Matière
à débattre & décider

Livestock grazing systems and sustainable development in the Mediterranean and Tropical areas

Recent knowledge on their strenghts and weaknesses

Alexandre Ickowicz and Charles-Henri Moulin, editors

éditions Quæ

2. Adaptation to local and global shifts in livestock grazing systems

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Introduction

While the concept of adaptation as a process and product of evolutionary processes has been the subject of constant investigation since the 19th century in biology, its original discipline (Simonet, 2009), it is only in recent decades that the agricultural sciences in the broad sense have adopted it. While it is difficult to provide a universally accepted definition within this field of science, adaptation can be understood as the act of coping with and adapting to circumstances.

In line with the systems approaches and the work on system resilience to which they are more or less explicitly linked, research on adaptation in agriculture is distinguished within the agricultural sciences by the dynamic vision it has of its objects and by taking into account the complexity of the interactions involved in adaptation, from a holistic perspective (Darnhofer, 2014). In line with this trend, a number of studies have focused on adaptation in livestock farming over the last two decades (e.g. Ancey *et al.*, 2013). The complexity of the interactions underlying livestock farming, notably when carried out on grazing land, is undoubtedly related to this development: the diversity of species and breeds of domestic ruminants, the feeding behaviour and physiology of livestock, the availability of fodder resources in time and space, herd mobility, the various functions and products resulting from livestock farming, and the sectors and markets in which it is placed are all interrelated elements that can be adapted. They constitute levers for dealing with a constrained and changing context, for instance in terms of climate and economy (Rigolot *et al.*, 2019).

The field is wide and the research on adaptation in animal husbandry is consequently diverse. A first key to reading the variety of these works can be provided by the answers to a series of questions arising from the term adaptation itself. Adaptation of what? The animal (the individual, herd, population, species), the plant (the individual, the meadow), the farm and the farmers collective are all objects potentially involved in adaptation, which refer to various and possibly combined scales of analysis and disciplines. Adaptation to what? A distinction can be made here between hazards and risks, from a more sudden shock (e.g. the arrival of a predator) or a set of relatively continuous changes such as climate change or globalisation. The scale and time interval considered in the study of adaptations varies accordingly. The nature of the disturbances causing adaptation - climatic, environmental, technical, economic, political, social, etc. - also leads to diversity in the work. What is the extent of this adaptation? The three levels distinguished in the study of resilience (Darnhofer, 2014) can be used here: (i) the unit under consideration absorbs the disturbance and persists by remaining the same; (ii) the unit is slightly modified by the disturbance; (iii) the unit is radically transformed in reaction to the disturbance.

Another approach to research on adaptation in livestock farming is to distinguish between the significance given to the processes, properties or outcomes of adaptation (Gasselin *et al.*, 2020). Those focusing on processes will for example study the adaptation patterns of animals or farms, while those focusing on properties will analyse their response capacities, taking into account for example their resource allocation or their learning capacities (Chia and Marchesnay, 2008). For example, research on adaptation outcomes will examine the positive and negative effects of adaptation in relation to sustainable development.

This chapter aims at illustrating the extent of this work on the adaptation of grazing livestock systems. For this purpose, we have selected five sets of results from research conducted by UMR Selmet researchers over the past few years that deal with an original question, approach or object in relation to adaptation: diversity and adaptation of grazed plant cover to climate change, physiological levers mobilised by the animal, genetic diversity and adaptation of local animal genetic resources to their rearing environments, adaptive capacities of pastoral households and communities of livestock farmers, and adaptation trajectories of livestock farming in territories. Overall, the study provides the basis for reflection on adaptation in grazing livestock farming by highlighting the different levers and processes involved in adaptation and analysing its limits.

Adaptation in Mediterranean and Tropical pasture vegetation

SIMON TAUGOURDEAU, JOHANN HUGUENIN

Mediterranean and tropical livestock systems rely to varying degrees on grazing vegetation as a food source. Vegetation dynamics are influenced by various factors such as biophysical conditions (including climatic hazards), livestock practices, changes in livestock numbers, the cultivation of grasslands, etc. It can adapt to changes through two processes:

- intraspecific adaptation: a single plant species can modify its functioning to adapt to changing conditions through morphological, physiological or phenological changes.
- interspecific adaptation: the botanical composition can be modified to allow the vegetation to adapt to change; this adaptation can be expressed simply by a modification of species abundances or by the appearance or disappearance of species.

These adaptations then have impacts on the characteristics of grazing vegetation, including grazing value (biomass, nutritive value). Understanding the adaptation of vegetation to global changes can help predict the trajectory of grazing value.

In the Sahel, the use of historical data helps to determine the adaptation of grazing vegetation to drought

Grazing in the Sahel is mainly found on the steppes and savannah vegetation. The Sahel has experienced periods of severe drought, in particular between the 1970s and 1990s, with significant reductions in rainfall over several consecutive years. Since then, there has been a general return of rainfall. Within the Pastoralism and Drylands research platform[1] (PPZS), numerous studies have been conducted over several decades to investigate the vegetation response, both the herbaceous stratum (Ndiaye *et al.*, 2015) and the woody stratum (Diouf *et al.*, 2002; Sarr *et al.*, 2013).

Change in Sahelian savannah communities following drought episodes

Recent studies combine both satellite data and historical botanical survey data in northern Senegal. Woody vegetation changes before, during and after the drought period are studied (Dendoncker *et al.*, 2020). This work was partly based on the use of historical vegetation databases, in particular the Flotrop database (Taugourdeau *et al.*, 2019) which contains more than 340,000 observations of plants between the 5th and the 25th parallel north for the African continent between 1920 and 2012 (figure 2.1). Data freely available on GBIF[2].

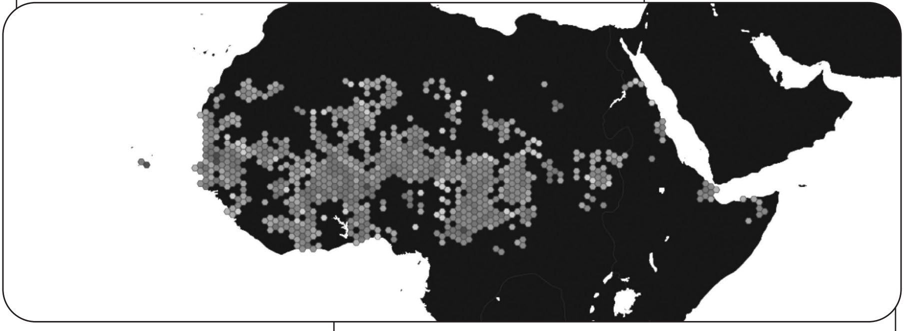
This study illustrates that tree density decreased between 1965 and 2008 but remained stable between 2008 and 2018 (around 10 trees per hectare). However, significant changes in species composition were noted, indicating an interspecific change in ligneous communities. Numerous species have decreased in abundance over this period. Only one species, *Acacia tortilis*, increased between both periods. The ligneous flora in the region is therefore less diverse and probably less resilient. Various factors are involved in this dynamic, such as grazing and human activities which restrict the development of new trees.

Study of intraspecific adaptation using herbariums

Historical data are also preserved in the form of herbarium samples. Herbariums can be used to study changes in the flora (interspecific adaptation) but can also be used to identify variations within species, in particular morphological characteristics such as leaf area from images of these samples. We measured leaf areas on typical Sahelian species from images available at the Recolnat[3]. For example, there is a relationship between the leaf area of *Zornia glochidiata* and the rainfall index in the Sahel (figure 2.2). For this annual species, the surface area was lower in dry years, showing a morphological adaptation to rainfall.

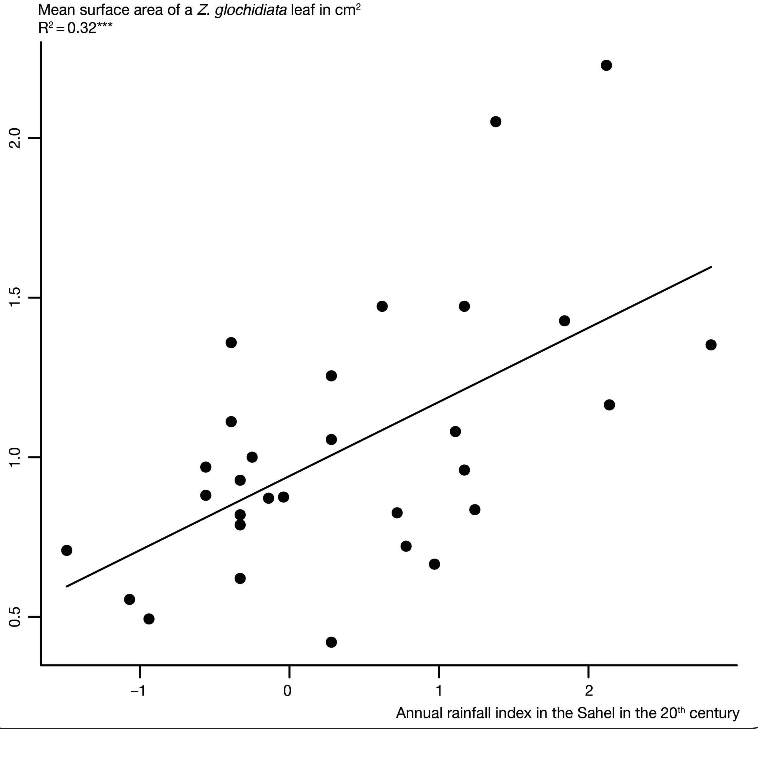
1. http://www.ppzs.org.
2. www.gbif.org/dataset/eb605c7a-a91c-4ab8-a588-85d0ccb2be9e.
3. www.recolnat.org/.

Figure 2.1. Distribution of Flotrop data (GIBF, 2019).



The intensity of the dots represents the data density of the online botanical surveys. The greater the intensity, the greater the density.

Figure 2.2. Relationship between the leaf area of Zornia glochidiata measured in the herbarium and the rainfall index in the Sahel.



It would be of interest to conduct similar work on variables other than surface area, notably chemical characteristics. However, these measurements are currently destructive. This creates a dilemma between data production and sample preservation. The development of indirect methods to avoid damaging the samples would be beneficial. Near infrared spectrometry analyses of herbariums are in progress to assess biochemical measurements indirectly (non-destructive method) (Svensk *et al.*, 2018).

Impact of livestock husbandry practices on vegetation adaptation and degradation of the steppes in the Maghreb

The north African steppes are located between the 400 mm/year rainfall isohyet to the North and 100 mm/year rainfall to the south and are covered with low, sparse vegetation. The symbolic grass *Stipa tenacissima* grows vegetatively on shallow drained soils. It accounted for 90% of the phytomass (5-10/t/year, with 20% green). Steppes covered in *Lygeum spartum* have a wider ecological range and are linked to sandy veils (260 ± 120 kg DM/ha/year). They replace *S. tenacissima* alongside low woody plants (*Artemisia*, *Salsola*, etc.). In areas of desertification where sandy veils reach 15 cm, *Stipagrostis pungens* develops (Hirche *et al.*, 2018). Shrubby steppes account for large areas, such as those with *Artissima herba-alba*, appreciated for its grazing value (Aïdoud *et al.*, 2006).

The North African steppes have been subject to a very ancient form of human exploitation through extensive sheep and goat rearing combined with shifting cereal cultivation (Aïdoud *et al.*, 2006). During the 20th century, this type of livestock farming underwent changes due to the evolution of demography, the expansion of crops in rangelands, the growth of livestock, the evolution of access to resources, persistent droughts, new livestock farming practices (e.g. use of concentrates and random mobility), the lifestyles of grazing communities (e.g. schooling), the economic context and rural policies (Bencherif, 2018; El Bilali *et al.*, 2020). Cultivation (mainly of cereals and arboriculture) and the silting up and subsequent desertification of the most intensively used areas of the steppes have led to a reduction of more than 25% of their surface area (Hirche *et al.*, 2018).

The impact of changing practices on steppe vegetation

Numerous factors have weakened steppe grazing vegetation, starting with more pronounced droughts, but above all anthropogenic factors: cultivation of rangelands, increase in livestock numbers, (Bencherif, 2018; El Bilali *et al.*, 2020; see also “Adaptation trajectories of livestock in the territories” in this section).

In the course of studies in areas with homogeneous soil and climate conditions, we noted a spatial heterogeneity of plant formations with *Stipa tenacissima*, *Lygeum spartum* and *Stipagrostis pungens*. In the same area, degradation is reflected in the disappearance of the *S. tenacissima* community and the appearance of the *L. spartum* community, with worsening degradation of this community which also disappears to make way for the *S. pungens* community. This is a regressive ecological succession characteristic of steppe grazing vegetation under severe constraints. In the study areas, each of these vegetation community was distributed differently in space, in the form of a patchwork. After identifying the grazing access rights of each herder in the 'terroir', we were able to establish relationships between the zoning of the different vegetation communities and their method of use. Consequently, agropastoralists who only had a grazing area of 0.25 to 0.5 ha/head of sheep and who lacked the means to migrate often had very deteriorated *S. pungens* pastures. Conversely, agropastoralists with multiple rangelands and engaging in transhumance generally kept pastures in good condition with *S. tenacissima* (Hammouda, 2019). The vegetation on their rangelands had rest periods. The land situation and dynamics of the rangelands may therefore lead to high-impact livestock farming practices, although they need to be identified (Daoudi, 2021).

Steppe regeneration, a method to prevent degradation?

Actions to regenerate the steppes have been undertaken since the 1960s, through the use of grazing fences and the establishment of aerial grazing (woody plants whose forage leaves do not fall to the ground) (Corriols, 1965; Gintzbuger *et al.*, 2000). Plant regeneration in the absence of grazing is proving satisfactory, though it is still linked to weather conditions. However, the results obtained after several years of grazing are disappointing, because farmers, realizing the high forage potential, impose intensive grazing over long periods of time, which weakens the vegetation (Louhaichi *et al.*, 2019).

In the framework of a research-action project in a steppe commune (rainfall of 250 mm/year), an assessment of the condition of the pastures was carried out in order to identify, jointly with the agropastoralists, the most degraded and fairly degraded rangelands. For the former, fodder bushes (*Atriplex* spp.) were planted with a 3-year grazing ban. As for the latter, they have been subject to 3-year fencing. Monitoring of these rangelands started in 2009 and ended in 2017 (grazing resumed in 2012). It involved 7 rangelands planted with *Atriplex* spp., 4 grazing fences and 3 controls.

