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Resilience of the pastoral component of Moroccan small ruminant systems in mountain areas

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Abstract. Small ruminant farming is the main rural occupation in mountain areas of Morocco. This activity is subject to numerous pressures, including repeated climatic hazards that modify pastoral resource availability and trigger changes in production systems. This study aimed to identify and analyse changes in availability and utilisation of pastoral resources acknowledged by farmers over the past 40 years for the small ruminant farming systems of the Central High Atlas region of Morocco. We hypothesised, on the basis of previous research, that resilience of the pastoral component of such systems increases with elevation. We interviewed 50 farmers in three municipalities of *Azilal* province, at moderate (800–1400 m), medium (1400–1800 m) and high (1800–3000 m) elevations. In the 1970–1980s, pastoral resources were abundant and mobile flocks grazed collective rangelands. Subsequently, repeated droughts and the increased stock numbers promoted by agricultural policies led to the deterioration of resource abundance and quality, especially palatable plants. At moderate elevations, wooded areas and phytomass declined; erosion occurred at high elevations. Traditional systems diversified by including agricultural activities. At moderate elevations, livestock farming intensified, with the adoption of a productive breed, concentrate distribution and the grazing of fallow land. Currently, flock mobility is limited and rangelands provide less than 60% of sheep requirements. At high elevations, the pastoral component persisted at the cost of a diversification of pastoral areas and greater flock mobility. Rangelands are still collectively managed and provide almost 90% of sheep requirements. Since rangelands remain a major feed source, changes in pastoral resources can be considered as a major driver of change in livestock systems. The sustainability of small ruminant farming systems at these elevations thus depends on the conservation of rangeland.

Keywords: rangelands, feeding practices, elevation, climate change, sheep.

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Introduction

Small ruminant farming characterises Moroccan pastoral areas, which cover ~53 million hectares. It significantly contributes to the national meat supply and to the food and financial stability of farmers' households, especially in mountainous and marginalised areas (FAO 2011). Until the 1970–1980s, small ruminant systems were pastoral; mobile flocks were grazed on large areas of collective rangelands under the supervision of a shepherd (Bourbouze 2000, 2006). In the past 40–50 years, such small ruminant farming systems have been confronted with various climatic, socioeconomic and political factors that potentially affect their sustainability. The rangelands are subject to high grazing pressure, with high stocking rates intended to meet the growing national demand for meat. Exceeding rangeland carrying capacity is exacerbated by significant supplementation, mainly concentrate, which supplements the intake of fibrous feeds at pasture. The combined effect of successive droughts and overgrazing, accentuated by the settlement of pastoralists and the expansion of cultivated areas at the expense of pastureland, has caused rangeland degradation (Bechchari *et al.* 2014).

It is estimated that 4 million hectares of Moroccan rangelands are slightly degraded, 8.3 million hectares are highly degraded, and the remainder is moderately degraded (MAPDREF 2017). Rangelands that produced an average of between 50 and 90 fodder units (FU)/ha.year exhibit a productivity decline of 25–45% (Fikri *et al.* 2004). As a consequence, livestock are underfed, especially during dry years, with production being well below the animals' productive potential (Bechchari 2020). This has led to a decline of the pastoral component of small ruminant farming systems, with a shift from the traditional extensive systems to more or less intensive agro-pastoral systems. The disappearance of traditional extensive systems would result in an increase in the rate of poverty and food insecurity, especially in rural areas, because livestock are a source of

savings and income for the local population whose livelihood is highly dependent on natural resources (FAO 2009). The intensity of such changes has recently increased, raising an urgent need for adequate development strategies to address social and environmental issues.

The notion of resilience is gaining importance as a concept for understanding and managing complex production systems, especially those linking natural resources (e.g. animal and pastoral resources) and society (e.g. farmers' practices; Walker *et al.* 2002; Walker and Salt 2006, 2012; Allen *et al.* 2011). In extensive farming systems, resilience is a framework for studying the adaptation strategies to the environment used by individuals or populations (farmers) throughout their lives. The challenge for these systems is mainly to use pastoral management to ensure their resilience to disturbances so as to maintain their long-term functions, i.e. their capacity to provide fodder and water to herds as well as their multipurpose character (Nettier *et al.* 2017).

Recent studies have analysed the impact of climatic and socioeconomic changes on extensive livestock farming systems. They have shown that the characteristics and management of livestock farming systems vary according to ecosystem type, farmers' livelihood strategies, the resources mobilised, and the environmental changes experienced (French Alps: Nettier *et al.* 2017, 2010; Senegal: Amy 2013; north-eastern part of the Middle Atlas of Morocco: Boughalmi *et al.* 2015; the Algerian steppes: Kanoun 2016). Several studies (Jemaa *et al.* 2016; Chedid *et al.* 2018; Alary *et al.* 2019) have reported the adaptation strategies of pastoral systems to drought and to the reduced availability of pastoral resources; such adaptation strategies varied depending on exposure and elevation. Other studies (Gibon *et al.* 2004; Gavinet 2007; Nettier 2016) have suggested greater persistence of pastoral farming systems in mountain areas owing to the specific bioclimate and the diversity of available pastoral resources. Depending on the socioeconomic context, pastoral systems would either benefit from opportunities of remunerative niche markets (French Alps: Nettier *et al.* 2017) or be marginalised (Eastern Middle Atlas: Nassif *et al.* 2011; Boughalmi *et al.* 2015; Central High Atlas: Ibnelbachyr and Mounsif 2011). Unfortunately, marginalisation is common in Moroccan pastoral systems. Given their social and (still) economic importance in the country and the major ecological issues related to rangeland degradation, a better understanding of the adaptation processes of pastoral farming is needed to identify the factors of resilience and to propose means to support changes in these systems and, ultimately, ensure their sustainability.

