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Shrub cutting as a habitat transforming factor: a review

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Abstract: Grasslands are among the most diverse habitats in the world therefore they play an important role maintaining the diversity of the species and landscape. Many recent surveys have verified that natural disturbances play a fundamental role in the life of these ecological factors. Many of these grasslands are secondary semi-natural grasslands, therefore disturbances are largely of anthropogenic origin. These habitats are maintained mainly by mowing, grazing or shrub cutting. Many surveys have found that abandoning these techniques can lead to increasing shrub cover, which is one of the most important threats on grasslands. This paper compiles the potential causes and effects of shrub encroachment. Furthermore, it instances many invasive woody species and recaps the methods applied in order to decrease shrub cover on grasslands.
Keywords: Nature conservation management, shrub encroachment

I. Introduction

In the practice of nature conservation the main paradigm has been that ecological systems are closed, self-regulated and are in stable balance, in which the main driving force is to reach a balanced climactic state [1], [2]. However, in recent decades many surveys have verified that disturbances can increase stability of the systems [1], natural disturbances are fundamental parts in the life of ecological systems [3], [4], [1]. These disturbances can also be antropogenic. It is important to know the landscape history of the habitat and interventions in the past [1], [5]. In order to maintain diverse and valuable habitats and to predict the changes of their role in ecosystem services it is important to know more about the interplay among biodiversity, changing landscape use and ecosystem functions [6].

Grassland vegetation types are very rich species and play a significant role in maintaining the diversity of the species and the landscape [7]. However, they are among the most endangered terrestrial ecosystems [8]. One of the most common threats is the increasing cover of shrub.

II. Headings

1. Causes of shrub encroachment

Inappropriate land-use is a key factor in shrub encroachment. Many of these grasslands are secondary, anthropogenic, semi-natural grasslands, which were maintained by extensive methods, such as grazing or mowing techniques [9], [8], [10]. Many surveys have described the abandoning of the mentioned techniques as the main reasons of increasing cover of shrub. Long-term protection from grazing results in increasing cover of mesquite in North America [11].

On the other hand, overexploitation of habitats can also lead to shrub encroachment. Many grasslands have been overgrazed by cattle in South Africa [12], [13], in North America [14], [15],[16],[17], South America [18], Australia [19].

Although grazing is an important factor in maintaining the vegetation balance in Chihuahuan Desert grasslands, when it gets uncontrolled, it can lead to increasing cover of shrubs [20].

Natural fire is an important factor in regulating shrub cover on grasslands. In many surveys it has been stated that the cause of shrub encroachment is the lack of regular fire. Often it is the case at Juniperus spp. [21].In North America many savannah grasslands converted to shrub-grassland dominated ecosystems, given that shrub islands have grown to the size resistant to annual fires over the past decades [22].

While some types of grassland vegetation have a lower risk of invasion, some are more vulnerable, such as sandy grasslands [23].Spatial heterogeneity also plays a crucial role in the invasion of woody plant seedlings. [24]

Shrub encroachment can also be caused by environmental issues, mainly climate change. A survey [25] an interconnection between shrub cover and microclimatic issues. Many surveys draw a parallel between changes of environmental issues such as precipitation and temperature and the interactions between shrub and grass species [26], [27].

Among the reasons why arboreal species invade grasslands right after abandonment are their higher seed production, vegetation production and longevity, more effective propagule dispersal exponential growth and higher tolerance for water or drought stress, all of which give them significant competitive advantage [28]. The competitive effects between neighbour species can influence the abundance of herbacous or woody plants

[29]. Spatial and temporal variation in competition between species can open „competition windows" which give the opportunity to germinate and invade woody species into grasslands [24].

