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Overgrazing in the *Montado*? The need for monitoring grazing pressure at paddock scale

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Abstract *Montados* are presently facing the threat of either abandonment or intensification, and livestock overgrazing has been suspected of contributing to reduced natural regeneration and biodiversity. However, reliable data are to our knowledge, lacking. To avoid potential risks of overgrazing, an adaptive and efficient management is essential. In the present paper we review the main sources of complexity for grazing management linked with interactions among pasture, livestock and human decisions. We describe the overgrazing risk in *montados* and favour grazing pressure over stocking rate, as a key indicator for monitoring changes and support management decisions. We suggest the use of presently available imaging and communication technologies for assessing pasture dynamics and livestock spatial location. This simple and effective tools used for monitoring the grazing pressure, could provide an efficient day-to-day aid for farm managers' operational use and also for rangeland research through data collection and analysis.

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Introduction

Grazing systems are an integrated combination of animals, soils, plants and procedures, used to address animal production in ever changing environments. Being manipulated by humans, these systems generate a wide range of managerial options where the common central goal is the maximization of livestock production on a sustainable basis. Therefore regardless of the grazing system, management that is made of decision-making and production planning, is a key concern. As a result of the multiple grazing choices and the large number of factors that influence grazing, management is always a challenging task. This is particularly pertinent in complex agro-silvo-pastoral systems such as Mediterranean oak woodlands (i.e. *montados* in Portugal and *dehesas* in Spain, covering ~3.5 million ha (Pinto-Correia et al. 2011)), (Fig. 1).

Montados are human-shaped ecosystems, characterized by open canopy woodlands (evergreen

*Quercus sub*er and *Quercus ilex* spp. *rotundifolia*) with an undercover of semi-natural grasslands and traditionally exploited by multiple land uses (Pinto-Correia et al. 2011). Other than cork harvesting, the economic viability of *montados* has been achieved through low intensity and large scale grazing systems, based on indigenous livestock breeds. Traditionally *montados* have been grazed by sheep, with cattle limited to most humid areas, and pigs introduced between October and February to feed on acorns (Marañón 1988).

One may think that *montado*'*s* historical existence, with areas established centuries ago (Pinto-Correia and Fonseca 2009; Plieninger 2007a), are a self-evidence of sustainability. However, opposite trends of land abandonment and intensification are responsible for loss of oak woodland areas, respectively through shrub encroachment or conversion to open grasslands (Plieninger 2006). In addition many oak stands are currently facing regeneration failures (Plieninger et al. 2010; Ribeiro et al. 2010).

Among the several threats liable for the system degradation, overgrazing has been assumed as an important factor. In fact overgrazing relates to a mismatch between livestock use and pasture productivity. Both sides of the problem can be managed for the benefit of the whole *montado* system. However, changing livestock numbers and location is usually the most common way to manage grazing at a short temporal and spatial scale.

The term overgrazing implies some degree of environmental damage, which must be measurable and documentable, and must also be clearly distinct from grazing. Extensive grazing systems are intrinsically linked to spatial and temporal variations. For instance, temporary changes occur in the pasture botanical composition and in the body condition of free-ranging livestock without irreversible consequences. It is when changes became permanent, meaning that the degradation of the vegetation cover is beyond recovery, thereby increasing soil erosion, that we are facing overgrazing. The combined effects of vegetation loss and soil degradation lead to the reduction of soil infiltration capacity, influencing primary production and ultimately animal productivity (Homewood and Rodgers 1987). A dynamic simulation model addressing the processes of desertification due to overgrazing, illustrated in *dehesa* extensive livestock farming scenarios (Ibáñez et al. 2007), proposes some early warning ecological and economic

Fig. 1 Area of *montado* and *dehesa* in the Iberian Peninsula (adapted from Grove and Rackham 2001)

indicators, of which the quantity of pasture stands out. Grazing pressure, accommodating simultaneously the pasture quantity, livestock numbers, and the time spent grazing is another observable system degradation indicator, useful for monitoring overgrazing.