The objective of this study was to characterise the resilience of the pastoral component of small ruminant farming systems.

Materials and methods

Study area

The study was conducted in 2019 in the province of Azilal in the Central High Atlas of Morocco (Fig. 1). This province has 554 001 inhabitants, 82% of whom live in rural areas, and covers about one million hectares, being almost entirely mountainous (Haut Commissariat au Plan 2015). It is characterised by a Mediterranean climate with a continental tendency, semiarid in the north and subhumid in the south. The mean annual rainfall is 400 mm, with snow accounting for 20–30% of the precipitation. The minimum average temperature is 4–10°C, the maximum 20–40°C, depending mainly on the elevation (Direction Provinciale de l'Agriculture d'Azilal 2019).

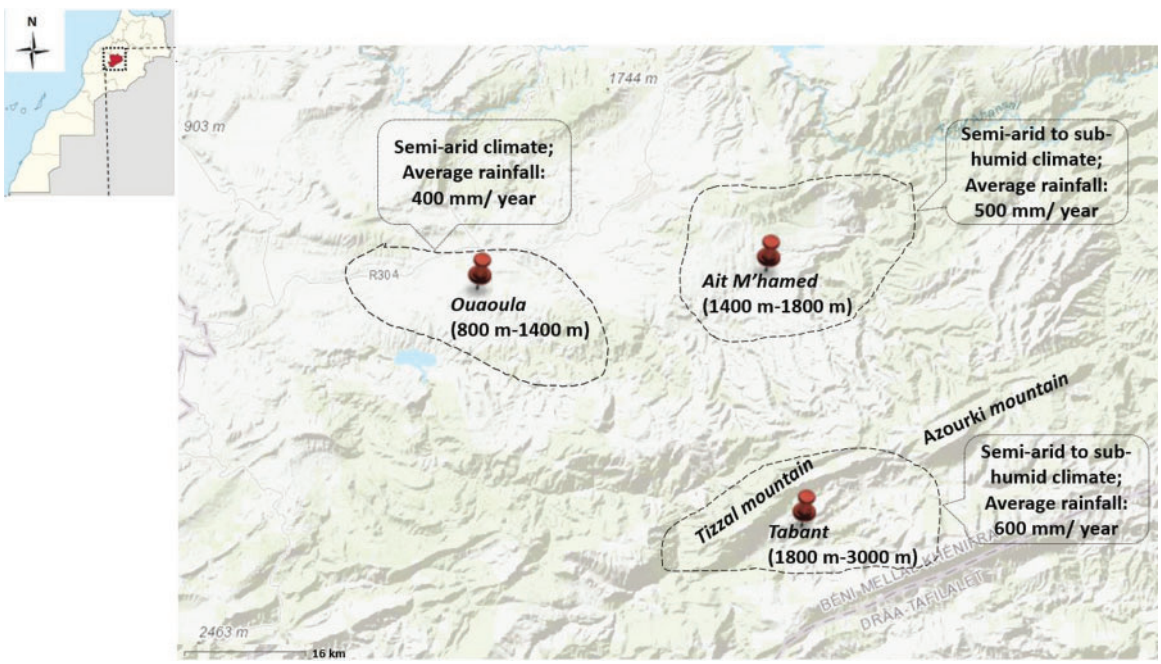

Fig. 1. Localisation and climatic characteristics of the study area (Direction Provinciale de l'Agriculture d'Azilal 2019; Stackhouse 2021).

Table 1. Characteristics of the four livestock farming systems identified on the basis of a statistical classification, on the basis of 90 comprehensive interviews in the study area (source: El Aayadi *et al.* 2020)
Means within a row different letters differ significantly ($P < 0.05$)

Characteristic	Farming system			
	Small sedentary farmers with medium-size properties (S1)	Semi-sedentary farmers with large properties (S2)	Small farmers with low mobility and small properties (S3)	Large farmers with high mobility and medium-size properties (S4)
Municipality	Ouaoula	Ouaoula	Ait M'hamed and Tabant	Ait M'hamed and Tabant
Number of farmers	9	21	33 (18 and 15)	27 (12 and 15)
Total area (ha)	10.5 ± 3.1a	23.9 ± 6.4b	3.7 ± 1.1c	11.6 ± 5.0d
Cultivated area (ha)	6.0 ± 2.8a	13.3 ± 6.2b	2.7 ± 1.1c	6.2 ± 1.2a
Number of sheep (heads)	31 ± 7a	64 ± 17b	49 ± 22c	135 ± 38d
Number of goats (heads)	3 ± 1a	31 ± 15b	16 ± 6c	65 ± 25d
Sheep breed	Sardi	Sardi	Timahdite	Timahdite and Tirahaline
All-year-round supplementation (% farmers)	100	100	64	18
Type of mobility (% farmers)				
Sedentary	100	0	38	0
Semi-sedentary	0	100	62	0
Transhumant	0	0	0	100

