Time to outbreed animal science? A cattle-breeding system exploiting structural unpredictability: the WoDaaBe herders in Niger

Saverio Krätli

Correct citation: Krätli, S. (2008) *Time to outbreed animal science? A cattle-breeding system exploiting structural unpredictability: the WoDaaBe herders in Niger*, STEPS Working Paper 7, Brighton: STEPS Centre

First published in 2008

ISBN-13 978 1 85864 699 5

Thanks to Harriet Le Bris for help with copy-editing and Graeme Cumming and Brigitte Kaufman who kindly provided peer reviews.

Design by Wave (www.wave.coop) and Barney Haward

Printed by MCR Print (www.mcrprint.co.uk)

For further information please contact: STEPS Centre, Institute of Development Studies, University of Sussex, Brighton BN1 9RE, UK

Tel: +44 (0)1273 606261

Email: steps-centre@ids.ac.uk

Web: www.steps-centre.org

CONTENTS

ABSTRACT

Cutting-edge research on agri-food systems contends that mainstream agricultural science is ill-equipped to address issues of complexity, diversity and uncertainty. The paper tackles this issue looking at animal breeding, an area of agricultural science that has so far remained marginal to the analysis concerned with dynamics and uncertainty. The focus is on systems operating with low external inputs and a structurally unpredictable environment. The paper builds on my DPhil research on cattle breeding amongst the WoDaaBe herders in Niger.

The breeding/production system is geared towards exploiting unpredictable variability as a key resource (rather than contrasting or externalising it) and securing a reliable flow of production. Selection wise, the system makes use of both genetic and extra-genetic inheritable resources (extended inheritance). At the core of the system is the organisation of the cattle population in matrilineal lineages, as the main method for structuring animal diversity and ensuring the transmission of economically crucial functionality, both within the breeding population and across cattle generations. Examples of such functionality are competence as feeders (season-specific diet preferences in face of a great variety of grasses and browses, efficient heath management of negotiating of difficult terrain) and competence/specialisation for minimum-stress interaction with other herd members and with the herder (stable hierarchy, preferential relationships and social bonds, selective trust).

The paper argues that the breeding/production system run by the WoDaaBe (exploiting animal-human-environment interaction, using extended inheritance and geared towards high reliability) constitutes a form of enhanced production and land development only marginally represented by the current scientific model of animal breeding (environment-blind, focusing on genetics and geared towards streamline efficiency).

INTRODUCTION

A growing front of research on human-environment interaction is challenging the adequacy of modern agricultural science to represent agri-food systems on a global scale. This restriction applies especially to low external input systems, most of which operate in conditions of unpredictable variability (stochastic environments). As the argument goes, if agricultural science is effective in increasing productivity under certain conditions (namely where stability is easily achievable and cost-effective), it fails to deliver sustainability on a large scale, particularly for small farmers. An important reason for this failure is identified in the fundamental commitment to equilibrial models in ecology, biology and economics, which makes agricultural science ill-equipped to address issues of complexity, unpredictability and diversity — that is issues that are at the core of most production systems in developing countries and, increasingly, worldwide (Folke et al., 2002; Walker et al., 2004; Gliessman, 2006; Hall, 2007; Thompson et al., 2007). Whilst the standard model in agricultural science represents natural processes as linear, predictable and controllable (treating non-linearity as a disturbance), empirical data from low external input agri-food systems worldwide suggest that complex dynamics and recursive causation are the norm rather than the exception (cf. Scoones et al., 2007). Efficiency-driven management practices that aim at excluding uncertainty through a command-and-control approach, can erode precisely those characters of local agri-food systems — e.g. diversity and flexibility — that make them capable of dealing with the shocks and stresses of a dynamic world. In this paper, I look at a sector of agricultural science, animal breeding systems, that has so far received only little attention from non-equilibrial perspectives. The paper builds on my DPhil research on cattle breeding by the WoDaaBe herders in Niger, as a case of specialised livestock system operating with low external input and structural unpredictability.[1]

The fundamental objections against the 'equilibrial bias' of agricultural science, apply also to the sciences of animal production. Scientific animal production

[1] The WoDaaBe refer to their own breed of cattle as na'i boDeeji (lit. 'red cows'). In the scientific literature, this zebu breed is mainly referred to as Red Bororo, M'Bororo or Red Fulani (cf. Joshi et al., 1957; Bourn et al., 1992; Mason, 1996). For short, in this paper I simply use the term Bororo, referring specifically to the na'i boDeeji of Niger. A historical analysis of the sources has recently revealed fundamental flaws in the scientific characterisation of this breed (Krätli, 2005).

perspectives are gaining momentum in debates on development and food security, following predictions of 'livestock revolution' scenarios in the near future (Delgado et al., 1999; Rosegrant et al., 2001) and as an effect of the globalised concern for the erosion of domestic animal diversity (UN, 1992; FAO, 1999; 2007). A great emphasis is placed on livestock systems in developing countries, particularly low to medium external input systems. These systems are characterised by operating conditions where unpredictability and complexity are rapidly increasing and often structural (Chambers, 1991; Scoones, 1995). Questions about the adequacy of current mainstream animal science to address such issues are therefore crucial.

The standard model in animal production rests on fundamentally equilibrial assumptions combining mechanistic views in biology, ecology and economics, with representations of both nature and market as optimisers. The model of microevolution at the root of scientific animal breeding postulates the conceptual separation of organism and environment and rests on a notion of hereditary variation based on randomly varying genes unaffected by developmental conditions. Following from these premises, the scientific criteria for animal selection have been characteristically environment-blind.[2] With some remarkable exceptions (Bonsma, 1949; Horst, 1983) the history of scientific selective breeding is a history of the effort to externalise the influence of the environment from the mechanism of natural selection, replacing environmental pressure with human choice in the process of generating differential reproductive success amongst domestic animal populations (Trow-Smith, 1950, 1959; Herman, 1980; Russell, 1986; Montméas and Jussiau, 1994; Jussiau et al., 1999). Scientific animal production strategies for tropical conditions have focused on increasing productivity, either by improving the animals' genetic potential and/or through minimising the constraints to such a potential within the production environment (Phillips, 1949; McDowell, 1972; FAO, 1977; Ronchi et al., 1991; cf. Collison, 2000 for a broader perspective on agricultural science). When applied genetics moved to its present dominant position within the discipline, in the 1950s, the reductionist identification of animals with 'genetic resources' found little resistance in a disciplinary tradition that had represented them for almost a century as mechanical units (Denis and Théret, 1994; Jussiau and Montméas, 1994; Landais and Bonnemarie, 1996). From this gene-centred position, breeds have been described as 'storehouses of genetic variation' and domestic animal

[2] With this expression, I refer to the fact that the model assumes an environment that can be controlled and treats actual deviations from the controlled state as a disturbance. I interpret the introduction of the ad hoc notion of 'productive adaptability' (Horst, 1983), for dealing with selection where production environments are impossible to control, as a sign of awareness, within animal science itself, that the dominant model is problematically blind to the environment.

diversity has been understood as 'the spectrum of genetic differences within and across all breeds and species utilised in agriculture' (FAO, 2000: 22, 103; Phillips, 1981: 2; cf. Hall, 2004).

Non-equilibrial perspectives looking at livestock systems have focused on population dynamics of grassland and animals, either in relation to management issues (Oba et al., 2000; Homewood et al., 2001; Anderies et al., 2002; Uphoff et al., 2006; on Niger, Hiernaux, 2000; Schlecht et al., 2000) or as a consequence of environmental adaptation (i.e. different survival rate) between breeds (Bayer and Waters-Bayer, 1995; Bayer, 1989). Some of these studies have hinted at the links between local breeds and herd-management practices in relation to range ecology, touching upon herders' manipulation of animals' diet (Bayer, 1990; 1986), but without venturing into the analysis of such links in the context of the breeding systems. Non-equilibrium thinking in range ecology has led some authors to propose a model of pastoralists' economic strategy alternative to the standard 'risk-aversion' framework and based on 'high-reliability systems' theory (Roe et al., 1998). These scholars contend that livestock systems in harsh environments are often better understood as developed to harness and exploit unpredictability as a key resource, rather than trying to minimise and externalise it as in risk-aversion models — hence the affinity with high-reliability systems such as, for example, nuclear power stations or air traffic control. Overall, the direct or indirect ecological perspective of the works looking at animal production through a non-equilibrial lens, meant that the actual breeding systems, and particularly their dynamics of animal-human interactions, have largely remained out of the picture.[3]

Outside ecology, but equally relevant for animal production and breed development, challenges to the equilibrium paradigm have also been made within biology. In particular, these challenges concern the conceptualisation of the organism-environment interaction and the nature of inheritance. The positions emphasising the empirical evidence for fundamental reciprocity in organism-environment interaction, have questioned the optimising assumption embedded in the metaphor of adaptation (by which adapted organisms are a fit to pre-existing environmental niches). Organisms engage in the positive alteration of the selective pressures acting upon them (Lewontin, 1983). Many of the arguments developed along these lines have been gathered under the umbrellas of 'evolutionary systems' (Salthe, 1993; Van de Vijer et al., 1998; Salthe, 2000) and 'developmental systems theory' (Oyama, 1985; Griffiths and

[3] An exception is the breeding in organic farming, and the 'family breeding' method practiced by some farmers in The Netherlands (cf. Baars et al., 2003). I am grateful to Brigitte Kaufmann for drawing this work to my attention).

Gray, 1994; Oyama et al., 2001; Griffiths and Gray, 2005). They target specifically the gene/environment dichotomy characteristic of the modern synthesis of evolutionary biology, rejecting the assumption of pre-existing and independent configurations on either side — whether instructions that shape the organism from within or niches/environmental 'problems' that shape populations from without (Oyama et al. 2001; Odling-Smee et al., 2003).

Today, new developments from many branches of biology challenge the gene-centred version of evolutionary theory, the model that provides the overarching framework to the current scientific understanding of animal breeds and breeding. A reconsideration of the concept of inheritance in this light, demands to extend it beyond the DNA elements, to include the transmission of ecological and cognitive elements, that is, of 'any resource that is reliably present in successive generations, and is part of the explanation of why each generation resembles the last' (Griffiths and Gray, 2001: 196). Such a notion of 'extended inheritance', finally, comes to terms with the critical mass of empirical data difficult to accommodate within the present model. As nicely summarised in a recent overview of the issue, such growing body of data indicate that 'there is more to heredity than genes; some hereditary variations are non-random in origin; some acquired information is inherited; [and that] evolutionary change can result from instructions as well as selection' (Jablonka and Lamb, 2005: 1). The concept of 'extended inheritance' (also 'multiple heredity systems') strikes as particularly useful in the face of high environmental variability, for its capacity to address information transfer not only at the scale of the generational cycle but also within the lifetime of individuals.

