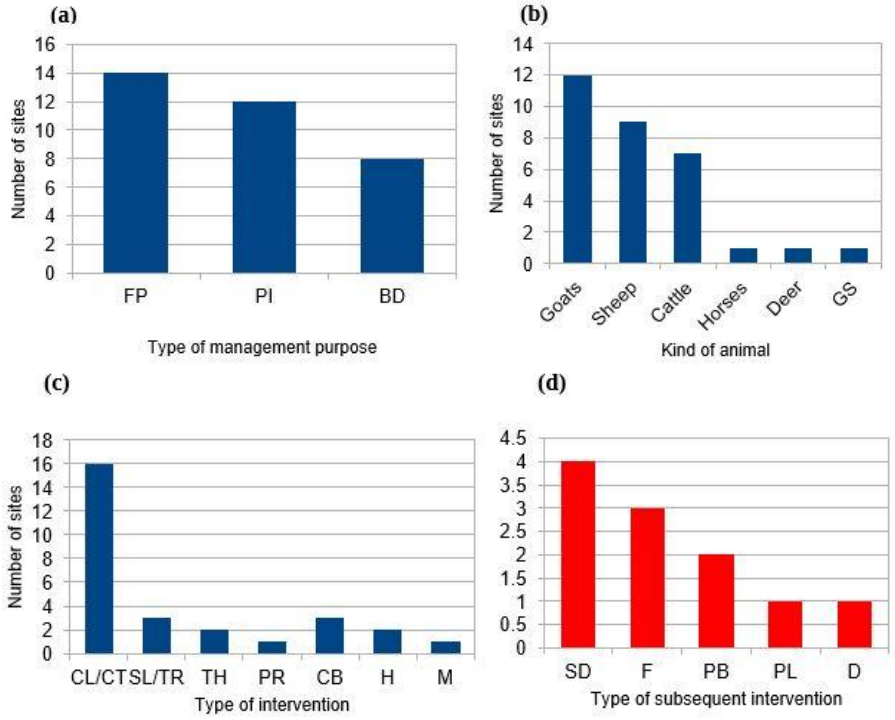

Figure 3. Allocation of (**a**) type of management purpose, (**b**) kind of animals, (**c**) type of intervention and (**d**) type of subsequent intervention into the studied sites. Treatments: FP (fire prevention), PI (pasture Improvement), BD (biodiversity), GS (grazing simulation), CL (clearing), cutting (CT) SL (slashing), TR (trimming), TH (thinning), PR (pruning), CB (controlled burning), H (herbicide), M (mastication), SD (seeding), F (fertilization), PB (pile burning), PL (ploughing), and D (draining).

3.2. Effects on Vegetation Structure

Changes in vegetation structure due to the applied treatments were assessed in a total of eighteen studies (Table 2). When grazing was combined with a prior management intervention, shrub cover did not reach the cover of shrubs in control plots. Moreover, in cases where a control plot did not exist it never reached the same levels as those prior to intervention. This happened for all studies considered, except in the case of grazing by cattle at Ramat HaNadiv Park, northern Israel [47]. In this particular case, the applied grazing was of a low intensity, thus resulting in vegetation cover similar to that of the control. On the contrary, the high grazing intensity in the same area, which included garrigue and batha vegetation, affected shrubs [48]. Although there were no data on the effect of grazing on the cover per se, it was nevertheless pointed out that the shrubland was converted into grassland [48].