Attempts to discern grazing effects are hampered by the difficulty to distinguish those from other different management practices (e.g. soil mobilization and mechanical shrub control). Overgrazing may occur when the demand of feed resources by grazing animals exceeds the supply. This outcome could be achieved at any stocking rate. Overgrazing is more than just a function of animal numbers, it is also a function of time and mostly, it is a function of coupling pasture productivity and livestock use (Schlesinger et al. 1990). Management decisions generate an array of grazing systems. Pasture use by grazing animals bounce from unconstraint livestock movement to a fenced rotational grazing system. Also foraging options can vary between the use of natural resources and improved pastures, which may be supplemented with concentrate or hay (Milán et al. 2006). Within this multitude of grazing systems, the biomass production and the stocking of animals will be highly variable and a common indicator of overgrazing is required. Grazing pressure stands out as a key variable adequate to instantaneously measure the animal-to-forage relationship.

In the present paper we address the sources of complexity that challenge grazing management in *montados* (addressed in Fig. 2). Moreover, we suggest monitoring of grazing pressure using presently available information and communication technologies as an efficient management tool to avoid/reduce the risk of *montados* overgrazing.

Sources of complexity for grazing management

Many of the problems encountered in grazing management result from the expectation of a continuous income source trough livestock production without compromising the sustainability of the system. What is the best way of doing it? The dilemma emerges when coupling primary production with stocking rate on a continuous time scale, is attempted (Briske et al. 2008).

Depending on historical use and location, *montados* can be structurally and even functionally very diverse (Pinto-Correia et al. 2011). This diversity that generates imbalances between feed resources supply and demand, should be well understood.

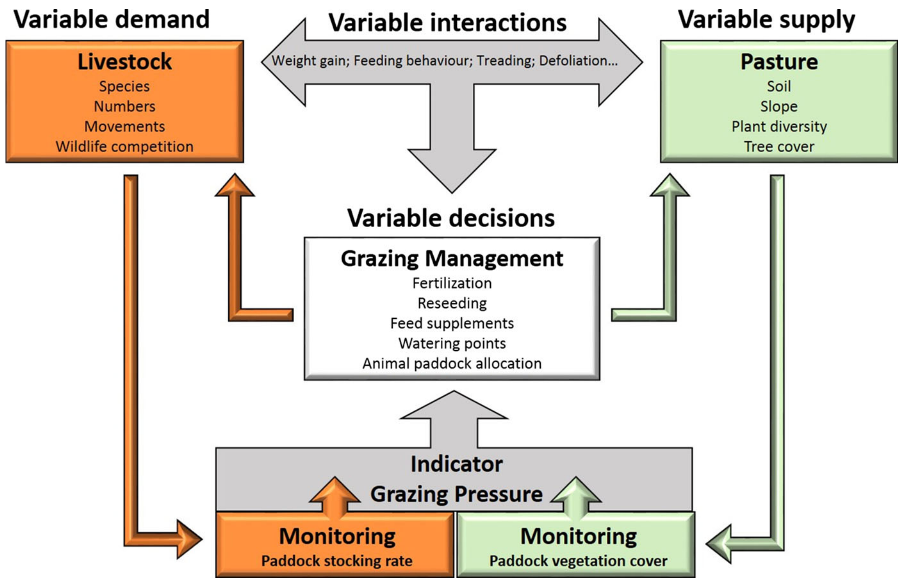
Variable supply—primary production

Pronounced patchiness of vegetation communities and marked seasonality of plant cycles are characteristic of *montado* grasslands dominated by annual species (Ferraz-de-Oliveira et al. 2013). The complexity of the herbaceous layer further increases with the combination of the shrub and the tree layers (Almeida et al. 2013), which provide additional sources of feed, with emphasis to acorns. As a consequence, the volume of feed resources supply is not homogeneous and is often difficult to predict.

The variability of precipitation and the length of the summer drought are among the most important drives for vegetation quality and availability (Joffre et al. 1999; Jongen et al. 2013). The overall pattern of pasture biomass production is characterized by a production peak in late spring, around the month of June despite the great inter-annual variation (Fig. 3), and an almost absence of biomass availability, at the end of summer (i.e. September) (Ferraz-de-Oliveira et al. 2013). Besides sharply seasonal disparity, illustrated in Fig. 3 by the two different pasture spots, there is also a high inter-annual biomass variation (Bugalho and Milne 2003). Another source of variation in biomass supply relates to topographic gradients that often promote patchiness within pastures (Marques da Silva et al. 2008). Lower-lands are more productive than upper-lands, possibly due to higher fertility and moisture conditions (Vázquez-de-Aldana et al. 2008).