The results (Table 2.1) are based on annual rainfall (in millimetres).

Table 2.1. Change in mean overall vegetation cover (OVC) in % on the different rangelands over time (Bouchareb *et al.*, 2020).

Years	2009	2010	2011	2012	2013	2015	2017
R (in mm)	390	425	337	245	277	221	202
C	35	42.2	38.6	38.41	33.4	34.11	33
PR	56	78.3	69.7	64	62.5	54.3	48
PL	27.1	58.4	57	54.8	62.8	65.3	61

R: annual rainfall. C: control rangeland.
PR: protected rangelands.
PL: rangeland planted with fodder shrubs.

Planted and fenced rangelands have benefited from the first rainy years. As of 2012, the decrease in the mean overall vegetation cover (OVC) of the protected areas can be explained by the drop in rainfall and the reintroduction of grazing. These factors do not affect the planted rangelands (PL), whose OVC is multiplied by 2.25, whereas these rangelands were initially the most deteriorated. *Atriplex* plants dampen the rainfall (which runs off less) and their denser bush structure alleviates the effect of grazing by limiting livestock grazing.

Species richness was expressed by the Shannon index calculated for rangeland and areas irrespective of the rangeland management (Table 2.2).

The index remains at a satisfactory level in the protected areas. The decline is evident in planted rangelands as the plantations grow. In the case of *Atriplex* plantations, biodiversity decreases initially, followed by a gradual return of local species in response to the improvement of stationary ecological conditions. This is confirmed in the lands subject to fodder plantations in the last year of monitoring, despite low rainfall. Protected environments, such as the rangelands that have been protected and the rangelands where fodder plantations have been carried out, manage to maintain a floral diversity linked in part to the “umbrella” aspect that the clumps generate, protecting all of the accompanying species (Slimani and Aïdoud, 2018).

Table 2.2. Changes in the Shannon index over time on the various rangelands.

Years	2009	2010	2011	2012	2013	2015	2017
R (in mm)	390	425	337	245	277	221	202
C	2.7	2.84	2.57	2.43	2.37	2.11	1.78
PR	3.21	3.13	3.03	2.72	3.24	2.81	2.92
PL	2.75	2.85	2.8	2.63	2.44	2.25	2.32

R: annual rainfall. C: control rangeland.
PR: protected rangelands.
PL: rangeland planted with fodder shrubs.

There is a clear correlation between cover and productivity, as well as rainfall (Table 2.3). The productivity of the reserves increases in the first few rainy years but cannot be maintained in drier years. The protected rangelands exhibit a significant increase in productivity in the third year after a three-year rainy cycle that enabled the annual and perennial species to be expressed at their maximum. This phenomenon of successive favourable years has often been analysed (Slimani and Aïdoud, 2018). *Atriplex* plants exhibit differing functional traits, which mitigate the rainfall effect, both up and down. They demonstrate an aptitude for mitigation, as even in recent dry years they remain the most productive, even though they have been heavily grazed.

A survey of farmers enabled us to note that, when grazing was resumed on the protected rangelands or those with fodder plantations, given the fodder supply, farmers increased their livestock (by 140%). We also noted that farmers with fodder plantations reduced their area planted with barley. This was not compensated for by the external purchase of barley, as they had reduced their concentrate intake.

Due to the high inter-annual rainfall variations in the Algerian steppes, livestock farmers seem to have developed strategies of intense exploitation of the resource when the year is suitable, considering that whatever their vegetation practices, the following years may be subject to drought and therefore to extremely low pastoral resources. This observation highlights the importance of dialogue with herders, so that they can recognise the vegetation of regenerated rangelands, notably through fodder plantations, as a resource that can partly withstand droughts if these rangelands have not been overgrazed the previous year. The participatory research work undertaken during the clearing and planting should have continued when the land was opened to grazing, but could not be carried out because the project was coming to an end. In the case of the younger generations, support should be considered. Such an approach would require work on the alliance rules and access to rangelands by mobilising the human and social sciences.

Table 2.3. Productivity of rangelands over time in kg/ha/yr.

Years	2009	2010	2011	2012	2013	2015	2017
R (in mm)	390	425	337	245	277	221	202
C	250	270	300	280	265	255	205
PR	313	790	1000	485	600	400	320
PL	221	390	460	615	605	575	450

R: annual rainfall. C: control rangeland.
PR: protected rangelands.
PL: rangeland planted with fodder shrubs

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Livestock grazing is a system that relies on the use of spontaneous vegetation as the main source of feed for livestock. This spontaneous vegetation is influenced by soil and climatic conditions and also by livestock practices. The adaptation of vegetation can be based both on changes in a species (intraspecific) and changes in plant communities (interspecific variation). These adaptations can only be observed in the long term and require studies based on multiple historical data. The main trend indicates an expansion of desertification areas by 10% per decade. Rehabilitation and fodder crops can stabilise this progression by means of co-construction work that take account of social dynamics and revive the logic of regulated collective grazing.

Livestock robustness: physiological and behavioural levers of adaptation

Eliel González-García, Alexandre Ickowicz, Nathalie Debus, Moutaz Alhamada, Habibou Assouma

In Mediterranean and Tropical livestock production systems, animals are faced with sometimes drastic variations in the availability of food resources, for example during more or less predictable and extended droughts, leading to episodes of thermal, water and nutritional stress. In such conditions, grass and more generally biomass production is limited, either temporarily or over a longer period. In order to survive, ruminants, who are dependent on this resource must adapt either directly (individual physiological adaptation) or indirectly (with adjustments of management practices). By individual physiological adaptation, we are referring to the overall beneficial regulation of the physiological processes implemented by an individual subjected to new conditions and which allow it to respond in a more or less effective manner (dynamic process). Among the range of physiological adaptations, one of the main levers is the ability to adjust feeding behaviour, based on the implementation of mechanisms related to food choice and intake as well as spatial mobility. In conditions of extreme shortage, to compensate for the consequent negative energy balance, another physiological compensation mechanism on which ruminants rely is the mobilisation and reconstitution of body reserves. In addition to body condition, other traits such as the animals' reproductive performance are negatively affected by such food and nutrient deficiency events. Underfed females adapt their behaviour by changing the nature and frequency of estrus and mating. The reproductive behaviour of males is indirectly affected via the attractivity of females. Understanding the complex cascade of these physiological mechanisms (either singly or in combination), at both individual and herd levels, is an integral part of efforts to make good use of them in an adaptation strategy for these farming systems at various levels of organisation.

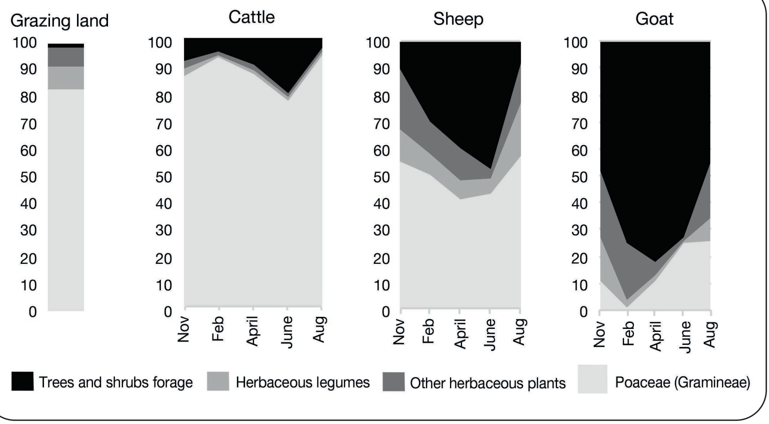
The feeding behaviour of grazing ruminants as an adaptation strategy

In grazing systems, the spatial and temporal variability of climatic conditions (mainly temperature and rainfall) results in a variable distribution of food resources for ruminants (quantity and quality of herbaceous and woody plant biomass). One of the primary adaptation levers for these livestock systems is the ability to adjust their feeding behaviour. This is based on three essential levers: food choice, food intake and mobility.

Selective feeding behaviour of ruminants on pasture

The selective feeding behaviour of ruminants is difficult to describe with precision, as these animals are freeranging, mobile and sometimes difficult to approach (Guérin *et al.*, 1988; Bonnet *et al.*, 2015). Studies show that it varies according to the ruminant species (Guérin *et al.*, 1988; Ickowicz, 1995) with a specific proportion of the diverse vegetation class contribution to the daily ration (figure 2.3).

Figure 2.3. Selective intake behaviour of three species of domestic ruminants (cattle, sheep, goats) on the same pasture in the Sahel depending on the season (in % of the botanical composition) (according to Guérin *et al.*, 1988; Ickowicz, 1995).



It should be noted that during the dry season or under conditions of low availability of herbaceous fodder, woody plants, in the form of leaves or fruit, can sometimes contribute even more to the diet, up to 50% of the biomass ingested by cattle for example, especially in the dry season (Ickowicz and Mbaye, 2001; Assouma *et al.*, 2018). These differences in selective ingestion behaviour of ruminants indicate complementarity between species that exert distinct grazing pressure on vegetation compartments and induce positive interactions for production at moderate grazing pressure. These differences advocate a mixed composition of herds, a regular practice in Mediterranean and Tropical arid zones (Guérin *et al.*, 1988). Consequently, the specific and adaptive behaviour of ruminants on grazing land is a significant lever for adapting to the spatial and temporal variability of resources on an intra- and interannual scale, but also over the longer term, for sustainable resource management. These mechanisms offer farmers the opportunity to adjust the specific composition of their herd in order to react to changes in climate and the environment while maintaining the productivity level of their herd by exploiting all plant diversity.

Adaptation of the ingestion capacity of ruminants

The ingestion capacity on rangeland (expressed in grams of plant dry matter intake per second, g DM/s) in part determines animal performance and is mainly a function of the animal species and its size (stature, bite or bite size), but also of the vegetation cover (Hodgson and Illius, 1996; Figure 2.4), and will be inversely proportional to the animal's speed of movement.

A recent study in a tropical environment (Chirat *et al.*, 2014) gives details on the model linking the ingestion capacity to the forage biomass available on the range (figure 2.5). We note here that below an availability of 1 tDM/ha, the animal is no longer able to compensate for the scarcity of resources by accelerating its forage intake, which exhausts the animal. Conversely, with offers above 3 tDM/ha, there is a reduction in the speed of ingestion linked to a vegetation structure that is too dense and bushy and often not very palatable. These interactions drastically reduce the daily intake capacity, especially in the dry season (Figure 2.6; Assouma *et al.*, 2018). Adapting to this dynamic may require the involvement of the farmer (or shepherd) for example by moving the grazing animal and offering a better density or quality of forage in order to avoid a drop in performance (Chirat *et al.*, 2014; Meuret, 2010).

Figure 2.4. Effect of available biomass (grass height in cm) on (A) bite weight (in mg) and on (B) intake rate (in bites/min) and (C) the resulting daily organic matter intake (kg OM ingested/day).

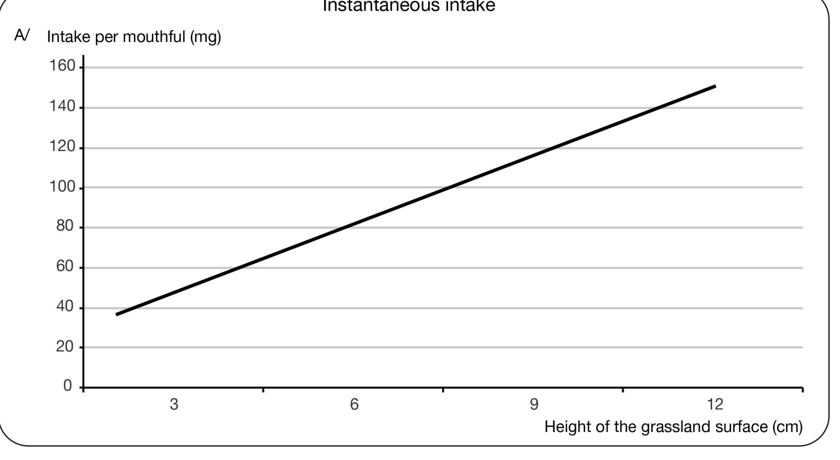
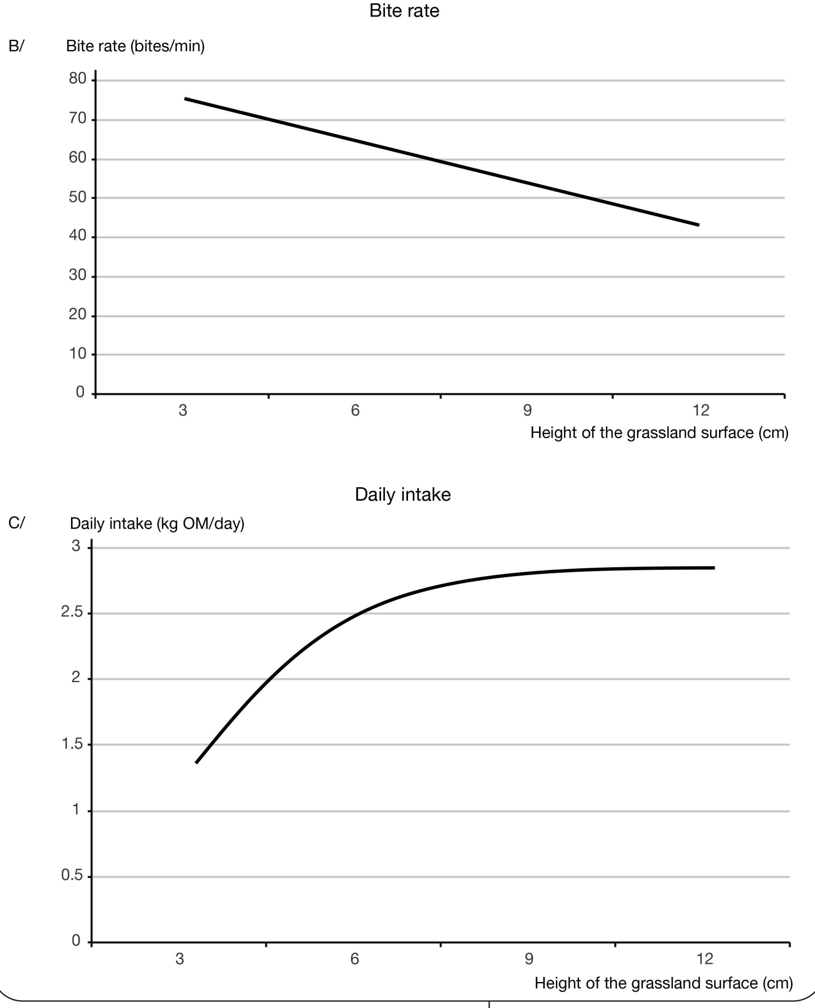
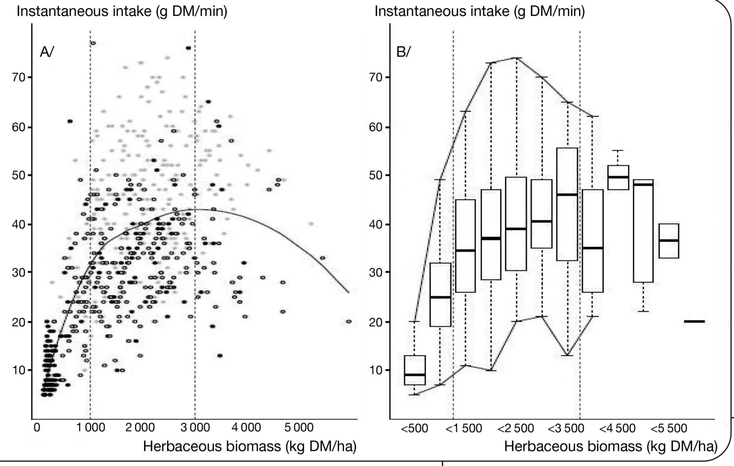


