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Importance of vector-borne infections in different production systems: bovine trypanosomosis and the innovation dynamics of livestock producers in Senegal

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Summary

In Senegal, a project has been undertaken to eradicate a population of tsetse flies (*Glossina palpalis gambiensis*) from a prime area for intensifying livestock production – the coastal region of Niayes. The project is intended to remove the constraint of trypanosomosis and allow the ecological intensification of cattle production.

A cross-sectional analysis of ten case studies was the inductive phase of an assessment to gauge the impact of removing trypanosomosis on livestock production strategies. The methodology used was comprehensive analysis, with participatory epidemiology tools to understand farmers' rationales. The authors analysed the strategies of three main types of livestock producer (agro-pastoralists, mixed crop/livestock farmers and intensive dairy farmers). The strategies were in line with the farmers' goals and their ability to mobilise the socio-technical network.

The risk management of trypanosomosis has been incorporated into livestock management practices through the use of trypanotolerant breeds, medical prophylaxis or placing livestock in low-risk areas. Removing the risk of disease would therefore have a major impact on decisions about the composition and strategic direction of herds. This change in the animal health environment would steer livestock production along different routes of intensification in a highly competitive environment.

The indicators of innovation capacity revealed by this study will be used to quantitatively monitor various change scenarios, taking livestock producers' reasoning into account, in order to assess the socio-economic impact of eradicating the tsetse fly population in this area. The methodology presented in the study can be used to understand the impact of controlling other vector-borne infections on the innovation dynamics of livestock producers.

Keywords

Actor–network theory – African animal trypanosomosis – Animal health risk – Bovine – Case study – Cattle breed – Comprehensive analysis – Ecological intensification – Livestock production system – Niayes region – Vector-borne disease – Senegal.

Introduction

Agro-ecological conditions and livestock production systems in sub-Saharan Africa are such that vector-borne infections represent a constraint on the intensification of ruminant production. African animal trypanosomosis transmitted by tsetse flies (Diptera, Glossinidae), a disease known in Africa as *nagana*, is considered to be the main animal health constraint on the intensification of cattle production (1). Its impact varies, according to the production system being used and the ability to implement an integrated control strategy, which usually calls for innovation through investment and changes in livestock production practices (2).

In Senegal, a project has been undertaken to eradicate a population of tsetse flies (*Glossina palpalis gambiensis)* from the coastal region of Niayes, a 30–40 km strip located along the Atlantic coast, where the special micro-climatic conditions make it ideal for the intensification of agriculture and livestock production. The project is coordinated by the Department of Veterinary Services, with the goal of ecological intensification (3): that is, improving livestock productivity and increasing the production of meat and animal products while reducing the cattle population. The authors studied the impact on different production systems of removing the animal health constraint (African animal trypanosomosis) by eradicating this population of vectors. The assumption is that removing the risk of trypanosomosis not only has a positive impact on the productivity of cattle production systems but also influences innovation trajectories by fostering changes in the socio-technical regime (groups of actors patterning technological development and their shared cognitive routines) (4). Understanding these trajectories is an important challenge in quantifying the socio-economic benefits of eradicating the tsetse fly population and calls for an analysis of dynamics across the socio-technical network (set of 'actants' involved in a collective action mobilising technologies).

Methods

Changes in livestock producers' strategies and practices were studied through a cross-sectional analysis of ten case studies, based on comprehensive interviews (four interviews per producer at intervals of at least one week). Participatory epidemiology tools were used to discuss the animal health context with the livestock producers. The producers were selected at random from the project's target area, after stratification of their population (around 1,000 livestock producers, of whom 513 were located during a preliminary survey) in accordance with livestock production systems, identified in advance by a socio-economic study (3). The final selection comprised three livestock producers using mainly exotic breeds (representing 17% of livestock producers in the study area); two livestock producers using mainly the Gobra breed (18%) and five livestock producers using mainly trypanotolerant cattle (65%).

Comprehensive interviews as an overall approach to determining farming strategies

Case studies were used to identify new processes and concepts (5). The aim was to build a recursive abduction/deduction/induction loop (Fig. 1) (6). Livestock producers' practices reflect their rationale, which is based on their perceptions of the way things are and of what is desirable (social norms). To understand an action, we must ascertain how the subjects themselves explain and justify it (7). To understand the dynamics at play, the authors therefore linked producers' practices with the ideas behind them and studied how they develop (8). Indeed, day-to-day decision-making processes are derived from collective ideas, which are reshaped by the debates that take place among the subjects' discussion network, and risk management is incorporated into these decisions.

The assumptions and causal links identified during this induction phase were subsequently explored by a socio-economic survey based on a larger sample (hypothetico-deductive component) (Fig. 1).