For decades, researchers have argued that the increase of atmospheric CO2 can lead to shrub encroachment [30]. The principle of this theory is that on temperate grasslands herbaceous plants usually use the C4 photosynthesis pathway, while shrubs use C3 with less water-use efficiency and thus are less comparative [31]. But the increasing CO2 level enhances the gradient between atmospheric and intercellular CO2 level, thereby improving their efficiency at water-use and paving the way for invading C3 shrubs at the same time [32],[33].Drier grasslands can be more sensitive to shrub encroachment caused by increasing atmospheric CO2. However, these processes do not explain many local differences between the changes in grassland vegetations, which can originate in changing land-use. [34]

2. Effects of shrub encroachment

The effects of shrub cutting on vegetation has been examined in fewer surveys than other management methods, such as mowing and pasturing. One possible explanation is that shrub cutting requires much more human labour, it can be mechanised to a lesser extent than mowing. However, it is clear that the increasing level of shrub has a negative effect on grasslands in several ways: besides decreasing biodiversity [35], [36], shrub overshadows shorter herbaceous plants [37],[38] and inhibits their growth mechanically [39]. The greater amount of litter shrub produces can succour allelopathic material [40],[41] or set back the growth of herbaceous plants mechanically [42]. Greater cover of shrub leads to decreasing litter decomposition [43], and increasing, or at least maintaining soil organic matter [43],[44],[45],[46]. It also decreases the nutritive value and animal production of the grassland [47],[48], [49][50].Shrubs can mean a disadvantage for grass nutrient uptake [51]. The increasing cover of shrub can also lead to greater risk of fire [52].

Changing the distribution of moisture and nutrients can also increase the chances of desertification [53]. By decreasing the cover of herbaceous plants, shrub cover increase can lead to the extinction of some of the specialist species, resulting in homogenization [54].

The global phenomenon of grasslands turning into shrublands can be associated with the rapid and substantial carbon and nitrogen accumulation and turnover in the soil [55]. A survey [56] has found a clear negative relationship between precipitation and changes in soil carbon and nitrogen content on grasslands, which had been invaded by woody species 30 to 100 years ago. However, woody encroachment on semiarid grasslands can cause a stable soil organic carbon level [57].

The increasing cover of Juniperus virginiana on prairie grasslands can have a significant impact on regional carbon storage by increasing ANPP from 3690 kg/ha-1/year-1 to 7250 to 14440 kg/ha-1/year-1. [58]. Juniperus virginiana is a good example for pioneering shrub species, which can easily invade unmanaged grasslands and agricultural fields [59]. However, an extensive review [60] states that considering there are many possible factors causing shrub encroachment, one cannot draw a direct connection between ecosystem decline and shrub encroachment on a global scale.

Once woody plants invaded the grasslands, they can create a positive feedback by enlightening the invasion by other arboreal plants, making the whole process irreversible after reaching a certain level of tree cover [61], [62], [63], [64].One of the main factors in increasing shrub cover are woody individuals' age and the fact that younger plants have weaker resprouting availability, independently of managing method [65]. In the life cycle of shrub species, belowground biomass takes priority over aboveground biomass, and in this way woody plants can persist in frequently disturbed grasslands [66].

Grasslands are very sensitive to impacts of changing land use, and its biodiversity is affected by most of the factors the survey had installed (land use, climate, nitrogen deposition, biotic exchange and atmospheric CO2). [67]

In recent decades, it has become clear that the increase of shrub cover is a global issue [34]. There are many well documented cases where grasslands turn into shrubland. A survey [68] have examined using aerial photos of the invasion of Acacia nilotica in riparian grassland through 20 years. Another one [69] examined the reasons of increasing calden cover on Argentinian semiarid savannas. Bragg [70] did research on connections between increasing shrub cover on Kansas bluestem prairies, soil characteristics and topography. Costello et al. [71] found that 30 years of Acacia sophorae invasion can decrease plant diversity of coastal grasslands in Australia by 76%. Lindsay et Bratton [72] have predicted that in 3-6 decades, grassy balds can turn completely into woody vegetation in Smoky Mountains, USA.

D'Odorico et al. [30] has outlined four stages of the shrub encroachment process: stable grasslands (I), increasingly encroached shrubs (II and III) and cappice dunelands (State IV). They pointed out that it is important to manage the driver feedback directly, for instance through erosion. Reversibility is more likely when grasses have a competitive advantage on shrubs in the habitat.