Extensive small ruminant farming is the main agricultural activity, with ~584 000 sheep (mostly Timahdite and Sardi crossbreeds) and 412 000 goats (mostly Noire de l'Atlas and Barcha breeds) (MAPDREF 2017), representing 63% of the small ruminant population in the Béni Mellal-Khénifra region. Livestock farming benefits from the large surface areas of rangelands and forests (52% of the total area of the province; Haut Commissariat au Plan 2015). The study concerned three municipalities along an altitudinal and climatic gradient (Fig. 1): Ouaoula, Ait M'hamed and Tabant. These municipalities differ in elevation, terrain and bioclimate. The latter two points influence accessibility as well as available pastoral resource diversity and access to extension services (El Aayadi *et al.* 2020).

The Azilal mountains are characterised by a wide range of shrubby or woody vegetation, adapted to the semiarid to subhumid climatic conditions (Bourbouze 1999; Mhamdi 2010), including:

- Shrubland and woodland at low elevations (<1400 m; temperate winters) characterised by *Quercus rotundifolia* Lamarck, associated with *Quercus canariensis* Willdenow or *Callitris articulata* Murbeck, *Juniperus phoenicea* Pallas, *Thymus satureioides* Menitsky, *Ormenis scariosa* Litardière & Maire, *Adenocarpus anagyrifolius* Cosson & Balansa, *Retama dasycarpa* Cosson, *Alyssum spinosum* Linnaeus, *Bupleurum spinosum* Gouan, *Dactylis glomerata* Linnaeus and *Stipa nitens* Ball.
- Shrubland and woodland at medium elevations (1400–1800 m; semiarid to subhumid conditions with temperate to cold winters), composed typically of *Quercus rotundifolia*, *Juniperus phoenicea* Linnaeus, *Thymus pallidus* Cosson, *Globularia alypum* Linnaeus, *Dactylis glomerata* Linnaeus, and locally *Callitris articulata* Murbeck.
- Shrubland and woodland at high elevations (>1800 m; subhumid zone, cold winters), dominated by *Juniperus oxycedrus* Linnaeus and *Juniperus thurifera* Linnaeus, sometimes in association with *Quercus rotundifolia.*
- Elevated grasslands (>1800 m) with *Festuca ovina maroccana* Saint-Yves, *Festuca weilleri* Litardière, *Festuca rubra* Linnaeus, *Koeleria vallesiana* Ascherson & Graebner, *Bromus tectorum* Linnaeus, *Euphorbia nicaeensis* Allioni, *Catananche caespitosa* Desfontaines, *Scorzonera pygmaea* Smith, *Nardus stricta* Linnaeus, and sometimes *Trifolium repens* Walter.
- Elevated steppes (>1800 m) with different species associations: (i) *Artemisia herba-alba* Asso with *Bupleurum spinosum* Gouan, *Ormenis scariosa* Litardière & Maire, *Astragalus armatus* Willdenow, *Thymus pallidus*; (ii) *Erinacea anthyllis* Linnaeus with *Cytisus pungens* Sprengel; (iii) *Alyssum spinosum* Linnaeus (dominant); and (iv) *Genista quadriflora* Munby (dominant).

Livestock farming systems in the study area

El Aayadi *et al.* (2020) identified four livestock farming systems in the same area by comparing 90 farms on the basis of their location (Table 1). Two systems at lower elevations (Ouaoula) heavily relied on complementarity with agriculture and raised Sardi sheep, with year-round supplementation; these systems differed in the spatial area used (excluding rangeland) and in flock size. Two other systems characterised the upper elevations (Ait M'hamed and Tabant). One was subsistence-oriented and included farms that utilised small agricultural areas with a small, slightly mobile flock of Timahdite sheep. The other, based on a maximum valorisation of sylvo-pastoral resources and minimum feed supplementation, included large properties and large mobile flocks of Timahdite and Tirahaline sheep. This typology is consistent with the constraints and opportunities that characterise each elevation level (El Aayadi *et al.* 2020) and is therefore important when analysing the resilience of the pastoral component of livestock systems.

Farmer interviews

On the basis of in-depth interviews with local farmers, we assessed the past and current importance and condition of local

rangelands, and identified the changes in the feeding practices and the main drivers of the changes affecting the pastoral component of the production systems.

Individual interviews were conducted with a sample of 50 'old' farmers (≥54 years old, which meant >30 years experience as a farmer or shepherd) from Azilal province. Interviewees were chosen from among those willing to communicate, with a geographically accessible farm (located less than 2 h walk from the road), and were sampled according to their distribution in the livestock farming systems identified by El Aayadi *et al.* (2020; Table 1). The sample was chosen to cover most of the existing farming system diversity, but does not claim to be representative of the entire population. It was selected so as to cover a maximum of villages (douars) in each municipality, because practices are generally homogeneous within a village.