The integration of complex dynamics in the model of ecology and evolutionary change, opens up new and exciting dimensions in our understanding of the opportunities for improving animal breeding and production in structurally unpredictable environments. Theoretical simplifications that externalise recursive causation between organism and environment might fit in well with the requirements of applied genetics but, as the analysis of the WoDaaBe cattle breeding system will show, can get in the way of understanding animal production in conditions in which the environment is not stable and cannot be easily neutralised/controlled. Unpredictable distribution of precipitation in time and location makes the Sahelian rangeland an unforgiving place for herding, where even small management mistakes can easily escalate with disastrous consequences. On the other hand, it is precisely the spatial and temporal diversity in the vegetative cycle of the bush (caused by random precipitations and further enhanced by the diversity of soils and plants) that can be turned into an advantage and a powerful resource. Producers under these conditions can treat environmental variability as a problem and develop strategies geared towards

minimising their exposure to it (high-input and risk-aversion systems); or they can actively seek such exposure and specialise in the exploitation of diversity (high-reliability systems). The distinction is crucial, as each scenario involves a fundamentally different perspective on animal production. The scientific study of animal production, stemming from European, modernist visions of agricultural reforms and equilibrial views of nature and the economy, has grown entirely within the first scenario. The information available on the production strategy pursued by the WoDaaBe, on the other hand, indicates that they are better represented by the second. My analysis of their cattle breeding system supports this view.

METHODOLOGY

The research used a transdisciplinary approach[4] integrating, within a development studies perspective, a front of knowledges cutting across social anthropology, history, applied animal behaviour, range management, animal science and political ecology, as well as the herders' expertise. Fieldwork was carried out amongst several groups of WoDaaBe herders in central Niger, from August to December 2002; November 2003 to July 2004; and November 2004 to March 2005. Data generation used standard methods from social anthropology (participant observation, focus group discussions, semi-structured interviews) and a set of tools developed in the course of the research from a range of participatory techniques. The resulting 'Herd Analysis Exercise' (HAE) embedded multiple cross-checking devises and was specifically designed for handling memorised cattle genealogies. The HAE is a seven stage process: the herder's family tree (1); the break-down of the herd into its different lineages (2); the analysis of the origin/ownership of each lineage (3); an overview of particular features of each lineage (4); a time line (5); the collection of detailed genealogical history of each lineage going as far back as the herder can remember (6); and finally the analysis of all the lineages that have entered and exited the herd during the period under consideration (7). The genealogical data used in this paper refer mainly to two

[4] Interdisciplinarity, multidisciplinarity and transdisciplinarity in Development Studies have been distinguished on the basis of the kind of expertise involved in the approach. The first two involve disciplinary expertise in the traditional sense, but whilst in interdisciplinarity, expertise in more than one discipline is supposed to be combined in one specialist, in multidisciplinarity, this is clustered in a team. Transdisciplinarity, on the other hand, defines an integration of various disciplinary expertise that is specific to the Development Studies work itself (Tribe and Sumner, 2004: 5).

herds of respectively 28 and 66 head (for a total of about 260 head over twenty years) belonging to kin households within the Ute'en baleeBe sub-group of the Gojanko'en clan. These data were analysed against four sets of HAE data from other clans, a broader body of semi-structured interviews and the literature on the WoDaaBe. There were differences in management 'style' between households, mainly due to different types of resource access, availability of labour and animals (and family habits). Overall, the herders I met agreed on the fundamental tenets of the breeding system described below, although some, by general recognition, applied them more strictly than others.[5]

Systematic herd analysis found that the herders in the sample could remember with remarkable precision the genealogy of virtually every animal born into their herd over the last twenty years (that is after the 1984 drought), including pinpointing its year of birth (with the help of a timeline and in relation to the age of the dam).[6] This genealogical knowledge also included the name of the bull that sired the animal in question, the name of the bull's owner, and often the season of the fertilisation and the households in the neighbouring camps. The herders remembered the cows' age at the time of their first calf, and the age of bulls when they were used as sires for the first time, or when they had been castrated. The age of an animal at the time of its sale or death, the reason or cause, and even the name of the market, were also remembered; so were many details concerning the actual origin of each animal. In the case of heifers used in 'loan contracts' (haBBanaaji, sing. haBBana.e), the herders usually knew at what age the animal had been given out, at what age and after how many calvings it had been returned, whether the calves were male or female and what had happened to them.[7]

Most stages of the HAE were partially overlapping, providing effective ground for triangulation as the work developed (for example with questions repeated at different stages of the analysis, or when bulls from one genealogical set also appeared as sires in another set). Slow-pace analysis of an entire herd by the same team, and the inclusion of dates and ages, enabled to spot and investigate incongruences as they emerged. Database analysis of this information enabled

[5] The WoDaaBe use the term 'garsoo' to describe a herder who shows particular dedication to the job, has above-standard competence and breeds exceptionally good cattle. The two data-set providing the empirical evidence for this paper come from such dedicated herders.

[6] With an approximation of about ten months with regard to the western calendar, due to the different way of quantifying age (i.e. counting the rainy seasons). that is specific to the Development Studies work itself (Tribe and Sumner, 2004: 5).

[7] The two households in this sample proved particularly reliable during the HAE. In other cases, the data were not as coherent and precise. However, all herders interviewed clearly believed that having a sound knowledge of the herds' genealogy was part and parcel of a herder's competence.

detailed cross-sections of the herds at any given year within the period in consideration, including the age, ancestors and exact kin relationships of each animal in the herd. Series of cross-sections provided dynamic reconstructions of animal's reproductive history, mortality, and marketing patterns. Finally, combining these data with human genealogies and life histories enabled the reconstruction of patterns of circulation of sires (through borrowing for a fertilisation) and dams (through loan contracts) across herds, and therefore to identify the actual network of breeders. The breeding practices emerging from this work were then analysed in the context of WoDaaBe's strategies of production and in the light of scientific knowledge on the links between ruminants' behaviour and their productive/reproductive performance under extensive conditions.

THE BREEDING SYSTEM

The WoDaaBe are full-time herders. They are specialised in cattle breeding and produce for the beef market.[8] In Niger, over the last sixty years, their Bororo zebu has represented an important supply to the internal beef market and has consistently been the most appreciated cattle breed on the export market.[9] Yet, the conditions in which, with low external inputs, the WoDaaBe achieve their production, are challenging in the extreme.

My findings show a sophisticated system of selection, with production at the core of the herders' concern. The 'herds' are developed from a handful of animals allocated to a newborn child, and left to reproduce amongst the stock of the

[8] Marketing of Bororo females for breeding purposes is extremely low, although WoDaaBe herders (more often from within the same extended family) do occasionally buy or exchange cattle with one another. Outside these circles, productive females are only marketed out of very pressing need. Bororo bulls are more accessible on trading channels (although reproduction bulls (kalhali) are normally castrated before being marketed). Some Touareg herders use Bororo bulls to cross-breed their Ezawagh zebus (Kel Tamasheq spelling of Azawak), particularly the Kel Egheris (Gourma Rharous) in Mali (Ibrahim ag Youssouf, personal communication). Amongst the other Gourma-Rharous groups, the Kel Serere, Kel Gossi, Kel Ulli, Ifulanen and Igawodaren have also been known to keep herds of Bororo (Mike Winter, personal communication).

[9] The veterinarian responsible for the outpost of the Niger livestock service on the border with Chad, Kassoum Koné, pointed out that Bororo zebu were preferred to the Kouri cattle on the markets of Nigeria (Koné, 1948). Surveys of the major abattoir of Fort-Lamy in Chad in the 1970s (now N'Djamena) underlined the outstanding economic role played by Bororo (cows and bulls) as beef animals (Tacher, 1971; Bertaudiere and Djimadje, 1978; Tacher, 1979). According to a recent survey, the Bororo zebu dominates the market of Lagos (absorbing nearly seventy percent of cattle exports from Niger) preferred for their large body size and low proportion of fat (Djariri et al., 2003).

father until the offspring is strong enough to sustain a new herding household on its own (usually 25-30 years later). That herds, as the basis of a pastoral enterprise, come into being only by developing within other herds is, as we will see, a crucial aspect of the breeding system. Contrary to common opinion, despite the absence of material constraints (not even night enclosure), cattle reproduction in the sample herds was strictly controlled. The Bororo zebu have periods of oestrus as brief as a few hours. The WoDaaBe's intensive management secured timely detection, and preparation for planned dam-sire matching for virtually every fertilisation[10] (a cow who is expected to soon enter oestrus, is kept at the camp during the night grazing). Only about four percent of the bulls born into the herds over twenty years had been regularly used for reproduction (the others being castrated or, more often, sold out of necessity before they reached reproductive age). The herds rarely had more than one or two reproduction bulls (at times none). In the case of these 'special bulls' (kalhali, sing. kalhaldi), careful matching of well-known lines is the rule: the father of a kalhaldi is always a kalhaldi and the mother is always from a lineage that has produced kalhali. With the exception of the kalhali, attention to avoid inbreeding, promote diversity and secure good quality bulls seemed to be key to decision making concerning dam-sire matching. Sires were borrowed from outside the herd in about ninety percent of births, even when a 'pedigree' sire was actually present in the herd. Dams were matched to a different sire at almost every fertilisation. Inbreeding was rare and the risk of breed degradation normally avoided.[11] This was made possible by organising the breeding population along matrilineal lineages,[12] and by maintaining a detailed memory of animals' genealogies within the network of breeders (including the patrilineal genealogies of selected sires). Lineage names are more than genealogical earmarks. By clustering cattle along maternal lines, the naming system has a direct influence on the way the herders perceive individual animals in relation to one another and the way they conceptualise temporal dynamics of performance within the herd (for example, a herder's expectations on the productivity of a young animal are affected by the overall performance of its maternal line). Both these processes are key variables in herders' decision-making about selection.