Grazing following prior shrub clearing affected shrub recovery, and thus the structure of vegetation, for the sites reported in three studies [39,47,49]. Similarly, in cases of shrub thinning, regarding *Quercus calliprinos*, subsequent grazing was an impediment to shrub recovery [43,44]. In the 9-year study, including combined treatments of clearing and simulated grazing (mowing), the remarkable effect of reducing total vegetation cover was shown [41]. This was in contrast to that of controlled burning treatments with different schedules applied on the same site in the same period, where the cover became dense again two years after the burnings. The cover of woody species also decreased. The potential of intensive grazing to keep open spaces in grasslands was also reported [50]. Thus, there is a total of seven studies reporting that grazing contributes to the reduction in or maintenance of lower shrub cover in comparison to the cover after an initial intervention. Another two studies showed no change in cover due to grazing [46,51]. An absence of change was

also reported, regarding the implementation of different grazing intensities (moderate and high) in batha (phrygana) [43]. For the results above, grazing intensity probably played a role, with the exception of the last study [43], which was a case of a plant community of *Sarcopoterium spinosum* and *Calycotome villosa*. These dwarf shrubs are undesirable for selection by animals. The halting of the encroachment of grasslands by those plants is a key management problem in the Eastern Mediterranean grasslands [52]. Interventions such as fire and grazing have been recorded as insufficient or having little effectiveness at halting encroachment [53], even though a wildfire can have an effect on the cover, at least for a short period of time [54]. Finally, for four studies there was no comparison of the results between the application and lack of application of grazing after other structural interventions [55–58]. Although there was no comparison between clearing with grazing and clearing without grazing in the publications concerning the La Rioja region, such comparisons are applied, according to a deliverable of the LIFE MIDMACC Project [59]. The monitoring protocol is mentioned by [59].

For six of the studies, an assessment of herbaceous vegetation cover was conducted. In the case of simulated grazing [41], the herbaceous cover in treated kermes oak shrublands showed increasing trends in all treatments for at least three years. This was not the case in another site when grazing was applied, where in this case, despite the initial increase in herbaceous cover as a result of canopy opening, the herbaceous cover remained stable for three years (i.e., until the end of the experiment) [56]. However, the two studies are quite different. In the study in [41], frequent mowing corresponded to a much higher grazing intensity in respect to the intensity referred to by the authors of [56]. Additionally, grazing intensity appears to have played an important role in increasing herbaceous cover in a site dominated by *Quercus calliprinos* [43]. High grazing intensity after thinning caused an increase in the herbaceous cover, but with moderate intensity the woody vegetation recovered, as well as did its cover. The study in [42] reported that herbaceous cover was increased compared to that under the use of no grazing treatments in all forest stands. In a study of a chaparral ecosystem, the cover of many herbaceous species (native and alien) increased after cutting, pile burning, and herbicide application but decreased with subsequent grazing [51]. Another study showed increased herbaceous cover after the combination of clearing and grazing compared to that after pure clearing, despite the tendency of shrub vegetation to recover in both treatments [39].

With respect to bare ground cover, two studies [40,56] reported an increase in the early stages after clearing or slashing, followed by a gradual decrease. In the case of [40], bare ground cover was higher than that in the pre-treatment situation every year of the experiment only in unfertilized plots. In contrast, in fertilized plots, after a remarkable decrease in bare ground cover during the fourth year of the experiment, its values came close enough to the pre-treatment situation. Afterwards, it showed some yearly variations, which were possibly related to each year's drought. The study in [44] showed that thinning increased bare ground cover, but subsequent grazing did not. Finally, the authors of [49] reported that bare ground cover reached the levels of that of a reference dry grassland, as a result of a combination of annual clearings and grazing.

There are also records of vegetation height, which was measured in eight studies. In all the studies, the combination of initial interventions with grazing reduced vegetation height in comparison to that of the control or the initial height, with the rate of recovery varying according to the experiment, vegetation type, and intervention. In all the cases where data or references are available, grazing significantly affected the understory vegetation height [46,48,49,60]. In the latter study, the height was reduced during the fourth year of grazing compared to that under no grazing. The study in [51] reported changes in the herbaceous height but not in the shrub height. The study in [44] should be considered an exception, as it refers to tree-like shrubs of *Quercus calliprinos*, examining the height of the oaks that remained after thinning. The average shrub height was increased, a fact that must be attributed to the opening of the canopy layer, which allowed their further development, with no significant statistical effect due to grazing. The remaining studies did not report a

comparison of vegetation height with and without grazing after the first sampling, so it is not known in how many of these studies grazing had an impact on vegetation height.