Use of participatory epidemiology tools

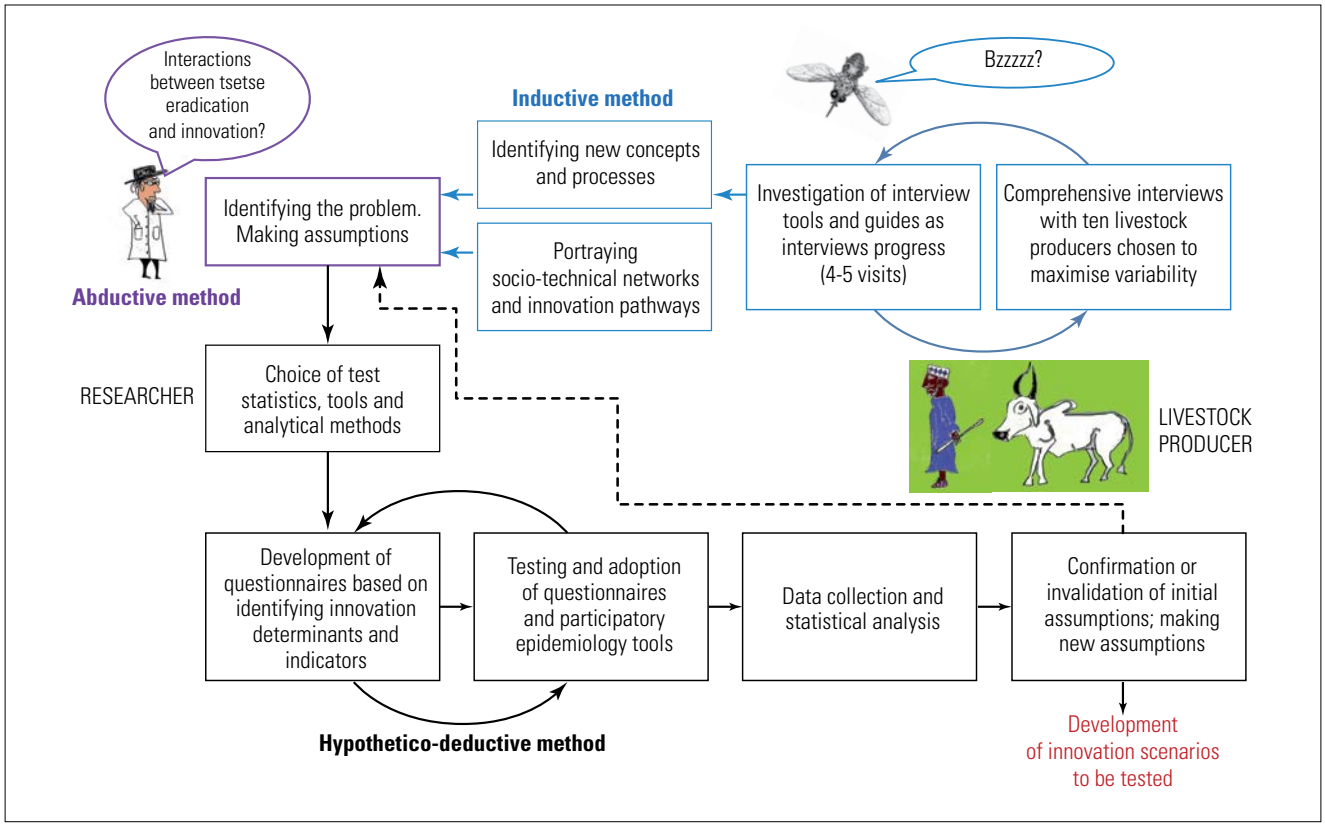
Although the risk of trypanosomosis varies widely in the Niayes region, precise data are available on the spatial distribution of the cyclical vectors of African animal trypanosomosis (9).

In order to adopt a common language on diseases, to assess the perceived risk of vector-borne diseases and to gather specific information on, and assess perceptions of, African animal trypanosomosis, each livestock producer was asked to complete a disease-scoring matrix (10, 11). The annual incidence of African animal trypanosomosis since 2010 was estimated using proportional piling. These semi-quantitative data were then integrated with quantitative data from trypanocidal and other treatments performed in 2010 and 2013.

After a comprehensive interview phase, livestock producers ranked cattle breeds in accordance with the three most recurrent criteria in the descriptions (aesthetics, productivity and hardiness).

Analysis of socio-technical and discussion networks

Individual ideas underpinning action stem from a collective construct, and the use of technology and innovation relies on



Deduction: derive a consequence from a general rule and an empirical observation (case)
Induction: find a general rule that could account for the consequence if the empirical observation is true
Abduction: develop an empirical observation that connects a general rule to a consequence (return to the consequence if the rule is true)

Fig. 1
Methodological approach to characterise interactions between trypanosomosis risk and livestock production systems in the Niayes region, Senegal
The results presented in this study concern the inductive approach

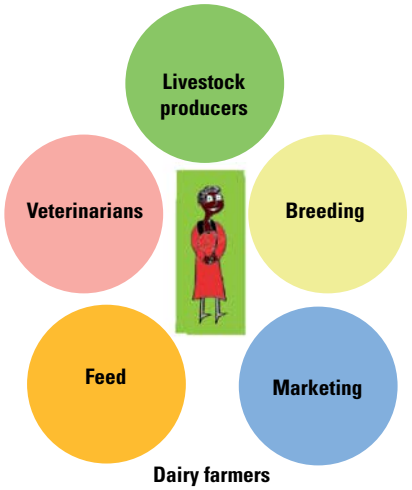
a socio-technical network (12, 13). The study of dynamics therefore necessitated upscaling from individual farms to the socio-technical networks of which they form part. The methodological framework adopted for this was actor–network theory (14), which considers the contribution of human and non-human entities in the same way (in actor–network theory both are described as 'actants'). Social groups and discussion networks were characterised because farmers' diverse relationships and discussions (with their peers, technical partners and others) foster innovation.

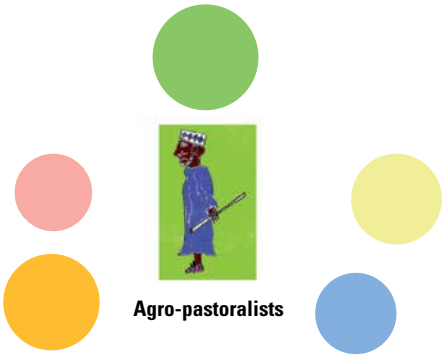
Results

Co-existence of three livestock production systems in the Niayes region

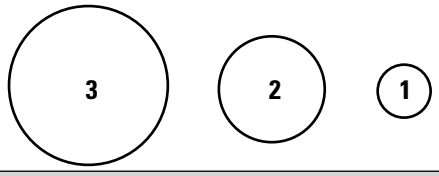
The livestock production trajectories associated with the personal goals of livestock producers can be used to characterise objective viewpoints (8) and to understand innovation trajectories. The authors therefore modified the typology used for sampling. The first distinction can be seen between, on the one hand, livestock producers who put their herds out to pasture (n = 8/10) and, on the other, dairy farmers who had used funds from another income-generating activity to start livestock production and had bought an exotic breed of dairy cattle, which they kept in permanent housing (n = 2/10). The former group includes pastoralists and agro-pastoralists (n = 6/8) who own medium-to-large herds, mainly for meat production. It also includes mixed crop/livestock farmers (n = 2/8), who started off as crop farmers before going on to acquire small-to-medium herds, with a view to mixed meat and dairy production.

Dairy farmers have invested heavily by purchasing pregnant heifers from France, practising routine artificial insemination and equipping themselves with modern infrastructure and facilities. They use both public and private Veterinary Services and service providers in France for genetic improvement and animal health purposes (Fig. 2). This system is characterised by the intensive use of inputs and the cultivation of forage crops (maize and sorghum).