Although herders showed stronger attachment to particular lineages, usually due to links with the family history, this did not translate into maximising their size within the herd. On the contrary, herds typically included several lineages, with diversity between them being deliberately sought after and preserved. The analysis of animals' reproductive history showed a significant degree of heterogeneity, with each lineage within the herd presenting a specific pattern of reproductive performance (age at fist calf, male/female calf mortality, male/female ratio in births). Moreover, the analysis of cattle marketing over the twenty year period in the sample, indicated a well defined strategy, with poorly performing animals being selected out according to a combination of both their level of performance and the degree of economic pressure. Also heifers in poorly productive sub-lines, within the respective lineages, were more likely to be marketed before reaching reproductive age. Such a strategic marketing, targeted individuals and sub-lines struggling to reproduce[13] under the operating conditions of the WoDaaBe production strategy. Whilst 'harvest' marketing (young males, oxen and large old cows) peaks in the early cold-dry season (October/November), when the animals are at their best, 'culling' marketing peaks at the beginning of the rainy season, when maximum strain on the animals' foraging capacity gives contrast to differences in performance.

[10] Over the twenty-year period captured by the HAE, accidental fertilisations were below three percent.

[11] Inbreeding was limited to 'cousins', while the animals belonging to the same lineage were not normally allowed to mate..

[12] The WoDaaBe name newborn calves (males and females) after their mothers. Similar matrilineal cattle-naming systems are also found amongst other groups of pastoralists (cf. Andom and Omerw, 2003; Galaty, 1989; Bernus, 1981).

Both selective mating and the marketing strategy, although sensitive to traits such as fertility and milk yield, were primarily geared towards the maintenance (within the herd or, at least, the immediate network of breeders) of lineages with a long record of good performance within the family herd and, more generally, within the breeding population: the 'original lineages' (na'i iriiriiji).

The integration of breeding in the production strategy

Empirical evidence of what the WoDaaBe breed their cattle for, is embedded in productive herds: which functions have to be performed by the animals for the production strategy to be successful; and what does it take for cattle to perform such functions well and reliably? A herder's yearly production strategy can be affected by several factors (most importantly, herd size, availability of labour and competence, the extension of the household's social network and, at times, insecurity). However, as long as the combination of these factors allows, the strategy preferred by the WoDaaBe aims at keeping the rate of reproduction

[13] With the exception of the 'bull-cow' (nagge ngaarye, cf. Bonfiglioli, 1981) welcomed for its stabilising role as a go-between.

within the herd high by focussing on the quality of animal nutrition (Bonfiglioli, 1981; Schareika et al., 2000, Schareika, 2003). With some differences in 'style' between households, the herders concentrate on two management goals: making sure that, all year round, the animals feed on the most nutritious fodder available; and making sure that they take as much advantage as possible from it. The herd is moved across zones of heterogeneous plant-growth patterns, exploiting the variability of precipitations and the productive diversity of soils and plant species. The camp is always in the proximity of prime fodder and away from other herds, so that the animals can feed undisturbed day and night. This system involves standing a watering regime as severe as only watering every second day at the peak of the dry season, with wells up to 25-30 kilometres away from the camps (the quality and intensity of foraging between journeys compensates, in the view of the WoDaaBe, for the time used to travel to the well). But these are only the most visible features. A lot of work, competence and long-term commitment go into fine-tuning both animals and environment in ways that will shortly become more evident.

In the course of the year, the animals feed on combinations on plants from more than forty varieties. Most of these plants can be especially beneficial or, conversely, can cause even very serious problems to the animals according to the season (Bonfiglioli, 1981).[14] Feeding on poorly nutritious hay during the hot dry season can abate the appetite just when the animals would need to eat most. The WoDaaBe correct this descending curve through management, supplementing their cattle's diet by promoting shrub and tree browsing as well. When availability allows for choice, only the most nutritious parts of the plants are eaten. The Bororo's browsing habits on the range have been well recorded (Boutrais, 1995; Schareika, 2003). With the nutritional value of the bush being subject to extreme seasonal variations, the animal nutrition programme followed by the herders is to minimise weight loss during the long dry season and maximise recovery during the period of available fresh vegetation. Their primary objective is to prepare the animals for reproduction and withstanding the next dry season. At the beginning of the rainy season, the most difficult moment in the year, management input increases sharply (Bonfiglioli et al., 1984) and every effort is made in order to enable the herd to feed on the new grass as soon as possible. Every day of advantage, at this stage, can have a significant impact on the success of the animals' reproductive cycle and their condition at the beginning of the following dry season. As documented in detail by research combining anthropology, animal nutrition and soil science (Schareika, 2000), this programme is painstakingly fine-tuned.

[14] Some of these dangers can be very insidious. Cenchrus biflorus, for example, is dangerous if eaten during the dry season because the hollow stalk often contains sand (Ibrahim ag Youssouf, personal communication).

Break down of animal performance

The success of the WoDaaBe production strategy rests on the capacity of their herds to perform complex functions as required. Their harsh operating environment offers no resting point. The performing herd must be capable of successfully engage with such a challenge all year round, year after year. First of all, the animals must be capable of physically reaching the patches chosen by their herders and at the desired time. An exceptional capacity for mobility is therefore critical. For this reason, its maintenance is embedded in the system to the point of being implicit, as part of the definition of cattle as such (it is often said by the WoDaaBe that the, less mobile, Azawak zebus 'are not real cattle' because 'they can't walk'). Once on prime fodder, not all the vegetable mass available will be equally nutritious.[15] The animals must be capable of selectively ingesting the most nutritious bites and digesting them efficiently (as per their herders' strategy). In order to do so, they must know which plants to feed on and which ones to avoid, and must be able to ingest them or, more often, to ingest the 'right' parts of the plant. A foraging herd of Bororo will make use of the available pasture in a very different way from other local cattle breeds (e.g. the Azawak).[16] Eating efficiently and selectively from a wide range of bush plants — including not only grass species but, according to the season, shrubs and trees, and even wild melons and water lilies — requires competence in negotiating many different terrains, plant shapes and defence systems. In many cases, such a competence must be season-specific.

At the beginning of the rainy season, when even small nutritional gains are crucial to the success of the entire year, eating the new short grass on sandy soil (whilst avoiding the potentially fatal ingestion of sand) requires a specific foraging technique. Cattle must use the front teeth, more like goats do, instead of their usual twining and pulling with the tongue. The herders are aware of this difference, and have a name (noppina) for this alternative foraging technique (cf. Bonfiglioli, 1981; Schareika, 2003). They favour it morphologically, by preferring sires with a slender head and a small muzzle, and cognitively by integrating in their herd management system, elements that enable and promote the social transmission of knowledge amongst their animals (as we are going to see). To

[15] An analysis of the quality of grass in the diet of the African buffalo found that 'seemingly equal swards often consist of different clones, which would suggest that different patches of even the same food species at the same time can be different from the herbivore's point of view' (Prins, 1996: 259)..

[16] According to both WoDaaBe and Touareg herders, as well as staff of the Niger livestock service, while the Azawak graze all the grass from a patch, the Bororo only browse through the best bites. A French veterinarian writing about the browsing habit of Bororo herds in Cameroon, noticed that 'foraging is so selective that at the end of the season the animals are in the grass up to their bellies' (Brouwers, 1963, quoted in Boutrais, 1995: 281).

summarise, therefore, for the WoDaaBe cattle nutrition programme to work, their herds must be capable of reaching, choosing, ingesting and efficiently processing the highly nutritious diet their herders lead them to.

From empirical studies of ruminants' feeding behaviour, we know that none of the complex functions listed above can be taken for granted (Provenza and Balph, 1987; Launchbaugh et al., 1999a; Ganskopp and Cruz, 1999).[17] Cattle are creatures of habit, and their first inclination would be to stick to feed and grounds that are familiar to them (Hodder and Low, 1978; O'Reagain and Schwartz, 1995; Burrit and Provenza, 1997; Howery et al., 1998; cf also Provenza and Launchbaugh, 1999; Emmick and Provenza, 2004). We also know that the morphological and physiological bases of diet preferences can be breed specific (Bailey, 1999; Hovery et al., 1996). On the other hand, these scholars underline the 'intertwined nature of learned and innate behaviours' (Launchbaugh et al., 1999b: 28). Even features such as digestive and detoxification abilities (the enzyme system) have been found to be affected by experiential learning (Distel and Provenza, 1991; Robbins et al., 1991; Distel et al., 1994). Feeding competence amongst ruminants is acquired in two ways: from previous post-ingestive experience of trial and error (a long, potentially dangerous, and therefore understandably 'conservative' process); and/or through the example of influential herd members who possess it already, typically the dam. Learning is recognized as being sensitive to social dynamics (e.g. can be socially transmitted; is affected by social relationships) and historical continuity (e.g. can be cumulative and trans-generational, and is affected by previous learning events: learning event n affects the environment of learning event n1) (Provenza and Balph, 1987; Provenza and Cincotta, 1993; Launchbaugh et al., 1999b). The understanding of foraging behaviour as mediated by cognitive variables and recursive causation lets real-life's complex dynamics into the picture, but also introduces an important element of flexibility, as the basis of diversity in foraging abilities is now seen as both genetic and extra-genetic.

The social dimension of feeding does not only account for the spread of dietary competence in a more rapid and safer way than through individuals' trial and error. Social influence can also have a negative impact on feeding performance. Antagonism between foraging animals can disrupt the best-designed feeding strategy and cause unsustainable loss of energy (Dumont and Boissy, 1999;

[17] Distinguishing between this perspective, based on empirical observation, and optimal foraging theory, cf. Provenza and Cincotta (1993: 78) underline that: 'Functional models (e.g. optimal foraging theory) [...] do not [...] explain empirical observations such as why: 1. individual within species select different kinds and amounts of forages (Provenza & Balph, 1988; 1990); 2. wild and domesticated herbivores over-ingest plants that contain toxins (Provenza et al. 1992); 3. herbivores do not necessarily select foods of the richest nutritional quality (e.g. most energy-rich foods) when given a choice (Grovum 1988)'.