Figure 2.4. Next



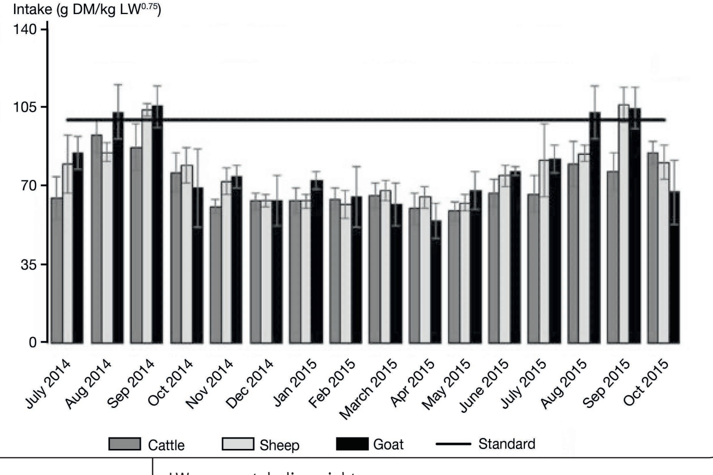
Adapted from Hodgson and Illius, 1996.

Figure 2.5. Adaptation of the ingestion capacity of ruminants on tropical rangelands (in g DM/min) as a function of the available plant biomass (in kg DM/ha). A. basic observed data and resulting intake curve. B. representation of observed means, standard deviations and extreme values for each biomass class.



Extracted from Chirat *et al.*, 2014.

Figure 2.6. Variations in daily intake of three ruminant species (bovine, ovine and caprine) (in g DM/kg metabolic weight) on rangeland in the Sahelian pastoral zone (Assouma *et al.*, 2018).



LW0.75: metabolic weight.
Significant reduction in the dry season when the availability of plant biomass is too low.

The role of mobility and the herder

The ingestion behaviour described above at the vegetation patch level can be significantly modified by the animal's mobility, with or without the intervention of a herder. The acceleration of food intake that the animal resorts to in order to compensate for the scarcity of fodder may be combined with an increase in the area of pasture prospection. The distances travelled lead to an increase in the energy expended in feeding, which may contribute to a decrease in performance. However, for adapted breeds, increased daily walking (within the distances reported) does not significantly increase weight loss due to lack of forage resources, but increases water requirements in situations where scarcity of water points may lead to animals having to drink every other day. The judicious intervention by the farmer in these situations is all the more essential as they know the space and the potential competition from other herds. For these two parameters, choice and ingestion capacity, the action of the farmer or the shepherd who accompanies the herd on the grazing land can be decisive in facilitating the organisation in time and space of food intake and ruminants getting used to new pastures (Meuret, 2010).

Body reserves as a characteristic trait in constrained conditions

The mobilisation-reconstitution dynamics of body reserves (BR) is an essential mechanism to compensate for all or part of the food and energy deficit incurred under stressful rearing conditions. This includes energy reserves stored in the form of lipids (adipose tissue) in subcutaneous regions or combined with internal organs. BRs are an essential asset especially for females that are accustomed to using them in late gestation and during early lactation to support milk production levels that induce adverse energy balances when their feed intake capacity is not at its maximum. These BRs are also mobilised when animals must compensate for energy deficits resulting from the time-varying quantity and quality of the grazing resource, as described above.

It is this component and its mobilisation-reconstitution processes that are studied in specific observed or induced situations using the breeding ewe as a model. The objective is to identify and understand the determinants that favour the functions related to the survival of the individual in short or longer periods after the disturbances undergone in conditions of undernourishment in Mediterranean and Tropical environments. The aim is to work on individual and collective scales (the herd), through the study of functional groups (e.g. according to physiological stages) and throughout the career. The phenotyping of individuals, in a dynamic perspective, is consistent with a detailed consideration of genotype × environment interactions, in time and space, and a hierarchical approach of adaptation processes. Finally, this approach enables the design of alternative feeding strategies while proceeding with genetic improvement of individual capacities identified as advantageous.

In combination with live weight (LW) and body condition score (BCS) monitoring, we use a set of plasma metabolites and hormones to characterise metabolic status involved in the adaptive mechanisms to negative energy balances. Studies of the robustness of ewes have been conducted in contrasting conditions at the INRAE experimental area of La Fage (Causse du Larzac, 800 m in altitude).

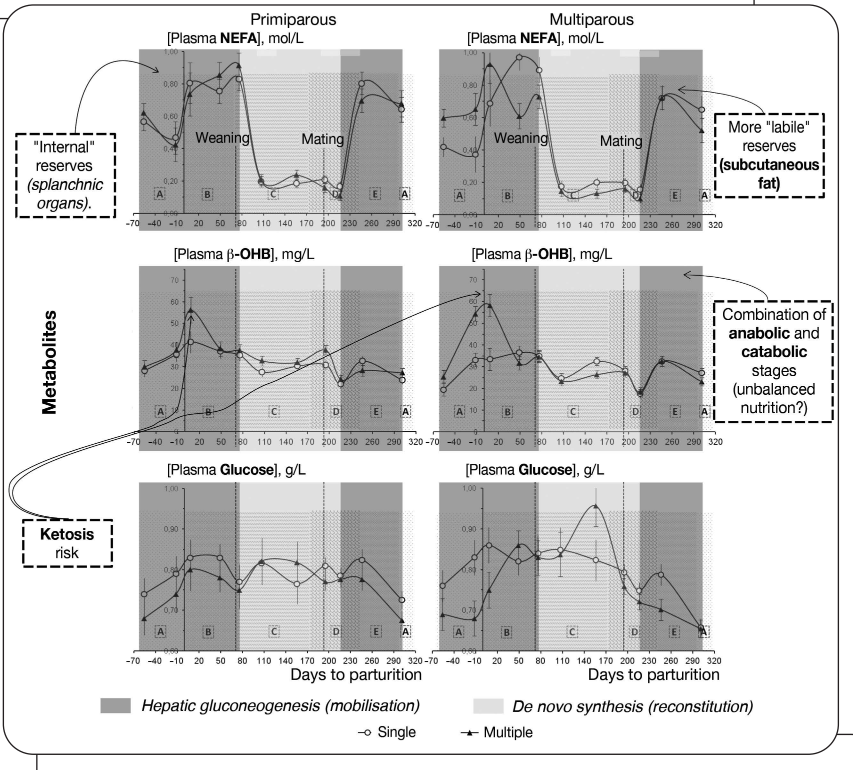
To illustrate, we monitored a batch of lactating Lacaune breed dairy ewes over several weeks with differing energy balances according to milking rhythm (standard or mono-milking) while voluntary intake (free choice offer with identical ingredients and rationing) remained unchanged (González-García *et al.*, 2015; Hassoun *et al.*, 2016). We also monitored suckling ewes of the Romane breed on rangeland for several months (González-García *et al.*, 2014). For each protocol, we monitored the trajectory of quantifiable biological parameters over the course of a full physiological year, such as LW, BCS and the concentration of plasma metabolites and hormones related to the mobilisation-reconstitution processes of BRs. The multiplicity of the chosen indicators enables understanding the diversity and complexity of the mechanisms and biological components inherent to adaptation to negative energy balance.

Our approach consists in subjecting the various genotypes to situations beyond the standards usually associated with the classical progression of successive physiological stages. In the case of dairy ewes, the experiment consisted in modifying the milking frequency (Once a day milking vs. Twice a day milking) in order to affect the energy request ("pull effect") related to milk production. For Romane ewes, the energy constraint was based on the combination of litter size (more energy demand in ewes with multiple litters compared to those with single litters) with the age of the female (priority or not to growth in primiparous or multiparous). These constraints were associated with a specific diet, representative of seasonal variations in rangeland forage and successive feeding regimes. The concentrations of metabolites and hormones then reflect the dynamics of metabolic energy flow in these conditions (figure 2.7).

Clear effects of parity, litter size, passage through a sequence of physiological states on metabolic profiles and milking frequency in the Lacaune breed and changes in biomass availability on the range in the Romane ewe were demonstrated. The combination of experimental factors taken into account reveals differences due to the age of the ewe (related to parity) and in the distribution of nutrients according to the biological priority at a given time (trade-offs or compromise). As a result, the changes observed during the post-weaning period are quite marginal when compared to the readjustments that occur at farrowing and up to weaning to compensate for the negative energy balance during this period.

Over and above the understanding of the mechanisms and dynamic processes implicitly mobilised during negative energy balance, all parameters evaluated enable us to detect sensitive and critical periods during an annual productive cycle for the two breeds in question in their rearing conditions. In this way, we have identified critical physiological states that are generally underestimated during early and mid-gestation, periods during which

Figure 2.7. Body reserve dynamics of Romane ewes (young or adult, with one or more lambs), raised in the open air on the La Fage range during a production year.



The graph illustrates two distinct phases of mobilisation (around farrowing and during gestation, as of the first month) and reconstitution of body reserves (from weaning to early gestation). Phenotyping of the metabolic profile of plasma non-esterified fatty acids (NEFA), ketone bodies (β-OHB), and plasma glucose provides an account of the energy balance of females.

The capital letters in the boxes represent the feeding regime of the farm: A, preserved feed (silage and hay) from the end of gestation up to calving; B, fertilized pasture and native rangeland during the lactation phase in spring; C, native rangeland grazing during drying off in the summer; D, native rangeland grazing during drying off in the autumn; E, cultivated grassland grazing (regrowth) during early and mid-gestation.

nutritional management could be improved. We have demonstrated the applicability of long-term studies on efficiency in the processes of mobilisation and replenishment of BR in ruminants. It is a component with a direct impact on the overall resilience of the herd under conditions where fluctuation in feed quantity and quality is one of the main constraints. A similar characterization of BR dynamics has been conducted with Arles Merino ewes subjected to varying energy balances (González-García *et al.*, 2020a).

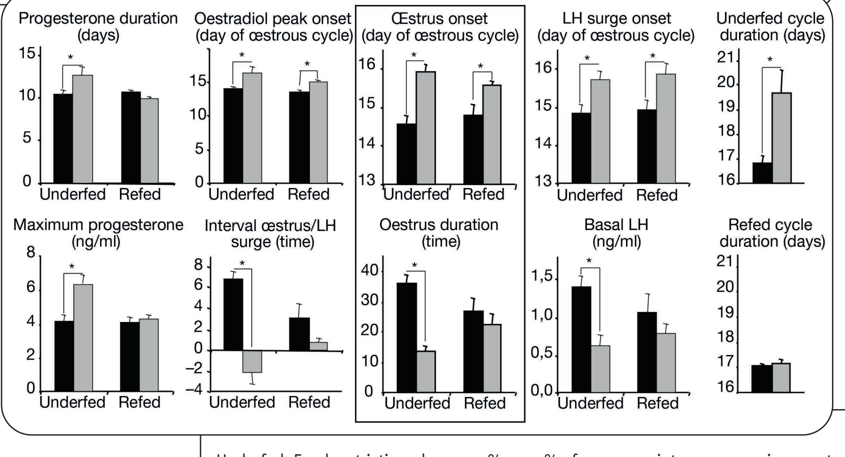
To understand the relationship between female growth rate and age at first breeding (early, 7 months vs. late, 19 months), a study with historical data from 1,359 females from the La Fage Romane herd born between 2002 and 2012 highlighted the effects of such a decision (early or late breeding) on the subsequent productive life of the female and the behaviour of her offspring (González-García and Hazard, 2016).

The adaptation of ovine reproductive behaviour in response to dietary constraints

By using sheep in a Mediterranean context as animal models, we focused on the behavioural adaptation of both females and males to ensure successful reproduction in situations of food constraint.

We assessed the static and dynamic effect of nutrition on the sexual behaviour and on the hormones of the estrous cycle of Merino d'Arles ewes. We demonstrated (Debus *et al.*, 2005; Blanc *et al.*, 2004) that a 50-day feed restriction (40% vs. 100% of energy maintenance requirements): 1) delays the time of estrus onset by 1.5 days and reduces the duration of estrus by almost 3 times, 2) increases plasma progesterone levels and delays their return to baseline, 3) delays the onset of the estradiol peak, 4) decreases luteinizing hormone (LH) baselines and delays the onset of its preovulatory peak, 5) greatly reduces the interval between the onset of estrus and the onset of the preovulatory LH peak, 6) extends the duration of the estrous cycle by 3 days (Figure 2.8).