Scores quantifying the dynamism of the relationship according to the type of agent



Livestock producers: discussion networks
1. Livestock producers that are affiliated to just one network and are not members of a Livestock Producer Organisation (LPO)
2. Livestock producers that are affiliated to more than one network or are members of an LPO
3. Livestock producers that are affiliated to more than one network and are members of an LPO
Veterinarians
1. Veterinarians contacted mainly for curative treatment
2. Veterinarians asked to establish an annual control programme
3. Veterinarians contracted to provide ongoing services
Breeding (genetic resources)
1. Use of local cattle breeds
2. Introduction of exotic breeds of breeding stock
3. Routine artificial insemination
Feed
1. Only pasture and purchased concentrates
2. Purchase of forage in addition to pasture and concentrates
3. Cultivation of forage crops
Commercial production
1. Products sold in the local area; either no processing or traditional processing (sour milk)
2. Product processing or new outlets
3. New products and a new sales network

Fig. 2
Relationship between livestock producers and the other components of the livestock socio-technical network of the Niayes region, Senegal, according to livestock production system

The distance between the boxes (livestock producers) and circles (other network components) is proportional to the frequency of contact; circle size is proportional to the dynamism of the relationship in terms of its capacity for innovation

Most of the pastoralists and agro-pastoralists interviewed were from the Fulani ethnic group (who formed the majority of the sample of 277 farms surveyed in 2010) (3). Their livestock production activities reflect their cultural identity; in particular, by owning a herd that is *tyosaan* or *diofndé aada* 'in order to be a real livestock producer' (Table I). Although most have a livestock farming tradition, some producers are raising a herd from inherited animals, while others have rebuilt a *nayi wuro* herd, which will once again become a *tyosaan* herd for their children (Table I). The

Table I
Meaning/description of a number of terms in the Wolof and Fula languages used by livestock producers in Senegal

Term	Translation/description	Meaning to users
Nagé, nayi	*Nagé* is the singular for 'cow' in the Fula language (plural: *nayi*)	Cattle in general
Tyosaan	'Tradition' in the Wolof language	The *tyosaan* herd is the foundation herd, which is passed down from generation to generation and whose role is to pass on the ancestral cattle-breeding lines within the family
Diofndé aada	'Traditional night paddock' in the Fula language	By extension, the 'traditional herd', which is equivalent to the *tyosaan* herd
Nayi wuro	'Cows of the house/town' in the Fula language	These are cows bought for breeding purposes and are not sold. Livestock producers may raise the breed of their choice
Thiogal	'Great herd' in the Fula language	Refers to bulls purchased under a traditional pastoral system (from outside the Niayes region) and sold for fattening
Moussane	'Exhaustion' in the Wolof language	Similar to African animal trypanosomosis in the scoring matrices; it paves the way for other diseases
Sompt, somptou	Equivalent to *moussane* in the Fula language	Similar to African animal trypanosomosis in the scoring matrices
Ripass	'Feed' in the Wolof language	Pelleted feed
Diambour	'Neutral person' in the Wolof language	Person chosen for his/her neutrality towards the parties to a dispute who is asked to arbitrate by amicable agreement
Louma	'Weekly market' in the Wolof language	Traditional weekly livestock market; often named after the town where the market is held
Gobour	'Gobra' breed in the Fula language (also referred to as *peuhl-peuhl*)	Fulani zebu cattle of Senegal

Table II
Herd feeding methods observed in ten case studies, according to livestock production systems, in Senegal

Production system	Pasture	Crop residues	Concentrates
Dairy farmers	Animals are placed in permanent housing twice a day to allow better control of health conditions and for milking	Some livestock producers not included in the study sample buy maize or bean residues. Straw is bought from outside the Niayes region	Chosen on the basis of the best value for money and given in accordance with calculated requirements for each batch (physiological stage)
Mixed farmers	Depending on the location, the grazing period varies from 12 to 4 months (when the aim is to avoid crop damage)	Derived from owner's fields or traded with neighbours at the best price. New supplemental feed comes in boxes	Preferably given to feeder cattle or lactating cows, without calculating the feed ration and in some cases erratically, depending on buying opportunities
Agro-pastoralists	Pasture is used year round. At the end of the dry season, herders feed animals on scrub	Use varies widely: residue toxicity versus pursuit of quality (depending on the impact on production). Traded collectively during the second half of the dry season when residues come from fields belonging to agribusinesses	Preferably given to feeder cattle or lactating cows, without calculating the feed ration and, in many cases, for a limited period at the end of the dry season

purpose of such herds is to perpetuate the ancestral cattle-breeding lines within the family (15): they are subject to special rules on transfer (by inheritance) and on husbandry management. These breeding lines belong to the zebu breeds Gobra and Djakore (the latter was originally a cross between the Gobra and trypanotolerant N'Dama breeds), and cattle are purchased at the traditional weekly market (*louma*). The social norm governing Fulani pastoralism is characterised by an initial low investment in infrastructure and facilities, together with the use of natural resources (through grazing and seasonal pasturing), with spending on supplemental feed being confined to the end of the dry season. The authors nevertheless observed a trend towards increased spending on feed among the livestock producers interviewed, caused by difficulties in accessing natural resources and a switch to new breeds (Table II).

Highly contrasting methods of grouping cattle were observed. Among dairy farmers there are, on the one hand, batches of heifers and cows from European breeds (the proportion of these breeds within the batch is justified technically), and, on the other hand, batches of cows from local breeds (Djakore,

or Gobra or Maure zebu cattle) or crossbreds. The aim of this strategy is to keep hardier cows to limit the decline in milk output during the warmer months.

The agro-pastoralists (*n* = 6/8) were observed either to have a herd consisting entirely of breeding cattle (*tyosaan* or rebuilt herd), or to have separated their herd into a batch of *tyosaan* cattle, a batch of feeder cattle and, sometimes, a batch of fostered cattle (cattle belonging to butchers). In an urban/peri-urban environment, downsizing of some *tyosaan* herds is in evidence, even though the social norm is to increase herds. Agro-pastoralists cite a number of constraints apart from a decline in rangeland, depending on the location of their farms: fear of sudden death caused by the ingestion of plastic bags, fear of theft of larger animals or conflict with neighbours because of the nuisance the animals may cause. The production and sale of feeder bulls born outside the Niayes region (*thiogal*) enables agro-pastoralists to meet their economic needs with reduced rearing times because the cattle are purchased on markets as adults, with different criteria from those needed for breeding stock.

Several variants of social norms are seen in the breeding management of *tyosaan* herds. Some livestock producers refer to the old rule that sires must have been born in the herd, others introduce breeding stock of a different breed (with a similar phenotype) and some even practise artificial insemination. There is much less variety in the social norms surrounding transfer rules (inheritance), and livestock producers are likely to adhere to these rules strictly, citing religious requirements as the reason.