3. Examples of dangerous woody species

Invading arboreal species can be adventive, but in some cases they are natural inhabitants and live on grasslands at lesser amounts when grass species are dominant [14].

In their study, Rodwell [73] identifies Crataegus monogyna and Prunus spinosa as the main potential invaders on calcareous grasslands. Many surveys have investigated the increasing cover of *Juniperus communis*[74], [75], [76] on grasslands. However, Belsky [77] argues that Juniperus occidentalis has negative effects on biodiversity and streamflow on North American grasslands. In American prairies, *Baccharis pilularis* is a potential invading shrub species [78],[79],[80].the invading tree and shrub species, such as Pinus pinaster, Pinus radiata and Hakea sericea can decrease the biodiversity of South-African Fynbos biome significantly. [81] Many North American surveys deal with the increasing cover of the genus Prosopis on dry semidesert grasslands [15],[11], [82],[83],[84],[85],[86],[87]. In North America, the encroachment of creosote bush (Larrea tridentata) is also well-documented [16],[88].

Protopopova et al. has pointed out the following species as the most dangerous invading arboreal plants on palearctic grasslands in Ukraine: *Robinia pseudoacacia*, *Ailanthus altissima, Elaeagnus angustifolia, Hippophae rhamnoides*, *Amorpha fruticosa* and *Acer negundo*. [89] Rejmánek and Rosén had similar results when they found that the increasing cover of Juniperus communis can cause a significant drop in grasslands' biodiversity. [74]

Hobbs et al. have made an experiment with Baccharis pilularis by sampling a series of stands ranging from 1 year two 9 years of age. According to their results, the herbaceous plant diversity has dropped by approximately 80% after 2 or 3 years, and remained at this level for the rest of the study. [79]

Many studies have also pointed out that the increasing cover of shrub can have a negative effect on the biodiversity of other group of species. Grant et al had found that when the cover of Populus sp and Salix sp. had exceeded 25% on a North-American mixed-grass prairie, the habitat became unsuitable for 9 bird species out of 15, including 3 endemic ones. [90]

The restorative shrub cutting on calcareous meadows has promoted the rejuvenation of *Rhamnus cathartica* and this restored the habitat and increased the population of butterfly *Satyrium spini*. [91] The habitat of the two thirds of European butterflies is temperate grasslands [92]. Mortimer et al also suggest the usage of insect indicator species together with plant species to measure the success the management because of their short life cycles and rapid reactions. [93]

However, very few studies have quantitative data of shrub colonization caused by land-use changes. This would be more important on protected areas, where the main value of grasslands has converted from economical to nature conservational [94].

The small grassland patches, species with short life cycle and with shorter lived seeds and species with narrow habitat tolerance are the most vulnerable to increasing the cover of shrubs, even in the extensively managed grasslands. This declining tendency is particularly dangerous for rare and protected species, and it can lead to their local extinction. [95],[96]

Shrub cutting can endanger some animal species but on the other hand, the increase of shrub cover is dangerous to grasslands [97]. Habitats with more shrub or tree cover can act as as ecotones between grasslands and forests. One must examine their influence on the habitat, because it can be useful to maintain smaller patches of arboreal flora [98]. Thus the aim of grassland restoration management is often to maintain a balance between open grasslands and scrubs [99],[100]. Burgess argues that desert grasslands in North America can be treated exclusively as „grasslands" because of the various forms of plant growth. [101]

This entails the need for shrub cutting as these grasslands have significant nature conservational and economical values. Marriott et al. [102] summed up the topic in an extensive review.

Thus, the goals of grassland management can be broken down into three categories: (1) preserving high biological diversity; (2) preserving open landscape; (3) preserving aesthetical value of the habitat [103].