Figure 2.8. Mean values ± standard error of the mean (n = 9) of 9 endocrine or behavioural reproductive parameters in restricted (grey bars) or well-fed (black bars) ewes.

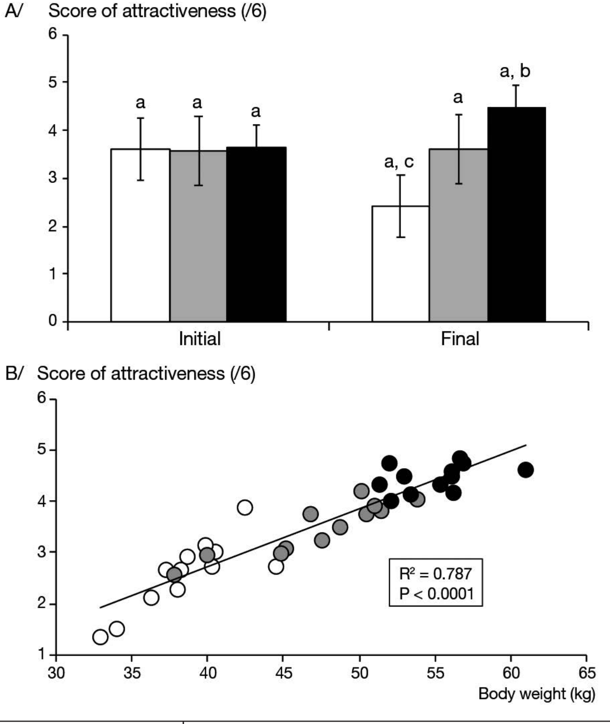


Underfed: Food restriction phase 100% or 40% of energy maintenance requierements. Refed: re-feeding phase. Statistically significant differences (Mann-Whitney U test) between batches are indicated by an asterisk ($p < 0.05$).

However, all ewes ovulated and exhibited cyclic variations in progesterone levels. Follicle stimulating hormone (FSH) secretions and ovulation rate were also unaffected by the feed restriction. Following this period of restriction, a re-feeding of 17 days was sufficient to restore parameters similar to those of control animals.

In the case of males, we observed the behaviour of 6 rams in relation to 36 Merino d'Arles ewes (12 ewes per batch) fed for 3 months with contrasting diets covering between 68 and 180% of maintenance requirements. We measured the attractiveness of the ewes to each male. After 3 months, we observed that ewe attractiveness was positively related to changes in body weight (Figure 2.9). Rams have a good

Figure 2.9. A. Mean attractiveness scores of ewes (white bars: batch with 68% of maintenance requirements; grey bars: batch with 113% of requirements; black bars: batch with 180% of requirements) before and after 3 months on a differentiated diet. B. prediction of the attractiveness score of Arles Merino ewes according to their live body weight. Attractiveness score measured with the Ovimate device (figure 4.4).



Bars with differing letters are statistically different ($p < 0.05$).

perception of the nutritional status of ewes and prefer ewes in good body condition to lean ewes. Moreover, they can discriminate ewes within a flock based on their body weight (Alhamada *et al.*, 2017b).

We demonstrate for the first time, the behavioural origin of the subfertility observed in undernourished ewes: the rams do not primarily seek lean ewes that are responsive for a shorter time than ewes in good condition. Underfed ewes with insufficient body reserves are therefore less likely to be mated. This means that they can replenish their body reserves and focus on survival rather than on completing a difficult pregnancy. This sub-fertility can be quickly overcome by re-feeding the animals. Our study demonstrates that ewes adapt individually to nutritional hazards in order to preserve their integrity and that at the flock level, male × female interactions favour the most productive females. From a practical point of view, these results indicate that a different breeding management is required (male/female ratio, batch management, *flushing*, etc.) depending on the nutritional status of the animals.

Genetic diversity and adaptation of local breeds to their breeding environment

Laurence Flori, Anne Lauvie, Eliel González-García, Jessica Magnier, Lola Perucho

The use of animal genetic diversity is one of the main levers to be considered so as to improve the adaptation of livestock systems to the major current changes. Among domestic ruminants, there is a high intraspecific diversity, as illustrated by the high number of cattle breeds registered (more than 800) and classified as zebu (*Bos taurus indicus*), taurine (*Bos taurus taurus*) and zebu × taurine crossbreeds, or the more than 1,500 sheep breeds documented globally[4]. The main factors that have contributed to the generation of this diversity are domestication, the sometimes distant migration of ruminants from their domestication centers, and the different pressures of recent natural (such as exposure to new climatic conditions and pathogens, and the abundance or scarcity of food and water resources) and artificial selection (selection of animals by farmers based on morphological criteria, coat colouring, docility, or their performance, for example). Local hardy and heritage breeds, mainly considered in grazing systems, are the result of an evolutionary process that has determined their ability to live in a specific environment.

In order to conserve and make the best use of this genetic diversity within sustainable breeding systems, it is essential to characterise it well (for example at the population level or within the herd in relation to traits of interest such as feed efficiency or the dynamics of mobilisation-reconstitution of body reserves), to understand the demographic history of these breeds and to identify the genetic mechanisms underlying their

4. www.fao.org/dad-is/fr/

adaptive capacities. It is also necessary to characterise the perceptions that breeders have of the adaptation of their breeds, their herds and their animals and to better understand how they take this adaptation into account and manage it through their practices.

Genetic characterization of local breeds adapted to tropical and Mediterranean conditions

Over the last twenty years, the genomic revolution accompanied by the development of new high-throughput[5] genotyping and sequencing tools has greatly facilitated the fine genetic characterization of ruminant breeds. These tools have, for example, provided reference genotyping data for many cattle and sheep breeds stored in the Widde database[6] (Sempéré *et al.*, 2015).

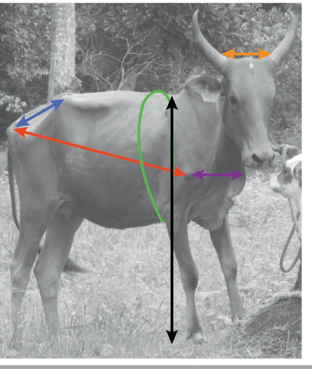
Exploring the structure of genetic diversity in local breeds (through multivariate approaches or supervised and unsupervised hierarchical clustering) applied to individual genotyping data is an essential step in describing these breeds and a prerequisite for further study of their demographic and adaptive histories. In cattle, for example, this exploratory approach has made it possible to better characterise the genetic diversity structure of some local breeds by comparing them to a panel of breeds representative of the genetic diversity of the species and to suggest historical hypotheses based on their origin, as exemplified by the Zebu of Mayotte and the Mediterranean cattle breeds (Ouvrard *et al.*, 2019; Flori *et al.*, 2019).

The genetic study of the Zebu of Mayotte[7] has effectively confirmed its originality and initiated the implementation of conservation measures. This local population (approximately 70% of the 20,000 head counted in Mayotte), whose presence on the island could date back several centuries according to archeozoological data (Boivin, 2013), is used in traditional local production systems (in family farms of a few head) and has a significant ceremonial and cultural value. However, some breeders have started to crossbreed with improved European taurine breeds (i.e. Montbeliarde, Jersiaise, Gasconne and Brune breeds) over the last twenty years, which is threatening the Zebu of Mayotte. Consequently, a process of recognition of this local breed was undertaken by the constitution of a file integrating a joint phenotypic and genetic characterization and led to its official recognition in 2018 (Ouvrard *et al.*, 2019). The phenotypic study of this breed, which is a prerequisite for the selection of animals to be genetically characterised, showed a significant heterogeneity of coat color patterns and of some morphological parameters in the 400 animals studied and established a detailed description useful for defining the breed standard (Figure 2.10).

5. These enable the simultaneous study of several thousand to several hundred thousand biallelic markers spread over the whole genome.
6. http://widde.toulouse.inra.fr/widde/.
7. Conducted thanks to a collaboration between the Coopadem farmers' cooperative and CIRAD, assisted by INRAE geneticists within the framework of the Rita project (agricultural innovation and transfer network) Defi-Animal, coordinated by Emmanuel Tillard (Selmet, La Réunion).

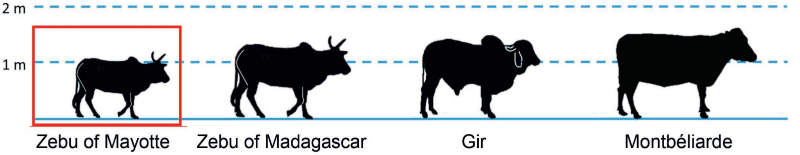
Figure 2.10. Example of parameters measured in 400 Zebus of Mayotte from 178 different farms selected on the entire territory of Mayotte.

Quantitative parameters



Measured parameters	Mean in cm (standard deviation)
Height at withers	106 (7)
Oblique body lenght	118 (9)
Chest circumference	139 (10)
Chest width	34 (5)
Pelvic lenght	39 (3)
Length between horns	15 (2)

Size comparison with other breeds



Sources: M.O., Mélissa Ouvrard ; J.M., Jessica Magnier.

In contrast, the genetic characterization of 150 of these unrelated animals, based on the genotyping of 50,000 biallelic markers distributed over their genome, revealed a high genetic homogeneity and proximity to Zebus of Madagascar (Ouvrard *et al.*, 2019), both breeds having a higher indicine cattle ancestry[8] than the African cattle breeds and a low African taurine ancestry. In 16% of the individuals, a low European taurine ancestry (‹5%), probably resulting from recent crosses with European taurine breeds, is also observed. The aim now is to extend the population inventory and to organise its management by setting up a conservation and management plan. These first genetic studies will also be continued by estimating certain demographic parameters and studying the production and adaptation capacities of this breed, which are still poorly known. Indeed, the Zebu of Mayotte population has developed adaptive capacities specific to the constrained environment of the island (hot and humid climate, pathogen pressure, low availability of water and food resources).

This exploratory approach was also applied on a larger scale to study the structure of the genetic diversity of 21 local Mediterranean cattle breeds (640 individuals genotyped for more than 50,000 biallelic markers) from Algeria (i.e. Cheurfa, Chelifienne, Guelmoise), Cyprus, Egypt (i.e. Baladi), Greece (i.e. Brachykeratiki), Italy (i.e. Maremmana, Romagnola, Sarda, Sardo-modicana, Cinesara, Modicana), Morocco (i.e. Oulmes Zaër, Tidili, Atlas brown), Spain (i.e. Mallorquina, Menorquina, Marismena, Negra andaluza), and France (i.e. Raço di Biou and Corse) (Flori *et al.*, 2019[9]). As the Mediterranean basin has been crossed by several migration routes used by herders, the demographic history of these breeds appears relatively complex. The genetic study indicates that the majority of breeds studied have European and African taurine ancestry, the proportions of which depend on the latitude. However, a certain proportion of indicine ancestry is also detected in the Egyptian, Greek and Cypriot breeds and to a lesser extent in the Italian breeds Maremmana, Modicana and Sarda-modicana and in the Corsican breed, testifying to crossbreeding with populations of indicine ancestry in Southern Europe, the level of which decreases from East to West. This ancestry pattern is consistent with the known migration history of Neolithic farmers from the centre of taurine domestication in the Fertile Crescent westward via the Mediterranean and its main islands along the so-called “Mediterranean route”, 6,000 to 6,500 years ago. It is also consistent with the migration of taurines from North Africa to Spain after their introduction into Africa via Egypt, 6,500 years ago. The intersection in Egypt, at roughly the same time, of several migration routes taken by human communities through Europe and Africa may have simultaneously favoured the interbreeding of different bovine populations. Populations of indicine ancestry or admixed with zebus were probably imported into southern Europe (between 200 BC and 1720) by the Silk Road that connected Asia to the Mediterranean Sea, ending in Italy, in accordance with the decreasing gradient of indicine ancestry observed from Sicily to mainland Italy and Corsica. The weak indicine ancestry also detected in some Algerian breeds (i.e. Cheurfa

8. From *Bos indicus*.
9. Galimed project (Inra, Métaprogramme Accaf), coordinated by Denis Laloë (Gabi, Jouy-en-Josas).

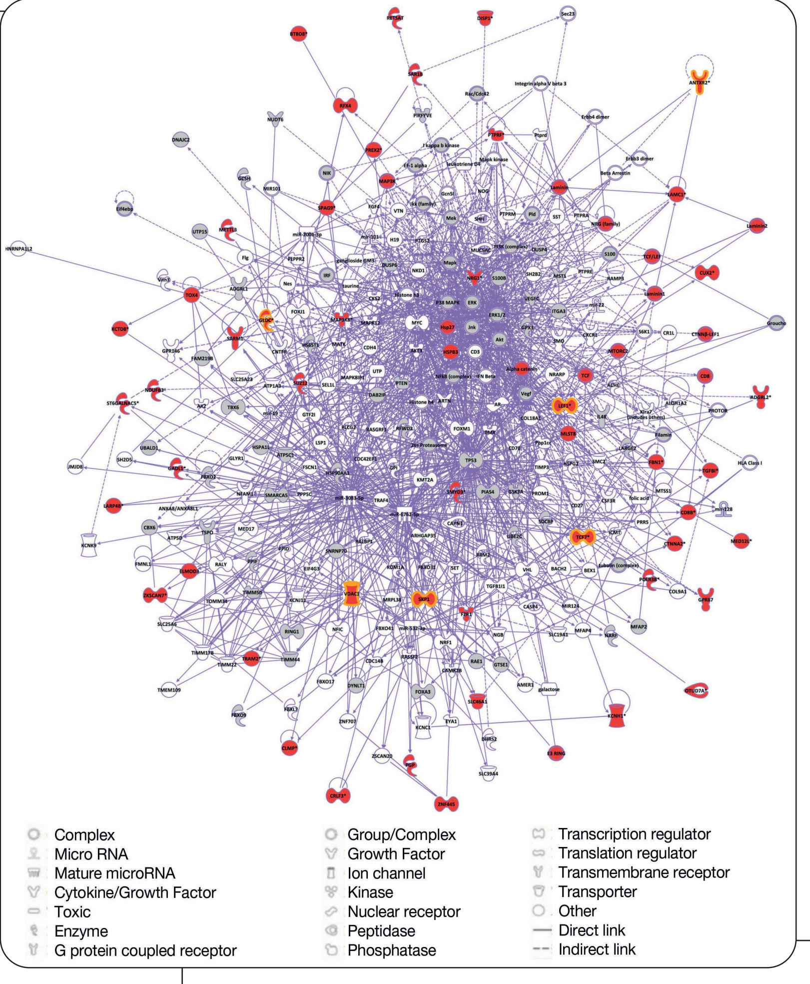
and Guelmoise) probably results from a residual crossbreeding between African taurine and zebus, while the European taurine ancestry detected in the other North African breeds indicates more recent crossbreeding, during the last century, with European taurine. All of these more or less complex scenarios suggested by these exploratory approaches of the genetic structure will, however, have to be confirmed by more detailed modelling of demographic processes.