The link between breed perceptions and livestock production systems

Agro-pastoralists and pastoralists (*n* = 6/10) appreciate the Gobra breed of zebu cattle for cultural reasons and because it represents a good compromise between aesthetics, productivity and hardiness (Fig. 3). Known locally as *gobour* or, more descriptively, as *peuhl-peuhl* [*Peuhl* is the French word for Fulani], the Gobra is the only breed to have been the subject of a description similar to a breed standard (Box 1). This breed is valued for its large size, hardiness and the quality of its milk, which is high in fat (Box 1). Livestock producers prefer to remain within the breed standard for the *tyosaan* herd and to diversify breeds for feeder bulls. For the mixed farmers and dairy farmers interviewed, the Gobra is also the preferred breed for crossbreeding. These animals are highly susceptible to African animal trypanosomosis (16).

Djakore cattle, sometimes referred to as N'Dama or *nago ordinaire*, are appreciated by mixed farmers and agro-pastoralists alike for their hardiness and long reproductive career (Fig. 3). Some farmers consider the Djakore and the N'Dama breeds to be the same. One agro-pastoralist who, despite a high trypanosomosis risk, has diversified breeds through rigorous medical prophylaxis, indicated that his N'Dama females had the greatest longevity and highest number of calvings. Where there is less of a risk of trypanosomosis (outside the tsetse-infested area), the breed drops in the ranking for aesthetics, productivity and even hardiness. Non-specific crossbreeding is seen through the introduction of breeding stock from various breeds and by insemination, which is sometimes practised in inherited herds.

European breeds are perceived very differently from one livestock production system to another (Fig. 3). The intensive farmers' network has gained specific knowledge on the performance of different breeds in the local context, whereas the other livestock producers try different breeds with no specific preference (crossbreds are referred to as *nago pompés*). One of the recommendations circulating in the intensive dairy farmers' association is to maintain a herd ratio of two-thirds Montbeliard or Jersey, for their milk quality, to one-third Holstein for its milk quantity. The Holstein is described as the most productive breed in terms of lactation but not in terms of lifetime performance because of its shorter longevity. Breed selection and ideal herd size are an ongoing subject of debate in this network, influenced by local experience and trade relationships.

Mixed farmers rank European breeds higher than agro-pastoralists do, based on their better forage supplies. Those who have tried insemination find that first filial generation (F1) crossbreds are not 'resistant' enough and have poorer conformation when they go out to pasture, and so these farmers would like to improve crossbreeding. However, they have increased their health spending by using veterinarians to set up better animal health prophylaxis.

When it comes to local breeds, the livestock producers who were interviewed in the three categories said that they preferred calves to be suckled, as this led to healthier breeding stock. They therefore sell only a portion of their milk production (see Box 1). Lastly, the Guzerat cattle breed (an exotic breed imported and distributed by the Senegalese government in the 1960s and 1970s) has acquired a very good reputation among agro-pastoralists and mixed farmers, who appreciate its aesthetics (similar to those of the Gobra breed) and productivity, although they say that it is difficult to find breeding stock. The Pakistani breed is preferred for dairy farming.

Farm location, risk exposure and perceived risk

The distribution of livestock production systems is closely linked to that of the vector: 34% of farms in the tsetse-free zone use mainly trypano-susceptible breeds, compared with 4% in the tsetse-infested area (3). The threefold decrease of trypanosomosis risk within the tsetse-free zone