Grazing intensity affected the results in most of the cases, with the exception of batha vegetation in [43], as long as there was a comparison between different ones. The structure remained open in case studies where high intensity levels were applied. In contrast, low or moderate intensity left more room for shrubs to develop in the same or adjacent sites [43,47,48,50]. Similarly, an increase in grazing intensity showed a boost in height differences between grazed plots and ungrazed ones [60].

3.3. Effects on Productivity

Impacts on productivity were assessed in a total of sixteen studies, with annual yields and total biomass being the most common parameters assessed (Table 2). In one case, none of these factors was mentioned for shrubby vegetation, but the number of shrubs was considered a measure of productivity instead [50]. While this kind of information was not available, productivity was assessed either through the consumption of vegetation by animals [45,60] or by the pastural value [61]; the latter was also mentioned in [40]. Clearing seems to achieve better results in terms of yields in herbaceous vegetation for two different types of plant communities (shrublands of *Quercus coccifera* and shrublands of *Cytisus scoparius*) compared to slashing or trimming [50,56,62]. The opposite was observed for woody vegetation in all three studies mentioned above, with shrubs recovering more vigorously after the third year from the initial intervention [56]. In the study in [50], there was no relevant reference. However, it was pointed out that the percentage of the surviving shrubs was at least 60% higher after trimming compared to that after other treatments, with increased grazing intensity largely affecting the further elimination of shrubs. Controlled burning + grazing, especially in lands experiencing high stocking rates, was even more effective than clearing + grazing at reducing the number of shrubs, with similar results of herbaceous vegetation [50].

Another important note is that the effects of fertilization and seeding affected biomass in most cases, increasing the available herbaceous biomass and favoring it in its competition with shrub biomass [41,56,57,62–64]. In the case of [57], there was no effect of fertilization on one of the three sites, though the experiment lasted for one year less than it did in the other two sites. This effect was shown during the last year of the experiment, with authors attributing the low impact to poor soil conditions.

In clearings without the use of fertilization, herbaceous biomass did increase in one case [43,51] compared to the control plots, but a decrease was reported in two other studies [39,65]. Specifically, the authors of [39] reported a decrease in herbaceous biomass in the first year after the clearings compared to that after the uncleared + grazed treatments. Cleared plots without grazing had a higher herbaceous biomass than the uncleared treatments did during the second year, but this was not the case in cleared + grazed plots. Additionally, in the study in [65], both shrub and herbaceous biomass decreased in the controlled burning + continuous grazing treatment. Herbaceous biomass was somewhat higher than that before the intervention of the controlled burning + rotational grazing treatment. It was shown that, before the interventions, herbaceous biomass was much higher in the plots that were then continuously grazed than in those that were then rotationally grazed ones [65]. In the study in [66], clearing favored access to herbaceous plants that had already emerged, which were previously covered by dense shrubs. The pastural value was reported by the authors of [66] to have increased after clearing + grazing, while the same happened in the case of [40].

In cases of prior interventions followed by grazing or not, herbivores were effective at decreasing both shrub and herbaceous vegetation, a finding that is valid for all the communities of *Quercus coccifera* where it was studied [56,62,65]. The consumption of shrubs was also notable in the cases of [45,60]. It was noted that this consumption compensated for the regeneration levels for two consecutive years. In these two studies, biomass changes were examined only in terms of shrub and not herbaceous vegetation. On the contrary, although