Besides herbage mass availability, plant diversity and nutritive quality also vary seasonally, among years and with spatial location as occurs along a topographic slope (Carmona et al. 2012; Pérez Corona et al. 1998; Vázquez-de-Aldana et al. 2008). Protein decreases sharply during the growing season (Fig. 2) and arises as one of the most important attributes of herbage quality, because it limits animal production. In Mediterranean grasslands average crude protein (CP) concentration varies between 4 and 15 % in the dry matter (DM) (Ferraz-de-Oliveira et al. 2013; Vázquez-de-Aldana et al. 2008) nevertheless higher values may occur in particular spots (Fig. 3). Herbage quality is mainly determined by plant species and functional

Fig. 2 Schematic diagram of grazing system interrelations in *montados*: sources of complexity for grazing management and the use of grazing pressure as a decision support tool



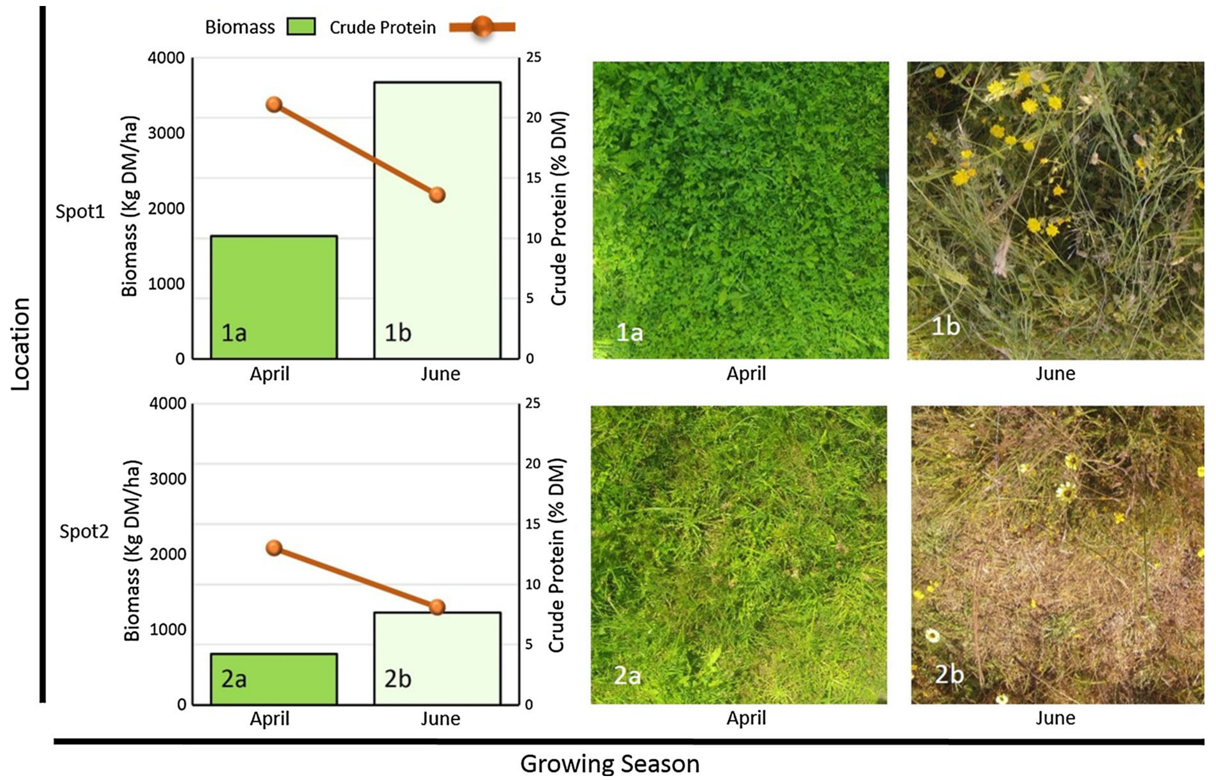


Fig. 3 Biomass (kg DM/ha) and crude protein (% DM) spatial variation (spot 1; 2), temporal variation (beginning (**a**); end (**b**) of growing season) and matching ground-cover images. Spots 1 and 2 represent *high* and *low* biomass availability respectively (Ferraz-de-Oliveira and Sales-Baptista, unpublished data)

group (e.g. legumes have more protein than grasses or forbs; Vázquez-de-Aldana et al. 2008). Furthermore, quality is also influenced by plant parts (leaves/stems) and plant maturity, with young plants having higher protein, soluble sugars and starch levels and mature plants a higher fibre and secondary plant metabolites.

