

# Efficiency and resilience of forage resources and small ruminant production to cope with global challenges in Mediterranean areas

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# Management and restoration of pastures and rangelands in the Mediterranean basin from the Northern and the Southern perspective

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**Abstract.** Pastoralism is a traditional land use in the Mediterranean region lasting for several thousands of years, where vegetation and animal communities are adapted to deal with summer drought periods and grazing pressure. There is a difference between the two shores of the Mediterranean in terms of pastoralism, it is more a mode of subsistence in the South, whereas in the North is a complementary activity each time less profitable. In addition, there is a clear North-South climatic gradient that determines rangelands productivity, carrying capacity, sustainable management and resilience. The environmental and socio-economical differences among the Northern and the Southern shores of the basin determine separated trends in both shores, leading to different management and future perspectives of rangelands. In addition to climate, differences in demographic pressure and socio-economical context influence rangeland status across the Mediterranean basin. Abandonment of grazing activities in North Mediterranean region vs. grazing intensification or even sedentarization in South Mediterranean region are the main socio-economical drivers, with important consequences on rangeland conservation. Despite regional differences, global warming affects the Mediterranean rangelands as a whole, increasing the shortage of water availability and the summer stress. These common perspective should promote that northern and southern rangeland managers and researchers learn from each other to deal with rangeland conservation, management and restoration. The latest research address pastoral production systems as a whole, and considers pastoral improvement techniques as a component in a holistic approach.

**Keywords.** Mediterranean rangelands – Productivity – Land abandonment – Overgrazing – Climate change.

## ***Gestion et restauration des pâturages et des parcours dans le bassin méditerranéen du point de vue du Nord et du Sud***

**Résumé.** Le pastoralisme est une forme d'utilisation traditionnelle des terres dans la région méditerranéenne depuis plusieurs milliers d'années, où la végétation et les communautés animales sont adaptées pour faire face aux périodes de sécheresse estivale et à la pression du pâturage. Il existe une différence entre les deux rives de la Méditerranée en termes de pastoralisme : il s'agit davantage d'un mode de subsistance au Sud, alors qu'au Nord c'est une activité complémentaire chaque fois moins rentable. En outre, il existe un gradient climatique Nord-Sud très net qui détermine la productivité, la capacité de charge, la gestion durable et la résilience des parcours. Les différences environnementales et socio-économiques entre les rives nord et sud du bassin déterminent des tendances distinctes sur les deux rives, ce qui entraîne une gestion différente et des perspectives d'avenir différentes pour les parcours. Outre le climat, les différences de pression démographique et de contexte socio-économique influencent l'état des parcours dans le bassin méditerranéen. L'abandon des activités de pâturage dans la région nord-méditerranéenne et, au contraire, l'intensification du pâturage ou même la sédentarisation dans la région sud-méditerranéenne sont les principaux facteurs socio-économiques, avec des conséquences importantes sur la conservation des parcours. Malgré les différences régionales, le réchauffement climatique affecte les parcours méditerranéens dans leur ensemble, en augmentant la pénurie d'eau disponible et le stress estival. Ces perspectives communes devraient inciter les gestionnaires et les chercheurs du nord et du sud à apprendre les uns des autres en matière de conservation, de gestion et de restauration des terres de parcours. Les dernières recherches abordent les systèmes de production pastorale dans leur ensemble et considèrent les techniques d'amélioration pastorale comme une composante d'une approche holistique.

**Mots-clés.** Parcours méditerranéennes – Productivité – Abandon des terres – Surpâturage – Changement climatique.

## I – Introduction

Grazing land ecosystems occupy approximately one third of the earth's land area (MEA, 2005; Gibson 2009, Delgado *et al.*, 2011; Sayre *et al.*, 2013) and support about 50% of the world's livestock and wildlife (Niamir-Fuller 1999, Allen *et al.*, 2011). At least 1 billion rural and urban people depend on these ecosystems for their livelihoods, often through livestock production, or for ecosystem services that affect human well-being (Ragab and Prudhomme, 2002). Extensive grazing on rangelands for livestock production represents the key food production and livelihood system in the world's drylands. Pastoralism is recognized as one of the most important agricultural systems with high natural value in Europe (European Council Regulation (EC) 1698/2005). In the Maghreb, a population of 12 à 15 million lives in harsh environment regions (steppes, mountains, arid areas) where dominate agro-pastoral systems based on the use of rangelands (PASTRES, 2018). Pastoralism continues to be an important source of livelihood in the Maghreb; share of livestock in agricultural GDP ranges from 26 percent in Morocco to 70 percent in Mauritania (PASTRES, 2018).