Macdonald and Mosley, 2006). Direct competition in feeding or even the mere proximity of dominant individuals (whether or not in the presence of fodder scarcity), affects the intake of lower-ranking animals (Bennett et al., 1985; Bennett and Holmes, 1987). Similarly, the overall foraging performance can be disturbed by particular features of the feeding site (for example a difficult terrain or the presence of irritating vegetation) and particularly by high environmental temperature (Williamson and Payne, 1978; Kadzere et al., 2002). Even under this respect, acquired information can be crucial. Cattle experience in mastering thermoregulatory strategies and efficient rambling has been found to add a considerable advantage to morphological abilities (Morand-Fehr and Doreau, 2001; Brewer, 2005). For example, good timing of feeding and resting, exploiting shade and negotiating difficult terrain significantly enhance the thermoregulatory advantage provided by morphological traits such as a thick and movable hide of high vascularity and an agile and narrow body high from the ground. Finally, animals performing well in all the aspects of feeding discussed above, can still be severely affected by stress associated with human handling and management practices (Seabrook, 1972; Rushen and de Passillé, 1997; Waiblinger et al., 2002; cf. also for a general overview Waiblinger et al., 2006).

The cattle breeding system based on maternal lineages, and the WoDaaBe herd management strategies (described below) are designed to favour the social transmission of knowledge within the herd. At the same time, they are careful to abate antagonistic behaviours and the production of stress that could undermine overall herd performance. Antagonistic bulls (and cows), for example, are quickly removed from the herd. Socially triggered differential nutrition within the herd is minimised by artificially enhancing the herd's internal cohesion (through nurturing social bonds and hierarchical stability).

Such a sophisticated management system involves an intense degree of human manipulation of the cattle-environment interaction, with closely controlled animals led to perform complex sets of functions. According to applied animal behaviour science, this would be a recipe for high levels of stress in the animals. Yet, daily and nightly routines of human-driven tasks are performed by these cattle in virtually complete absence of coercion. The cattle bred by the WoDaaBe know nothing of enclosures, follow their herder of their own accord (rather than requiring to be herded from the rear)[18] and it is common, in the

[18] Driving a herd from the front, as opposed to from the rear, is a complex and skilled practice, common amongst pastoral systems, but usually ignored amongst less specialised cattle-keepers. In Eritrea, Tigrinya speaking pastoralists in the lowlands also drive their herds from the front, whilst farmers keeping cattle in the highlands, herd their animals from the rear (Andom and Omerw, 2003). In northern Nigeria, the herds of pastoral Fulani have been recorded to follow their herders even swimming across broad rivers (de St Croix, 1945).necessarily select foods of the richest nutritional quality (e.g. most energy-rich foods) when given a choice (Grovum 1988)'.

bush, to see entire herds controlled by one or two young children only waving a twig. Indeed, although sophisticated and intensive, the WoDaaBe herd management is so smooth and light-handed that it appears, from the outside, as if the Bororo zebus bred by the WoDaaBe were actually committed to 'co-operating' with their herders. Behind such an impression there is, in fact, a characteristic 'attitude' of these animals, the development and maintenance of which is a key aspect of the WoDaaBe breeding/production system.

Persuasive management

The WoDaaBe are fine observers of their animals' behaviour. Their language, Fulfulde, has a rich vocabulary describing behavioural patterns in livestock. A herder's prising of his own herd typically includes references to behavioural features. At the core of the herders' ethological competence are an educated attention to what their animals eat and an understanding of the links between individual feeding preferences and production, particularly with regard to the qualities and quantity of milk and to the animal's health and reproductive process. Herd management exposes the animals to a wide and functionally selected range of experiences (e.g. the encounter with a great variety of fodder plants, foraging conditions and herding 'styles' through intense herd mobility and through the circulation of females resulting from loan contracts across the breeding network). It also promotes a stable and non-conflictual social environment within the herd, and facilitates the transmission of knowledge along both vertical and horizontal social relationships.

Such a management system is modelled on patterns that scientists have observed in the behaviour and social organisation of wild populations of cattle and other ruminants. Practices as structural as limiting the herd (sefre) to about fifty individuals, and their organisation through the matrilineal naming system, reproduce the social organisation of feral cattle (Lazo, 1994, 1995). On the other hand, studies of cattle in 'excessively large' groups under domestication show a sharp increase in aggressive interactions, as 'individual animals appear to have difficulty in memorising the social status of all peers' (Bouissou et al., 2001: 130)[19]. The integration of cattle-specific behavioural patterns (e.g. herd size and matriarchal social structure, herding from the front, grooming) pervades the

[19] Splitting of large herds, a phenomenon that behavioural ecologists call 'fusion-fission pattern', is known across several ruminant species. Competition within the herd has been found to be less severe in small herds (Prins, 1996)..

WoDaaBe herd management system down to its smallest aspects.[20] During the watering process, for example, in order to allow every animal to drink, exuberant individuals are disciplined by beating them with a stick on the horns (and only on the horns) in a way that simulates horn clashing in antagonistic behaviour between conspecifics.

The integration of species-specific behaviour is consistent with an approach to herd management characterised by the systematic use of habituation practices and a preference for gentle handling over coercion. In the WoDaaBe myth of domestication, the cows are initially attracted by the campfire of a child-herder, then gradually follow him away from their hiding place, of their own accord (cf. Stenning, 1959; Dupire, 1962; Loftsdóttir; 2000).[21] This persuasive management style is key to constructing the social organisation of the herds of the WoDaaBe and their characteristic, functional patterns of animal-human interaction. Calves are allowed to spend several hours per day with their dams, both around the camp in the evening and during the morning grazing. The proximity of the feeding site to the camp, enables even the very young calves to accompany their dams on the range for a part of the day. In this way they are also gradually socialised into the group of the adults. On the other hand, the calves stay together in the afternoon. Social bonds are even fostered during the night, as the young calves grow accustomed to one another tethered to the calf-rope, side by side in order of age, usually in the same relative position. Bonds with the herders are cultivated with equal attention. Ethological studies have pointed out that following calf-dam separation in weaning, calves experience a compensating drive to socialise, that can be exploited for habituating them to interacting with humans (Boivin et al., 1992). Under WoDaaBe management, the group of calves remain separated from their dams for a few hours per day well before weaning starts, when the herd leaves for the afternoon grazing. During these early periods of separation from their mothers, calves wander around the camp, and are exposed to intense positive interaction with children (who play with them and groom them) and women (who groom them, light the cattle fire and, as weaning begins, give them supplement feed and extra care).

Bororo's singular selective attachment to humans (referred to as being geeti) is perhaps the behavioural feature most appreciated by the herders. The

[20] With reference to pioneering work in applied-ethology, amongst FulBe pastoralists (Hinrichsen, 1979; Lott and Hart, 1979), Waiblinger et al., remark that the reliance on 'species-specific' patterns is what 'may provide the basis for the success of Fulani herdsman in the control of cattle' (2006: 191). On the advantages of integrating imitations of species-specific behavioural patterns in the management system, cf. Grandin (1987); Seabrook and Bartle (1992); Seabrook (1994).

[21] Still today, in every WoDaaBe camp a 'cattle fire' is lit every evening. The animals like to rest incredibly close to it. The smoke protects them from parasites.

Bororo are exceptionally vigilant and nervous animals, yet obedient and docile with their herders. By integrating human-triggered stress-relief mechanisms into the management system (e.g. social bonds with members of the herding household, the cattle-fire at the camp, grooming), the WoDaaBe exploit their animals' propensity to stress as an asset to ensure their dependence on human handling. Bororo are bred to need the presence of the herder in order to relax. The WoDaaBe's persuasive management turns on its head the issue of management-related stress. As in the case of environmental variability, also in this respect the animal breeding/production system operated by the WoDaaBe exploits what is considered a problem, as a source of unpredictability, in western animal science.

Cattle breeding and complex dynamics

All the elements of the WoDaaBe cattle breeding system work together to secure the reliable exploitation of unpredictability, but three are particularly important.

First, by organising their cattle into matrilineal lineages (operating selection within but not between lineages), the WoDaaBe both nurture and structure animal diversity within their herds and, by extension, within their cattle breeding population at the various scales of the breeding network (extended family, clan, clusters of clan, etc.). Rather than being a homogenous population maximised in respect of a specific productive trait (as in standard breed selection) the Bororo breed looks more like a fragmented population, with a variable number of similarly (but not uniformly) performing sub-groups. Culling through marketing contributes to keeping each lineage within the boundaries of functional performance relative to the household's production strategy. Over a few human generation/herd cycles (50-60 years), this process reveals original lineages. Each original lineage embeds a specific (although not fixed), successful configuration of animal-human-environment interaction (combining physiological and morphological traits, competence, skills, patterns of social interaction and learning abilities). Within each herd, these different configurations are contextually and continuously developing (also in relation to one another) as diversified responses to the same household's production strategy (depending on how long a lineage has been in the herd for). In a way similar to the use of redundancy in high reliability systems (cf. Roe et al., 1998) or of portfolio diversity in economics (cf. Stirling, 1998), structuring animal variability into dynamic patterns of lineage-based diversity scales down the randomness of the operating conditions and increases the overall reliability of herd performance.

Second, the breeders exploit the capacity for both genetic and extra-genetic inheritance in their cattle breeding population (what developmental system theorists call 'extended inheritance'). In other words, they use the animals' capacity of actively engaging with their environment (including rangeland, conspecifics and humans), their capacity for responsive change during their lifetime, and their capacity for transmitting such resources along kin and social networks. These capacities are nurtured and honed through all sets of strategies integrated in the breeding/production system: the production strategy, the herd management, and the selection strategy. The production strategy defines the framework for the animals' experience of the environment, therefore establishing the conditions under which the animals both affect the environment and are affected by it (in a series of recursive causation that involves both present and future generations). The herd management fine-tunes these modalities, orchestrating and directing, within the breeding population, social and cognitive resources for the animal-human-environment interaction. The selection strategy, through planned mating and strategic marketing, promotes, consolidates and secures the continuity and dissemination of successful configurations of such interactions. These configurations are developed during each herd-cycle (roughly a herder's lifetime) as well as across human generations within the breeding population in the various levels of the network of breeders.