Genetic study of the adaptive history of local Mediterranean breeds

The identification of the genes involved in the adaptation of local breeds to their specific environment, coupled with the dissection of the underlying molecular mechanisms, allows a better understanding of the adaptive mechanisms. It can also be considered as an additional means to characterise local breeds and reveal their originality from a genetic point of view. It involves locating footprints (or signatures) of natural and artificial selection in the genome by analysing the dense genetic information of several dozen individuals. Functional annotation of candidate genes identified in regions under selection using systems biology tools (Flori *et al.*, 2012; 2014; 2019) allows to make hypotheses about the key functions, biological pathways, and gene networks in which genes under selection are involved and about the selection pressures that may have occurred. The complementary use of association methods with population-specific phenotypes or environmental variables (Gautier, 2015) can make a connection between genomic selection signatures and these variables and hence confirm some of these hypotheses.

The 21 previously studied Mediterranean breeds have been subjected for centuries to the different variants of the Mediterranean climate. The joint screening of selection signatures in their genomes and of associated chromosomal regions with population-specific variables discriminating the different subtypes of the Mediterranean climate made it possible to establish a direct link between some selection signatures and climatic variables and to propose a genetic map of the association with climate (Flori *et al.*, 2019). Nine regions under selection and 17 candidate genes located on five separate chromosomes were identified, including several candidate genes (LEF1, ANTXR2, VDAC1, TCF7 and SKP1) that are also associated with climate variables. The 55 genes associated with at least one climate variable (Figure 2.11) are involved in several biological functions that play a role in adaptation to the Mediterranean climate, such as thermotolerance, ultraviolet (UV) protection, pathogen resistance or metabolism. The main selection pressures affecting cattle in the Mediterranean area are likely to be variations in heat and UV exposure, availability of food and water resources and exposure to pathogens. Among the strong candidate genes associated with climate (e.g. NDUFB3, FBN1, METTL3, LEF1, ANTXR2 and TCF7), the ANTXR2 gene, already found under selection in West African cattle breeds and associated with climatic variables in humans and sheep, encodes the receptor for the *Bacillus anthracis* anthrax toxin. These results suggest that anthrax, the oldest known zoonosis with a global distribution, must have exerted significant selection pressure on cattle breeds in the Mediterranean basin and West Africa and illustrates a clear link between this disease and climate. The *Bacillus anthracis* spores can persist in the soil for years and climatic factors such as temperature and precipitation are decisive in the occurrence of anthrax epizootics.

Figure 2.11. Gene network comprising genes under selection and those associated with climate variables in 21 Mediterranean breeds (Flori *et al.*, 2019).



The network was obtained using the Ingenuity Pathway Analysis software. Genes under selection are highlighted in yellow, those associated with at least one climate variable are in red. Shaded genes are not associated with any climate variable. The shape of the molecules is representative of their different families.

Taken together, these results indicate that local breeds are valuable genetic resources that should be preserved and integrated into appropriate management and genetic improvement schemes. This preservation appears crucial in the current context of the increasing incidence of crossbreeding with supposedly more productive breeds (under different environmental conditions) that can threaten these local breeds. It is also crucial in the context of climate change which imposes new environmental constraints. Genomic prediction of the vulnerability of breeds to these constraints is a new field of research, the results of which could make it possible to promote certain breeds that are less vulnerable in a given environment and to advise against others.

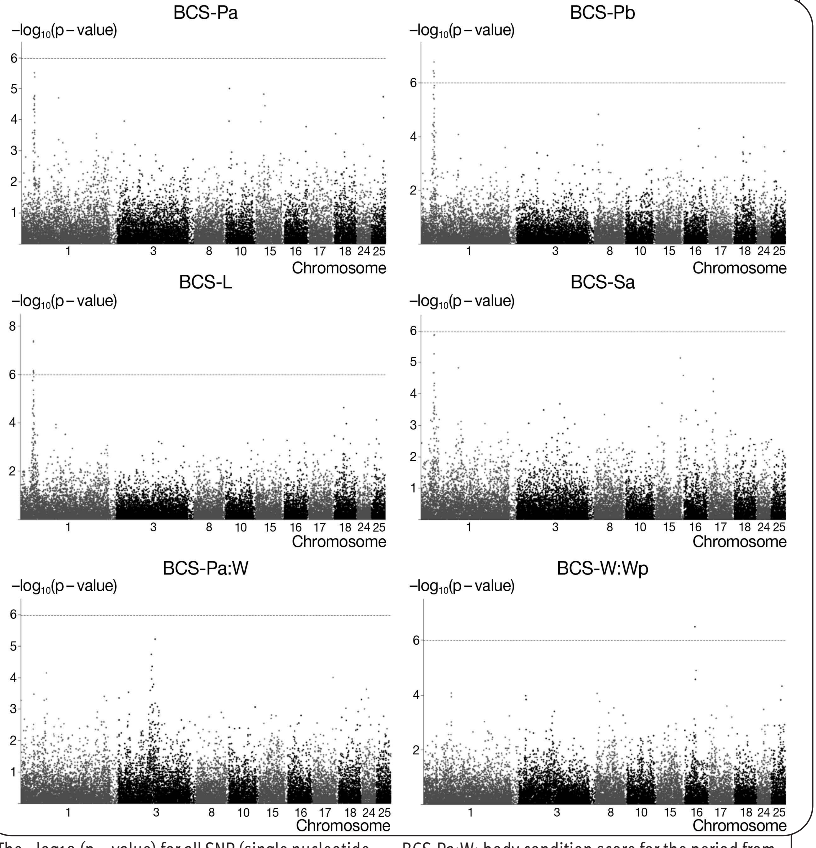
Study of intra-herd genetic variability in adaptation to constrained feeding conditions

In addition to previously reported work on cattle, in the conditions of the Massif Central in France, bordering the Mediterranean, we demonstrated a significant genetic component accounting for intraflock variability in BR mobilisation-reconstitution processes in the Romane ovine meat breed (Macé *et al.*, 2018a; 2018b; 2019). We have identified and described the spectrum of PV and NEC profiles present in the females of the flock and demonstrated intra-flock variability of these parameters and their dynamics during the mobilisation and reconstitution phases of the production cycle, and during the entire ewe cycle. Values of heritability h^2 greater than 0.2 were obtained, confirming the influence of genetic factors in the variation of these parameters in the Romane breed. Strong phenotypic and genetic correlations between mobilisation and reconstitution phases were also estimated (Macé *et al.*, 2018; 2019). In addition, we identified quantitative trait loci (QTL) responsible for the variability detected in the BR dynamics (Figure 2.12). Several candidate genes were identified, including three of interest: the LEPR gene, which encodes the leptin receptor, a plasma hormone of major importance in the regulation of adiposity levels and intake in mammals, the metabotropic glutamate receptor 1 (GRM1) gene, and finally the TRPS1 (*Tricho-rhino-phalangeal syndrom type I*) gene associated with weight gain during the post-weaning period, and regulator of the hypothalamic-pituitary-adrenal (HPA) axis acting on energy storage and expenditure. These results provide interesting avenues for the use of this (BR) adaptive trait in the design of genetic improvement schemes adapted to new challenges (climate change and agroecological transition of livestock systems), where the contribution of the animal component in the overall resilience of the systems should be important.

Managing the adaptation of local breeds at the farm level through farmer practices

The characteristics of adaptation of local breeds to their environment mean that they are theoretically interesting resources to be mobilised by farmers in the areas concerned. However, as we shall see, it is not so simple and the notion of adaptation can refer to a diversity of definitions and perceptions, but also to multiple practices implemented to manage or promote it.

Figure 2.12. Identification of QTLs that determine body condition score (BCS) in Romane ewes during several physiological stages (Macé *et al.*, 2022).



The −log10 (p – value) for all SNP (single nucleotide polymorphism) was plotted for chromosomes 1, 3, 8, 10, 15, 16, 17, 18, 24 and 25. The dotted line indicates the genome-wide significance threshold (BONFgen = 5.94). Chromosome-wide significance thresholds were OAR1: 5,02, OAR3: 4,96, OAR8: 4,57, OAR10: 4,52, OAR15: 4,49, OAR16: 4,45, OAR17: 4,42, OAR18: 4,43, OAR24: 4,14, OAR25: 4,26.
Candidate genes related to fat traits and lipid metabolic pathways.
BCS-Pa: body condition score during early gestation.
BCS-Pb: body condition score during late gestation.
BCS-L: body condition score during lactation .
BCS-Sa: body condition score for the period during early lactation, after lambing.
BCS-Pa:W: body condition score for the period from early gestation to just after weaning.
BCS-W:Wp : body condition score for the period beginning just after weaning and ending 1 month after weaning.
Five major regions identified on chromosomes OAR1, 3, 8, 9, 11.
Candidate genes related to fat traits and lipid metabolic pathways.
Pa: beginning of gestation.
Pb: end of gestation.
L: during lactation.
Sa: early lactation phase, after lambing.
W: just after weaning.
Wp: up to 1 month after weaning.

The livestock breeders perception of the adaptation of local breeds refers to a diversity of animal characteristics

In the framework of the genetic study of the local Mediterranean cattle breeds mentioned above, twenty surveys were carried out among breeders of the Corsican cattle breed so as to improve their perception of the breed's adaptation[10]. These semi-structured interviews, with mountain and plain breeders, breeders or not, crossing or not with other breeds, and belonging or not to the breed's management association, involved the following themes: history of the farm, characteristics of the breeding system, points of view and practices related to the adaptation and the link to collective action related to the breed. Not only do these surveys capture the diversity of adaptation characteristics cited by breeders (Table 2.4), but the thematic analysis of the interviews made it possible to clarify the diversity of ways of seeing each adaptation characteristic. In analysing the parts of the interviews associated with "animal autonomy for feeding" for example, we note that according to the breeders, this theme is associated with various animal characteristics: low animal needs, feeding behaviour, body condition that is seen by the breeders as a positive or negative characteristic of the breed, and various food resources valued by the breed. This analysis also provides elements on the perceived consequences of this autonomy, including the associated low cost, ease of management, the fact that the activity is not very time-consuming, and the fact that this autonomy could be out of line with social expectations. Finally, this analysis provides an explanation of the farmers view on the causes of this autonomy: some breeders consider that the morphology of the breed allows this adaptation, some consider it to be innate while others consider that it can be acquired, and finally some breeders consider that the practices can influence this adaptation favourably or unfavourably (Lauvie *et al.*, 2013).

Table 2.4. The frequency of quotation of adaptation characteristics mentioned by the Corsican cattle breeders surveyed.

	Percentage of farmers surveyed who mention the criterion at least once in the entire interview
Animal autonomy in feeding	100%
Morphology and external aspects	100%
Reproduction	95%
Adaptation to the territory	90%
Behaviour	85%
Resistance	80%
Meat quality	20%
Territory maintenance	50%

10. Interviews conducted during the internship of C. Rolland, INRAE, UR LRDE (2012-2013).

Taking adaptation into account in breeders practices and collective management

Perceptions of the adaptation of local breeds by livestock farmers are significant as they interact with their management practices and choices. Based on the cases of dairy sheep farming in Corsica and Thessaly, Lola Perucho's (2018) dissertation has made it possible to clarify the genetic management practices implemented by breeders in relation to their breeding system. This study highlights the different modes in which the adaptation characteristics of local breeds or individual animals are involved in these processes.

Adaptation characteristics may be involved in the choice of genetic types raised. Accordingly, the study of the trajectories of several breeders in Thessaly to analyse changes in breeds and in feeding systems (notably pastoral components of these systems) reveal that among livestock breeders who identify a mismatch between the genetic composition of the herd and the feeding system, three types of responses are possible: crossbreeding with a local breed, discontinuing the use of a highly productive breed, trying a different breed, or changing the feeding system. When the first response is chosen, it is clearly related to the adaptive characteristics attributed to the local breed (Perucho, 2018).

The notion of hardiness, frequently highlighted when referring to local breeds, can refer to a diversity of traits and also to various management methods according to the breeders. For some Corsican sheep breeders, for example, it can refer to different meanings: sensitivity to disease or climatic conditions, the development of rangelands in relation to production, walking skills, longevity of females (Perucho, 2018). Some breeders individually select their breeding stock on hardiness through indirect indicators, mainly morphological (coat, standard). Others consider that this hardiness is "acquired" via the breed or the breeding conditions. For example, transhumance enables a de facto selection by eliminating the ewes least able to follow the herd (animal loss) (Perucho, 2018).

For a same adaptation trait, the levers used by breeders to obtain a herd in line with their expectations are multiple: for example, out of 23 Corsican breeders mentioning susceptibility to disease as a trait of interest, only one breeder makes it a criterion for choosing internal renewal, while the majority only make it a criterion for culling (Perucho, 2018). In addition to internal renewal and culling practices, other levers may also come into play such as the criteria for choosing breeders who supply male breeding stock (Perucho, 2018).

The research conducted by Perucho (2018) also raises issues of interactions between individual breeder choices and collective breed management tools. Among the eight breeders of Corsican ewes surveyed in this study, all take into account the criteria of milk production and index (estimated genetic value) when choosing ewe lambs.

However, six of them also take into account other criteria (from two to four additional criteria depending on the breeder, including ancestry, fleece colour, breed standard, milking behaviour, dairy persistency and udder characteristics). As such, they combine the use of a collective tool and individual criteria to build a herd that is tailored to their expectations and systems (Perucho, 2018).