Ruminants and associated grazing lands provide a number of important benefits for humans and the environment (Teague *et al.*, 2016). Provision of these ecosystem services is dependent on appropriate management (Teague and Barnes 2017), while unsuitable management practices have caused an overall decline in historic ecosystem services generated through the grazer/grassland relationships (Hillenbrand *et al.*, 2019). Nearly all pastoral cultures are facing great difficulties (Weber and Horst, 2011) because rangelands are degrading worldwide, primarily due to inappropriate land use practices, among other reasons (Delgado *et al.*, 2011), especially in arid and semi-arid rangelands (Schacht and Reece, 2008). For instance, on most of the world's grazing lands, continuous or relatively unmanaged grazing in excess of carrying capacity has resulted in degraded vegetation and soils (Teague *et al.*, 2011), declines in productivity and biodiversity, and a reduction in ecosystem resilience (Frank *et al.*, 1998).

Mediterranean climate has distinctive traits shared all around the basin, which are a summer water deficit and growths periods in spring and autumn. This fact determines a yearly heterogeneous management driven by the the seasonal plant productivity (Perevolotsky and Seligman, 1998). Besides this common feature of the whole basin, in the Mediterranean region there are strong spatial gradients, mainly a North-South gradient in rainfall and temperatures, reflected at the end in a strong and clear aridity gradient (Bolle, 2012). This aridity gradient ranges from humid at some regions of the North Mediterranean shore to hyperarid in the driest regions of the south Mediterranean region, with all the conditions in between these two extremes. Aridity strongly determines rangeland productivity, management and degradation processes. In this sense, plant communities that support the Mediterranean rangelands are highly diverse, with vegetation ranging from closed forest (i.e. *Pinus* sp., *Quercus*), shrublands and grasslands.

Climate change is one of the most challenging environmental issues in the whole Mediterranean region. Climate is expected to become warmer and drier in many regions of the world, and these trends are predicted to be strong and fast in the Mediterranean region (Cramer *et al.*, 2018). Climate change is going to increase aridity in the Mediterranean region, which will impact Mediterranean rangeland productivity and diversity, and ultimately can impact people well-being and rural life. Climate change could be the direct cause of desertification (irreversible ecosystem degradation) in many Mediterranean areas (UNCCD, 1994). The consequences of combined effects of climate change and overgrazing can be worse in the South Mediterranean rangelands, but desertification risk is also high in the West and East Mediterranean regions (Alados *et al.*, 2007; Kouba *et al.*, 2018; Rubio *et al.*, 2009).

Ecological research on grazing systems can help preventing and mitigating desertification in the Mediterranean ecosystems. Firstly, the understanding of the processes and functioning of the grazing systems from the ecosystem perspective can help preventing irreversible degradation. From an ecological point of view, Mediterranean grazing systems are ecosystems, whose structure and

dynamics are influenced by processes and factor that occur at a wide range of spatial and temporal scales. Structure and functioning of rangelands are maintained by ecological processes that occur at individual scale, such as seed dispersal, biotic interactions and plant growth and persistence. From the landscape level there are factors and processes that also affect grazing systems, such as climate and other abiotic factors, the type of grazing management and land fragmentation among others (Alados *et al.*, 2014; Gartzia *et al.*, 2016a). Looking at grazing systems as ecosystems, we can identify relevant ecological parameters, of ecosystem components, to control in order to evaluate the effect of grazing on vegetation, such as productivity, species diversity and plant height (Perevolotsky & Seligman, 1998). Both productivity and diversity are usually maximum at intermediate grazing pressure (Escos 1997; Alados *et al.*, 2003).

On the other hand, technics based on ecological restoration can help mitigating desertification once has occurred. In the ecological restoration the target ecosystem should reach similar species composition and structure, biotic fluxes, self-sustainability and resilience. Nevertheless, in order to evaluate the success of restoration efforts, both biophysical and social-economical indicators should be taken into account. (Bautista *et al.*, 2010; Cortina *et al.*, 2011).