An irregular feed supply restricts animal choices and hence will condition the foraging behaviour.

Variable demand—foraging behaviour

Cattle, sheep and goat herds grazing in *montados*, are mostly suckler herds which have seasonal variations in their nutrient requirements. Often, the peak of nutrient requirements (late pregnancy and lactation), is not coincident with the maximum biomass availability in the pasture. This generates a fluctuation in live weight that animals try to overcome through foraging behaviour (Potes 2011).

Grazing animals can adjust to the variable feed resources supply, trough their foraging behaviour, altering locations within pasture, patterns of movement, time spent grazing, total intake and diet composition. Interactions of livestock with the ecosystem imply the choice of grazing location through discrimination and selection among vegetation patterns (Adler et al. 2001). Decisions on feeding areas may be affected by feed abundance and also other valued assets such as watering points, location of supplementary feed distribution including mineral blocks, refuge and shade (Bailey et al. 1998). These variations of attractiveness of resources in space and time create a spatial mosaic pattern of animal distribution. The consequent uneven grazing will affect vegetation dynamics (Alados et al. 2004) and can increase or decrease pasture spatial heterogeneity (Adler et al. 2001).

Forage availability and quality (and associated characteristics, such as herbage height) are important determinants of forage intake (Wade and de Carvalho 2000). Daily intake is a function of intake rate and time spent grazing. Higher biomass productions will affect intake rate because intake per bite will be increased (Hodgson 1982). On the other hand, chemical composition (nutrient and plant secondary metabolite content) and also structural features (thick bark, waxy coverings, hardy leaves, lignified or thorny stems) determine plant palatability, which in turn stimulates a selective behavioural response defined as animal preference (Heady 1964). Animal preferences for areas that have been recently grazed can be explained by their prevalence of herbage re-growth shoots which are more palatable than ungrazed material (Viiralt and Selge 2012). When forage supply is high, animals select fewer plant species and focus their selection on those which offer the maximum amount of green forage per bite. When forage supply becomes limiting and as the amount of senescent material increases, livestock reduce search time between feeding stations and increase selection time at the feeding station (Stuth et al. 1987).

In shortage circumstances, the consumption of woody plants increases and differences in grazing behaviour, between cattle and sheep emerge. Livestock species have different feeding styles as a result of evolutionary diet specialization. Compared to sheep, cattle have lesser browsing ability because of their wider muzzle and other morpho-physiological characteristics. Cattle are mainly indiscriminate consumers of grass in the higher herbal layer while sheep are more selective grazers (Dumont et al. 2002). As a consequence, in response to changing forage availability and phenological stages, different livestock species will behave differently (Stuth et al. 1987).

The capacity of adjusting foraging behaviour to different ecological circumstances represents a potential benefit, since grazing pressure is redistributed in space and time (Illius and O'Connor 2000).

Variable interactions—animal impacts

Despite consequences on vegetation diversity and structure at a large-scale, the effects of grazing animals at small-scale (within pasture) will always result from a variety of interrelated mechanisms, such as defoliation, treading and other damages (e.g. juvenile tree breaking) and also from dung deposition (Dobarro et al. 2013). The interactions of those mechanisms with soil and vegetation will be ultimately responsible for the positive, neutral or negative impacts of livestock on pastures. Negative impacts will be potentiated with increased stocking rates.

Plants overcompensate (increase biomass production), equally compensate or undercompensate after grazed depending mainly on their species (Guitian and Bardgett 2000), phenological growth stage and physiological status. Plant tolerance to herbivory is related to mechanisms such as increasing photosynthetic rate, branching and tillering after damage. Pre-existing carbon root storage will also determine tolerance to defoliation (Strauss and Agrawal 1999). Plant response also varies with the intensity and frequency of grazing. If defoliation is intense, vegetation is prevented from maintaining high nutrient and water uptake capacity and accumulating reserves that allow overcompensation responses (Turner et al. 1993). A study of the changes in plant functional groups resulting from cattle exclosure and ploughing in a *montado* pasture, dominated by annuals (Lavorel et al. 1999), revealed that small species with leafy stems were the only group favoured by grazing whereas ploughing favoured grasses. Large rosettes, large species with leafy stems and legumes were generally intolerant to both grazing and ploughing.