Third, the breeders rely on lineage duration (rather than peak productivity) as the primary criterion for selection. Reproduction bulls (kalhali), either in the herd or borrowed from within the breeding network, are always from original lineages (both parents). Although original lineages are not maximized at the cost of the others, they are sought after and particularly sheltered from non-strategic marketing (for example the unwilling marketing of productive survivors after a drought). There is lineage duration when a lineage gives a consistently functional performance within the production strategy over an extended period of time including events of severe stress. Ecological dynamics makes it extremely difficult to link performance to any inherent quality (including adaptive fitness). In these conditions, the duration of a matrilineal lineage, because it is tested with hindsight, is the only 'quality' known for sure. Lineages that withstand the test of time, become 'original lineages'. This fundamentally historical notion, describes tested duration more than purity of blood. Long-lasting matriarchal lineages are carriers of the Bororo's characteristic physiological and morphological abilities (although most likely in different combinations). Amongst their ranks are the most competent and most 'co-operative' social groups of animals available within the breeding population (relative to a given breeding network). The use of duration as criterion for selection is similar, in principle, to the progeny test approach: both work on a confirmed rather than a predicted quality. This strategy too, like structured variability, contributes towards scaling down randomness.

Besides these key elements — structuring animal variability, exploiting extended inheritance, and relying on lineage duration as the primary criterion for selection — keeping the system running is a matter of ensuring that sets of functionalities enabling the herd to take the maximum advantage of the WoDaaBe programme of animal nutrition, are effectively disseminated throughout the breeding network. This process is neither improvised nor erratic. Circulation of cattle uses institutionalised channels (e.g. sire borrowing and loan contracts of productive cows), closely integrated with the WoDaaBe social organisation. Household's mobility also plays an important role in accelerating the breeding process. Mobility of people and animals intensifies the exploitation (throughout the network of breeders) of the available sets of functionalities as breeding resources. Herd analysis of herds including both original and recent lineages, shows that original lineages are the ones most intensively circulated. Circulation is more intense within the extended family, particularly amongst cousins. As original lineages are only revealed through history, the system welcomes high levels of lineage diversity and encourages the continuous development of new lineages (e.g. through the acquisition of females from outside the WoDaaBe breeding networks). In favourable conditions, this results in a variety of distinct although largely overlapping functional groups of original lineages (i.e. successful configurations of functionalities relative to the production strategy). As long as a viable number of original lineages are operating at any one point in time, lineages can disappear or be introduced without significant disturbance to the system as a whole. Original lineages themselves, if accidentally lost from a family-herd, can usually be regenerated by acquiring another productive member of the lineage from the breeding population at the next scale of the network of breeders.

Through inheritance and loan contracts, lineages are typically exposed to a variety of herding 'styles' (within the overall production strategy characteristic of the WoDaaBe). As a consequence, the reliability of original lineages is tested both across time and space. By being centered on the original lineages, the WoDaaBe breeding/production system achieves reliability at each scale of the breeding network. Behind the WoDaaBe's commitment to their characteristic breeding/production system lies this confirming 'test' of duration. Half-a-century-old lineages in the breeding population are a mirror of families' economic history and constitute robust evidence of both the performance and the resilience of the breeding network in the face of uncertainty. Following the major droughts in the 1970s and 1980s, the pattern of livestock property in Niger has changed substantially. Amongst the producers with entitlements similar to those enjoyed by the WoDaaBe, but relying on different strategies, almost all have lost their assets and their economic autonomy.[22] On the other hand, despite the often-unsympathetic policies, the majority of WoDaaBe households, even if impoverished, are still in business.

The table below shows the key peculiarities of the WoDaaBe breeding system next to the corresponding aspect in the standard scientific model of animal breeding.

[22] Several sources indicate that during the major droughts, the WoDaaBe in Niger, although suffering severe losses, were hit significantly less than other pastoral groups with similar or even higher resource entitlements. Cf. Habou and Danguioua (1991) on the drought of 1984; Bernus (1977) and Mesnil (1978) on that of 1969-73; and SZE – Pécaud (1932) on that of 1931.

	WoDaaBe breeding system	**Standard scientific animal breeding**
Main actors	Rural breeders/producers, local breeding networks.	Commercial breeders, agribusiness, research institutes, breeding societies.
Selection aim	Maximising reliability (resilient continuity of good performance).	Maximising peak productivity
Selection goals	Maximising the number of original lineages, i.e. building redundancy in tested configurations of complex performance patterns related to cognitive variables: animal-environment interaction patterns (feeding competence and diet preferences, walking and rambling skills, heat management skills, social organisation and transmission of knowledge); and animal-human interaction patterns (selective docility, attachment, cooperation).	Maximising specific discreet traits: productive (e.g. milk, beef); phenotypical (e.g. short horns, coat); morphological (e.g. conformation); physiological (e.g. adaptive fitness; resistance to particular diseases); behavioural (e.g. docility).
Strategy	Manipulating extended inheritance genetic selection through dam-sire matching, persuasive management and strategic marketing, dissemination and circulation of lineages within the breeding network. Attention to both patrilineal and matrilineal inheritance:	Manipulating genetic inheritance: genetic selection, artificial insemination, culling. Focus on patrilineal inheritance.
Time scale	Relatively short (quick adjustments), both across generations and within the lifetime of individuals: genetically transmitted from parents to offspring, extra-genetically and cognitively transmitted from parents to offspring, across kinship and social relationships.	Relatively long, across generations: genetically transmitted from parents to offspring.
Final product	Breeding populations: competent and specialised communities of animals tested for duration in the actual operating conditions of the breeders/producers. Must be reliable.	Genetic resources: stable and inheritable genetic configurations for the production of high-performing, interchangeable productive units. Must be marketable.
Economic goal	Achieving and maintaining high reliability in livestock production	Maximising sale of genetic resources.
Dissemination	Of dynamic extended inheritance (semen, animal culture): is part of the breeders' manipulation of extended inheritance and the process of building redundancy into the system	Of stabilised genetic inheritance (bulls, semen): follows the successful manipulation of genetic inheritance.

Target ecological environment	Production-strategy specific, unpredictable (non-equilibrium); unpredictability is harnessed as a key resource for production.	Standardised or neutralised, predictable (equilibrium); unpredictability is externalised.
Target production environment	Production-strategy specific, constructed through inputs of expert labour and manipulation of use patterns.	Standardised, constructed through inputs of capital and technology.
Impact of selection	Diversity: inbuilt redundancy through structured variability (original lineages), with selection replicated at each scale of the breeding network (household, clan, clan cluster etc.) and through human generational cycles.	Uniformity: emphasis on controlled inbreeding and stabilising optimal performance, with selection relatively centralised.

DISCUSSION

The empirical evidence emerging from the study of cattle breeding amongst the WoDaaBe, challenges in several ways the adequacy of the standard model in mainstream animal breeding and production. At the same time, it also points to key elements of an alternative model.

In mainstream livestock breeding, based on genetic inheritance, environmental influence is considered a disturbance to be minimised (risk aversion perspective). The environment of the sahelian range however, has so far proved extremely difficult, if not impossible, to control. On the other hand, the WoDaaBe breeding/production system needs an 'active' environment. Animal production depends directly on inheritable functionalities of the breeding population that are not only of genetic origin (extended inheritance). Extended inheritance includes those learned and social behavioural patterns that contribute to an animal's construction of its own environmental niche (including conspecifics and humans). As the herders' work of selection makes use of extended inheritance, the environment is actually necessary to the economic functioning of the system (high reliability perspective). The present focus, in science and policy, on the genetic dimension of breeding, misses out most of the (yet economically determinant) properties of extended inheritance. Although elusive, perhaps, to

the current orientation of breeding companies, such properties are crucial to the livelihood of producers in low external input systems (as well as to the sector of the economy that such producers sustain in their respective countries). A model of animal production that claims relevance on a global scale (hence also for low external input systems) must be capable of dealing with the entire spectrum of the inheritance exploited by livestock breeding systems around the world, including those operating with structurally unpredictable environments.

This raises important issues also with regard to the management and conservation of domestic animal diversity. Animal populations selected for the exploitation of extended inheritance, are not stocks of performing units purely defined by their genetic configuration. The functional performance of a Bororo breeding population within its livestock system is strictly linked to lineage structuration and the continuity of complex social processes, both within the population itself and between animals and herders. As we have seen, these functionalities are only addressed by a notion of inheritance extended to represent extra-genetic components. The context of breeding is key to both the characterising features and the economic function of the breeding population. By leaning towards context-free conservation and focusing on the preservation of genetic resources, the global policy debate on domestic animal diversity therefore fails to safeguard precisely those highly-diverse and hard-to-replace breeding populations that are supposed to be at the centre of concern (FAO, 1999; 2007). Moreover, carefully engineered extended inheritance increases the system's resilience in the face of extreme operating conditions. Economically functional configurations of extended inheritance, however, can be lost (at different scales: the breeding network, the production system, the environment) even if the population size does still guarantee the conservation of genetic inheritance. For example, a large-scale disruption in the continuity of original lineages could bring the WoDaaBe production system to a potentially irreversible tipping point, whilst standard risk-assessments for the Bororo breeding population, based on a genetic 'critical-size' parameter, would indicate no danger.

The critique that non-equilibrial perspectives (e.g. resilience theory) move against an efficiency-driven approach in natural resource management, also applies to mainstream animal production models. In animal production, such an approach aims, amongst other things, at minimising disturbance (e.g. variability or the influence of the environment) and streamlining the livestock system by eliminating redundancy (i.e. all functionality that does not appear to be directly involved in achieving the target of increasing productive capacity). The feasibility of the second goal presumes a stable environment, but such a requirement can be unrealistically costly to achieve under certain conditions of production, like that of the WoDaaBe. In the face of complex dynamics, resilience theory says, streamlining a system by eliminating redundant functionality can abate its resilience, making the system more vulnerable. On the other hand, the example of the WoDaaBe shows that the conventional efficiency-driven approach is not the only way to develop a livestock system. Enhanced production in low external input systems can be achieved through exploiting precisely the structural unpredictability that gets in the way of streamline efficiency.

Intensive production is currently defined by the use of high inputs of resources (other than labour) in order to control the production process and production environment, so that the animals do not need to adapt but can, as much as possible, show their production potential. However, in a non-equilibrium perspective animals and environment are not fully separable, both sides being co-constructed (not even just co-evolving according to some blind rule). The WoDaaBe don't wait for their cattle breeding populations to 'adapt' to the changes in the environment: they have a sophisticated system in place to harness, enhance and even train their animals' individual and social capacity for niche construction. Through the animals' orchestrated and piloted life activities, their 'environment' is manipulated into patterns that favour the herders' production objectives. Under this respect, the system is very modern and deals with issues — turning unpredictable variability into a resource — that are relevant also to other agricultural contexts.[23]

Instead of sheltering the animals from the rigour of the ecosystem and relying on external inputs to maximise peak production, the WoDaaBe engineer the animals' encounter with the ecosystem, through sophisticated knowledge/labour-intensive inputs. As with other systems based on the exploitation of unpredictability (cf. Roe et al., 1998), efforts for improvement are geared towards generating high reliability of a steady flow of production. The system relies on 'high inputs other than labour' in order to secure an economically favourable (and constantly adjusting) match between the animals and their environment: social capital (in the form of networks for the circulation of animal resources); knowledge capital (in the form of knowledge that is embedded in herd management practices and social institutions); the historically tested configurations of extended inheritance within their breeding populations. Although this is still different from 'intensification' in its current technical meaning, it is also far from the notion of a traditional system based on natural adaptation to a harsh environment.