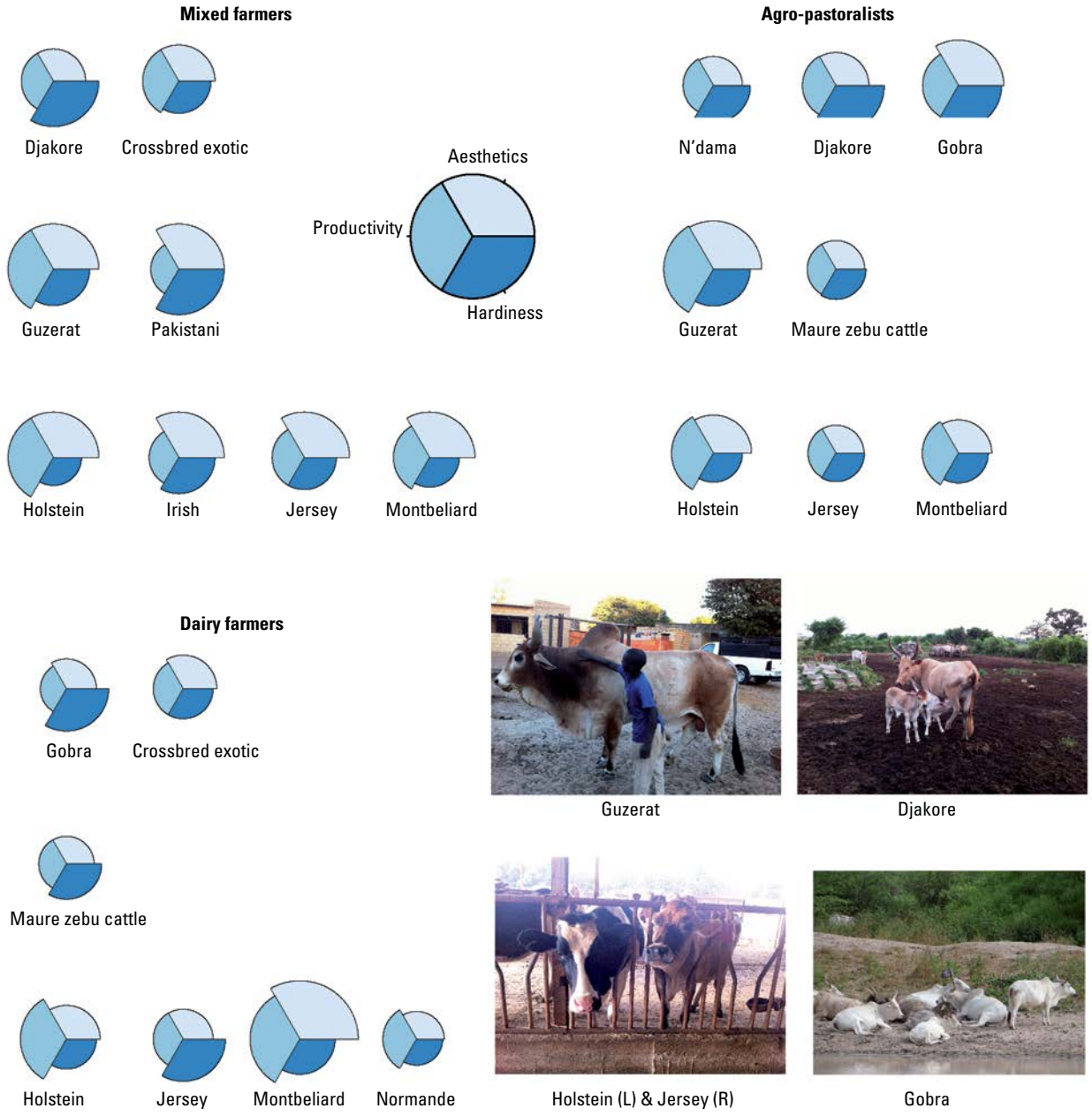


Fig. 3
Livestock producer perceptions of cattle breeds in Senegal

The different types of livestock producers ranked the breeds in accordance with three criteria: aesthetics, productivity and hardiness. The four highest-scoring breeds were retained in each ranking and any breeds unranked for one parameter but cited for another parameter were assigned a score of five. The points assigned are inversely proportional to the position in the ranking (by parameter) and an average was calculated by type of livestock producer to create the diagrams

(17) has therefore led to innovation at the breed level. Moreover, as soon as they set up in business, intensive dairy farmers employ veterinarians as farm managers or permanent service providers. Veterinarians frequently share information through the dairy farmers' association, as well as informally (Fig. 2).

The mixed farmers and agro-pastoralists interviewed explained that they started farming with the local breed (which, in the Niayes region, is the Djakore breed) because it is readily available and suited to the animal health environment. The constraint of African animal trypanosomosis is not explicitly cited as a selection criterion

Box 1
Extracts from comprehensive interviews with ten livestock producers in the Niayes region of Senegal, 2013–2014

'The gobour [Gobra] *is white, it is very attractive!* […] *Apart from the colour, the animal has a long tail and a pronounced dewlap. It has big horns and a large hump.'*
(Mr S, pastoralist and cattle trader in Thies)

'The gobour [Gobra] *is the favourite breed. When it is well fed, it beats them all! It is more resistant to heat and drought. It also tolerates thirst. It can go all day without drinking.'*
(Mr S, pastoralist and cattle trader in Thies)

'My herder only milks in the evening and leaves the calves to suckle night and morning so that they grow faster…'
(Mr B, mixed farmer in Niacoulrab)

'I always know when an animal has suckled well, when it has been well fed with milk. If it has not been well fed in its early years, it will never be good. I know this from experience. I look at the base of the horns, the forehead.'
(Mr S, pastoralist and cattle trader in Thies)

'The Djakore is an adapted breed that has remained in the area. With advances in veterinary medicine, we are able to produce other breeds: the Maure, Gobra, crossbreds.'
(Mr B, agro-pastoralist and butcher in Ndiakhirate-Digue)

'The gobour [Gobra] *is accustomed to the land around here.'*
(Mr D, agro-pastoralist in Thies)

'If she goes into the bush, she is sure to get sompt [African animal trypanosomosis]*.'*
(Mr S, agro-pastoralist in Diacksaw Peuhl, Sangalkam)

'We don't see [somptou/African animal trypanosomosis] *in our animals because we treat it. It is common in the Niayes region […]. It rarely kills. It hinders the animal's development but it does not kill quickly. There's less milk.'*
(Mr B, agro-pastoralist and butcher in Ndiakhirate-Digue)

'We want to develop agriculture and livestock production. Agriculture and livestock production go together.'
(Mr K, mixed farmer in Kayar)

'Agriculture and livestock production are linked; they should be paired together.'
(Mr B, mixed farmer in Niacoulrab)

'Local breeds are more resistant here but they produce less milk! The government has given Pakistani breeds, which are currently in high demand. No, not Guzerat. I don't like Guzerats. That's a meat breed and I am looking for milk. Milk is sold at Keur Massar the same evening, at [CFA] *500 francs wholesale. I sell it to my wife for 500 francs and she sells it on at 600 francs.'*
(Mr B, mixed farmer in Niacoulrab)

'Being in an economic interest group is an asset because the government recognises groups. If anyone wants to do insemination but isn't in an economic interest group, it's difficult.'
(Mr K, mixed farmer in Kayar)

'Crossbreeding […] to improve the breed. We were advised that it isn't easy to keep such animals. You need to grow forage crops and give them pelleted feed and crop residues as well.'
(Mr K, mixed farmer in Kayar)

'I started with the local breed but was told that animals bred from insemination are more profitable because they produce more milk. They even sell much better than the local breed. The Guzerat breed brings in a lot of money too because it is large in size. If these two breeds [crossbred and Guzerat] *aren't available, I choose the local breed.'*
(Mr K, mixed farmer in Kayar)

because livestock producers take a comprehensive view of hardiness. However, they do state that trypano-susceptible breeds are less suited to the animal health environment (Box 1).

For cultural reasons, the Fulani livestock producers of northern Senegal (n = 2/10) prefer to rebuild their herds using the Gobra breed: they live mainly in the tsetse-free zone (Thies region). In this animal health context, it is the Gobra breed that is cited as being the most hardy/resistant to disease, due in particular to its resistance to dermatophilosis (*gaye* or *ram*), which is associated with the presence of ticks (likely *Amblyomma variegatum* [Acari, Ixodidae], but this diagnosis was not confirmed during the survey) (Box 1).

In the scoring matrices, the clinical pictures referred to as *moussane* or *sompt* are similar to that of African animal trypanosomosis and the description of clinical signs is more comprehensive among agro-pastoralists with a livestock tradition than among mixed farmers and those using medical prophylaxis. However, confusion with certain tick-transmitted infections (anaplasmosis, babesiosis) is possible. The livestock producers' ranking of animal health

constraints reveals differences in perceived risk, according to their exposure to animal health risk: the five farmers in the tsetse-infested area cite African animal trypanosomosis as one of the leading animal health constraints, with three citing it as the foremost constraint. This is in contrast to livestock producers outside the tsetse-infested area, three of whom do not cite it at all, with trypanocidal prophylaxis being used for trypano-susceptible breeds.

The recent reduction in risk secured by the tsetse eradication programme is perceived only by livestock producers from the tsetse-infested area who farm Djakores and do not use prophylactic treatments. They point to a sharp decrease in the number of animals infected in the year following eradication, although they make no prognosis for the future.