no comparison of treatments with or without grazing was reported, the delayed regrowth of *Genista scorpius* was not attributed to grazing by cattle and sheep [57]. It was rather due to the low regrowth rates, while the increase in herbaceous biomass was probably due to clearing and fertilization. In a study conducted in the Pyrenees with a subcontinental climate, goat grazing on *G. scorpius* communities was involved, and a remarkable effect on productivity was observed [67]. In this case, the grazing season was the most strongly determining factor, rather than the grazing intensity. Additionally, the elimination of *G. scorpius* shrubs following nine years of grazing simulation (through mowing) was reported by [40]. However, the authors also noted that the same did not happen in an experiment where sheep grazing took place. The differentiation of the kinds of grazing animals must therefore be considered. The only case where the shrub biomass did not decrease due grazing, but only the herbaceous biomass decreased, was reported by the authors of [51]. This reduction in the herbaceous component should be partially attributed to the sampling protocol. The comparison between grazing and no grazing was performed in the same year and treatments, before and after the grazing application. Vegetation was sampled during July 2018 before grazing and October 2018 after grazing. The authors also stated that goats can act as browsers under heavy grazing or with a prolonged time for grazing in pastures. The study in [45] concluded that a heavy grazing regime played a decisive role as a biotic shape factor in a chaparral landscape. Indeed, goats covered their feeding demands at high rates of utilization, even if shrubs in the chaparral were initially considered ab undesirable feeding resource for them. These results are in accordance with those of other reviewed studies, where an increase in grazing intensity led to an increase in herbaceous production [43] and/or a decrease in the woody component [50,60].

Finally, only five studies concerned the changes in dead biomass or in the fuel parameters of the pastures, with two of them recording changes in the litter [43,51], one recording dead fuels of a diameter lower than 0.64 cm, also known as 1 h fuels [65] and another two recording the changes in the fuel models at a landscape level in the La Rioja region [66,68]. The combination of grazing with previous interventions reduced the number of fuels in all the above studies. The impact of grazing on fuel reduction was characterized as positive [65] with the authors of [43] mentioning only a decrease in litter under a high grazing intensity.

3.4. Effects on Floristic Diversity

Four different indexes in relation to floristic diversity and grazing followed by other interventions were used in twelve studies, including those on species richness, Shannon–Weaver diversity index, Bray–Curtis dissimilarity, and contact-specific contribution (CSC) (Table 2). Species richness was mentioned in eleven of them and generally followed a pattern similar to that of the other indexes, except for CSC. It should be noted that the three studies concerning the area of Herault in France referred to the same experiment [38,40,41], and two studies referred to the La Rioja region (Spain) [55,68].

Clearing + grazing had mixed results in terms of species richness, particularly in relation to pure clearing. In comparison to the control plots or the pre-treatment situation, in a shrubland of *Quercus coccifera* [40], chaparral, [46] and forest with understory brambles (*Rubus ulmifolius*) [60], there were positive results in terms of the species richness that was observed after some years. For the first study, this may be attributed to the vigor of *Quercus coccifera* and the various ways it reproduces [69,70], although there are site variations, as was shown by the authors of [71]. As for *R. ulmifolius*, its high seed dispersal was not always reflected in its recruitment patterns [72]. According to [49], rapid growth, a rich seed bank, and drought resistance are the main reproductive advantages of plant species as soon as they are established in a field. A restoration experiment on grassland invaded by *R. ulmifolius* showed visible positive results in terms of richness immediately after the treatments [49]. In the study in [42], positive results were observed at the end of the interventions. The same was true for a couple of studies on the La Rioja region [55,68].