The objective of this paper is to briefly address and discuss the different approaches for management and restauration of pasturelands and rangelands and review the latest advances on the management and restauration of pasturelands and rangelands across Mediterranean conditions.

## II – The Northern shore perspective

The North Mediterranean region is a complex mosaic of diverse landscapes ranging from humid to semiarid climatic conditions. The environmental value of extensive grazing systems is officially recognized and many of them are included among the High Nature Value (HNV) farmlands by the UE (EEA, 2012). The concept « HNV faming » is a recognition of the role of traditional low-intensity farming systems for biodiversity conservation in Europe. Environmental conservation and the protection of natural heritage are developed in different laws that provide for the conservation, sustainable use, restoration and enhancement of the grasslands. The ecosystem services provided by extensive grazing systems in the North Mediterranean countries are diverse and well-recognized (i.e. forage production, open landscapes that prevent fires, save habitats for wildlife, ensure biodiversity, aesthetic values for tourism, cultural life, rural vitality...).

During traditional pre-modern period (previous to 1970) social capital of rangeland ecosystems were dominated by extensive grazing and traditional non intensive agriculture. With the Common Agricultural Policy (CAP) regulations the rural activities in the north Mediterranean countries changed in the traditional pasture management and breeder involved. For example, while traditionally sheep has been predominant in Central Pyrenees Mountains, after the CAP subventions, there has been a transition from sheep to cattle with important implications on the pasture dynamics. This has several consequences for the management of pastures, whose preliminary results do not bring good news. The overgrazing by cattle on the “best pastures” and the absence of cattle in other areas can bring fatal consequences with the loss of high valuable grasslands. In other areas as in Ateroussia Mountains, subsidies favored the implementation of husbandry activity, increasing overgrazing (Alados *et al.*, 2014; Gartzia *et al.*, 2016a, 2016b).

The socio-economic development that has taken place in the period 1991-2011 in southern European countries has given rise to an increase of leisure and tourism activities. An important tourism development related to two different models of tourism in mountain ecosystems are: ski resort or sport tourism and nature tourism, based on singularity, biodiversity and landscape quality. An important factor in the implementation of CAP aids has been the Measure of “unique payment” referring to all CAP subsidies. The direct aid for agrarian rents in the first pillar of the CAP (direct payments) and the second pillar of the CAP are Rural Development Program.

Extensive grazing systems of North Mediterranean region are threatened by socio-economical trends in European countries, including a clear tendency to rural life abandonment in the last decades (Morand, 1983; Fernandez *et al.*, 2017; Alados 2014). In addition, policies and regulations concerning the conservation of rangeland ecosystem lead to the prohibition of traditional management practices as fire and clear cutting to control shrub colonization into the grasslands. As a consequence of this trend a landscape transition has been identified as the key threat to ecosystem services and human well-being since the second half of 20th century (MEA 2005). In grazing systems, the most important land cover transition is the grassland-woodland transition that took place in many European countries after the mid-20th Century. These changes had important implications in the provision of ecosystem services on which human societies depend. Grassland-Woodland transition appears to result from a number of distinct factors and their interactions including grazing pressure and management, anthropogenic disturbances or from long-term climate change. In addition, as a consequence of this trend, an heterogeneous use of the pastures and rangelands is common. While the most accessible resources are intensively used, there is a massive abandonment of the most inaccessible grazing lands (Gartzia *et al.*, 2016). Large scale grazing systems are being massively abandoned (Caballero *et al.*, 2009; Alados *et al.*, 2014) while forage supplements are increasingly included in the grazing management instead.

Both climate change and social-economical trends are the main challenges for the conservation of pastures and rangelands in the North Mediterranean countries, often in an interactive and synergistic way (Gartzia *et al.*, 2016a). The nature of the degradation process depends on the type of rangeland. In semi-arid rangelands the degradation process is related to desertification, and both climate change or an inappropriate use of the resources are involved (Bainbridge, 2007). On the other extreme, in humid pastures, the land abandonment leads to the loss of the pastures by shrub encroachment, often exacerbated by climate warming (Komac *et al.*, 2013; Gartzia *et al.*, 2014). Both degradation processes are irreversible without human intervention, requiring active restoration to revert. However, restoration techniques at these two extremes of the grazing land degradation are different.