4. Managing the shrub

4.1. Europe

Bonanomi et al. has surveyed the short-term effects of shrub cutting on Mediterranean grasslands. Although management has decreased biomass significantly through the three years of the survey, biodiversity has increased. According to the authors, regular shrub cutting can be a good remedy for the cumulation of nitrogen. [41]

Maccherini et al. has compared the vegetation on calcareous grasslands 1 year prior and 3 years after shrub cutting (mainly *Prunus spinosa*). They have found that shrub cutting alone is not enough to restore and maintain vegetation because after 3 years the vegetation of ex-arable lands was similar to that of the control shrublands. On restored grasslands there was greater similarity to reference grasslands, but among the newly introduced species there were many ruderal and arable ones. [104]

Dzwonko et al. have examined the regeneration of xerotherm grasslands through 12 years after clearing an 35-year pine wood. Because of the increasing shrub cover and its increasing effect on ruderal and disturbance tolerant species, they insist on the yearly cutting of grasslands after forest clearing. [105]

The same team [106] verified the hypothesis that on grasslands covered with arboreal plants, the vegetation formed after clearing are greatly influenced by the species composition that the grassland had had before the shrub cover increased. They examined the vegetation of a limestone grassland through 5 five years after the clearing of 35-year pine wood. Using CCA analysis, they found significant differences between the vegetation of former wood gaps and of restored grasslands in the place of former closed woods.

Barbaro et al have carried out research studies on calcareous prealpine grasslands. They executed shrub cutting through six years, and in this way, they could increase the diversity of vegetation significantly; and many protected and rare herbaceous species re-appeared. They emphasise that besides species diversity, the function of species in the vegetation and the possibilities of propagule spreading should also be examined in similar studies because grasslands' longterm perpetuance depends greatly on it. [107]

Anthelme et al. focused on fragmented arboreal stands (Alnus viridis) when managing prealpine grasslands. However, they have found that woody cover of 25% can actually contribute to plant diversity, but 45% is the critical level when management becomes necessary. [108]

Baba called for systematic shrub cutting when he compared the vegetation on managed and unmanaged areas in calcareous grasslands. Shrub cutting supported with mowing increased the diversity of grasslands significantly, although the author adds that significant differences have remained between restored grasslands and semi-natural ones that had been managed regularly for decades. [109]

Maccherini et al had made a 3.year.before-3-year after survey on the effects of shrub cutting on calcareous grasslands in Southern Italy. They had examined the role of detection scale in the analysis, using the method of principal response curve (PRC). They have found that the ability to differentiate between control and managed grasslands changes if they increase the size of quadrats (they used 0,5×0,5 m, 1×1 m and 2×2 m samples), but not monotonously. [110]

Baba also investigated the restoration of xerothermic grasslands after clearing shrubs. He puts an emphasis on the nature conservational importance of these habitats and points out that in the end of the two-year survey, the number of saplings on unmanaged, otherwise species-rich, seminatural grasslands started to increase, which indicates the trend of succession to xerothermic shrubland. Soil thickness is also an important factor and the restoration of grasslands in more advanced stages of succession on thick soil, restoration was impossible. [111]

Pärtela et al. had surveyed the importance of propagule availability on a small scale on shrub cut and grazed grasslands through shrub cutting and then transplanting sods between species-rich and overgrown habitats. They have pointed out that former species-rich which are now overgrown calcareous grasslands, do not need the artificial introduction of diaspores if the local species pool has not changed yet. [112]

Hansson et al. has conducted a 15-year experiment surveying different management methods. One of these was removing woody plants mechanically in every 2 or 3 years. He has found that this management in itself doesn't enhance plant diversity and the opened bare grounds gave the opportunity to nitrophilic species (*Rubus* spp, *Geranium sylvaticum* etc) to invade. By the end of the survey, a few tall species have dominated these plots, such as Filipendula ulmaria, Geum rivale, Molinia coerula. Smaller-growing plants, like Briza media or Nardus stricta has disappeared. [103]

Sundberg has surveyed the restoration of species-rich grasslands after the cutting of shrub (mainly Juniperus communis) in Sweden. His results show that grassland habitat can nearly fully recover in 6 years when cattle is also present, dispersing the diaspore of herbs. [76]