Thus, African animal trypanosomosis is a constraint recognised by all the livestock producers in the authors' sample. All use trypanocidal treatments curatively and half use prophylactic treatments two to four times a year, even in the tsetse-free zone. However, livestock producers do not cite African animal trypanosomosis as a current concern, unlike diseases such as lumpy skin disease, foot and mouth disease or Rift Valley fever, the annual incidences of which vary widely (abortions due to Rift Valley fever being a concern mainly to dairy farmers). Livestock producers make no mention of the tsetse eradication project. They have integrated trypanosomosis risk into their livestock management practices by using either trypanotolerant breeds or medical prophylaxis, or both. African animal trypanosomosis control using curative treatments alone is observed only among Gobra herds with little or no exposure to tsetse flies, or among Djakore herds.

Farmers exposed to a major trypanosomosis risk view it as an inherent feature of the environment for which there is no remedy (Box 1). Those using trypanocides prophylactically believe that they are controlling the risk using this prevention strategy, while being aware of its impact on productivity (Box 1).

Livestock production strategies and feed management methods

The different feed management methods (Fig. 2) (Table II) can be characterised by whether farmers graze their animals on rangeland, grow forage crops, purchase concentrates or purchase crop residues and other types of forage (hay, straw).

Grazing animals on rangeland is the norm among traditional livestock producers: only intensive dairy farmers keep their European-breed or crossbred cows in permanent housing. One intensive farmer who used to send his batch of Djakore cows on short-distance seasonal pasturing decided to stop this practice due to the high mortality rate, attributed to poor care of animals with lumpy skin disease and Rift Valley fever, coupled with a shortage of food.

While Djakore and Gobra herds usually graze on rangeland all year round (n = 7/8), livestock producers unanimously report growing problems with dwindling land areas accessible to herds. The alternatives observed are the use of two grazing sites depending on the season (dry season/rainy season), spaced a few kilometres apart, and the tethering of livestock for long periods (more than six months) to prevent crop damage in market-gardening areas. The strategy of mixed farmers is to maintain a small-to-moderate herd size and to intensify mixed meat and dairy production (Box 1). The use of crop residues is highly variable. There is even controversy about the toxicity of crop residues due to pesticides. Efforts to procure crop residues therefore vary widely: while some mixed crop/livestock producers feed their animals on their crop residues and supplement this by negotiating low prices with other market gardeners, others invest heavily during the dry season by bargaining collectively with agribusinesses for access to bean or maize residues by the hectare. Prices vary widely and livestock producers adopt differing strategies. The longest-standing custom has been to spend as little as possible in order to limit losses during the dry season, even if it means moving the herd 'closer to the millet stalks, which cost half the price'. However, a new variant is being observed among agro-pastoralists, which is to buy more expensive residues because of their observed effect on production: 'It's expensive but good quality'.

Lastly, the practice of growing forage crops was observed only among dairy farmers, whose goal is to produce enough silage feed to meet the herd's annual needs. Hay and straw are purchased outside the Niayes region.

Variable access to technical services

Two networks for the provision of veterinary care and advice were observed: government officials delivering veterinary care in addition to their regulatory duties; and private veterinary clinics. These service providers are unevenly distributed and, while livestock producers in urban areas (such as Thies or Sebikotane) have a choice, the availability of veterinarians is a recurring problem among livestock producers living far from urban centres.

The government initiated the latest artificial insemination campaign in 2009, using semen from European dairy breeds (18). The aim of the campaign was to encourage extensive livestock producers to rear F1 crossbred cows for dairy production. Some livestock producers reported that they had formed economic interest groups (EIGs) or associations to benefit from artificial insemination (Box 1).

The information circulating among livestock producers was that 'one cow [of European breed] is enough to maintain an entire family'. Farmers had received the technical message that crossbred cows needed to be raised indoors and that they were more demanding than Gobras or Djakores in terms of feed (Box 1). Farmers who have not practised insemination cite either the *tyosaan* status of their herd and their preference for the breed 'raised by [their] father and grandfather', or the fact that they do not want to spend more on feed. Of the farmers who have already practised insemination (n = 7/10), the ones who continue to practise it are the two dairy farmers, who use it exclusively, and those who are engaged in genetic improvement for mixed production (the two mixed farmers and one agro-pastoralist). Those using genetic improvement consider the risk of this innovation acceptable, due to deferred payment and the government subsidy for insemination and the fact that crossbred cows sell for a higher price, even when sold at an earlier age than Gobras or Djakores (Box 1).

Extensive livestock producers state that they find it difficult to raise crossbred cows profitably because several years' investment is needed before reaping the first returns (gestation and rearing period prior to the first lactation). It is livestock producers with another source of income (such as agriculture or trade) who manage to raise crossbred cows for dairy farming. A national programme to promote livestock production loans is under way but the issue of access to credit is still a subject of debate for the producers.

Discussion

Existing data on livestock production in the Niayes region represent mainly the views of livestock officers (3, 18, 19, 20, 21). The participatory approach of the comprehensive interviews used in this study has helped to depict rationales from the livestock producers' viewpoint (22).

Socio-technical networks and innovation capacity

The recurring concern for all livestock producers is land pressure (20). It leads to reduced access to pasture, conflict between extensive livestock producers and crop farmers, and uncertain access to arable land for those growing their own forage.

While some livestock producers develop strategies to avoid conflict with crop farmers by keeping their animals tethered or practising short-distance seasonal pasturing, others continue to graze their animals in the neighbourhood, even though they have to pay fines when their animals damage crops. A number of strategies are observed for coping with such conflicts: recourse to mediators (*diambours*) or to negotiation between associations and crop producers concerning conditions of access to crop residues.

However, there is a new issue of concern for some livestock producers: a lack of access to crop residues as a result of competition from intensive farmers in other rural communities who come to negotiate with local crop farmers.

One of the primary responsibilities of the dairy farmers' association is to lobby the Ministry of Livestock. Its main concern, therefore, is to secure animal feed and health. Indeed, as livestock producers do not own land, every year they face uncertainty about access to leased land. In addition, the socio-technical innovation network for forage crops is in need of improvement. For instance, livestock producers have no access to good-quality agricultural equipment and forage seed is unsuited to their needs. In addition, these farmers are demanding speedier access to vaccines when the animal health context changes (i.e. there are epizootics of diseases such as foot and mouth disease, lumpy skin disease or Rift Valley fever).

Breed selection is a frequent issue of debate among livestock producers, and between them and public and private veterinarians. Veterinarians play an active role in the discussion networks of livestock producers who are in the process of intensification. Some of these producers are only in one discussion network, consisting solely of other intensive producers, others have a significant degree of multiple affiliation (i.e. they engage in discussion with different social groups) (Fig. 3). The more traditional livestock producers tend to refer to the experiences of their peers (their discussion network is confined chiefly to the local group of farmers).