[23] Brigitte Kaufmann describes similarly sophisticated forms of enhanced production in resource-poor livestock systems as 'information-intensive' systems under the umbrella of 'precision agriculture' (Kaufmann, 2005).

Beyond the theoretical dimension, there is an important practical implication. Intensification is frequently used in rural development as the key indicator of rational exploitation or land development (the French mise en valeur). Definitions of rational and efficient use of resources on this basis, hinge on material investment in visible infrastructures and the physical transformation of the environment — e.g. fencing, fodder cultivation, water collection, tree-planting, 'modern' wells. Legal frameworks on land tenure in Sahelian countries rely on these notions of land development (cf. Hesse and Thébaud, 2006). Full-time pastoralists, as such, are not typically eligible for land rights under these frameworks, on the basis of the view that, although they might use the land and maybe adapt to it, they do not transform/improve it for economic purposes. My findings make a case in the opposite direction. The WoDaaBe 'cultivate' their animals' complex capacity to construct the environment and, through their animals, the herders actively and strategically transform the land for economic purposes.

I therefore contend that the breeding/production system run by the WoDaaBe (exploiting unpredictability as a resource, selecting according to extended inheritance, and oriented towards high reliability) represents a form of land development that is marginally and incompletely represented by the current scientific model of animal breeding (environment-blind, focusing on the genetic level and efficiency-driven). This calls for a fundamental rethinking in animal science. It is time to let go of the disciplinary commitment to mechanistic linearity and homeostatic equilibrium, and invest in making the theoretical model more representative of the empirical world also including low external input systems. Moreover, in times in which environmental stability is becoming increasingly difficult and expensive to achieve, a perspective on animal production that included the possibility of exploiting unpredictability as a resource, rather than just externalising it as a disturbance, would come handy. A development of scientific animal production in this direction could already rely on a substantial body of work within foundation disciplines, from biology to ecology and economics, as well as cutting-edge schools of range management and applied animal behaviour science. Such a development could also rest on the ongoing efforts, within the discipline itself, to compensate for the environmental blindness of the standard model building on notions such as 'productive adaptability' or 'lifetime performance' (Peters, 1989; Lemke et al., 2004; Kaufmann, 2007). My findings suggest that these perspectives would be greatly advantaged by extending their attention beyond the genetic dimension, to include learned and socially transmitted behaviour and a full understanding of animal-human-environment interaction in local breeding systems. Finally, an animal production approach that, like that of the WoDaaBe, focuses on dynamic patterns of human-animal-environment interaction and variability rather than on 'natural' resources and linearity, not only enables production enhancement with low external inputs, but significantly scales down the risk of conflict over resource access and contributes to make the entire economic sector more resilient.

CONCLUSION

The study of cattle breeding amongst the WoDaaBe suggests that a fundamental revision of the model of scientific animal breeding is needed, in order to capture the integration of breeding and production strategies in livestock systems where structural unpredictability results in targeting reliability of functional performance rather than the increase of productive capacity.[24] Such a reconsideration of the model is particularly pertinent to low external input systems in highly variable environments, where the standard command-and-control approach is not cost-effective. However, it could also provide an alternative perspective on livestock production in medium-high input systems faced with increasing standards of unpredictability, for example induced by climate change. Work on complex dynamics in biology, ecology and economics over the last thirty years, as well as applied research on animal behaviour, offer a well-developed base for such a rethinking. The orientation towards high reliability, in low input livestock systems, should be at the centre of concern in pastoral development policy. That such livestock systems are tailored towards exploiting structural unpredictability needs to be fully understood and taken on board with all its implications. Finally, rural development policy frameworks (for example in the Sahel) should recognise that breeding systems using animals' extended inheritance are indeed an alternative way to construct an enhanced production environment (one capable of preserving high nature value). Such systems should therefore be granted full status as a type of land development.

Specifically with regard to the WoDaaBe, given the substantial proportion of the livestock-related economy that, in Niger, relies directly on their Bororo cattle (butchers, cattle traders, hide traders, market mediators, transporters,

[24] A recent study on breeding strategies for small ruminants in the tropics, gets as close to this position as possible while remaining within the risk aversion framework: 'The most promising breeding strategy to improve and sustain the indigenous small ruminant population is probably to address the issue of risk aversion through management measures and sire exchange rather than setting selection criteria for output-oriented traits, which cannot be matched without additional external inputs' (Kosgej, 2004: 12).

traditional-well builders, and sellers of salt and grass amongst others), the reliability of their production/breeding system is to be seen as a benefit shared by many, well beyond the group of direct producers. Moreover, because of the system's focus on fostering variability within the breeding population (a variability structured into lineages), the herders constantly tune-up domestic animal biodiversity, including economically crucial, extra-genetic diversity, at no cost to the state.

REFERENCES

Anderies J. M., Janssen M. A. and Walker B. H. (2002) 'Grazing management, resilience and the dynamics of a fire-driven rangeland system', *Ecosystems*, 5: 23-44.

Andom G. and Omerw M. K. (2003) 'Traditional cattle-husbandry systems in Eritrea: Cattle-man relationships', *Journal of Arid Environments*, 53: 545-556.

Baars T., Spengler A. and Spranger J. (2003) 'Is there something like bio-dynamic breeding?' Paper presented at the workshop 'Initiatives for animal breeding in organic farming in Europe and evaluation for future strategies', 17-18 October 2003, Louis Bolk Institute, Driebergen, The Netherlands.

Bailey D. W. (1999) 'Influence of Species, breed and type of animal on habitat selection', in Launchbaugh K. L., Mosley J. C. and Sanders K. D., *Grazing Behaviour in Livestock and Wildlife*, Pacific Northwest Range Short Course, Station Bulletin No. 70, Moscow, ID: University of Idaho.

Bayer W. (1986) 'Agropastoral herding practices and grazing behaviour of cattle in the subhumid zone of Nigeria', *ILCA Bulletin*, 24: 8-13.

Bayer W. (1989) 'Low-demand animals for low-input systems', *ILEIA Newsletter*, December: 14-15.

Bayer W. (1990) 'Use of native browse by Fulani cattle in central Nigeria, International Livestock Centre for Africa, Subhumid zone programme, Kaduna, Nigeria', *Agroforestry Systems*, 12: 217-228.

Bayer W. and Waters-Bayer A. (1995) 'Forage alternative from range and field: pastoral forage management and improvement in the African drylands', in Scoones I. ed, *Living with Uncertainty: New directions in pastoral development in Africa*, London: Intermediate Technology Publications Ltd.

Bennett I. L., Finch V. A. and Holmes R. C. (1985) 'Time spent in shade and its relationship with physiological factors of thermo-regulation in three breeds of cattle', *Applied Animal Behaviour Science*, 13: 227–236.

Bennett I. L. and Holmes C. R. (1987) 'Formation of a feeding order in a group of cattle and its relationship with grazing behaviour, heat-tolerance and production', *Applied Animal Behaviour Science*, 17: 9-18.

Bernus E. (1977) 'Les tactiques des éleveurs face à la sécheresse: le cas du sud-ouest de l'Aîr, Niger', in Gallais, J. ed, *Stratégies pastorales et agricoles des sahéliens durant la sécheresse 1969-1974*, Bordeaux: CEGET/CNRS.

Bernus E. (1981) *Touaregs nigériens: unités culturelles et diversités régionales d'un peuple pasteur*, Paris: O.R.S.T.O.M.

Bertaudiere L. and Djimadje M. (1978) *Les abbattages de bovins à l'abattoir frigorifique de Farcha (N'djamena) en 1977*, Paris: IEMVT.

Bonfiglioli Maliki A. (1981) *Ngaynaaka. herding according to the WoDaaBe*, Tahoua: Niger Range and *Livestock* Project, Discussion Paper n. 2, Republic of Niger, Ministry of Rural Development and USAID/Niger.

Bonfiglioli A. M., White C., Loutan L. and Swift J. J. (1984) 'The WoDaaBe', in Swift J. J. ed, *Pastoral Development in Central Niger: Report of the Niger Range and Livestock Project*, Niamey: République du Niger, Ministère du Développement Rural, Service de l'Elevage and USAID.

Bonsma J.C. (1949) 'Breeding cattle for increased adaptability to tropical and subtropical environments', *Journal of Agricultural Science*, 39.2: 204.

Bouissou M. F., Boissy A., Le Neindre P. and Veissier I. (2001), 'The social behaviour of cattle', in Keeling L. and Gonyou H. eds, *Social Behaviour in Farm Animals*, Wallingford UK: CAB International.

Bourn D., Wint W., Blench R. and Wolley E. (1992) 'Nigerian Livestock Resources. Volume II: National Synthesis', Federal Department of Livestock and Pest Control Services, Resource Inventory and Management Limited, Nigerian Livestock Resources Survey.

Boutrais J. (1995) *Hautes terres d'élevage au Cameroun*, 2 vols, Paris: OSTROM Éditions, Institut Français de recherche scientifique pour le développement et la coopération, Collection Études et Thèses.

Brewer T. K. (2005) *Livestock Grazing Distribution Patterns: Does animal age matter?* http://www.behave.net (26 February 2006).

Burritt E. A. and Provenza F. D. (1997) 'Effect of an unfamiliar location on the consumption of novel and familiar foods by sheep', *Applied Animal Behaviour Science*, 54: 317–325.

Chambers R. (1991) 'Complexity, Diversity and Competence: Toward sustainable livelihood from farming systems in the 21st century', *Journal of the Asian Farming System Association*, 1.1: 79-89.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. (1999) 'Livestock to 2020: The next food revolution', *Food, Agriculture and the Environment Discussion Paper 28*, Washington, DC: International Food Policy Research Institute/Food and Agriculture Organization of the United Nations/International Livestock Research Institute (IFPRI/FAO/ILRI).