Fifteen farmers in Ouaoula and Ait M'hamed and 20 in Tabant were interviewed. Each farmer was visited several times at key periods (lean seasons, selection of sires, fattening period for Eid festival, farrowing period) between April and October 2019. Data were gathered via a semi-directive interview that allowed collection of useful and unpredictable information. In addition, the interviewee was able to explain freely and in his own way his systems of practice (Kauffman 1996). The interviews focussed on topics previously prepared and identified in a survey sheet: (i) types of rangelands used and their pastoral resources; (ii) modalities of rangelands use for feeding flocks; (iii) farmers' perceptions of change in the status of rangeland resources and in their use during their years of involvement in animal husbandry; and (iv) strategies used by farmers to adapt to these changes. Interviews were conducted in the farmers' language, usually Berber; interviews lasted 2–3 h per farmer and per visit, for a total of 5–7 h per farmer.

Data processing and analysis

Data collected concerned two main dimensions: (1) the current status of pastoral resources and feeding practices of flocks; and (2) changes in pastoral resources and their uses. For the first dimension, types of rangeland grazed and period of use, conservation status, dominant plant species, drinking water availability, animal residence time, distances travelled by the flocks, periods of supplementation and animal categories supplemented were identified. On the basis of these data, we estimated (1) the contribution of rangeland to animal feed requirements, on the basis of the number of days of rangeland use and the knowledge that all categories of animals use the pastures together, and (2) the importance of other feed resources, on the basis of the number of animals supplemented and the amount and timing of supplementation. Farmers described the major changes observed in grazing conditions and feeding practices over the past 40 years, considering the current conditions of the rangelands used. When farmers reflected on all the changes mentioned, they were also able to suggest their causes.

A thematic analysis was performed on the data to produce qualitative variables. The changes in pastoral resources and feeding practices declared by the farmers were defined as variables, and we calculated the number of farmers who cited the change for each livestock farming system. The results obtained were expressed in percentage of farmers and were subjected to a chi-square test to determine significant ($P < 0.05$) differences among the livestock farming systems. The statistical analyses were performed with R software (RStudio Team 2019, https://www.rstudio.com/).

Results

Past and present characteristics of the farms visited in the study area

Prior to the 1970s and 1980s, farming methods were uniform throughout the province of Azilal (according to older farmers). They were based on the complementarity between the different pastoral and sylvo-pastoral areas, because of seasonal mobility, depending on the elevation. In addition, all farmers practiced the Agdal,[1] which enabled both the regeneration of pastoral plants and the constitution of reserves of standing biomass and, consequently, the extension of the grazing period. Since the 1980s, Azilal's extensive livestock farming systems have been subject to many pressures, mainly climatic. In the years of 1970–1980, pastoral resources were abundant. However, after repeated droughts between 1980 and 1995 and the increased stocking rate promoted by agricultural policies, the abundance and quality of these resources had deteriorated by 2019.

The farmers interviewed were a subset of the 90 farmers used to characterise local livestock farming systems. The 50 interviewees were representative of the four systems (S1–S4) listed in Table 1, although the distribution of farms among the systems was uneven. Six farmers (*Ouaoula*) were associated with S1. They maintain a small flock (on average, 29 sheep and two goats). The average total utilised area in this group is 10.3 ha, of which 5.7 ha are rain-fed and the rest (rented land or in association) is devoted to grazing. Nine farmers (*Ouaoula*) were associated with S2. They maintain an average of 73 sheep and 38 goats, managed separately. This group has a large total utilised area (on average, 24.0 ha, of which 13.7 ha are cultivated in rain-fed systems) compared with the other systems. All of the farmers practice an optional transhumance when fodder resources from nearby available lands become scarce. S3 was represented by 22 farms (10 in Ait M'hamed and 12 in Tabant) with very small areas (an average of 3.6 ha), mostly cultivated and irrigated, and small flocks (45 Timahdite sheep and 13 goats, often managed together) with low mobility. In total, 55% of the farmers in this group practice optional transhumance when local forage resources are scarce. S4 was represented by 13 farmers (five in *Ait* M'hamed and eight in Tabant) who utilise large total agricultural areas (an average of 11.4 ha, of which 5.8 ha are cultivated and mainly irrigated) and maintain large flocks (135 Timahdite and Tirahaline sheep and 65 goats, often managed together) that are very mobile and poorly supplemented. This system is based on the maximal valorisation of sylvo-pastoral resources through annual transhumance. These four livestock farming systems result from changes that occurred in the

[1]Agdal: traditional community-based system of control of sylvo-pastoral resources in Berber societies of the High Atlas, by which certain areas of pasture are temporarily excluded and protected from grazing and trampling in order to constitute a supply of standing biomass for the next seasons.

climatic, agricultural and socioeconomic contexts of the study area in the past 40 years.