Besides effects on vegetation through mouth actions, animals can also directly affect pasture through hoof action which is largely dependent on animal weight (Metera et al. 2010). Treading or trampling negative impacts on pasture production result from direct damage to plants and indirectly through destruction of soil structure, restrictions on soil water movement and consequent effects on plant root growth (for a comprehensive review see Bilotta et al. 2007). Particular sites on pasture, where animals assemble (gates, water points and feed supplement distribution sites) often present large areas of bare ground. Individual pasture species respond differently to treading. Because legumes tend to be more sensitive to treading damage than grasses, a shift on pasture composition toward grasses may occur under heavy hoof action with consequent reduction on plant diversity. Damage from treading is typically higher on heavy clay soils and is greatly increased under high soil moisture conditions (Kauffman and Krueger 1984). Treading can also create gaps in the sward, which may be suitable for plant regeneration thus having a positive effect on the establishment of annual and bi-annual species (Metera et al. 2010). Furthermore, animals tend to create paths as a result of displacement movements. Treading on those situations create trails, which are frequently used, avoiding impacts on the remaining pasture (Trimble and Mendel 1995).

In addition to the impact on the physical soil properties caused by treading, grazing animals also affect chemical properties of soil. Deposition of dung and urine influence nutrient cycling and availability. For example, nitrogen recycled through urine and dung occurs in forms that are more available to plants and soil microorganisms (Harrison and Bardgett 2008) therefore improving soil fertility. Increased nutrient concentration on dung deposition places may also indirectly affect competitive advantage between plant species as animals will not graze near those dung places (Rook et al. 2004). Furthermore, livestock also act as seed dispersers contributing to an increased species and structural diversity of vegetation (Peco et al. 2006).

Besides the non-anthropogenic sources of complexity for grazing management in *montado*, human related constraints must also be considered since they pose important limitations to the efficient management of grazing.

Variable decisions—anthropogenic factors

Grazing management variables that require a degree of decision are linked to both pasture and livestock. Main pasture interventions are related to decisions on soil mobilisation, shrub mowing, fertilization and reseeding, while livestock managing decisions regard mostly choices on species, grazing place, grazing time, grazing frequency and feed supplementation. Consequently, management options are multiple and there is no rule that can be employed everywhere (Sayre et al. 2012) and therefore approaches to management, known as adaptive management, emerge as a useful option.

Adaptive management, rely on past experience and promote an iterative process among management, monitoring and adaptation producing a structured robust decision making process in the face of uncertainty (Provenza 2003; Briske et al. 2008; Sayre et al. 2012). Adaptive management is based on a learning process via system monitoring which among other components, implies the existence of information on key variables. However, for the silvo pastoral systems of Iberia, data concerning grazing management variables such as those related both to pasture and livestock, are frequently lacking. Farm managers, that in *montados* are not always the landowners, are often reluctant to keep records of animal movements among paddocks and of pasture condition. Furthermore, grazing variables (e.g. biomass production and grazing time) implied in the management decision process are difficult to assess.

Apart from the lack of data to support judgements, farm managers tend to make grazing decisions based on past experience and "intuition" rather than based on supporting information aids. Nuthall (2012) investigated the decision making process of farm managers and concluded that the rules and systems used by one farmer are not likely to apply to another due to their uniqueness. An assessment of *montado* area distribution revealed that land management, compared to environmental and spatial factors, accounted for more than 50 % of the *montado* area loss between 1990 and 2006 (Godinho et al. 2014). Moreover management decisions in *montados* are also affected by the Common Agricultural Policy (CAP). The 2.5 times increase in *montado's* cattle population over 16 years (INE 2006) is probably a direct result of the CAP payments, and particularly the still coupled livestock payments and the high prices paid for cattle (Pinto-Correia and Godinho 2013).

In face of the multitude of sources of complexity for grazing management in the *montado*, a common indicator of practical use for monitoring changes and support management decisions would be an advantage.