## 1. Reverting shrub encroachment

During the last decades, the abandonment of traditional land use practices are largely contributing to the colonization of unpalatable woody species in grasslands, what is called as shrub encroachment. This is a common trend in Europe, and especially in the European Mediterranean area, there is a massive process of revegetation of grazing lands (Gartzia *et al.*, 2014, 2016a). Shrub encroachment causes irreversible changes in ecosystem functioning. Once the pastures are colonized by shrubs, the new conditions are very difficult to revert. Land managers employ different restoration techniques to reverse plant succession, such as burning or clear-cutting. Ongoing long-term ecological studies in the Pyrenees are giving light on to the best way to control and revert shrub encroachment (Komac *et al.*, 2013; Nuche *et al.*, 2018; Alados *et al.*, 2019). After several years following trends in soil and plant community properties after different treatments (shrub burning vs clear-cut; Figure 1) results point towards different conclusions based on the shrub species involved. In general, in the case of the pyrophite dominant shrub *Echinopartum horridum*, clear-cut is the best strategy always followed by high grazing pressure to control the *E. horridum* germination. In the case of species able to regrowth after cutting, such as *Rosa* sp. burning is better strategy because those species live at low altitude close to forest, the use of burning is not advised, consequently the only option possible is clear-cut with heavy grazing in humid habitat as Pyrenees. In ecosystems with a long evolutionary history of grazing vegetation is adapted to large herbivores and consequently, livestock grazing is necessary to maintain ecosystem biodiversity. Grasslands-grazers positive feedback is based in one hand in the capacity of grasses to re-growth from intercalary meristems located at the base of the defoliated shoot and the new stems that develop at the ground surface, and the increases of nutrients contents of that young plant tissue, resulting in the favorable effect of grazers on grassland biomass and nutrient concentration.



Fig. 1. Burning (left) and clear-cut (right) treatments to control *Echinospartum horridum* expansion in Pyrenean pastures.

## 2. Restoring desertified rangelands

Semi-arid rangelands productivity and functioning are controlled by strong plant-soil feedbacks (Rietkerk and van de Koppel, 1997). Vegetation cover enhance soil water infiltration and fertility, which in turn benefit plant establishment and productivity. Overgrazing causes negative effects on these systems though the loss of vegetation cover and the bare soil compaction, that hamper soil conservation (i.e. decrease water infiltration, increase erosion processes and salinization) and plant establishment, leading to an irreversible degradation of the rangeland (Bainbridge, 2007). This degraded state is highly stable and persistent, and it is characterized by low vegetation cover, low diversity and poor forage quality (Suding and Hobbs, 2009; Figure 2). To restore previous preserved conditions is challenging, as soil conditions are not suitable any more for seedling establishment. Traditional restoration of these areas includes abiotic amelioration and soil conditions improvement through ploughing the soil to increase infiltration or creating small dams to prevent run-off and erosion. However, these techniques are often expensive and quite invasive (Papanastasis, 2009). Positive biotic interactions among plants (i.e. facilitation) are well known in arid and semiarid ecosystems to be a relevant ecological mechanism that increases plant establishment and sustain diversity and productivity (Callaway 2007). Facilitation of species of interest by « nurse plants » has been successfully applied in semi-arid Mediterranean rangelands (Pueyo *et al.*, 2009; Padilla, 2006). More research on this low-cost restoration treatment is necessary, as pioneer results are promising.



Fig. 2. Well-preserved semi-arid grassland dominated by *Lygeum spartum* (left) and eroded and salinized land (right). Both in the Middle Ebro Valley (Spain).

### III – The Southern shore perspective

The vast majority of pastoral systems in Africa, changed during the 20th century. The trends and perturbations faced by pastoralists across the world include drying of the environment due to recurrent droughts, population increase, agricultural encroachment, preferential subsidies and policies supporting crop cultivation, lack of government support for transhumance, breakdown of the traditional, local institutions and systems for managing natural resources, inappropriate development approaches, sedentarization and concentration of livestock and the growing economic vulnerability of pastoralists (Niamir-Fuller 1999).

A brief history of the development policies undertaken in the Southern shore will provide the succession approaches and the lesson learned (Figure 3).