In addition, work on the practices of local breeders also reveals that in the processes that enable breeds to adapt to certain situations or constraints, other dimensions than biological ones can be considered, such as more social or organisational dimensions linked to the breeds. Consequently, Perucho et al. (upcoming) demonstrate how the group organisation of breeders around a breed can contribute to deal with a health hazard that the animals in that breed are facing.

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The issues of local breed adaptation therefore involve biological and genetic characteristics that are valued and managed by breeders in their individual and collective practices. The characterization of the biological and genetic mechanisms at work provide valuable information to improve the management of these breeds. Likewise, a better understanding of the practices of management stakeholders, and primarily of breeders, as well as the underlying views, contributes to the understanding of the evolution of genetic resources. The integration of approaches stemming from complementary disciplines is necessary for a better understanding of the interactions between human populations, animal populations and livestock environments, for which the adaptation of animal populations is one of the consequences.

The mechanisms of adaptation analysed at the level of families and local communities

Jacques Lasseur, Véronique Alary, Lina Amsidder, Martine Napoléone, Abdrahmane Wane

This section focuses on the analysis of adaptation processes of pastoral and agropastoral households in arid and Mediterranean zones, jointly addressing the social and biotechnical dimensions involved. Specifically, we analyse the contribution of three levers: (i) the diversity of situations considered at a household level from the point of view of a “capability portfolio” and at the local level from the point of view of a diversity of production systems, (ii) the importance of institutions and collective organisations considered through social networks and collective actions, (iii) the forms of learning while considering the references to standards and values that guide the action. The research conducted in Egypt, Chad, Morocco and France and described here illustrate the manner in which livestock owners mobilise and sometimes combine them, resulting in a shift from a situation that weakens households to one that strengthens solidarity and reinforces their sustainability.

The household capability portfolio as capital for implementing adaptation

In the context of a series of projects in Egypt between 2011 and 2021, a systematic approach of the living conditions of rural households was developed based on the conceptual framework of livelihood conditions developed by Scoones and made operational by Ellis (Sustainable livelihood Framework). From a conceptual point of view, we can distinguish between human capacities (the composition of the household and its degree of involvement in off-farm activities, in relation to the level of education), physical capacities (cultivated areas, their status and the numerical composition of the herd by species) and functional capacities (including the diversification of practices of supply and use of inputs, as well as the valorization of products and co-products at the interaction between agricultural and livestock activities, whether at the household, the community studied or the market level). This latter capacity is closely connected to existing social networks, such as intra-household and intra-community organisation capacity, but also in relation to the extended or formal family networks. These capacities were analysed in regard to the living conditions (at the studied time). The living conditions were determined through indicators of profitability (gross margin), food security (degree of food self-sufficiency in terms of family coverage of calorie and protein needs) and cash flow to meet basic needs (notably health, education and household food). Several approaches were used, namely narrative approaches based on life stories (enabling an understanding of the accumulation or lack thereof of physical capital), multifactorial approaches (highlighting the links between the various capacities) and multicriteria approaches to identify the causal processes between the various forms of capacities and living conditions.

All research demonstrates that the diversification of activities and practices, both agricultural and non-agricultural, constitutes a means (capacity for action) of sustaining household living conditions in the face of present hazards, whether it is a drought or a major health or ceremonial expense. And the intensity of this diversification is highly dependent on the diversity of social networks, particularly at the local level. However, this diversification of activities and practices does not systematically guarantee an improvement in living conditions. Moreover, it is most frequently developed to the extreme in households that have little physical capital and whose intergenerational sustainability through the land base is severely compromised (Alary *et al.*, 2014; 2016). In terms of medium-term adaptation capacity, research demonstrates how the diversification of livestock systems in terms of animal species, feeding practices, and the use of products and by-products can be used to deal with various hazards. As an example, in the newly developed lands in the West Delta, multi-species livestock production has made it possible to finance the costs of installation (whether it be a house floor or the cultivation of land) with the annual sale of calves, and to finance the operational costs of the household and the farm with the sale of sheep products (Alary *et al.*, 2018). In terms of long-term capacity (relative to intergenerational transmission), the study in the Nile Valley region illustrates how livestock production, in particular through diversification towards more prolific species (sheep and goats), has the potential to become the main source of sustainability for production systems, in relation to land fragmentation (Alary *et al.*, 2015).

In short, as highlighted in other cases, livestock activity is a guarantor of the viability of rural households and the sustainability of systems (Duteurtre and Faye, 2003; Pica-Ciamarra *et al.*, 2015). This capacity of livestock farming to contribute to the adaptation of rural households to changes in their social, economic, or climatic environment is based on the variable and adaptable combination of different services, products, and co-products that it generates, in addition to its intangible value in terms of recognition.

The role of the family in the adaptive mechanisms of Sahelian pastoral societies in the face of shocks

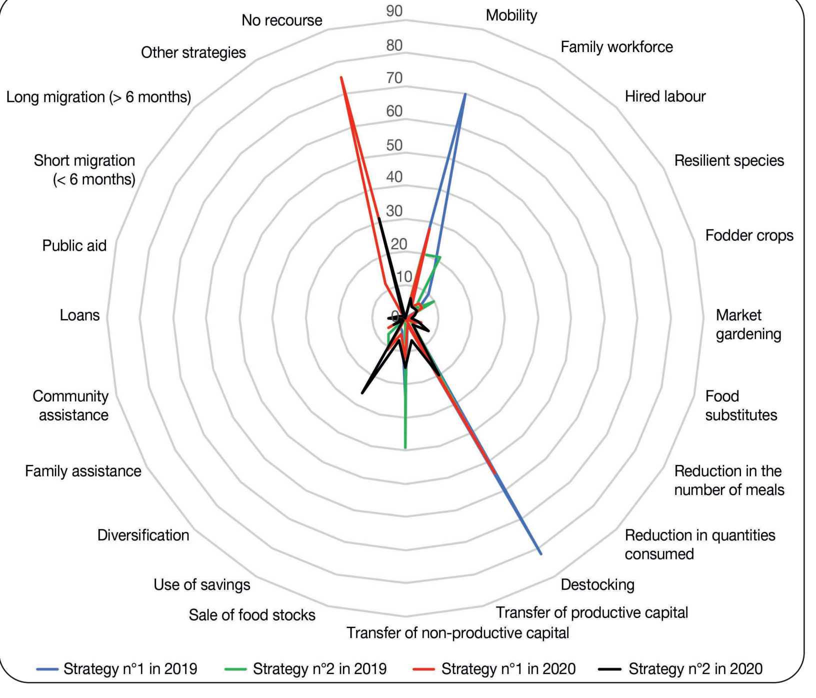
Agro-pastoralists in the Sahelian zone live and operate in an environment subject to multiple hazards and shocks. Climate variability has a direct impact on the dynamics of natural resources, leading herders to manage an uneven space-time availability of these resources. This climatic variability is also a factor that aggravates other economic, social, cultural and political disturbances. In addition, herders are confronted with a lack of basic economic goods and services that significantly impact their living and working conditions. The unequal distribution of productive resources is accompanied by limited information on the markets for goods and services, so that herders have an incentive to adopt a cautious position that is contingent to their socio-economic environment (Wane *et al.*, 2020b). As a result, herders must constantly compromise between their short-term consumption needs and their long-term herding strategy to satisfy future consumption (Fadiga, 2013).

The multifaceted shocks faced by herders can be “idiosyncratic” when they affect one household exclusively, or “covariant” when they affect a group of households, a community, a village, a region, an agroecological zone or a country (Wane *et al.*, 2020a). Faced with idiosyncratic shocks, herding households react based on their perceptions and try to overcome them by mobilising their own available skills and resources in the short or medium term, such as their family social networks and their livestock (**coping capacity**). In the face of covariant shocks, they use their ability to adjust, to mitigate the harmful effects of shocks or to exploit their beneficial effects, notably through diverse mobility regimes (**adaptative capacity**). The differentiated responses of herders to multiform shocks can reveal the significance of their perceptions of variations in their environment. An illustration can be provided by the case of (agro)pastoral households in the Wadi Fira, Batha and Ennedi regions of Chad. First, 504 households were interviewed in 2015 through detailed questionnaires on their activity and living conditions. After constructing a typology of these households, a sample of about 100 households were selected to respond successively in 2019 and 2020 to the same questionnaires with additional shock data. The objective was to identify various scenarios of shocks experienced during a predetermined period, to prioritize the three shocks that had the greatest effect on their income, assets, food production and purchases, food stocks and livestock, and to rank the various coping strategies according to their importance.

Herders in these three major livestock regions of Chad indicate that drought is experienced in the same way in 2019 and 2020 (around 15% of declarations reported by households). However, perceptions of the effects of bush fires and flooding are muted, and no reports of out-of-season rains have been recorded. The occurrence of animal disease has increased, while problems with access to veterinary care appear to be relatively less felt. Although proportionately small, animal health expenditures increased from 4 to 8 percent of reporting frequencies. Price shocks became more pronounced between 2019 and 2020 with an acute sensation of rising food and feed prices while animal prices declined.

In this context of multifaceted shocks, (agro)pastoral households developed a range of strategies deployed in sequence and implemented in a prioritized manner (Figure 2.13).

Figure 2.13. Changes in strategies deployed by (agro)pastoral households before and during the Covid-19 pandemic (Wane *et al.*, 2020a).



In 2019, households prioritized (no1 strategy) destocking livestock (35% of response frequencies), adopting mobility (30%) or disposing of non-directly productive capital (10%) such as jewellery. As a secondary strategy (no2 strategy), they favoured disposing of non-productive capital (22%), followed by destocking (21%) and finally, using family labour (12%).

In 2020, there was a shift in the form of stupor on the part of agropastoralists who, with the effects of the Covid-19 pandemic (drastic restriction of movements and ban on gatherings), lost an average 34% of their overall income. In fact, households reported having no strategy (32%) and to a lesser extent, seeking to destock (23%) or even adopt mobility (12%). As secondary strategies (no 2 strategy), they continue to report either their inability to develop any strategy (19%), or the use of family savings (16%) and destocking (13%). They are not inclined to favour the use of aid, demonstrating their conscious choice to mobilise endogenous strategies and to rely, first and foremost, on their own system of actions rather than relying on third parties in the form of subsidies, aid and credit.

Ultimately, Sahelian herders cope with shocks of various kinds by mobilising their own resources. Their capacities are the result of a long process of learning by experience (Wane *et al.*, 2020a). Nevertheless, they seem to be very limited in the face of new shocks such as the Covid-19 pandemic. This is because government strategies to control the pandemic (restrictions on movements, prohibition of gatherings) have greatly altered the individual and collective means of action of Sahelian herders.

The reshaping of herder social networks to access pastoral resources

Research conducted on societies that live off camel herding in arid and semi-arid zones in Morocco between 2017 and 2021 highlighted the importance of customary collective organisations in the herder mobility practices. Qualitative analysis of semi-structured interviews conducted between July 2018 and February 2020 with a sample of 43 camel herders in the Guelmim Oued Noun region of southern Morocco on their mobility practices highlighted the importance of the tribe. In an arid and hostile environment such as the Sahara, it constitutes a sense of belonging, based on kinship and the existence of a common ancestor, within which herders benefit from a “protective and nurturing solidarity” (Caratini, 2003). Whether it is the individuals with whom herders share information about grazing locations or those with whom they travel or camp, the vast majority of herders turn to their tribe members, whom they can rely on in the name of fraternity and the value of blood ties. The interviews revealed the gift/contribution system on which tribal solidarity is based, which relies on intra-tribal marital alliances as well as on gifts of animals or money during ceremonies such as tribal feasts or weddings, or in the event of difficulties (divorce, conflicts). While the tribe constitutes a network on which herders can rely in the event of difficulties, it is also a source of significant social pressure insofar as all of its members must honour the system based on reciprocity of exchange, or else “become an outcast, at the mercy of any calamity” (Gaudio, 1993).

The historical bibliography ranging from the pre-colonial period to the years of independence (1958) as well as open interviews conducted in December 2019 with five chioukhs[11] and four women aged between 50 and 60 years with their children in their twenties highlighted the numerous socio-political changes that the Moroccan Saharan and pre-Saharan areas have undergone. The framework of analysis of political geography has led us to interpret these changes in terms of the reshaping of power relationships between tribal customs and state stakeholders for the control of the grazing area. The herders have adjusted to these changes by diversifying their networks to access grazing resources. In the pre-colonial period, the pastoral space consisted of a “mosaic” of tribal territories (Caratini, 2003), which evolved according to the tribal wars during which each tribe ensured that the territory under its control was extended. In this way, the tribal network was the only one in which the individuals were integrated and on which they depended for access to the tribal lands and for the guarantee of safety and protection. The Spanish and French colonisation from the end of the 19th century onwards brought about the placing of tribes under guardianship, the establishment of state borders and the ending of tribal wars in the name of “colonial peace”. The tribal network was still the fundamental network, but the climate of security created on the rangelands following “pacification” meant that herders had greater freedom of movement. In addition, the relationship with neighbours from other tribes became increasingly relevant as herders relied on these to gain access to new rangelands. Since Morocco’s independence in 1958, the issue of territorial control has been at the heart of state concerns. This results in a grid of pastoral space by means of an overlapping of state territories (caïdats, rural communes), within which the state grants power of control over space and populations to several stakeholders (caïds, communal presidents, chioukh). This state control does not translate into a decrease in the power of the traditional tribal stakeholder. The tribe continues to act in an implicit manner by integrating state institutions. The sons or grandsons of traditional chiefs from the colonial period or descendants of large families have been given official functions (chioukh, communal presidents) and rely on them to defend the traditional territory. In the face of an increasingly complex territorial network, where traditional and state territories are intertwined, herders must maintain networks with a variety of stakeholders in order to gain acceptance for their presence in the various territories in which grazing resources are located.

From individual adaptations to the sustainability of collective actions in the case of a regional product

In this example, we examine the tension in the process of adjusting to changes in food systems arising from the development of territorial dynamics and the management over time of a regional product, seen as a common asset. We draw on work conducted in south-eastern France on the transformations of dairy and cheese activities, in particular

11. Tribal leaders as well as state agents.

within collectives managing regional products (Napoléone, 2016). This study focuses on the trajectories of dairy and cheese activities in the territories, as well as the connections between individual and collective dynamics. For this purpose, comprehensive interviews were conducted with livestock farmers, local product groups and regional stakeholders between 1990 and 2020.