Using grazing pressure to assess overgrazing

Livestock have been frequently charged as liable for loss of biodiversity (Bakker et al. 2006), and other associated ecological costs such as disruption of ecosystem functions (Fleischner 1994). Likewise, grazing animals have been singled out as an important source of disturbance of *montados,* and ultimately responsible for one of the major problems farm managers are facing today: the increased mortality of stands and the lack of natural regeneration (Pinto-Correia and Fonseca 2009; Moreno and Pulido 2009). Natural regeneration depends on acorns and animals can directly change the seedling bank, through selective intake of acorns and seedlings. Additionally, direct damage on saplings (treading) and on juvenile trees (breaking) mainly produced by cattle, also reduces natural regeneration (Plieninger 2007b). However, effective data assessing the magnitude of the impacts of livestock on natural regeneration are scarce (Plieninger 2007b) and/or use a landscape level approach (Carmona et al. 2013). Furthermore, judgements regarding the role of grazing animals on the *montado* are biased by the observer point of view. A forester or conservationist may regard domestic animals as an intrusive element that destabilize the "natural" systems, while an animal and rangeland scientist or a landowner tend to perceive livestock farming as essential to the system. For example, in a study carried out by Acácio et al. (2010), farm managers have identified traditional farming abandonment as the second cause for stands mortality, after oak diseases.

Nevertheless, concerns with overgrazing in *montado*, amplified by the last decade's rapid increase in cattle population, are legitimate and mandatory questions are: How can we identify overgrazing? In a highly variable system such as *montado*, how can intrinsic variability be disentangled from potentially long-term degradation? And most of all, how can we prevent overgrazing? To answer all those questions we must, first of all, understand overgrazing and afterwards assess grazing pressure.

Overgrazing occurs when plants are exposed to intensive grazing for extended periods of time without sufficient recovery periods. Those situations are linked with excessively high grazing pressure, which in *montado* are more frequent in the end of summer and in dry autumns (Fig. 4). Grazing pressure is defined as the number of grazing animals per unit of available forage. To allow for comparisons, grazing animals are standardized as livestock units (LU) (Allen et al. 2011). Grazing pressure equals the ratio between stocking rate (the number of LU per unit area per unit time) and biomass (the total dry weight of vegetation per unit area per unit time) (Allen et al. 2011). Both variables (stocking rates and total biomass) can be altered by management practices however, stocking rate has emerged as the most consistent management variable influencing both plant and animal responses to grazing (Holechek et al. 1999). Estimated stocking rates in the *dehesa* system in the 1950s were around 0.10–0.15 LU/ha and remained stable up until about 1982 (c. 0.15 LU/ha) after which they increased to about 0.24–0.4 LU/ha (Plieninger and Wilbrand 2001; Plieninger et al. 2004; Plieninger 2006; Milán et al. 2006). Even with such figures, frequently considered as low stocking rates, grazing pressure could be high.

Grazing strategies are designed to achieve particular goals under uncertain conditions. In the *montado* the more usual grazing strategy is known as "conservative stocking rates", where the number of animals in a given farm will be kept constant along the year (Potes 2011). While stocking rates are constant (Fig. 4), grazing pressure fluctuates (high from the

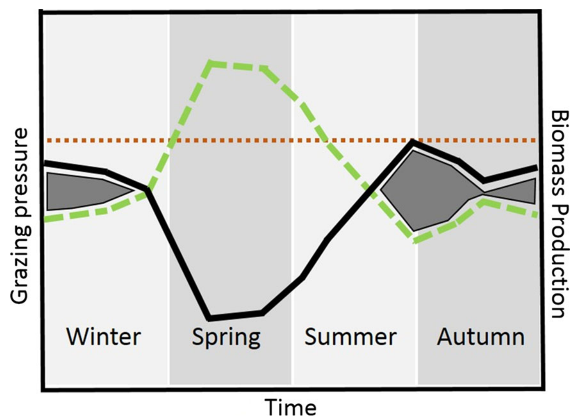


Fig. 4 Schematic diagram (trends and not absolute values) of biomass production (*dashed line*), stocking rate (*dotted line*) and grazing pressure (*solid line*). *Grey areas* represent periods of increased risk of overgrazing (adapted from Campbell et al. 2006)

end of summer until the end of winter and low in spring). When the stocking rate is higher than the pasture biomass production, an imbalance occurs with a negative impact, both on vegetation, compromising pasture persistence and on the animal, compromising productivity (Campbell et al. 2006).

The most frequent management option in the *montado* is continuous grazing using a stocking rate intended to exploit the spring peak of biomass production, which leads to a gap between forage demand and pasture supply in the autumn and winter, overcomed with the offer of supplementary feed (Milán et al. 2006). To minimize liveweight loss the supplementation with straw, hay, green fodder and concentrates is a common practice (Milán et al. 2006), from the end of summer until the next spring. Major risk of overgrazing can arise within this period (Fig. 4), when animals, although supplemented to maintain productivity, remain in the pasture. In severe drought years, an even greater risk of overgrazing occurs.