Farmers' perceptions regarding changes in the availability of pastoral resources in the past 40 years

All the farmers interviewed had observed changes over the past 40 years in pasture conditions (Table 2), namely (i) decreased phytomass, (ii) senescent plants of several species, (iii) accentuated degradation of vegetation around settlements, with decreased perennial species recovery, (iv) decreased annual herbaceous layer owing to droughts and the absence of Agdal, which allows the dissemination and reproduction of pastoral species, (v) decreased forest areas owing to the absence of Agdal and excessive pruning for forage and firewood harvesting, (vi) gradual disappearance of certain palatable species (such as e.g. *Astragalus armatus*, *Thymus satureioides*, *Santolina rosmarinifolia* Linnaeus and *Poa* sp. Koeler) and expansion of unpalatable species (e.g. *Thymelaea virgata* Endlicher and *Euphorbia nicaeensis*) and (vii) increased bare soil and exposed stones owing to erosion.

Degradation was perceived differently depending on elevation. The reduction of phytomass and the decline of perennial species and wooded areas characterised the lower level (S1 and S2) and the areas utilised by S3 farmers. Erosion was observed mainly at high elevations (S4). Undesirable species abundance was observed at all elevations.

Assessment of the quality of pastoral areas by transhumant farmers is also based on the availability of water for livestock and climate. These farmers sometimes look for places called 'Ameskou', places where even if pastoral resources are scarce, animals grow fat and feel good.

Water availability: the main driver of changes?

Several changes linked to climatic hazards were cited by older farmers as crucial in determining the evolution of breeding practices and the availability of pastoral resources (Table 3). The scarcity and low predictability of precipitation, with increased drought frequencies, negatively affected the growth and quality of the available vegetation at low elevations. At high elevations, the increased frequency of thunderstorms and rainfall intensity (from August to October) increased erosion and the availability of land for agriculture and livestock. Most (54%) of the farmers at these elevations had abandoned part of their agricultural lands because of floods (50% and 62% in S3 and S4 respectively). These farmers also observed a shortening of the duration of the snowfall season ('*in the past*, *the snow covered the summits of the mountains up to the months of June–July*, *whereas it currently does not go past April–May*'), and a decrease in the amount of snowfall, affecting water availability in spring and, consequently, vegetation growth during the year.

All the changes observed affected the number, the level, the flow of rivers and the water sources available in the province and, consequently, practices associated with irrigation ('*Before*, *irrigation was unrestricted and today it has to be done on a take-turn basis*') and the watering of animals. In summer more than in winter, farmers find it hard to provide water for their animals, and are sometimes forced to buy water (S1 and S2 farmers) or travel long distances (8–10 km per day) to obtain water from rivers and springs (S3 and S4 farmers).

Resilience of the system pastoral component to the changes in climatic conditions and in the availability of pastoral resources

According to the older farmers interviewed, in the years of 1970–1980, the whole region was home to a pastoral system based on extensive use of vast collective pastures because of seasonal movements. Such movements structured the whole farming system and allowed the utilisation of complementary rangelands, according to a double transhumance where flocks

Table 2. Changes in the pastoral resources cited by the farmers interviewed, expressed in % of respondents in each system

Significant differences between livestock farming systems were obtained by applying the chi-square test (paired). On a given row, the percentages with a different letter differ significantly ($P < 0.05$)

Change cited by farmers	S1	S2	S3	S4
Decrease in total phytomass	100a	100a	60b	69b
Decrease in perennial species	100a	89a	72b	30c
Decrease in forest areas	100a	100a	77b	23c
Decrease in palatable species	83a	78a	72a	77a
Increase in bare soils and stones	17a	22a	68b	85b

Table 3. Farmer perception of climate change, expressed in % of respondents in each system

Significant differences between livestock farming systems were obtained by applying the chi-square test (paired). For each row, the percentages with a different letter differ significantly ($P < 0.05$)

Change cited by farmers	S1	S2	S3	S4
Reduction in snow cover (in quantity, duration)	17a	22a	100b	100b
Increased frequency of thunderstorms and intensity of rain	67a	67a	91b	100b
Decrease in the amount of rain	100a	100a	77b	85b
Increased flooding	17a	22a	77b	85b
Decrease in the level and flow of rivers and water sources	100a	89a	72b	77b
Higher frequency of droughts	100a	100a	45b	46b

Table 4. Changes in sheep feeding practices cited by the farmers interviewed, expressed in % of the number of farmers interviewed
Significant differences between livestock farming systems were obtained by applying the chi-square test (paired). The percentages within a row with a different letter differ significantly ($P < 0.05$)

Form of adaptation	S1	S2	S3	S4
Diversification of pastoral areas grazed	17a	22a	45b	85c
Exceptional or optional transhumance departure	0a	100b	55c	0a
Increased amplitude of flock movements	0a	33b	32b	85c
Rental of fallow land for animal grazing	50a	89b	4c	0c
Systematic supplementation of animals	100a	100a	68b	8c
Diversification of production (agriculture–livestock association)	100a	100a	100a	100a

moved higher up in the mountain in summer, and towards the piedmont or the plain in winter. Rangelands covered over 90% of the flocks' feed requirements.