Denis B. and Théret M. (1994) 'Les grands traités de zootechnie et leur conception de cette discipline', *Ethnozootechnie*, 54: 3-24.

De St Croix F.W. (1972) *The Fulani of northern Nigeria: Some general notes*, Hants: Gregg International Publishers.

Distel R. A. and Provenza F. D. (1991) 'Experience early in life affects voluntary intake of blackbrush by goats', *Journal of Chemical Ecology*, 17: 431–450.

Distel R. A., Villalba J. J. and Laborde H. E. (1994) 'Effects of early experience on voluntary intake of low quality roughage by sheep', *Journal of Animal Science*, 72: 1191-1195.

Djariri B. and Saley M. with Dahiru H. B. (2003) *L'adaptation des circuits de commercialisation des bovins nigériens à l'évolution de la demande au Nigeria, Suivi des échanges transfrontaliers entre le Nigeria et les pays voisins*, Niamey: LARES and IRAM.

Dumont B. and Boissy A. (1999) 'Rélations sociales et comportement alimentaire au pâturage', *INRA Productions Animales*, 12.1: 3–10.

Dupire M. (1962) *Peuls nomades: étude descriptive des WoDaabe du Sahel Nigérien*, Paris: Travaux et Mémoirs 64, Institut d'Ethnologie.

Emmick D. and Provenza F. (2004) 'Green acres: aiding dairy transition from confinement to pastures 2004 Report', http://www.behave.net/projects/pastures_dairy2004.html (12 March 2007).

FAO (1977) 'Animal breeding: selected articles from the World Animal Review', *FAO Animal Production and Health Paper n. 1*, Rome: Food and Agriculture Organization of the United Nations, http://www.fao.org/docrep/004/X6500E/ X6500E00.htm#int (1 February 2008).

FAO (1999) *The Global Strategy for the Management of Farm Animal Genetic Resources Executive Brief*, Rome: Food and Agriculture Organization of the United Nations.

FAO (2000) *World Watch List for Domestic Animal Diversity*, 3rd edn, edited by Scherf B., Rome: Food and Agricultural Organization of the United Nations.

FAO (2007) *The State of the World's Animal Genetic Resources for Food and Agriculture*, edited by Rischkowsky B. and Pilling D., Rome: Food and Agricultural Organization of the United Nations.

Folke C. et al., (2002) 'Resilience and sustainable development: building adaptive capacity in a world of transformations', scientific background paper on resilience for the process of The World Summit on Sustainable Development on behalf of The Environmental Advisory Council to the Swedish Government.

Galaty J. G. (1989) 'Cattle and cognition: aspects of Maasai practical reasoning', in Clutton-Brock J. ed, *The Walking Larder: Patterns of domestication, pastoralism and predation*, London: Unwin Hyman.

Ganskopp D. and Cruz R. (1999) 'Selective differences between naive and experienced cattle foraging among eight grasses', *Applied Animal Behaviour Science*, 62: 293–300.

Gliessman S. (2000) *Agroecology: The ecology of sustainable food-systems*, second edition, Boca Raton, FL: CRC Press.

Grandin T. (1987) 'Animal handling', in Price E. O. (ed.) 'Farm animal behaviour', *The Veterinary Clinic of North America: Food Animal Practice*, 3: 323-338.

Griffiths P. E. and Gray R. D. (1994) 'Developmental systems and evolutionary explanation', *Journal of Philosophy*, 91.6: 277-304.

Griffiths P. E. and Gray R. D. (2005) 'Discussion: Three ways to misunderstand developmental systems theory', *Biology and Philosophy*, 20: 417-245.

Habou A. and Danguioua A. (supervised by Bloch P. and Keïta M.) (1991) *Transfert du Capital-Bétail au Niger (des Pasteurs aux autres Catégories Socio-Professionnelles), Illusion ou Réalité ?, Rapport Préliminaire de Mission (21.12.90/26-01.91)*, Niamey: University of Wisconsin and Secrétariat Permanent du Comité National du Code Rural.

Hall A. (2007) 'Challenges to strengthening agricultural innovation systems - where do we go from here?' Paper presented at the 'Farmer First Revisited: 20 years on' conference, 12-14 December 2007, IDS, University of Sussex, UK.

Hall S. J. G. (2004) *Livestock Biodiversity: Genetic resources for the farming of the future*, Oxford: Blackwell Publishing.

Herman H. A. (1981) *Improving Cattle by the Millions: NAAB and the development and worldwide application of artificial insemination*, Columbia & London: University of Missoury Press.

Hesse C. and Thébaud B. (2006) 'Will pastoral legislation disempower pastoralists in the Sahel?' *Indigenous Affairs*, 1: 14-23.

Hiernaux P. (2000) 'Fondements écologiques de la gestion des parcours au Sahel', in Tielkes, E., Schlecht E. and Hiernaux P. eds, *Elevage et gestion de parcours au Sahel, implications pour le développement. Comptes-rendus d'un atelier régional tenu à Niamey, Niger, du 2 au 6.10.2000*, Stuttgart: Verlag Ulrich E. Grauer.

Hinrichsen J. K. (1979), Mensch-Tier-Beziehung bei afrikanischen Rindernomaden', *KTBL-Schrift* 254: 103–110.

Hodder R. M. and Low W. A. (1978) 'Grazing distribution of free-ranging cattle at three sites in the Alice Springs District, central Australia', *Australian Rangeland Journal*, 1: 95–105.

Homewood K., Lambing E. F., Coast E., Kariuki A., Kikula I., Kivelia J. Said M., Serneels S. and Thompson M. (2001) 'Long-term changes in Serengeti-Mara wildebeest and land cover: Pastoralism, population, or policies', *Proceedings from the National Academy of Sciences 98*: 12544-12549.

Horst P. (1983) 'The concept of "productive adaptability" of domestic animals in tropical and subtropical regions', *Journal of the South African Veterinary Association*, 54.3: 159.

Howery L. D., Provenza F. D., Banner R. E., Scott C. B. (1998) 'Social and environmental factors influence cattle distribution on rangeland', *Applied Animal Behaviour Science*, 55: 231–244.

Jablonka E. and Lamb M. J. (2005) *Evolution in Four Dimensions. Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life*, Cambridge MA: The MIT Press.

Joshi N. R., McLauglin E. A. and Phillips R. W. (1957) *Types and Breeds of African Cattle, FAO Agricultural Studies No. 37*, Rome: Food and Agricultural Organization of the United Nations.

Jussiau R. and Montméas L. (1994) 'La zootechnie, une discipline d'enseignement vue à travers les manuels scolaires', *Ethnozootechnie*, 54: 57-75.

Jussiau R., Montméas L. and Parot J.-C. (avec la participation de M. Méaille) (1999) *L'élevage en France. 10 000 Ans d'Histoire*, Dijon: Educagri Éditions.

Kadzere C. T., Murphy M. R., Silanikove N. and Maltz E. (2002) 'Heat stress in lactating dairy cows: a review', *Livestock Production Science*, 77: 59–91.

Kaufmann B. A. (2005) '*Precision livestock farming in developing countries: creating order where uncertainty prevails*', in Cox S. ed, Precision Livestock Farming 2005, Wageningen, NL: Wageningen University Press.

Kaufmann B. A. (2007) *Cybernetic Analysis of Socio-biological Systems: The case of livestock management in resource-poor environments*, Weikersheim: Margraf Publishers GmbH.

Koné K. (1948) 'Le boeuf du Lac Tchad de la région de N'Guigmi. Milieu d'èlevage', *Bulletin des Services de l'Élevage et des Industries Animales de l'Afrique Occidentale Française*, 1.2-3: 47-65.

Kosgey I. S. (2004) *Breeding Objectives and Breeding Strategies for Small Ruminants in the Tropics*, Ph.D. Thesis, Animal Breeding and Genetics Group, Wageningen, NL: Wageningen University.

Krätli S. (2005) 'Animal science and the representation of local breeds: looking into the sources of current zootechnical knowledge on the Bororo zebu', paper presented at the conference on 'Veterinary Science, Disease, and Livestock Economies' St. Anthony's College, Oxford, 24-25 June 2005 (to be published by Ohio University Press).

Landais E. and Bonnemarie J. (1996) 'La zootechnie, art ou science? Entre nature et société, l'histoire exemplaire d'une discipline finalisée', *Le Courrier de l'environnement*, 27.

Launchbaugh K. L., Mosley J. C. and Sanders K. D. eds (1999a) *Grazing Behavior in Livestock and Wildlife*, Pacific northwest Range Short Course, Station Bulletin No. 70, Moscow, ID: University of Idaho.

Launchbaugh K. L., Walker J. W. and Taylor C. A. (1999b) 'Foraging Behavior: Experience or inheritance?' in Launchbaugh K. L., Mosley J. C. and Sanders K. D. eds, *Grazing Behavior in Livestock and Wildlife*, Pacific northwest Range Short Course, Station Bulletin No. 70, Moscow, ID: University of Idaho.

Lazo A. (1994) 'Social segregation and the maintenance of social stability in a feral cattle population', *Animal Behaviour*, 48.5: 1133-1141.

Lazo A. (1995) 'Ranging behaviour of feral cattle (Bos taurus) in Donana National Park, S. W. Spain', *Journal of Zoology*, (London) 236: 359-369.

Lemke U., Markemann A., Binh N. T., Thuy L. T., Delgado Santivañez J., Kaufmann B. and Valle Zárate, A. (2005) 'Set up on-farm performance testing schemes as a component of village breeding programs for pigs in north Vietnam', Deutscher Tropentag 2004, 5-7 October, Berlin.

Lewontin R. C. (1983) 'Gene, organism and environment', in Bendall D. S. ed, *Evolution From Molecules to Men*, Cambridge MA: Cambridge University Press.

Loftsdóttir K. (2000) *The Bush is Sweet: Identity and desire among the WoDaaBe in Niger*, Ph.D. dissertation, The University of Arizona.

Lott D. F. and Hart B. L. (1979) 'Applied ethology in a nomadic cattle culture', *Applied Animal Ethology* 5: 309–319.

Macdonald B. R and Mosley J. C. (2006) 'Effect of Social Behavior on Habitat Selection of Cattle, Habitat Selection and Social Behavior: Influence of social rank on feeding sites and performance of free-ranging cattle', http://www.behave.net/ projects/riparian_mosley2004.html (12 March 2007).