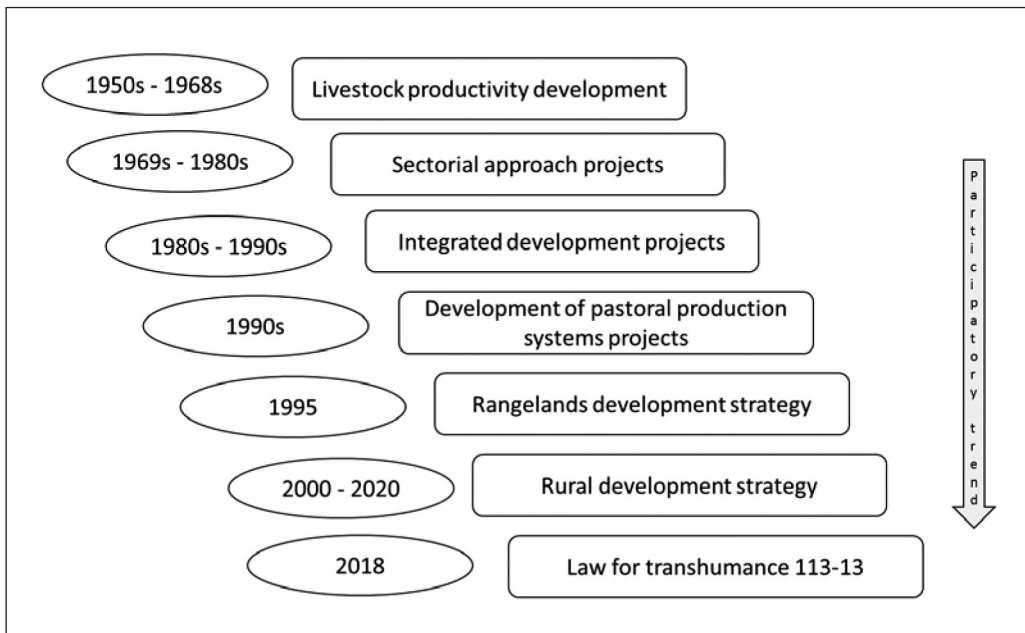


Fig. 3. Different approaches to pastoral development in Morocco.

Under the colonial era, the focus was on the livestock development rather than on the enhancement of the livelihoods (Niamir-Fuller 2019). After their independence, the state's interventions on rangeland were limited to health prevention campaigns against diseases with economic impacts. With the recurrent droughts and their negative impacts on livestock, the governments established strategies such as Livestock Safeguard Fund to provide support to livestock farmers, in the form of a livestock feed subsidy, and to cover transportation costs. During the period 1970s to the early 1980s, pastoral policy meant more classical approach based on pastoral improvement actions carried out in defined areas, i.e. Pastoral Improvement Areas (PAPs) in Morocco with no success. In Tunisia, the government linked the problems of rangelands with collective land tenure and implemented a law in 1971 to start of the privatization of collective lands that reduced drastically the area of rangelands (Ben Sâad and Bourbouze, 2010). As consequence of the reduction of rangelands area, there was an increase in the grazing pressure which resulted in large degradation of the remaining rangelands (Zaafouri, 1998). Between 1971 and 1997, one million hectares of good rangelands were cropped, mainly in arboriculture and cereals.

The following phase (1980s – 1990s) was the Integrated Development Projects (IDP). The aim was to associate the livestock producers and to correct the significant imbalance that existed between rain fed areas and irrigated areas. The results obtained did not live up to the expectations and the investments made. The Middle Atlas Central project in Morocco funded by World Bank was an example of IDP with a negligible impact.

The third phase that emerged in the early 1990s addressed the pastoral development in more holistic approach and take advantage from Lessons from the succession of policies. These projects are more participative and not top-down approaches, involved all stakeholders and use the pastoral cultural heritage to manage rangelands.

The threats to pastoral systems sustainability in the South shore of the Mediterranean are:

### A. The overexploitation of resources and the desertification

In the South of the Mediterranean, plant communities have been under high grazing pressure for long time. Usually overgrazing had been associated to uprooting shrubs such as *Artemisia herba alba* which increase the risk of desertification (Figure 4) and made those good plant communities crossing threshold to irreversible state (Standish *et al.*, 2014).