Since the 1980s, Azilal's extensive farming system has undergone continuous changes, with a decline in flock mobility and a tendency towards sedentarisation and dependency on purchased concentrated feed (Table 4). The contribution of rangelands to the feeding system is lower in farms at lower elevations than in those at higher elevations. Indeed, the farmers of S1 and S2 are sedentary and semi-sedentary respectively; their flocks leave in the morning to graze and return in the evening to the sheepfolds. The resources utilised come mainly from fallow land that may be privately owned and/or rented and/or in association (40% and 42% of the total agricultural area conserved for grazing for S1 and S2 respectively), and from forest rangelands (for S2). The flock movement radius did not exceed 10 km for S1 and 50 km for S2. Given the relatively large number of sheep in S2 flocks, the farmers practice an optional transhumance during drought periods, from the beginning of February until mid-May, with an orientation towards the piedmont in the north (Tanant, Demnate, Foum Joumaa). For S3 farmers, local pastures in the form of fallow land (26% of the total agricultural area, private, and/or in association, devoted to grazing) and collective pastures (Oukarda for the farmers of Ait M'hamed and Jbel Tizzal for the farmers of Tabant), constitute most of the animal feed sources. Most of these farmers (55%), in particular those with larger flocks, practice a simple optional transhumance (amplitude of movements <50 km) towards collective elevated rangeland (Agdal of Igourdane/Tamda and Ardouz) in summer (starting in May) when the fodder resources of the local pastures become scarce. In the absence of winter transhumance, feeding during the cold season depends mainly on stored feed (purchased or self-produced), on pruned foliage, and on the leaves and acorns of holm oaks from forests (availability starting in October).

Pastoral resources remain critical for the functioning of S4 because all the farmers in this system use them. In fact, the agricultural area does not satisfy the needs of the large flocks. In addition to the local rangelands, complementary areas with different ecological conditions are grazed, owing to the traditional movements (double transhumance in winter and summer), longer and greater in amplitude (>100 km) than for the other systems and ancient practices. The animals are conducted into rangelands that may be owned collectively (e.g. Agdal, forest), privately or in association (26% of total agricultural area for grazing in the form of fallow). Winter transhumance (from December to April) is practiced on foot (7–10 walking days) towards the south (Saghro, Kalaat Mgouna) to escape the cold, the snow and the scarcity of fodder resources. Summer transhumance (from May to October) brings shepherds and flocks to the elevated collective rangelands of Izoughar and Tamda (intertribal Agdal). Since the 1990s, the range of movements of transhumant farmers has been extended as a result of climate change, in particular the drought that has affected the regions of Kalaat Mgouna and Ourzazate (southern areas for winter transhumance). In the winter, livestock are transported by truck far from the farm in search of pastoral resources; farmers travel to the south-west (Souss, Tata), to the north (Nador, Berkane) and to the east (Bouarfa). Natural (or 'free') feed resources cover an average of 50%, 59%, 74% and 89% of sheep requirements for S1, S2, S3 and S4 respectively.

The trend towards sedentarisation has led to changes in the traditional feeding calendar of sheep farming (Fig. 2*a*, *b*). Systematic supplementation throughout the year is now practiced by all the farmers interviewed in Ouaoula (S1 and S2), by 68% of the farmers from S3, but only 3% of the farmers from S4. For the other farmers (32% of S3 and 97% of S4), the distribution of supplements is restricted to lean periods (for pregnant females) or the lambing period (for lactating females). The feed distributed can be produced on the farm (stubble and straw from cereals and legumes, barley grains, alfalfa green or hay, and, at higher elevations, vegetable crop residues as well) and/or purchased (usually barley grain and wheat bran). Agricultural vehicles have made it easier to transport these feeds to local rangelands, especially at the lower elevations where adequate roads are common. In addition, sedentarisation has encouraged rangeland cultivation, leading to a decrease in the area devoted to grazing and an increase in grazing pressure. In addition to animal husbandry, all interviewees practice agriculture (cereal crops, arboriculture, fodder crops, vegetable crops and legumes). Cereal crops (barley, durum wheat and soft wheat) dominate. The other crops are alfalfa (often grown under apple trees), onions and potatoes at the upper elevations; lentils, peas and beans are grown at all elevations.

Discussion

Our study focussed on a province located in a mountainous area formerly characterised by pastoral livestock farming, a practice always considered a risky activity (Faye 2001) and one that is often confronted with numerous socioeconomic and climatic hazards that are at the origin of the evolution of this type of livestock farming (Bourbouze 2006). Nevertheless, pastoral