Clearing without grazing had positive effects on species richness and diversity, while when clearing + grazing was applied these effects were reduced to some extent [48]. This was attributed to the fact that winter clearing contributed to the creation of an open landscape, favoring certain species, some of which were driven to extinction under intensive grazing during the subsequent growing season. The study in [39] also demonstrated a decrease in species richness and diversity due to grazing. The authors hypothesized that the decrease could have been linked to local geoclimatic conditions, tree shading, composition, and plant functional groups. On the contrary, when cuttings took place every three years in the originally treated plots without grazing + fertilizing, species richness was conferred by grazing [42]. Authors observed that grazing increased plant competition and prevented the dominance of certain species in the understory. In the area of Herault, France, clearing + simulated grazing was more beneficial to species richness than pure controlled burning was [41], although some species seem to have appeared only in the plots where fertilization was applied [40]. Richness was lower in heavily fertilized plots than in moderately fertilized plots, while less frequent mowing conferred it [38]. This site was the only one where two fertilization levels were applied; species richness responded negatively to heavy fertilization in comparison to a moderate level of fertilization, but the CSC index did not. In the same study, it was shown that the latest cutting time period, corresponding to the lowest grazing intensity, was the most beneficial one regarding floristic richness. In another study, in a site covered by brambles species richness increased with grazing and yearly clearings, but Shannon–Weaver diversity remained significantly similar, regardless the number of clearings and the addition of grazing the lack thereof [49]. In the other study taking place in a bramble-covered site, the positive impact of clearing + grazing in comparison to that of clearing + no grazing was the most significant one in 2016. In this year, there was an increase in grazing intensity, while in clearing + no grazing plots species richness remained the same as that of the previous year. In a similar study on chaparral, there was a negative effect on species richness in a single-year measurement, with reference not only to native, but also non-native species [51].

4. Management and Monitoring Implications

The mechanical, manual, burning, and chemical interventions mentioned in the above review contributed to a decrease in shrub cover, creating more accessible pastures for grazing animals. They also increased herbaceous production, and fresher and more accessible woody forage in many cases. The follow-up grazing regimes had different results depending on the site, the treatments and their purpose.

The maintenance of some shrub cover is important for productive purposes since herbivores need to utilize various forage components during the year [13,35]. However, when it comes to fuel management, keeping woody biomass at low levels is of high importance [51]. Higher fertilization levels in cleared stands could increase forage productivity but decrease floristic richness in comparison to moderate fertilization [38]. Therefore, it is always important to recognize that the management purposes of fire prevention, optimization of production, and maintenance of biodiversity might be contradictory to each other [47]. Thus, a landscape mosaic needs to be maintained, allowing all these environmental and economic aspects to be addressed in the best possible way. Such landscapes can be maintained via the presence of livestock for both commercial and targeted grazing purposes. Integrated management efforts such as the ones in Esterel hills (France) and La Rioja (Spain) can serve the above purposes, while there is a need for cooperation with livestock breeders, who should be trained and encouraged to share their knowledge and work in a professional way [58,66,73].

Stocking rates are very important in such efforts because proper grazing intensity, applied by trained and motivated grazers, can contribute to the maintenance of shrub biomass at low levels despite variations in animal feed preferences [43,48]. In some cases, it can even reduce herbaceous production and increase bare ground cover. The impact of the applied stocking rates on floristic diversity may be visible as well, since a heavy grazing

regime can negatively affect it [38,48]. Overall, our review study showed mixed results in terms of richness, although some studies did not include such data. A meta-analysis focusing mostly on non-Mediterranean ecosystems showed that a reduction in floristic diversity is common in cases of high stocking rates [74].

It is important to note that elevated rainfall levels can mitigate the effects of high stocking density, and thus there is a need for the adaptation of grazing to strong meteorological variations [75,76]. Such a managerial approach has not been adequately examined in the studies of the present review.

When fertilization and seeding are allowed according to cost evaluations, they can increase pasture production. Subsequent grazing can also promote floristically richer sites compared to pure controlled burning or clearing even if the latter are repeated [38,42]. Nevertheless, harsh climatic variations, such drought events, could affect environmental balance more in fertilized or seeded stands than in stands with a natural understory [40,64]. A repeated combination of mechanical intervention and annual grazing could sometimes be recommended to create herbaceous communities [49]. In terms of comparing different interventions, clearing seems to be more effective against shrubs than slashing, though, apart from the specific nature of management goals, the costs also need to be considered [56,62]. Unfortunately, only two studies compared controlled burning + grazing to mechanical interventions + grazing [46,50].