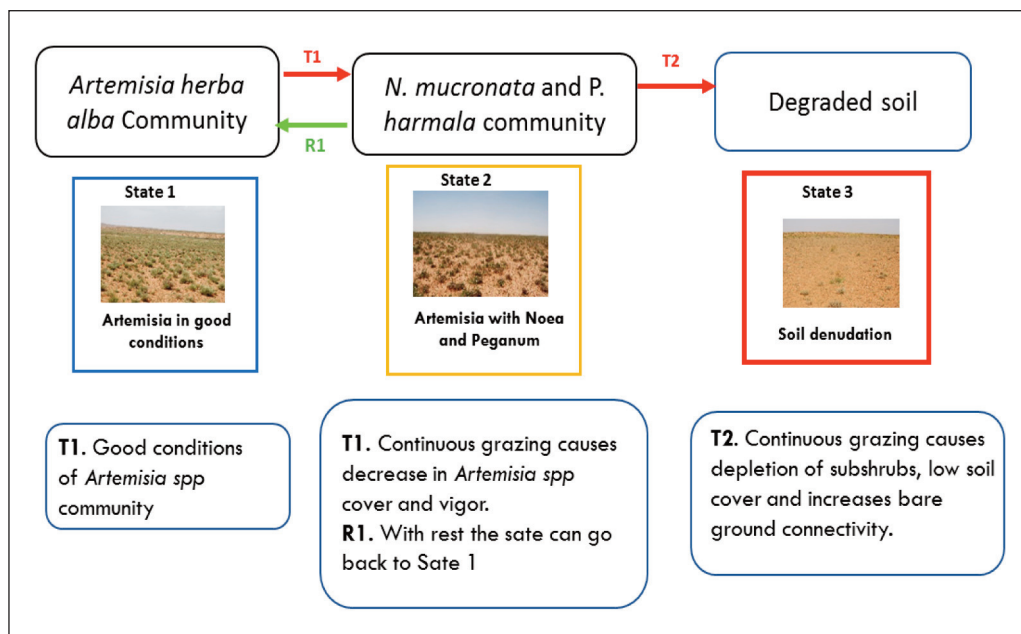


Fig. 4. Alternative States in the *Artemisia herba-alba* community as responses to the overgrazing (adapted from Bestelmeyer *et al.*, 2015).

### B. The threats of climate change

The Mediterranean is the second most exposed region in the world to climate change, with 25% rainfall reduction projected along its southern rim in forthcoming decade (Ouled Belgacem and Louhaichi 2013). All climate projection scenarios indicate that North Africa region will be exposed to three key climate change hazards: (i) long-term climatic desiccation; (ii) increased weather/climate variability, extremes and uncertainty; and (iii) rising temperature. Adaptation of rangeland



species will differ: Xerophilous species will stand higher temperatures, for instance, i.e., climate change seems to favor *Haloxylon* spp (Ouled Belgacem and Louhaichi 2013). In traditionally managed grazing systems, mobile pastoralism provides a way to respond to variations in intra- and inter-annual climatic fluctuations (Fryxell and Sinclair 1988) and prevent desertification by overgrazing (Homann *et al.*, 2008). Mobility of herds and people, i.e. transhumance /transterminance, allows a better exploitation of rangelands. Periods of resting helps to mitigate the effects of overgrazing and warming, restoring productive capacity, and mitigating erosion and desertification.

Recently, researchers have shown that livestock have little impact on forage resources ( Sullivan and Rohde 2002; Lind *et al.*, 2003) and so are not considered the main cause of degradation of rangeland and consequently desertification (Okayasu *et al.*, 2010). This is explained because high levels of climatic variability with peak droughts cause crashes in the animal populations, causing higher mortality rates in livestock and as a result overgrazing is halted before the desertification process is triggered (Derry and Boone 2010). This is only the case when animals are not provided with supplementary food during periods of food shortage.

### ***C. The absence of defined policy to sustain pastoral systems***

In the southern shore of the Mediterranean, there are no national policies to help pastoralists outside of the drought safeguarding plans. To cope with this, pastoralists are now trying to ensure the sustainability of their system through the use of the livestock/agriculture association in dry or irrigated by pumping deep water wells in addition to non-agricultural income from emigration, trade or other small jobs. In the steppe regions, most of the small livestock holders switched to other small jobs in other sectors rather than raising sheep and goats. It is certain that pastoralism can provide more global environmental benefits with greater attention to domestic markets where fewer trade barriers exist. Extensive low-input farming where livestock are fed on rangelands is certainly an organic system and niche markets could provide an important marketing option in the future. It should be noted that in most developed countries, the supply of organic meat cannot meet consumer demand which justify the need to promote such products from rangelands.