The commercialisation of milk production is a concern only for intensive farmers who have to change their processing and distribution practices above a threshold volume. A new network of actors and new consumer standards appear to be developing.

Although the government has played a key incentive role through its insemination campaigns (23), the private sector has now taken over and imports pregnant heifers and semen, as well as drugs and associated equipment, in some instances on behalf of the government. Partnerships with European firms and cooperatives based on trade relationships lead to flows of technical information and hence learning. Farmers' preferences for a particular breed are not enough to ensure success (for example, there is a lack of availability of Guzerat breeding stock): the network is struggling to reconfigure itself to its advantage while the movement of semen for insemination favours European breeds.

Innovation trajectories stemming from the eradication of trypanosomosis risk

The absence of trypanosomosis risk improves farmers' ranking of the productivity, aesthetics and hardiness of trypano-susceptible breeds and removes the advantage of trypano-resistance. This will prompt livestock producers to abandon Djakores in favour of more productive trypano-susceptible breeds that have better conformation in an African animal trypanosomosis-free context (Fig. 3).

Gobra farmers represent only 3% of livestock producers in the infested area, compared with 21% of those in the tsetse-free zone. Given that, in both livestock production systems, the socio-technical network is mobilised in much the same way for the Djakore breed (65% of all livestock producers) as for the Gobra breed, it is easy to change from one breed to the other. Uncertainty is greater when it comes to the transition to dairy farming. In 2004, dairy farms accounted for 1% of cattle farms in the Niayes region (18). By 2010, this had risen to 19% in the tsetse-free zone, compared with 8% in the infested area (3).

Dairy farmers are strongly committed to innovation, but such risk-taking is possible only with substantial funding. Their system of norms and network of actors have not yet stabilised.

Knowledge and practical experience of exotic breed husbandry are growing: they are developing in the network of intensive dairy farmers and among extensive livestock producers, especially mixed farmers, with information flow between the two. The degree of multiple affiliation of the livestock producers governs information flows and comparisons based on livestock production conditions.

There are many variants of herd management norms because socio-technical regimes are in a transitional phase. Some extensive livestock producers are wondering how to implement this transition technically and financially. In particular, livestock producers are experimenting with crossbreeding, with little technical supervision, in an attempt to combine hardiness with productivity to produce their own breeding stock, while the Ministry's policy provides for continued use of insemination. Intensive farmers are raising the issue of how to secure access to land and to develop commercial production. All livestock producers are raising the issue (still to be resolved) of how to secure their access to land. This constraint is conducive to intensification and hence to innovation.

Crop/livestock integration is a concept used by mixed farmers (24) aiming to keep a medium-to-small herd in seasonal or permanent housing, based on their forage supply capability. Their goal is mixed dairy/meat intensification based on exotic breeds, an area where knowledge and practical experience are still in their infancy. The eradication of tsetse flies will ease the transition that could lead to dairy intensification.

Corniaux writes that, in the lineage societies of northern Senegal, milk is a social product whose management is subject to social rules determining technical constraints (25). In this region, agro-pastoralists and pastoralists are considering selling milk as an additional source of income that will help 'to meet the costs of daily life' (their family's food expenditure), while maintaining their primary goal of meat production. Some are considering permanently housing a core herd of dairy cows; this is an indicator that should be monitored. The fattening and sale of trypano-susceptible cattle breeds, such as Gobra and Guzerat zebus, is a likely intensification route for these farmers because it enables them to generate more revenue for a constant herd size. As the network of actors and social norms is similar, the transition will be easy.

A recent study in the Niayes region showed that, in livestock production systems using trypano-susceptible breeds (Gobra or exotic breeds), herd size was 45% smaller and annual product sales (milk and meat) were €250 (standard deviation [s.d.] 513) per head, as compared with €74 (s.d. 38) in the traditional trypanotolerant farming system ($p < 10^{-3}$) (3). The expected gains from tsetse fly eradication are therefore based on changing livestock production systems and abandoning the Djakore breed, which is consistent with the trajectories being considered. However, financial viability depends on the speed of transition from one system to the other. In Zanzibar, a 2% annual rate of change of livestock production systems was observed in the first five years after eradicating *Glossina austeni* (26). However, given that the livestock production socio-technical network in the Niayes region is already being reconfigured, and is being boosted by a network of new actors, new norms and accumulated learning, the speed of transition is likely to follow an S curve of innovation: innovation will accelerate markedly following the initial adoption phase by early innovators (27). A social and animal husbandry survey with a larger sample of participants will allow the indicators of innovation capacity to be monitored. These indicators are: initial type of livestock production (particularly herd status); investment capacity (credit or income from a second job); cattle feed system; membership of a livestock producer organisation; breeding management method; and breed of breeding stock. The economic model can then be improved by using more credible scenarios than those previously tested (3). This is necessary to estimate the cost/benefit ratio of vector-control intervention. The authors estimate 10% growth in the project's internal rate of return under a scenario where an annual 2% of livestock producers owning trypanotolerant breeds switch to another production system, and 19% growth under an S-curve scenario (3).

Cross-case analysis enabled the authors to understand how trypanosomosis risk is incorporated into the thinking of livestock producers in the Niayes region. An assessment of the health effects and economic importance of vector-borne diseases is not, in itself, enough to measure the impact of a control programme.

The approach described here can be applied to other economically important vector-borne infections that influence livestock producer strategies and livestock production systems. Such infections in the Niayes region might include heartwater, transmitted by *Amblyomma variegatum*, or dermatophilosis, which is associated with the presence of the same tick. Integrated methods of controlling these diseases do exist and could be the subject of innovation in Senegal or elsewhere (28, 29). More generally speaking, the same applies to non-vector-borne infections, against which regional and global progressive control or eradication strategies are being developed. A thorough understanding of the dynamics within socio-technical networks is essential to foster innovation in control strategies and to assess their socio-economic impact.

References

1. Van den Bossche P., de La Rocque S., Hendrickx G. & Bouyer J. (2010). – A changing environment and the epidemiology of tsetse-transmitted livestock trypanosomiasis. *Trends Parasitol.*, **26** (5), 236–243.

2. Bouyer J., Bouyer F., Donadeu M., Rowan T. & Napier G. (2013). – Community and farmer-based management of animal African trypanosomosis in cattle. *Trends Parasitol.*, **29** (11), 519–522. doi:10.1016/j.pt.2013.08.003.