The protected designation of origin (PDO) syndicates constitute a forum for the construction of standards and values based on a common project, for a diversity of stakeholders concerned with a local product: farm or dairy producers, refiners, artisanal processors, SMEs (small and medium-sized enterprises) or national groups. Each stakeholder has its own objectives and strategies, for example in terms of marketing, but all share the same concern for differentiation and protection of a product.

Consequently, since the 1990s, in order to protect their products from being copied from outside the region, producers and processors of the four goat cheese sectors in south-eastern France (Picodon, Pélardon, Banon, Brousse du Rove) have applied for official recognition of their products through a quality mark linked to their origin. For the various stakeholders involved, the PDO constituted a means of identifying themselves, of taking advantage of their specificity and of protecting themselves from out-of-area copies, at a time when the main distribution channels were long circuits. The path towards certification has enabled stakeholders in these sectors to identify themselves around common values relating to farm and artisanal processing and breeding practices, and then to manage these values over time, as the specifications are revised, in order to adapt to a certain number of changes, for example the evolution of societal values, by emphasizing the link to local resources.

Currently, the development of territorial dynamics, the enthusiasm for the local and proximity promote the emergence of forms of sale that put producers and consumers in direct contact. These dynamics multiply and diversify the possibilities of product sales, in particular for farm producers. This encourages individual dynamics, with producers redefining expectations with regard to production methods and products, directly with their partners and with consumers. Forums for discussion and dialogue on local products are becoming more diverse and fragmented. In some PDOs, the renewal of operators is a challenge. If this type of dynamic continues, there may be a risk of losing a platform for collective discussion of quality.

This clearly demonstrates how individual adaptation to a changing situation (the multiplication of outlets in short circuits) can jeopardize a collective issue related to the management of a common asset. However, this product is an asset attached to a territory, which benefits from the values of the territory. Conversely, the territory builds its image and appeal from its resources. Moreover, the product is a messenger for the territory through the various sales channels, from local to global.

In a sustainability approach, PDOs are working to strengthen the synergies between territorial dynamics and those related to local products and individual strategies. Adaptation at the collective level therefore involves (i) connectivity between networks, those linked to product management and those linked to territorial dynamics, (ii) openness to diverse points of view, and (iii) multi-scale.

The diversity of exchange modalities between livestock farmers and other stakeholders to reinstate grazing activities in the territory

Livestock farming in the Provencal hinterland, primarily ovine, has changed over the last few decades as a result of changes in the conditions under which the activity is carried out in an adaptation or transformation process. Based on a study conducted on a regional scale in the Alpes-de-Haute-Provence (Lasseur and Dupré, 2017), we analyse ex post the contribution of these adaptations to the expression of a current diversity of modalities for carrying out the activity. We then illustrate the role of this renewed diversity and of the modalities of interaction between stakeholders in the ongoing redefinition of the local farming system. In order to do so, we rely on the theoretical and methodological proposals of J.-P. Darré, which aims to comprehend the production of action-oriented information as well as its transformation by considering it to be governed by standards and values that are established within communities (Compagnone *et al.*, 2015).

We have identified 3 contrasting types of livestock farming: small mountain farmers (PPM), dual transhumant herders (DTP), and diversified livestock farmers (DIV), which are distinguished (i) by their farming structures, (ii) by specific and distinctive practices, (iii) by the meaning given to their profession, and (iv) by special relationships outside the agricultural sector. These characteristics give them a unique weight in the innovations that have marked the recent period as well as in those that are currently in the making (Table 2.5).

The proximity of a farm to one or another of these ideotypes can be linked to specific conditions of location or resource allocation. In this way, the diversified livestock farmers are more likely to be at the head of small farms. These affiliations are also related to life choices and visions of the profession, which lead to highlighting one or other structuring practice of production orientations. For example, the PPMs emphasize forage cultivation (and mechanization) as well as the practice of grazing in parks.

This is in contrast to the DTPs, for whom a mainstay of their system is to favour grazing as far as possible, to keep large flocks, a sign of passion for the profession in reference to the emblematic figure of the “shepherd”. This has led them to develop winter mobility to ensure year-round grazing. This in turn has allowed them to free themselves from a high number limit conditioned by the quantity of forage that can be harvested from cultivated land, enabling wintering of the flock in the sheepfold, which is the basis of the reasoning of the PPMs for the sizing of the flock. The options for adaptation on the farm level are therefore not based solely on inherited structures, but also on the capacity to seize and create alternative opportunities, which must, however, remain compatible with local standards and values (under threat of ostracism).

Table 2.5. Main characteristics of the three identified breeding ideotypes.

	Farm structure	Emblematic practices	World view	Filiation and condition of emergence	Relationships with other parties involved (excluding agriculture)	Involvement in ongoing adaptations and transformations
Small mountain farmer (PPM)	300 to 500 ewes	Out of season lambing Quality label for marketing	Supporting each other within the farming sector to maintain the rural community	Inherited from farming modernization movement (1960)	Low: focused on the agricultural sector	Improvement of work productivity and farm margins
Dual tran-shumant pastoral (DTP)	500 to 2,500 ewes	Wide range mobility Focus on shepherding practices and favor grazing for the flock	A strong meaning of its work is within the relationship with the flock Manage room for its own individual freedom	Historical ways for pastoral livestock farming, supported now by the agri environmental policies	Medium: relationship with landowners and environmental operators to get new grazing areas	Strengthen the contribution of grazing to the management of ecological dynamics of «semi-natural» environments
Diversified (DIV)	Up to 300 ewes in diversified farms	**Marketing in short chains** **Get additional income from tourism activities** **Promote the use of local resources**	**Involvement in local interactions and valuing the activity among non-farmers**	**At first a default option, now supported by local development policies**	**High: targeting consumers** **Involvement in local associations** **Local elected**	**Development of marketing in short chains** **Associate the development of livestock with the development of tourism** **Care about the multiples uses of pastoral areas**

All of the livestock owners we met clearly identify with one or other of the ideotypes and distance themselves from the choices made by livestock owners who are closer to another type. Nevertheless, all agree that it is possible and legitimate to practice differently than they do. This allows some to transcend categories and to invest in the archetypal practices of other forms of animal husbandry: for example, one PPM displays a passion for herding that he implements as a mountain herder by subcontracting farming activities. Another PPM uses sylvo-pastoral developments and consequently develops intense interactions with territorial stakeholders in other sectors. This fluidity can be attributed to spaces that facilitate the sharing of opinions, notably within the pastoral groups, which are the collective organisation of summer grazing. As a result, all these livestock farmers meet in the summer grazing areas, and even combine their herds within the collective entities that constitute the pastoral groups. In addition to the structuring of a solid sector and organised industries, the adaptations/transformations that will strengthen the future of livestock activities in these areas are based on the ability to forge alliances with other stakeholders and on the re-legitimisation of livestock activities, on the fluidity of the exchange of ideas and viewpoints, which goes beyond the agricultural stakeholders alone, and which allows for the evolution of the standards and values that govern the activity. The role of DIVs and DPTs is fundamental from this point of view, as they ensure the porous character of the local livestock system to issues carried by stakeholders in the territory outside the agricultural sector.

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These five case studies illustrate the link between the three dimensions - (i) diversity, (ii) the role of organisations and institutions, and (iii) forms of learning to strengthen adaptive capacities. The latter occurs both at the level of individual herder families and at the level of the activity as a whole. Diversity is involved in the sense that it allows families to build a portfolio of resources to deal with the uncertainty. This dimension is also strongly implied in its capacity to promote innovation in the communities. This collective capacity to respond to changes in the conditions in which the activity is carried out is closely linked to the institutions and networks that allow for the expression of solidarity and constitute places of learning.

These case studies highlight the mechanisms of adaptation of the breeding activity and the livestock families to changes in the conditions in which the activity is carried out. Diversity is one of the components, whether it is the household capability portfolio supporting the living conditions of the households or the coexistence of a diversity of activity systems contributing to adapt the range of standards and values that govern the activity. The collective organisations and institutions that govern relations between individuals and the collective, whether they are networks of social interactions, traditional organisations or project collectives, also play a central role in the emergence of these adaptations and learning support. The adaptation of livestock farming societies is based on their capacity to deal with diversity and learning by relying on formal and informal collective organisations that allow them to reinvent themselves according to the environmental, social, economic and political changes and the multiform shocks that arid and Mediterranean zones experience.

Adaptation trajectories of livestock in the territories: where does grazing fit in? What are the key factors?

Claire Aubron, Johann Huguenin, Marie-Odile Nozières-Petit,
René Poccard-Chapuis

This section examines the adaptation trajectories of livestock farms in contrasting territories located on three continents, over a long time span of several decades. The research outlined here aims to: (i) reconstruct these adaptation trajectories, with specific emphasis on the evolution of the role of grazing; (ii) understand the determinants of these trajectories, whether local or global; (iii) assess the extent to which these trajectories are consistent with sustainable development.

The Causses and Cévennes: mechanised fodder production, farmers on the verge of extinction

Since the 1950s, farms in the Causses and Cévennes, like elsewhere in France, have experienced a period of specialisation and a continuous increase in size. The environmental conditions, less favourable than in the plains to an increase in physical labour productivity in crop production, have favoured a specialisation in livestock: dairy or suckling ewes in the Causses, dairy goats or suckling ewes in the Cévennes. The expansion of farms has also been based on a continuous increase in their investment in equipment, which currently amounts to several hundred thousand euros per farm. In places where it was possible to use them, increasingly powerful motorised mowing equipment, sometimes combined with motorised fodder distribution systems, enabled a significant increase in the volume of milk produced per farm (up to twenty times more milk than in 1950 in caussenard dairy sheep farming), with a low contribution of grazing to the ration (Aubron *et al.*, 2016; 2019).

Our research based on the comparative agriculture analysis framework shows that these developments, which are problematic both in terms of employment and maintaining an open environment, correspond to adaptations of farms to global socio-economic changes. European and French policies to support investment, the downward trend in agricultural prices in real terms, and the allocation of subsidies per hectare or per livestock capita with no strict capping mechanism following the abandonment of price policies from the 1980s onwards, all encourage farm enlargement and leave few alternative choices. As a result, the most modest farms or those with no easily mechanised land were not able to make these adaptations and disappeared massively, leaving the landscape to scrub. The larger and better situated farms (deeper soils on the Causses, wider valleys in the Cévennes) were equipped for mechanised fodder crops and turned to dairy farming under a quality label (PDO Roquefort and Pélardon). Those with less labour force and less mechanised land have often opted for suckling livestock, which grazes more but creates fewer jobs.

A different type of trajectory focused on product processing and marketing in short distribution channels completes this picture: initially taken by neo-rural farmers who set up goat farms in areas abandoned in the 1970s, this path is now also being explored by ewes (Causses) or goats (Cévennes) farmers who until now have delivered their milk and struggled to expand or maintain their access to milk collection channels. For similar reasons, suckler ewes or cows farmers are developing direct meat sales for all or part of their production (Nozières-Petit, 2019). Apart from a few so-called frugal farms, this evolution towards short distribution channels and processing is not systematically associated with an increased use of grazing in the animal's diet (Garambois *et al.*, 2020). It is nonetheless of interest as it reflects adaptations to local conditions that can counterbalance national and European determinants.

The Brazilian Amazon: restructuring the relationship between livestock and forests

Bovine rearing has long been emblematic of these "Open Veins of Latin America" where E. Galeano (1971) condemned the plundering of natural resources, notably at the expense of small rural producers. The short history of beef in the Amazon began in this way. In 1960, the federal government launched the "colonization by cattle ranching", which established cattle ranching as a tool for occupying the territory, and consequently deforestation and land conflicts.

This is a land of cattle ranching born out of the ashes of the forest: fifty years later, four times as many cattle as people live in the Brazilian Amazon. 86 million zebus graze on pastures twice the size of Germany, forming the world's largest livestock basin on the "Arc of Deforestation. Livestock farming, conducted in extensive systems, proved to be extremely well adapted to the conquest of territories in a pioneer front situation. Even if exotic, the Brachiaria grasses and the Nelore zebu breed adapted very well to the Amazonian ecology, and the migrants were able, with very little workforce, to open and expand cattle farms with fire as their main tool. As appropriating land was the primary objective of the migrants, livestock production was quickly democratised, stepping out of the traditional framework of large farms and spreading to family farms, some of which began to produce milk (Poccard-Chapuis, 2004). However, oversimplified animal husbandry practices, favouring expansion rather than grazing management, resulted in significant waste of natural resources, including organic matter accumulated in soils by forest ecosystems. Since 2005, the government introduced an arsenal of repressive measures to prevent further deforestation. The land logic that had previously governed livestock systems was halted, with the exception of the pioneer fronts where deforestation continued illegally.

A new period of adaptation then began, starting with limited land, degraded soils, and technical baggage that had become unsuitable for most farmers. Grazing is at the heart of the transition: it is no longer simply a matter of suppressing the seeds of woody species to prevent the return of the forest, but of ensuring an optimized forage supply, making the most of rainfall and sunlight in the equatorial climate. Livestock production must provide income, rather than the heritage function. This implies managing soil fertility: rotational grazing is the most accessible technique, as the integration of an annual crop of maize or sorghum in rotation with the grassland is not possible in all regions, nor for all farmers due to the high cost of machinery and fertilizers (Burlamaqui, 2015).

But behind this technical change, the whole landscape is changing, and the whole territory must be mobilised to lead this transition. By investing more resources, work and know-how in their grazing lands, herders tend to concentrate on their best lands, leaving the least suitable to revert to the forest. A new forest system is established that is better able to produce services because it occupies the slopes and wetlands, forming corridors that connect the forest blocks (Pinillos, 2021a). In conditions that have become drier due to the reduction in forest cover, accidental fire or fire used by individuals for land or cultivation purposes threatens the investments undertaken, and the territorial stakeholders must organise themselves to control it. To accelerate and control these large-scale processes, landscape restoration plans based on soil suitability are being developed by city councils, such as along the Belém-Brasilia road, where the first Amazonian pioneer front began. Systems for monitoring environmental performance are being created, so that producer groups and value chains can attest to their progress, and in this way organise value chains or attract sustainable investments.