In general, the most important factors that regulate productivity are grazing intensity and animal dietary preferences. There can be an effect on biomass even with a normal grazing intensity, especially if, in the case of goats, the consumption of grasses and shrubs can function in a complementary way. Even if consumption is limited to shrubs that are not dominant in the landscape, variation in annual shrub production may become apparent under sheep grazing [56]. The decisive role of grazing intensity was recorded in several studies [43,45,50,60]. According to the study in [45], fencing can increase the effect of grazing in clear-cut management treatments, via achieving objectives such as fuel reduction. In cases where previous clearing has taken place, fencing is not always necessary to regulate grazing as a fire prevention technique [45,77]. Grazing intensity and vegetation consumption can also be partially regulated by factors such as the placement of stockyards [60]. This is also mentioned by other authors in terms of the distance from stockyards; to the effectiveness of grazing at reducing shrub production seems to be regulated more at closer [78] than at longer distances [77].

Monitoring of the practices discussed above should involve longer-term changes. The highest duration in the reviewed studies was 31 years [66]. The changes in a *Quercus suber* ecosystem that was partially and periodically cleared were observed for 70 years, showing that longer monitoring schemes can be conducted [79]. The authors found that fuel management based exclusively on hand labor is costly. Thus, it can be hypothesized that grazing could serve as a low-cost alternative.

5. Conclusions

Mediterranean-climate regions (MCRs) have a long history of disturbance-based interventions for livestock use. Their use in newly transformed pastures has varied effects on plant structure, productivity, and floristic diversity. As far as humans can control these effects, important factors of the management regime, such as initial interventions and the presence of domestic (or wild) animals utilizing the pastures, along with grazing intensities, are very important. To our knowledge, the current biographical research is a novel attempt to summarize existing knowledge on the combined use of grazing and other mechanical or manual management interventions in the grasslands of MCRs.

Scientific society has shown increasing interest in meta-disturbance management in Mediterranean pastures. Since the first study by P. Poissonet and collaborators was published in 1978, several other relevant studies have emerged at a rate of 24% in 5-year time increments. The 26 publications included in this review focused on the effects of grazing

combined with other management tools on vegetation structure, biomass productivity and floristic diversity.

After a primary reduction inf shrub cover, more herbaceous forage is available. In some cases, shrubs tend to recover in grazed pastures but in general, grazing contributes to the maintenance of grassland formations. Vegetation height was reduced almost in all case studies. Additionally, floristic diversity could be adjusted according to the type and intensity of initial interventions and grazing. These findings are extremely useful for grassland restoration purposes.

Despite its possible recovery, shrub biomass is affected by grazing in most cases. The impact of grazing after the other interventions on floristic diversity was mixed, with richness being the index most frequently measured. Additional interventions for productive purposes, such as fertilizing and seeding, affect results, as do pasture management factors, such as the selection of animals and grazing intensity. Further research topics could include the adjustment of stocking rates in a vulnerable climate for longer periods, and the inclusion of fuel parameters of vegetation and wild fauna in the consideration of impacts, while more rangeland types, such as wet grasslands, could be included in the research.

Additional research may be required to define the spatial scale of application. Prediction tools, such as different development scenarios [80] or even spatially explicit models [81], can be incorporated in long-term management policies as well. The improvement of capabilities and the broader adoption of technologies such as GIS and remote sensing during recent decades nowadays offer opportunities for better pasture management and monitoring [82–84]. More studies on the fuel properties of vegetation in relation to its use by herbivores as a wildfire prevention tool should be implemented, and the practice should be considered even for countries where it has not been applied before [85]. Furthermore, research on the impact of such interventions on animal biodiversity is quite limited. Finally, combinations of interventions such as those discussed in this paper could also be considered for a wider variety of Mediterranean ecosystems.

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