Mason I. L. (1996) *A World Dictionary of Livestock Breeds, Types and Varieties*, 4th edition, Wallingford UK: CAB International.

McDowell R. E., with chapters by Jones R. G., Pant H. C., Roy A., Siegenthaler E. J. and Stouffer J. R. (1972) *Improvement of Livestock Production in Warm Climates*, San Francisco: W.H. Freeman and Company.

Mesnil J. G. (1978) *Rapport Succinte d'Activité. Zootechnie - Agrostologie*, Niamey: République du Niger, Service de l'Elevage.

Montméas L. and Jussiau R. (1994) 'La zootechnie dans l'enseignement technique agricole aujourd'hui', *Ethnozootechnie*, 54: 77-93.

Morand-Fehr P. and Doreau M. (2001) 'Ingestion et digestion chez les ruminants soumis à un stress de chaleur', *INRA Productions Animales*, 14.1: 15–27.

Oba G., Stenseth N. C. and Lusigi W. (2000) 'New perspectives on sustainable grazing management in arid zones of sub-Saharan Africa', *Bioscience*, 50: 35-51.

Odling-Smee F. J., Laland K. N. and Feldman M. W. (2003) *Niche Construction: The neglected process in evolution*, Princeton: Princeton University Press.

O'Reagain P. J. and Schwartz J. (1995) 'Dietary selection and foraging strategies of animals on rangeland, coping with spatial and temporal variability', in Journet M., Grenet E., Farce M-H., Theriez M. and Demarquilly C. eds, *Recent Developments in the Nutrition of Herbivores. Proceedings of the 4th International Symposium on the Nutrition of Herbivores*, Clermont-Ferrand, France.

Oyama S. (1985) *The Ontogeny of Information: Developmental systems and evolution*, Cambridge MA, Cambridge University Press.

Oyama S. (2000) *Evolution's Eye: A systems view of the biology-culture divide*, Durham and London: Duke University Press.

Oyama S., Griffiths P. E. and Gray R. D. eds, (2001) *Cycles of Contingency: Developmental systems and evolution*, Cambridge MA: MIT Press.

Peters K. J. (1989) 'Trends in on-farm performance testing of small ruminants in sub-Saharan Africa', in Trevor Wilson R. and Melaku A., African Small Ruminant Research and Development. *Proceedings of a Conference held at Bamenda, Cameroon, 18-25 January 1989*, ILCA, Addis Ababa, Ethiopia.

Phillips R. W. (1949) *Breeding Livestock Adapted to Unfavourable Environments*, FAO Agricultural Studies No. 1, Washington: Food and Agricultural Organization of the United Nations.

Phillips C. J. C. (1981) 'The identification, conservation and effective use of valuable animal genetic resources', in *Animal Genetic Resources. Conservation and Management. Proceedings of FAO/UNEP Technical Consultation*, FAO Animal Production and Health Paper 24, Rome: Food and Agricultural Organization of the United Nations.

Prins H. H. T. (1996) *Ecology and Behaviour of the African Buffalo: Social inequality and decision making*, London: Chapman & Hall.

Provenza, F. D. and Balph, D. F. (1987) 'Diet learning by domestic ruminants: theory, evidence and practical implications', *Applied Animal Behaviour Science*, 18: 211-232.

Provenza F. D. and Cincotta R. P. (1993) 'Foraging as a self-organisational learning process: accepting adaptability at the expense of predictability', in Hughes R. N. ed, *Diet Selection*, London: Blackwell Sci. Publ. Ltd.

Provenza F. D. and Launchbaugh K. (1999) 'Foraging on the edge of chaos', in Launchbaugh K. L., Mosley J. C. and Sanders K. D. eds, *Grazing Behavior in Livestock and Wildlife*, Pacific Northwest Range Short Course, Station Bulletin No. 70, Moscow, ID: University of Idaho.

Robbins C. T., Hagerman A. E., Austin P. J., McArthur C. and Hanley T. A. (1991) 'Variation in mammalian physiological responders to a condensed tannin and its ecological implications', *Journal of Mammology*, 72: 480-486.

Roe E., Hutsinger L. and Labnow K. (1998) 'High-reliability pastoralism versus risk-averse pastoralism', *Journal of Environment and Development*, 7.4: 387-421.

Ronchi B., Nardone A. and Boyazouglu J. G. eds (1991) *Animal Husbandry in Warm Climates. Proceedings of the International Symposium on Animal Husbandry in Warm Climates, Viterbo, Italy, 25-27 October 1990*, W.H. EAAP Publication No. 55, Wageningen: PUDOC.

Rosegrant M. W., Paisner M. S., Meijer S. and Witcover J. (2001) *Global Food Projections to 2020. Emerging Trends and Alternative Futures*, Washington DC: International Food Policy Research Institute.

Rushen J., De Passillé A. M. and Munksgaard L. (1997) 'Fear of people by cows and effects on milk yield, behaviour and heart rate at milking', *Journal of Dairy Science*, 80, suppl.1: 202.

Russell N. (1986) *Like Engendering Like: Heredity and animal breeding in early modern England*, Cambridge UK: Cambridge University Press.

Salthe S. N. (1993) *Development and Evolution: Complexity and change in biology*, Cambridge MA: MIT Press.

Salthe S. N. (2000) 'Regaining the riches of a lost heritage. Developmental systems theory and natural philosophy', ISSS Paper, http://www.isss.org/2000meet/ papers/20065.pdf (13 November 2007).

Schareika N., Graef F., Moser M. and Becker K. (2000) 'Pastoral migration as a method of goal-oriented and site-specific animal nutrition among the Wodaabe of south-eastern Niger', Die Erde, 131: 312-329.

Schareika N. (2003) *Know to Move, Move to Know. Ecological Knowledge Among the WoDaaBe of South Eastern Niger*, Rome: Food and Agriculture Organization of the United Nations, http://www.fao.org/DOCREP/006/Y5115E/Y5115E00.HTM (26 October 2004).

Schlecht E., Hiernaux P. and Turner M. D. (2000) Mobilité régionale du bétail: nécessité et alternatives?', in Tielkes E., Schlecht E., et Hiernaux P., *Elevage et gestion de parcours au Sahel, implications pour le développement. Comptes-rendus d'un atelier régional ouest-africain sur 'la gestion des pâturages et les projets de développement: quelle perspectives?' tenu du 2 au 6 octobre 2000 à Niamey, Niger*, Beuren, Stuttgard: Verlag Grauer.

Scoones I. ed (1995) *Living with Uncertainty: New directions in pastoral development in Africa*, London: Intermediate Technology Publications Ltd.

Scoones I., Leach M., Smith A., Stagl S., Stirling A. and Thompson J. (2007) *Dynamic Systems and the Challenge of Sustainability*, STEPS Working Paper 1, Brighton: STEPS Centre.

Seabrook M. F. (1972) 'A study to determine the influence of the herdsman's personality on milk yield', *Journal of Agricultural Labour Science*, 1: 45-49.

Seabrook M. F. (1994) 'Psychological interaction between the milker and the dairy cow. Dairy systems for the 21st century', in Bucklin R. ed, *Dairy Systems for the 21st Century*, St. Joseph, Michigan: ASAE.

Seabrook M. F. and Bartle N. C. (1992) 'Human factors', in Phillips C. and Piggins D. eds, *Farm Animals and the Environment*, Wallingford UK: CAB International.

Stenning D. (1959) *Savannah Nomads*, London: Oxford University Press.

SZE – Pécaud G. (1933) *Rapport annuel 1932*, Colonie du Niger, Service Zootechnique, Niamey.

Tacher G. (1971) 'Les abattages de bovins à l'abattoir frigorifique de Farcha (Fort-Lamy) de 1967 à 1970: analyse statistique et interprétation', in *Région de Recherches Vétérinaires et Zootechniques d'Afrique Centrale. Rapport annuel 1971*, Laboratoire de Recherches Vétérinaires de Farcha, Tchad.

Tacher G. (1979) *Rapport Préliminaire sur l'Elevage dans les Pays de la Région de la Commission du Bassin du Lac Tchad*, Paris: IEMVT et SOGREAH.

Thompson J., Millstone E., Scoones I., Ely A. Marshall F., Shah E. and Stagl S. (2007) *Agri-Food System Dynamics: Pathways to sustainability in an era of uncertainty*, STEPS Working Paper 4, Brighton: STEPS Centre.

Tribe M. and Sumner A. (2004) 'The nature of development studies: an exploration from the standpoint of the British-Irish Development Studies Association', paper prepared for the DSA Annual Conference, 'Bridging research and policy', 6 November 2004, Church House, London.

Trow-Smith R. (1950) *English Husbandry. From the Early Times to the Present Day*, London: Faber and Faber LTD.

Trow-Smith R. (1959) *A History of British Husbandry 1700-1900*, London: Routledge and Kegan Paul.

UN (1992) *Multilateral convention on biological diversity (with annexes). Concluded at Rio de Janeiro on 5 June 1992 (No. 30619)*, Rio De Janeiro: United Nations.

Uphoff N. Ball A. S., Fernandes E., Herren H., Husson O., Laing M., Palm M., Pretty J., and Sanchez P. (2006) *Biological Apporaches to Sustainable Soil Systems*, Boca Raton FL: CRC Press.

Van de Vijer G., Salthe S. N. and Delpos M. eds (1998) *Evolutionary Systems. Biological and Epistemological Perspectives on Selection and Self-Organisation*, Dordrecht NL: Kluwer Academic Publishers.

Waiblinger S., Menke C., Coleman G. (2002) 'The relationship between attitudes, personal characteristics and behaviour of stockpeople and subsequent behaviour and production of dairy cows', *Applied Animal Behaviour Science*, 79: 195–219.

Waiblinger S., Boivin X., Pedersen V., Tosi M.-V., Janczak A. M., Visser E. K. and Jonesg R. B. (2006) 'Assessing the human–animal relationship in farmed species: a critical review', *Applied Animal Behaviour Science*, 101.3-4: 185–242.

Walker B. H., Holling C. S., Carpenter S. R. and Kinzig A. P. (2004) 'Resilience, adaptability, and transformability', *Ecology and Society*, 9.2: 5.

Williamson G. and Payne W. J. A. (1978) *An Introduction to Animal Husbandry in the Tropics*, 3rd edition, London and New York: Longman.