3. Bouyer F., Seck M.T., Dicko A., Sall B., Lo M., Vreysen M.J.B., Chia E., Bouyer J. & Wane A. (2014). – Ex-ante benefit-cost analysis of the elimination of a *Glossina palpalis gambiensis* population in the Niayes of Senegal. *PloS Negl. Trop. Dis.*, **8** (8), e3112. doi:10.1371/journal.pntd.0003112.

4. Geels F.W. & Schot J. (2007). – Typology of sociotechnical transition pathways. *Res. Policy*, **36** (3), 399–417. doi:10.1016/j.respol.2007.01.003.

5. David A. (2003). – Études de cas et généralisation scientifique en sciences de gestion. *Rev. Sci. Gestion*, **39**, 139–166. Available at: http://econpapers.repec.org/RePEc:dau:papers:123456789/1444 (accessed on 25 November 2014).

6. David A. (1999). – Logique, épistémologie et méthodologie en sciences de gestion. DRM Publications, Châtenay Malabry, France, 23 pp.

7. Weber M. (1978). – Economy and society: an outline of interpretive sociology. University of California Press, Berkeley & Los Angeles, 1470 pp.

8. Ruault C. (1996). – L'invention collective de l'action: initiatives de groupes d'agriculteurs et développement local. L'Harmattan, Paris.

9. Dicko A.H., Lancelot R., Seck M.T., Guerrini L., Sall B., Lo M., Vreysen M.J.B., Lefrançois T., Williams F., Peck S.L. & Bouyer J. (2014). – Using species distribution models to optimize vector control: the tsetse eradication campaign in Senegal. *Proc. Natl Acad. Sci. USA*, **111** (28), 10149–10154.

10. Catley A. (2000). – The use of participatory appraisal by veterinarians in Africa. *Rev. Sci. Tech. Off. Int. Epiz.*, **19** (3), 702–719.

11. Catley A., Alders R.G. & Wood J.L.N. (2012). – Participatory epidemiology: approaches, methods, experiences. *Vet J.*, **191** (2), 151–160. doi:10.1016/j.tvjl.2011.03.010.

12. Akrich M., Callon M. & Latour B. (2002). – The key to success in innovation. Part I: The art of interessement. *Int. J. Innov. Manag.*, **6** (2), 187–206.

13. Lemery B. (2003). – Les agriculteurs dans la fabrique d'une nouvelle agriculture. *Sociol. Travail*, **45** (1), 9–25. doi:10.1016/S0038-0296(02)01302-X.

14. Akrich M., Callon M. & Latour B. (2006). – Sociologie de la traduction. Textes fondateurs (C. Méadel, ed.). Presses des Mines, Paris, 304 pp.

15. Ancey V., Ickowicz A., Corniaux C., Manoli C. & Magnani S. (2009). – Stratégies pastorales de sécurisation chez les Peuls du Ferlo (Sénégal). *J. Africanistes*, **78** (1–2), 105–119. Available at: http://africanistes.revues.org/2280 (accessed on 16 October 2014).

16. Bouyer J., Solano P., Cuisance D., Itard J., Frézil J.-L. & Authié E. (2010). – Trypanosomosis: control methods. *In* Infectious and parasitic diseases of livestock (J. Bouyer, P. Solano, D. Cuisance, J. Itard, J.-L. Frézil, E. Authié & G. Uilenberg, eds). Éditions Lavoisier (Tec. & Doc.), Paris, 1936–1943.

17. Seck M.T., Bouyer J., Sall B., Bengaly Z. & Vreysen M.J.B. (2010). – The prevalence of African animal trypanosomoses and tsetse presence in western Senegal. *Parasite*, **17** (3), 257–265.

18. Ba Diao M. (2005). – Situation et conditions de développement de la production laitière intensive dans les Niayes au Sénégal. PhD thesis submitted to Cheikh Anta Diop University, Dakar, 138 pp.

19. Ba Diao M. (2001). – Urban-rural linkages for animal products supply in Dakar. Development Planning Unit, University College, London.

20. Ba Diao M. (2004). – Situation et contraintes des systèmes urbains et périurbains de production horticole et animale dans la région de Dakar. *Cah. Agric.*, **13** (1), 39–49.

21. Dia D. (2009). – Les territoires d'élevage laitier à l'épreuve des dynamiques politiques et économiques : éléments pour une géographie du lait au Sénégal. PhD thesis submitted to Cheikh Anta Diop University, Dakar, 336 pp.

22. Darré J.-P. (1999). – La production de connaissance pour l'action. Editions de la Maison des Sciences de l'Homme, Institut National de la Recherche Agronomique, Paris, 244 pp.

23. Kouamo J., Sow A., Lèye A., Sawadogo G.J. & Ouédraogo G.A. (2009). – Amélioration des performances de production et de reproduction des bovins par l'utilisation de l'insémination artificielle en Afrique Subsaharienne et au Sénégal en particulier : état des lieux et perspectives. *Rev. Afr. Santé Prod. Anim.*, **7** (3–4), 139–147. Available at: http://eismv.org/IMG/pdf/KOUAMO_et_al._RASPA_6_3-4_2009139-148.pdf (accessed on 25 November 2014).

24. Bonfiglioli A.M. (1990). – Pastoralisme, agro-pastoralisme et retour : itinéraires sahéliens. *Cah. Sci. Hum.*, **26** (1–2), 255–266.

25. Corniaux C. (2005). – Gestion technique et gestion sociale de la production laitière : les champs du possible pour une commercialisation durable du lait. Cas des modes de production actuels du delta du fleuve Sénégal. PhD thesis submitted to the Institut National Agronomique de Paris-Grignon, Paris, 258 pp.

26. Vreysen M.J.B., Saleh K., Mramba F., Parker A., Feldmann U., Dyck V.A., Msangi A. & Bouyer J. (2014). – Sterile insects to enhance agricultural development: the case of sustainable tsetse eradication on Unguja Island, Zanzibar, using an area-wide integrated pest management approach. *PloS Negl. Trop. Dis.*, **8** (5), e2857.

27. Rogers E. (1983). – Diffusion of innovations. Free Press, New York, 576 pp.

28. Stachurski F. & Lancelot R. (2006). – Foot-bath acaricide treatment to control cattle infestation by the tick *Amblyomma variegatum*. *Med. Vet. Entomol.*, **20** (4), 402–412.

29. Stachurski F. (2000). – Invasion of West African cattle by the tick *Amblyomma variegatum*. *Med. Vet. Entomol.*, **14** (4), 391–399.