Finally, an important issue to address in the south is the change of the policy framework dealing with the land tenure in order to control animal numbers for the adjustment of the grazing pressure. In the meantime, a special consideration should be done to the pastoral cultural heritage that had ensured for centuries the ecological integrity of the pastoral ecosystems.

## **1. Latest advances on the management and restauration of rangelands in the Southern shore the Mediterranean basin**

The latest advances on the management and restauration of rangelands address pastoral production systems in their entirety and considers pastoral improvement techniques as a simple component of an approach to pastoral development.

### ***A. The revival of transhumance to conserve biodiversity***

The approach is built on the premise of “the revival of transhumance to conserve biodiversity” through the creation of pastoral associations in charge of the management of displacements and the development of routes (defenses, water points, etc.), but also on training (“capacity building”). Mobile pastoralism strengthens rangeland biodiversity, rangeland carbon stocks and supports the conservation of rangeland habitats. In pastoral systems in semi-arid areas of Spain sheep transhumance on traditional migratory corridors has been found to support habitat connectivity and biodiversity through the transport of seeds and insects by sheep (Manzano and Casas, 2010). In the Ouazazate areas, associations of transhumers aim to maintain the transhumance between the win-

ter pastures of the steppe and the grasslands of the High Atlas (Akasbi *et al.*, 2012). The management of the transhumance should be done according to the Law 113-13 relative to the regulation of the transhumance. Corridors are to be identified, delineated, mapped and equipped to facilitate mobility of herds and people. The regulation of transhumance is not new. In Spain, livestock mobility was promoted by an Act of Parliament passed in 1995 that legitimized the pastoral use of 120,000 kilometers of transhumance corridors in the country.

### **B. The creation of pastoral cooperatives**

The implementation of the pastoral cultural heritage to manage rangeland resources is another issue that is undertaken through the creation of pastoral cooperatives (Mahdi 2009). Among these projects, the Oriental Range and Livestock Development Project (PDPEO) is a large-scale operation initiated in the early 1990s by the Moroccan State, to improve the state of the rangelands, the conditions of the breedings and the populations income of Eastern Morocco. To achieve its objectives, the project has developed an innovative approach to raise the awareness of pastoralists to the problems of degradation of rangelands and to involve them in the process of planning, carrying out and monitoring pastoral improvement actions, through 34 pastoral cooperatives formed on the basis of the “ethno-lineage” principle. The main rangeland improvement techniques used by the pastoral cooperatives are rest of grazing areas for more than three years and fodder shrubs plantations. During the life of the projects, 62% of the grazing area for rest planned was achieved (Table 1).

**Table 1. Areas respected for rests for the 34 pastoral cooperatives**

Pastures put to rest (in ha)	Béni Guil	Tendrara et Maâtarka	Total
Scheduled	114 000	204 000	318 000
Realized	75 800	122 000	197 800
Completion rate (in%)	66	60	62

In addition to the rangeland restoration done by pastoral cooperatives, they were interlocutors to the administration for rangeland development. Pastoral cooperatives ensure the sustainability of pastoral improvement actions and take care of the pastoral infrastructure and equipment management.

## **IV – Common perspectives. Holistic management and related regenerative practices**

According to Hillenbrand *et al.*, (2019), agricultural production should be guided by regenerative management protocols that enhance soil and ecosystem function to improve long-term sustainability, including ecological, economic and social resilience. In this sense, land should be stewarded to enhance its potential for self-regeneration (MEA 2005) through practices that maintain or restore soil and ecosystem function and resilience that is required for sustainable use in the long term (Teague *et al.*, 2013).

Some form of grazing management is usually required to maintain pastures in a desirable composition and productive state (Kemp and Dowling, 2000). However, the appropriate intensity and management of grazing is still debated (McCosker 2000). Grazing managers and scientists have tried various forms of grazing management systems, varying from continuous through an abundance of rotational practices. However, conventional systems (e.g. continuous grazing) have been suggested as decreasing biodiversity (Alfaro-Argüello *et al.*, 2010) and, when widespread practiced at high stocking rates, inducing long-term land degradation (e.g., Teague *et al.*, 2013; Savory and Butterfield, 2016). Although other simple forms of grazing management (e.g. rotational grazing) have been recommended for over a century as an important tool to sustain grazing land productivity and im-

prove animal management, they have often been applied rigidly rather than adaptively, and with mixed results (Teague and Barnes 2017). In general, conventional systems have been designed without taking into account the full complexity of agro-ecosystems. To effectively address complex adaptive ecosystems such as Mediterranean grazing lands are, requires a planning process that embraces complexity, rather than a pre-determined management system designed for simplicity (Savory 1999; Teague *et al.*, 2013).