Therefore, to identify trends of overgrazing and to be able to take decisions accordingly, the knowledge of the grazing pressure at paddock scale, rather than the limited information provided by farm level gross stocking rates, is fundamental. The former is a dynamic measure, while the latter is static and independent from pasture biomass production. Furthermore stocking rates are often biased, both by overestimation of grazing areas and/or underestimation of LU. In the first case, considered grazing areas are generally confounded with the whole farm area and in the second case the presence of offsprings, mostly calves and foals, who remain with their mothers for 8 months until they are weaned, is often ignored. The knowledge of grazing pressure can only be achieved with a close monitoring at the paddock scale (both biomass availability and animal presence), producing key indicators to clarify the animal/plant relationships, to assess changes and to help in identification of problems. These indicators could act as warning signals allowing early assessment of vulnerabilities.

Monitoring grazing pressure using wireless sensor networks

The best strategy to avoid overgrazing is prevention. In order to be maintained as a grazing land, a pasture must have the opportunity to recover after being grazed. Increased alarming signs of degradation should not be overlooked until it is too late, when consequences of overgrazing may become irreversible. Consequently, early warning systems are needed. Early warning systems provide a useful framework to promote comprehensive and integrated data collection and analysis of risk indicators. More than just acting as a forecast, the provision of timely and effective information triggers adaptive responses for the maintenance of the system resilience.

Grazing pressure is a prospective candidate to integrate an effective overgrazing early warning system. Continuous and close monitoring of grazing pressure, coupled with the detection of impact indicators, acting as alarming signs, should be carried out. Examples of alarming signs at the pasture scale, within increased degradation risk areas such as watering points (Carmona et al. 2013) are: changes of plant functional types (Lavorel et al. 1999), changes of time spent grazing (Bailey et al. 1996), increases in bare ground cover and increases in animal trail densities (Walker and Heitschmidt 1986).

Although obtaining information to derive grazing pressure (assessing biomass availability and animal presence within a paddock) is apparently a straight forward task, farm managers seldom do so. Versatility and simplicity at the operational level is required to encourage monitoring. Only monitoring systems capable of addressing different scales and times, using inexpensive automated and robust equipment have the chance to be of practical use. Currently available technology, such as mobile phones and wireless sensor networks (WSN), appear to meet the requirements, offering a wide set of novel alternatives for long-term observation of complex phenomenon.

Mobile phones have become ubiquitous within our every-day life. Smartphones are sophisticated computing platforms with complex build-in sensor abilities, including cameras, global positioning system (GPS), different wireless networking standards and sufficient memory to run a variety of different applications. Smartphones allow farmers to be permanently connected with the farm information system and altogether bring interesting opportunities for interaction between the farmer and the monitoring systems.

One of the practical uses of smartphones within the pasture monitoring is the capability to capture, archive and share time stamped geo-located high resolution images. Ground image-based vegetation monitoring methods used to collect images at different places across different times allows monitoring vegetation through the detection of changes on a scale prone to protect resources (Cagney et al. 2011; Teacher et al. 2013). Photographic records could be used to assess ground cover, representing the amount of plant material (dead or alive) that covers the soil surface, expressed as a percentage. Ground cover, although not representing biomass availability, could be used as an alternative alarm indicator for overgrazing (Kauffman and Krueger 1984). To our knowledge, ground image information has not been used for monitoring *montados,* though, a preliminary study (Rato et al. 2013) where an image processing technique was tested has shown a 95 % correlation between manual and image processing evaluation of vegetation ground cover. A further important feature of image-based monitoring is that it could provide indication of short and long-term transitions between states and patterns of vegetation (Booth and Cox 2008). These data could be used by farm managers as *aide-memoire*, providing visual comparison, which are the base of the "intuitive" decisions. The same pasture images could also deliver scientific data combined with other soil and animal proximal sensors within a WSN (Gobbett et al. 2013, Zerger et al. 2010). It is now possible to create a large-scale sensor network by deploying applications on end-user devices to collect and report data back to servers, using commercially available mobile communication services.