Zobel et al. had examined the restoration of vegetation on a calcareous grassland after clearcutting, mowing and root-trenching. They had set apart two types of competition among newly colonizing herbaceous plants: between similar growth-forms ('fine-scale') and different growth forms ('coarse-scale'). As light demanding species have taken the place of shade-tolerant ones, 'fine-scale' competition became more evident and increased species diversity. On the other hand, without mowing the cover of woody plants, they began to increase again in the third year. [113]

Rosén has also pointed out the importance of regular shrub cutting in a comparative survey on grasslands covered by Juniperus communis in Oland, Sweden. He also emphasises that shrub cutting regime combined by grazing is much more effective than cutting alone. [75]

Tárrega et al. came to the same conclusions when examining the effect of shrub cutting on Quercus pyrenaica-dominated dehesas (arboreal-herbacous mosaic pastures) in Spain. The sample areas cut and then excluded from grazing contained significantly less herbaceous species than the ones which had been grazed by cattle after the management. [52]

The opening of *Quercus coccifera* shrub cover on mediterranean grasslands can lead to higher animal production because of the resulting higher herbaceous biomass, forage production and higher biterate of goats. They suggest a balanced management method which uses both shrub invaded and open cut grasslands. [48]

Calvo et al. combined the management methods of cutting, ploughing and burning in the shrublands of Northwest Spain, to examine the restoration of the vegetation. They have found that in general, the dominant shrub species of Erica australis needed 4 years to recreate its cover. Before that, in the first three years herbacous species were dominant. [114], [115]

Canadell et al. investigated the nutrient reserves of mediterranean shrubs. They had found that multiple clippings forced Arbutus unedo and Erica arborea to mobilize a large fraction of starch in their lignotubers. The concentration dropped with 96% after 2 years of clipping, which means multiple managements can be useful in turning the shrubs into grasslands. [116]

Klimkowska et al. have tested a method of managing willow shrubs by cutting on fen meadows. He points out that mowing decreases the height of new sprouts but increases the number of their leaves, and the use of Roundup decreases the number of sprouts effectively. The conclude that the best method is to combinate using Roundup with yearly mowing, or intensive (2-3 per year) mowing followed by yearly management on protected sites. [117]

Bartolomé et al. has examined the expansion of cover of Erica scoparia on heath grassland Biosphere Reserve, where shrub cutting has taken place of burning management. Their results show that at the edges of the grasslands and on bare grounds Erica had a good invading capability, and the authors suggest that combining higher grazing pressure with a higher shrub cutting frequency (every four years creating an ’infertile’ canopy) can sustainably prevent shrub encroachment. [118]

4.2. Australia

Paynter et al. also suggests combining methods, such as fire, herbicide and mechanic cutting rather than shrub cutting alone. His results showed that Mimosa pigra, an invasive species in the Australian wetlands, can manage more efficiently when applying these methods when one separates the Mimosa monocultures into smaller patches, making them more vulnerable. [119]

4.3. North America

Lett et al. examined the effect of shrub invasion on the nutrient uptake of mesic grasslands by removing islands of Cornus drummondii from an Andropogon gerardii-dominated grassland in the central United States. They have found that in the following year, the increased light and nitrogen availability caused high carbon uptake in the dominant grass species. It took two years for the habitat to get regain typical grassland characteristics, such as leaf cover and ANPP. They suggest that when shrub cover increases, the reduced light availability plays a larger role in decreasing graminoid cover than nutrient availability. [120]

In a shrub removal experiment on prairie, Köchy et Wilson have found that in patches where shrub abundance was relatively low, grass species and shrub species suppressed each other in a balanced way, but when shrub cover was higher (37 times of the grass cover), it suppressed grasses much more then grasses did. [121]

Throop et al. surveyed the effects of shrub removal on litter decomposition on a semi desert grassland in Arizona. They used sample areas shrub cut 3 weeks, 45 and 70 years prior the survey and had found that the legacy effect of arboreal species (Prosopis velutina in this case) can last more than 20 years in the soil after they had been removed. [122]

Rango et al. (2005) located and re-examined shrub-removing experiments in New Mexico from the 1930s. In this way they could survey the long-term reactions of the grassland, and regarding that shrubland completely invaded the area after 65 years, shrub cutting without other measures and managements does not create an equilibrium state in grasslands. [123]