Particularly promising strategies to effectively address complexity of grazing lands are adaptive grazing decision-making practices called Holistic Management (HM) developed by Allan Savory (Savory 1999) and HM closely associated grazing systems, such as adaptive multi-paddock grazing management (AMPG), intensive rotational grazing (IRG), cell grazing (CG) or high-density-short duration grazing system (HDG). All these systems have in common a systemic view, a regenerative approach for grazing lands, and they focus on better managing the spatio-temporal aspects of grazing. Sound financial planning, as well as the socio-cultural aspects within which it is integrally tied, are also addressed from HM and derived strategies (Savory, 1999; Weber and Horst, 2011; Briske *et al.*, 2014; Savory and Butterfly, 2016; Teague, 2018).

Holistic Management is an adaptive and highly flexible practice. It represents a decision-making framework that emphasizes the interdependence of environmental, economic, and social well-being. Under HM, decisions are made by focusing upon the relationships among resources (including land, wild and managed biodiversity, water, soil and other resources), people, and financial outcomes (Savory, 1999). HM focus not only on livestock and grasslands, but it takes also into account the whole ecosystem function to be maintained, wildlife needs, planning for facing drought, fire threats, cultural needs, regenerative approach for grazing lands, restoration of soil health and water infiltration and retention and it encompasses far more than systematic pasture rotations (Weber and Horst, 2011). It is becoming increasingly clear that the key to sustainable use and recovery from degradation involves grazing for short periods, concentrate livestock at relatively high densities rather than continuous grazing, planning recovery and adjusting stock numbers to match forage biomass (Teague *et al.*, 2013; Jakoby *et al.*, 2015; Savory and Butterfly, 2016; Wang *et al.*, 2016; Peel and Stalmans 2018). Moreover, HM often involves cessation or reduction in chemical fertilizer use, an emphasis on native pastures instead of exotic or annual pastures, grazing rather than fire as a way of recycling soil nutrients, and monitoring pastures in order to anticipating feed availability, e.g. under periods of drought (Sherren *et al.*, 2012).

Many studies have shown positive effects of HM and related practices across numerous studies in several continents (mainly in Africa, America and Australia), climates (from arid and semi-arid to mesic and humid) and ruminant species (cattle, sheep, goats, bison). While some studies have been performed under Mediterranean climate (<https://holisticmanagement.org/>), more regional studies are needed. There is a high variability in results and success reported, that may be due to different climates, soil and vegetation types, approaches and scales used (i.e., real commercial farms complex landscapes long term studies versus controlled limited-scale short term experimental studies), the use of similar –but not identical– types of management and disciplines (Briske *et al.*, 2014, Sherren and Kent, 2017; Teague and Barnes, 2017). Sherren and Kent (2017) suggested that an integrative work that combines social science and management, environmental scholars and experimental scientists is necessary to overcome the existing polarization in the literature.

The HM approach might be better suited to the North of the Mediterranean where there is no pressure on rangelands caused by the demographic increase and where land tenure is not the main constraint for grazing lands restoration. In the southern shore of the Mediterranean, most pastures used by traditional pastoralists are collectively owned while the livestock herd is privately owned. This opposition between the collective ownership of the grazing resources and the individual ownership of the livestock put no incentive to control animal numbers and duration of grazing which results in high damage of vulnerable range vegetation. The HM approach is certainly not appropriate for collec-

tive rangelands owned by heterogeneous ethnical group where there is no control on livestock numbers and where livestock is used for different purposes rather than just production as it is the North.

We suggest that future research should address Mediterranean pastures, rangelands and related pastoral systems through a holistic approach framework, taking into account the whole agroecosystem with all its components and interactions, developing key indicators related to ecosystem functions as well as to production and socio-economic aspects of the farms management and conducting trials at appropriate spatial and temporal scales in realistic contexts in collaboration with all stakeholders.

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