WSN are an assembly of mobile nodes and can be organized according to several topologies: star topology; mesh topology and tree topology (Baronti et al. 2007). WSN are designed to collect large-scale real-time data and provide such information to the end user. In a WSN a smartphone could act as a sensor node when used for image capture, as a gateway to relay information from sensor nodes, or just as an interface device to end users (Fig. 5). A sensor node is able to obtain large amounts of data on physical parameters (e.g. temperature and moisture), and on current characteristics of objects (e.g. speed and direction). Sensor nodes can be static (fixed in a pole) or mobile (attached to animals) and can be configured to wake up for a defined period of time and communicate across the network. Providing each animal with a sensor node enables the collection of relevant grazing parameters at regular intervals (Nadimi et al. 2012). Information on the total number of animals roaming in a particular area provides a measure of instantaneous stocking rate that could assist the farmer in the decision making process for an adaptive grazing management (e.g. merging paddocks, moving animals, supplement offer or even altering watering points).

As with vegetation image-based data, records of animal movements, would have a dual purpose for functional and research use. On one hand they could help farm managers to keep track of stocking densities across the different paddocks and, on the other hand, the collected data could be submitted to a central database, accessed through a website that could provide the tools for data analysis from many farm managers and different locations, enabling a different scale of analysis.

In a pasture monitoring context a WSN can be used to monitor grazing pressure by simultaneously providing information on the state of the pasture and on animal stocking rates, collecting and integrating data and obtaining indicators to trigger alerts.

Concluding remarks

Mediterranean oak woodlands are facing threats of degradation both through intensification and

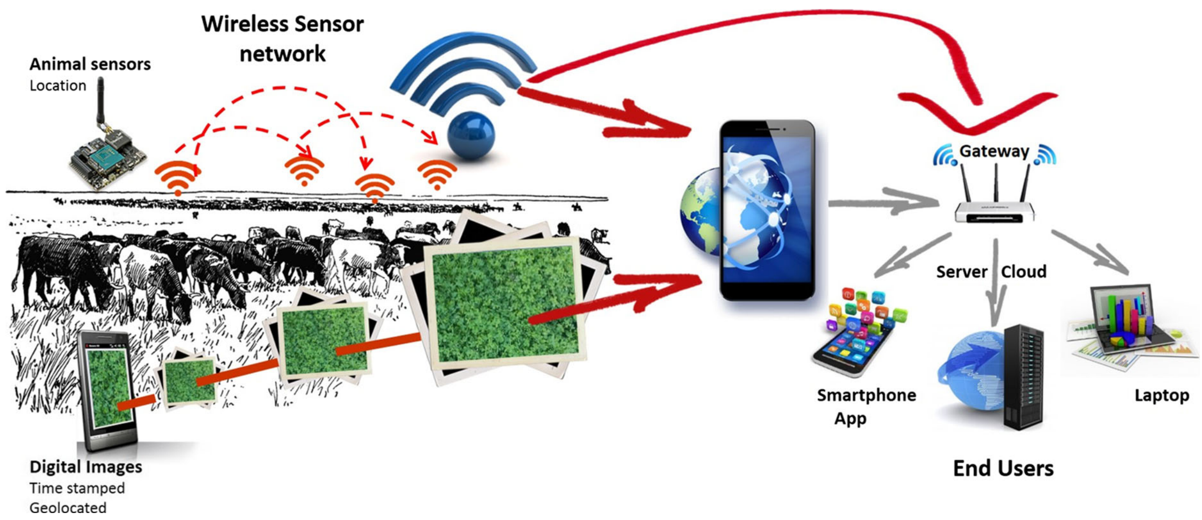


Fig. 5 Schematic diagram for grazing monitoring data acquisition, communication, storage and use

abandonment. Recognition of the variability of the grazing system and the complexity of the interactions established between animals and vegetation stresses the inexistence of a unique management protocol and impels the need of adaptive management. Recognition that changes in *montado* occur across larger time scales than those frequently addressed by research, stresses the need for monitoring. Livestock is both part of the problem (overgrazing risk), and part of the solution (adapting foraging behaviour and promoting vegetation heterogeneity). We suggest that monitoring of grazing pressure at paddock scale would provide an operational tool for managing grazing, useful for both farm managers and research assessment. Management decisions should be continually revisited as the system context changes. The importance of simple and easy-to-use tools, such as smartphones and WSN, would provide an opportunity for monitoring grazing pressure, which is essential for adaptive management in an ever changing *montado*.

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