Grant et al. has compared the long-term effects of fire, chemicals, root plowing and mechanized shrub cutting, namely, roller chopping on shrublands in Southern Texas and Mexico. Their results showed that the regeneration of woody plant cover was the fastest after the mechanical clearing methods (five years), which means that regular shrub cutting is necessary when protecting diverse grassland habitats. [124]

Bates et al. surveyed the effects of cutting juniper shrubs on understory production. They suggest that cutting can increase understory biomass, diversity and cover of herbaceous plants. Biomass and nitrogen uptake were 9 times greater in the cut sample areas than in untreated ones. They also state that it is likely that the vegetation after shrub cutting will be similar to the vegetation that lived in the habitats before the increase of shrub cover. [125]

Calvo et al. stated in their study that on heathlands, the natural perennial species need roughly 2 years to increase their cover to the level it had before the cutting. [126]

Bates et al. (2011) suggest a combined method of shrub cutting and burning on the Juniperus occidentalis-invaded grasslands. In their experiment, preparatory shrub cutting helped eliminating the late succesional Juniperus cover greatly and by the third year herbaceus plants have restored their cover. However, the authors warn that during this type of management the presence of invasive weeds may cause problems. [127]

4.4. Africa

Mortimore et al. states that when converting shrub-grasslands into farmed grasslands in northeast Nigeria, in some circumstances it can lead to a gain in plant production. [128]

Moleele et al. had examined methods for restore the grasslands from shrub encroachment around water points and kraals (mud-built enclosures for cattle). They suggest either enforced reduction of grazing intensity or selective management of opportunist grazing. [13]

Abdulahi et al has reviewed the methods of managing of invasion of Prosopis juliflora on grasslands. This is a controversial species in Ethiopia, where it has been advocated as a 'wonder plant' in stopping desertification and as firewood, forage, fencing and windbreak; however, as an aggressive spreading species, it causes great decrease in biodiversity. [129]

5. Managing methods in practice

The methods of shrub cutting depend on the size of trees and shrubs. Smaller arboreal species can be cut or pulled by hand (although it is a time-consuming task). For cutting larger plants, one can use a chainsaw and grease the trunks with herbicide to avoid regrowth [98].

Klimkowska et al. has pointed out in their survey that pulling shoots by hand is not as effective as mowing when rolling back the cover of shrub [130]. Pulling shrubs by hand through 56 years had no significant effect on the Chihuahuan desert vegetation. [131]Houérou has compiled the possible methods of managing shrubs and trees on African grasslands. [132]

According to Collins et al. remote sensing is a less expensive way to measure the effectiveness of shrub management. They insist that developed relation produced viable (RMSE= 8.5%, MAE= 6.4%) maps are the most viable in this sense. [133]

Alexander et al. has investigated the invasion of French and Scotch broom (Genista monspessulana and Cytisus scoparius) on Californian coastal grasslands. They have found that repeated hand pulling combined with burning can be most effective when removing the shrub. [134]

Adema et al. suggests that roller chopping is an inexpensive way of shrub controlling on dry rangelands in Argentina. They have found that treated grasslands were more efficient in consuming water. [135]

Love et Anderson have compared four management methods on degraded meadows in Pennsylvania (cut, mechanical removal, stump and foliar application of glyphosate) and have that cut and mechanical treating produces grassland community of highest quality, however one must combine this with planting native seeds and controlling with deer. [136]

During forage shortage, mainly in dry summers, cut shrub can serve as supplementary feed mainly for sheep and goats [137], [138], [139]. Douglas et al has surveyed the possibilities of using cut willow as sheep forage in New Zealand. They found that Chamecytisus palmensis and Salix matsudana × alba are particularly sufficient. [140]

Grass species Agropyron desertorum is an effective competitor for Artemisia tridentata, a common shrub species, in the competition for phosphorus. [141] According to O'Connor dense grass canopy can cause a drawback in Acacia karoo seedlings germination. [142]

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