After providing a land tenure function, environmentally disastrous due to its impact on the forest and soils, an intensification of Amazonian livestock is underway. Whether this intensification is agroecological (rotational grazing, legumes, fodder trees) or part of the green revolution (fertilizers, herbicides, mechanization), it is implemented by young farmers and represents a generational shift. The resulting increase in land value may, as has been the case elsewhere in South America, benefit the highest bidders, and see grazing land replaced by soyabean, eucalyptus or oil palm plantations, where the soil and transport infrastructure favour these crops (Osis, 2019).

Maghreb: less and less pastoral breeding, reinvented mobility

Grazing in North Africa was adapted to the biophysical constraints. It has fluctuated since Roman times. This extensive livestock farming was practiced by families with small ruminants grazing on modest vegetation, but adequate to provide milk, meat, skins and wool. The grazing ecosystem was maintained thanks to the mobility of families living in tents (the *khaïma*, the *guitoune*).

From the 1950/60s, several factors have impacted this grazing: population growth (32 million inhabitants in 1960 and 93 million in 2020), the development of crops on former rangelands, changes in access to resources (land laws, customary uses of the *Arch* (Bessaoud, 2013)) and multi-year droughts (OSS, 2008). During severe droughts (1970/1980), states began to provide partially imported and subsidised grain barley for animal feed. Once this practice was under control, livestock numbers increased. As a result, the ovine livestock population increased from 10 million in 1960 to 57 million in 2018 (FAOSTAT) for 62 million hectares of rangeland (¾ between isohyets 100 to 400 mm/year). Grazing productivity, under the combined effects of droughts and intense farming, has fallen by 60% (Mahyou *et al.*, 2018), as predicted by Le Houérou in 1995.

Barley cultivation is central to the livestock producer's strategies. They sow it every year. If rainfall is satisfactory, the grain is used for animals. It also allows for early spring grazing. After the harvest, the stems are valued grazing land (which can be rented at a high price) and in the fall, regrowth is grazed. In years with high rainfall deficits, barley crops are used as grazing land (damaged barley). In these livestock systems, the feed cover of animals by natural grazing is less than 35%, even 10% in central Tunisia (Jemaa *et al.*, 2016). The various pastures provided by barley and hay represent 25% of the requirements, while the remaining 40% is met by concentrates (Hadbaoui *et al.*, 2020). Even if its contribution to the feed is low, transhumance is still practiced by farmers who can use trucks, shelter areas (most often at a cost) and shepherds (family members or employees). As a result, farmers have at least two hundred ewes in their herds. Smaller farmers have access to grazing land adjacent to the homestead (stubble, damaged barley, fallow) and must maintain a constant supply of concentrate. These grazed lands are either rented or free for the shepherds who look after animals belonging to one or several owners working outside agriculture. Transhumance routes are rain dependent and are managed by telephones and trucks. Livestock owners take more varied paths than in the past and change from year to year depending on the rainfall in the regions and the price of land rental for grazing (Gaci *et al.*, 2021). Summer transhumance grazing (stubble, natural rangeland) saves farmers kilograms of grain (concentrate intake is reduced from an average of 600 to 300 grams per day and per head).

Sustained by high demand, notably during religious festivals, and with limited competition from imports, which are heavily taxed (200 to 300 percent depending on the country), the price of ovine meat is high. On the condition of having a certain number of animals and having access to enough grazing land and barley to cope with the variations in climatic conditions, livestock farming ensures an income. Livestock farmers have become agro-pastoralists, or even farmer-herders. This adaptation ultimately makes livestock farming vulnerable, as cultivation on fragile land and overgrazing of rangelands encourage desertification. Since 1980, 11 million hectares of rangelands have been cultivated, threatening neighbouring lands with desertification through silting, and 14 million hectares of the steppe zone are affected by desertification (Bencherif, 2018; Snaibi and Mezrhab, 2021; Abaab *et al.*, 2020).

Cross-sectional analysis

The cases presented in this section illustrate the continuous and significant adaptations of livestock farms in the territories. Over the last few decades, livestock farms in the regions studied have changed in *size* (enlargment in France), in *form* (family farms vs. large livestock estates in Brazil, recruitment of paid shepherds in North Africa), in *production* (shift from suckler farming to dairy farming in Brazil, opposite movement in France), but also in *practices*. In France and in North Africa, the contribution of grazing to the feeding of the herds has decreased significantly, replaced by fodder grown on the farm and by purchased feed concentrates. In Brazil, on family farms where livestock production has developed, grazing is managed more intensively: it has become rotational and is sometimes rotated with an annual crop of maize or sorghum. In response to predation by wolves, farmers and shepherds in France have sought to adapt their practices, in particular on mountain grazing lands (Box 2.1). Moreover, the territories and operators in the sector - in this case, mini-dairies - are also adapting, developing their local collection from a core group of farmers, contributing to the settlement of these groups and encouraging them to intensify their practices (Box 2.2).

The determinants of these adaptations are diverse and operate at varying scales. Public policies, and their impact on the price of products and inputs, have played a major role in France (credit, pricing policies, subsidies that replaced them), but also in the Maghreb via the price of concentrates, which in some cases have been subsidised, and the price of ovine meat, whose imports are taxed. The mandatory nature of a minimum local collection in order to operate in the country imposed in West Africa is another example of the influence of national or supranational political choices. In two of the regions under review, *land use regulations* have also played a role, whether by controlling deforestation from 2005 onwards in Brazil or enabling the private appropriation of cultivated areas and hence transforming the pastoral space into an agropastoral space in the Maghreb. At a more local scale, ecosystem transformations have also been at the origin of certain adaptations, whether it is the closing of landscapes (France), the rapid development of weeds on grasslands reclaimed from the forest (Brazil), climate change reducing the productivity of pastures (Maghreb) or the return of a predator like the wolf in France. *Human demographics*, the balance between generations among the local population, and their more or less extensive investment in local or more remote non-agricultural activities have also led to adaptations (e.g., neo-rural farmers in the Cévennes, management from cities of certain large grazing herds by prominent people in North Africa, and the pioneering migratory flow and different aspirations of their descendants in Amazonia). Finally, changes in the *demand for animal products*, whether expressed locally or nationally, have also played a role, encouraging family farms to produce milk in the Amazon, promoting the development of processing and short supply sales channels in France and stimulating the collection of local milk in West Africa.

It must be noted that these adaptation trajectories, which have now been explained, do not systematically lead to sustainable development in the territories.

Accordingly, the reduction in the contribution of grazing to animal feed observed in France and North Africa is contrary to the principles of agro-ecology: it limits the energy and feed autonomy of farms and contributes to the overgrowth and closure of the landscape in France. In addition, not all farms are always able to adapt and therefore these trends exclude some livestock farms: In the Causses and Cévennes, farms with limited

Box 2.1. When adaptation is no longer enough: farmers dealing with wolves in France.

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For reasons of safety to humans and damage to livestock, wolves had been eradicated in France in the late 19th and early 20th centuries. There were no wolves left when the country made a commitment in 1992, within the framework of the EU Habitats Directive, to contribute to the restoration of the species under protected status.

The arrival of wolves in France from Italy was only made public in 1993. As the arrival was not anticipated, farmers were in no way prepared to deal with it. This is in contrast to other regions of the world, such as north-western United States, where all parties likely to be affected by the wolf restoration programme, starting with farmers and hunters, had been invited to negotiate for 10 years before the first release (Meuret and Osty, 2015).

In nearly 30 years, farmers in French regions where wolves are present have tried to adapt to this new constraint, as soon as contracts and financial aid have allowed them to adopt the recommended protection measures: reinforced human presence, guard dogs, secure fences, systematic return to night pens or sheepfolds. Currently, in the Alps and in Provence, the adoption of these measures is widespread, embodying the adaptation effort of the farmers, with the number of protection contracts for farmers closely corresponding to the number of grazing units, in particular on the alpine meadows (Meuret *et al.,* 2017). However, the effects are sometimes harmful: difficult co-existence with a shepherd's assistant in cramped alpine huts; conflicts with hikers due to guard dogs; conflicts with hunters related to the erection and electrification of fences; twice-daily movements to and from the pen at night that disrupt the routes of the shepherds and also generate soil erosion and damage to the grasslands.

While farmers and shepherds have gradually adapted, most are experiencing considerable work-related discomfort due to the direct and indirect consequences of the attacks. In addition to the dead animals, there are also losses in physical condition, sometimes mass abortions, as well as drops in production linked to the stress generated (Meuret *et al.*, 2017). The constant and linear progression of the annual number of wolf victims: + 1,000 animals killed or mortally wounded per year between 2009 and 2019 in France (Meuret *et al.,* 2020), with a total in 2019 of around 15,000 victims (all animal species, those found but also those missing as a result of the attacks) demonstrates the limited results of the efforts to implement herd protection.

The adaptive capacities of wolves, highly intelligent and opportunistic carnivores, have not been anticipated or have been insufficiently anticipated. Wolves learn to bypass the obstacles erected by farmers, especially when there are no serious consequences for them and their offspring. This is a dynamic of co-adaptation between humans and predators, a constantly evolving process and one that it would have been much wiser to consider (Meuret *et al.,* 2020).

Box 2.2. The adaptation of industrial dairies to small-scale producers in West Africa.

Christian Corniaux, Guillaume Duteurtre

Collecting milk in West Africa is expensive. The fragmentation and low productivity of rural livestock farms have resulted in an increase in price of around 100 CFA francs per litre of milk collected, which is one-third of the price paid to the dairy. Competition with imported milk powder, notably from Europe, is intensified in a market dominated by urban consumers with low purchasing power. Dairy manufacturers, located in the capital cities, prefer this cheap powder. Out of a hundred companies, only twenty or so collect milk. Sometimes constrained by national enforcement measures (compulsory quota), they also see in this collection of local milk a focus for their corporate social responsibility (CSR) actions and a means to enhance the value of their products on a few profitable niche markets.

As a result, these companies adapt to the conditions of the farmers to encourage them to produce and sell their milk (Corniaux, 2019). The main lever is the price, which is kept relatively high throughout the year. The second is the provision of feed for milk. A major effort is also invested by the dairies to increase the size of the logistical resources. Furthermore, often with the support of development projects, they support the progressive setting-up of intensified mini-dairy farms to complement the established dairy farms. The cost of collection is then significantly reduced, making the processing of local milk more profitable.

land resources that are easy to mechanize were at a disadvantage in mobilising these new means and tended to disappear; in North Africa, farms equipped with trucks and able to employ hired labour can explore more distant grazing areas and thereby feed larger herds with greater security in the face of hazards; In West Africa, livestock with a strong pastoral component, highly mobile, have difficulty accessing the milk collection circuits of the mini-dairies and must therefore find alternative outlets for their milk. Finally, the adaptation to predators in France generates an intense stress for farmers.

Studying adaptation trajectories and their determinants appears to be essential in identifying the levers that can lead to the evolution of livestock activities in the direction of sustainable development. Rendered possible through the mobilisation (or even the construction) of adapted analytical frameworks and research devices, comparisons between nearby territories (the Causses and Cévennes, for example) or more remote ones (France and North America on predation) often prove profitable. This research makes it possible to highlight and reason various levers, such as the subsidy allocation rules of the Common Agricultural Policy (CAP) and the collective choices made within the Roquefort or Pélardon quality approaches in the Causses and Cévennes, on corporate social responsibility and dairy policies in West Africa, or on land tenure regulations in Brazil and North Africa.

Conclusion

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Several insights into livestock adaptation can be derived from the work outlined in this chapter.

First of all, even if this is a trivial result for any careful observer of livestock practices and the livestock world, grazing systems are continually adapting and transforming. In this respect, they are far from the archaic and unchanging character that they are sometimes portrayed as. Faced with changes in climate, variations in forage availability, the presence of disease, changes in price conditions, the arrival of a predator, the emergence of a demand for new animal products, or a major political upheaval, adaptation processes are in fact observed on these farms, which appear to be closer to permanent movement than to stagnation. This suggests that taking an interest in the adaptive capacities of animals, farms or value chains, for example, is just as important as evaluating their productivity.

Furthermore, it is clear that these adaptations are based on a variety of levers. These levers are of varying natures (physiological, genetic, technical, organisational, social, etc.) and operate at different scales (animal, farm, landscape, group of farmers, etc.) and on different time scales (short, medium or long term). Many of these levers are also interdependent, which renders the adaptation processes highly complex. It is crucial to take into account this diversity of levers in research and in the support of livestock development, which calls for the generation of information on each of these levers and for their integration through multidisciplinary and systemic approaches. This work highlights key elements that preserve or even increase the adaptive capacities of livestock, such as genetic diversity or livestock farmer groups, which are discussed in the subchapters on genetic diversity and adaptation of local breeds to their environment, on mechanisms of adaptation analysed at the level of families and local communities, and on the adaptation trajectories of livestock in the territories.

The fact that adaptation is not always synonymous with sustainable development constitutes a third lesson in this chapter. In fact, adaptation is sometimes associated with the exclusion, undermining or disappearance of certain entities that previously constituted the livestock sector of a region. The animals, landscapes, practices and forms of livestock production selected as a result of these multiple and intertwined adaptation processes are not necessarily those that best meet the objectives of sustainable development. This observation indicates that, in addition to including adaptation in research and support for livestock development, there is a key challenge in steering and managing these adaptation processes in the direction of more sustainable development. The production of integrated (multidisciplinary and multi-stakeholder) and situated knowledge, as well as public and collective action are key elements in meeting this challenge.

Finally, by taking the concept of adaptation a step further, we can question the capacity of these adaptations in livestock farming, however numerous and articulated they may be, to respond to contemporary social and environmental issues. As pointed out by authors working on the history of energy and biomass use by societies (sociometabolic regimes), does the transition to an agroecological agriculture that so many institutions are now calling for not require more profound changes, on the same scale as the Neolithic agricultural revolution or the industrial revolution (Haberl *et al.*, 2011)? Alongside the study of livestock adaptations and their management, work on the analysis, design and support of innovations and breakthroughs in agricultural practices, societies and policies appears necessary.