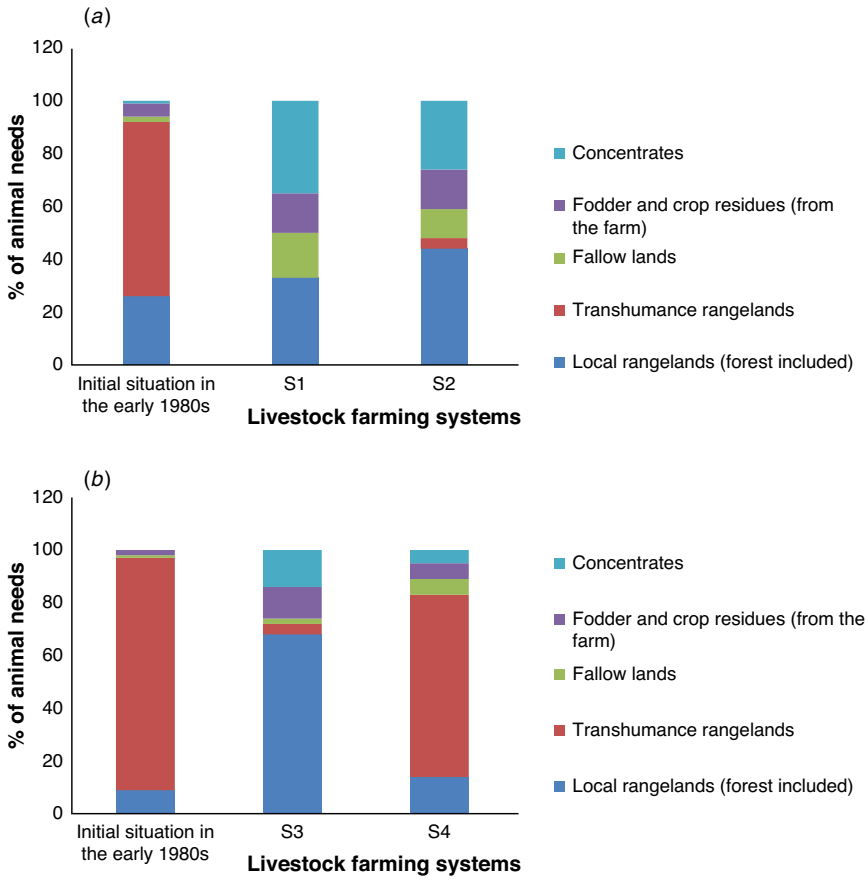

Fig. 2. (*a*) Evolution of the contribution of feed resources to meet the needs of sheep at the lower elevation. (*b*) Evolution of the contribution of feed resources to meet the needs of sheep at the upper elevation.

systems, known for their high resilience, have developed coping and adaptation strategies that allow them to overcome challenges and maintain the livelihoods of the local population (Chedid *et al.* 2018; El Aich 2018; Daoud *et al.* 2016). The study of the resilience of the pastoral component in livestock systems as a function of elevation is an original element that had not yet been treated in previous research. The latter aims at characterising the diversity of livestock systems in relation to available pastoral resources (Central High Atlas: Ibnelbachyr and Mounsif 2011) and the diversity of the adaptation methods implemented in recent years in these systems (Middle Atlas: Boughalmi *et al.* 2015; El Aich 2018). By focusing on changes in rangeland status as well as in grazing practices, we have shown that livestock systems evolve differently when confronted with hazards and global changes, depending on the elevation.

Applicability of our results to other regions

The farmers interviewed describe, for the years 1970–1980, a pastoral breeding system based on vast collective pastures and a double transhumance, which had been reported by Bourbouze (1982) for the Moroccan Atlas. In these rangelands, sylvo-pastoral resources were abundant and regulated, owing to the practice of Agdal, which contributed to the conservation of standing fodder (Auclair *et al.* 2011). The degradation of rangelands observed since the 1980s resulted in a loss of phytomass and an alteration of plant biodiversity. Similar changes have been reported in different Moroccan ecosystems (forest ecosystems: Naggar 2003; Middle Atlas: El Aich 2018; Eastern High Plateau: Bechchari *et al.* 2014). These dynamics were perceived differently depending on the elevation, as reported by Chriyaa *et al.* (2009) on the basis of the analysis of climate data for the province of Azilal in the second half of the 20th century. This is mainly due to the increased frequency of drought, leading to a shortage of water used for irrigation and livestock watering at the lower elevations, and frequent thunderstorms that cause flooding and the abandonment of agricultural lands at upper elevations (Herzenni and Azaroual 2012).

The degradation of pastoral resources and their availability appear to be important drivers of the evolution of livestock systems, with contrasting dynamics depending on the elevation. The decline in the mobility of low-elevation livestock farming systems (S1 and S2) results in low diversity of local pastoral areas compared with those of the high mountains (Gibon *et al.* 2004; Gavinet 2007). These farmers say that sedentarisation comes at the same price as transhumance because, since drought is generalised (even in the destination rangelands, in the north), they are forced to supplement the animals while on the move. Livestock mobility is in fact a function of the availability of

pastoral resources and of the number of animals. Both factors vary according to the elevation, as Boughalmi *et al.* (2015) pointed out in the Eastern Middle Atlas. Similar situations have been reported in European mountainous regions, for example, in Greece and Spain, where transhumance systems have long been established (Beaufoy *et al.* 1994). In addition, the logic of mobility at lower elevations has changed following the introduction of trucks and carts; feed and water are now taken to the flocks, thus reducing the range of movement (Deleule 2016). Conversely, at high elevations (S4), trucks are used for transportation, allowing flocks to explore distant areas during drought.

In this changing context, farmers' practices have evolved towards more intensive production methods in the sense that they increasingly depend on farm products and purchased feeds. These constitute a large proportion of animal feed (Alary and El Mourid 2007), especially for S1 and S2 where agricultural areas and significant financial resources allow farmers to supplement their sheep all year round. Livestock systems based on complementarity with agriculture (use of fodder, cereal grains and stubble) and the purchase of concentrates (barley grain, wheat bran), while reducing flock mobility, are observed throughout the Maghreb (Bourbouze 2006; Huguenin *et al.* 2014). In the Central High Atlas, for example, Ibnelbachyr and Mounsif (2011) estimated that the contribution of 'free' feed resources to meet the needs of sheep averages 72%, but does not exceed 50% in the Middle Atlas (El Aich 2018). In Central Tunisia, Jemaa *et al.* (2016) reported that concentrates constitute 13–24% of the dry matter ingested by ewes, and the remainder corresponds to the distributed or grazed fodder (cereal stubble or rangeland vegetation). Less mobile livestock systems (semi-sedentary and sedentary at low elevations) have developed coping strategies for the lack of pastoral resources, but they are more exposed to the risks associated with dependence on the feed supplement market (Deleule 2016).

The intensification of the traditional pastoral system and its transformation towards agro-pastoral systems (especially at lower elevations) was raised by the farmers interviewed, as a strategy to diversify sources of income and, therefore, to alleviate the effects of drought (Kanoun 2016). Funds from savings made by the marketing of agricultural products are mobilised to maintain the productivity of reproductive animals and manage uncertainty. Breeding alone cannot cover the needs of the family and flocks for the majority of the small farmers at higher elevations (S3). As a result, the latter undertake extra-agricultural activities (trade, eco-tourism) to maintain farm viability (El Amiri *et al.* 2007). Abandonment of animal husbandry is often considered. This situation is found everywhere among farmers in poor economic and social situations (small farmers in the Eastern High Plateau of Morocco, Bechchari *et al.* 2014; transhumant farmers in Central Tunisia, Jemaa *et al.* 2016; and in Lebanon, Srour 2006).

Our results, which are consistent with those from other research in Mediterranean countries, should be applicable to other mountain areas around the world, provided that there are similarities in terms of farm characteristics and management. For example, in the Asian plateaux (Bonnemaire and Jest 2013; Devienne 2013; Nori *et al.* 2008) and in the central Andes (Barrio de Pedro 2014), livestock farming systems at high elevations are characterised by smaller cultivated areas, larger flocks, systematic mobility and lower use of supplementation than farming systems at lower elevations. The isolation and the harsh climatic conditions explain these differences. In these areas, rangelands represent the most common feed resource for small ruminants, and their valorisation is made possible by the mobility of the herd and the farmer, thus allowing the continuity of these systems in the face of the difficulty of diversifying income (such as cultivation and fattening) and of access to imported resources.

Implications for research and development

Diversification and agro-pastoralism appear to be a means for farmers to make extensive farming systems technically viable. However, it should be noted that these systems evolve according to physical and socioeconomic constraints. Physical constraints (isolation, slope), accentuated with elevation, unevenly affect breeding practices at each elevation level. They make rangeland cultivation, animal feed supply, and marketing of fattened animals and plant products difficult at high elevations. The changes experienced by extensive farming systems on the social level (disinterest in the farming profession and the scarcity of specific labour because of the arduousness of the breeding activity), and on the 'animal component' level (replacement of local hardy breeds by more productive and less mobile ones) could also jeopardise their sustainability (El Amiri *et al.* 2007; Boughalmi *et al.* 2015; Gobindram *et al.* 2018). This last point merits more careful study because the resilience of livestock farming systems to a variable environment is based on the adaptive potential of animals, especially females (Blanc *et al.* 2004; Kanoun *et al.* 2013; Deleule 2016). This will make it possible to identify the role of the animal component in the resilience of pastoral livestock systems and to propose means to support change in these systems to ensure their sustainability.

Conclusions

In the Moroccan High Atlas, the rangelands and the traditionally pastoral small ruminant farming systems have considerably changed in recent decades. These changes were examined as a function of elevation. Despite the regressive dynamics of pastoral resources, followed by climatic hazards, they still contribute to the coverage of a significant part of the needs of small ruminants, especially among the farms at high elevations (>1400 m). These farmers have gradually increased mobility to compensate for erosion of local pastoral resources. However, livestock farming systems at lower elevations have intensified by using more inputs (supplements) and by appropriating new spaces intended mainly for cultivation. These adaptation strategies allow farmers to continue breeding activities. These strategies are part of a quest for profit with regard to farmers with large properties and significant financial means (especially at lower elevations), and self-subsistence for small farmers with small properties (upper elevations).

At upper elevations, ecological conditions and physical accessibility do not make it possible to anticipate future trajectories of intensification and diversification of systems, as is the case for other mountain areas. The sustainability of small ruminant farming systems at these elevations thus depends on

the resilience of the pastoral dimension. Consequently, public policies and future development projects must focus on the rehabilitation of these resources and the establishment of individual and collective practices that allow efficient and sustainable use of rangelands, especially at high elevations limited by the lack of alternatives.

Conflicts of interest

The authors declare no conflicts of interest.

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Data Availability Statement

The data that support this study are available and will be shared upon reasonable request to the corresponding author.

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