Neglected Zoonotic Diseases and Cross-border Livestock Movements in Northern Côte d’Ivoire: Towards Local and Regional Integrated Control

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Dekan

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ANADER	Agence Nationale d'Appui au Développement Rural
CBPP	Contagious Bovine Pleuropneumonia
CI	Confidence Interval
CSRS	Centre Suisse de Recherches Scientifiques en Côte d’Ivoire
DSV	Direction des Services Vétérinaires
ECOWAS	Economic Community of West African States
ELISA	Enzyme-linked immunosorbent assay
FAO	Food and Agricultural Organization of the United Nations
FCFA	Franc de la Communauté Financière Africaine
FMD	Foot-and-Mouth Disease
GDP	Gross Domestic Product
GPS	Global Positioning System
IgG	Immunoglobulin G
IgM	Immunoglobulin M
LANADA	Laboratoire National d’Appui au Développement Agricole
NCCR	National Centre of Competence in Research
NZDs	Neglected Zoonotic Diseases
OIE	Office International des Epizooties (World Organization for Animal Health)
PPR	Peste des Petits Ruminants
RBPT	Rose Bengal Plate Test
RVF	Rift Valley fever
SODEPRA	Société pour le Développement des Productions Animales
Swiss TPH	Swiss Tropical and Public Health Institute
TADs	Transboundary Animal Diseases
WAHID	World Animal Health Information Database
WHO	World Health Organization

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Summary

Background: Neglected zoonotic diseases (NZDs) are less prioritized in Africa, which is in contrast to their impacts on human and animal health and livestock production. Brucellosis, Q fever and Rift Valley fever (RVF) are among the most common NZDs that occur in Western Africa. Cross-border livestock movements are frequent in Africa given the centuries-old practice of mobile pastoralism. They are described to be associated with the spread of "highly contagious epidemic animal diseases with significant economic and food security concerns, known as Transboundary Animal Diseases -TADs", which include NZDs of interest in this PhD thesis. Although movements are central to livestock production in the Economic Community of West African States (ECOWAS), they are mostly uncontrolled. Additionally, veterinary services of the neighboring countries have hardly collaborated with respect to cross-border control of diseases. Currently the epidemiology as well as the public health and economic importance of TADs in general and NZDs in particular remain unknown in the region. The aim of this research was to generate epidemiological data on NZDs and TADs in order to assess their economic impact as well as to design appropriate regional control strategies.

Methods: Multi-stage cross-sectional cluster surveys in livestock and humans between 2012 and 2014 in a random selection of 63 villages and a sample of 633 cattle, 622 small ruminants and about 100 people were conducted. Sera were tested with the Rose Bengal Plate Test (RBPT); indirect ELISAs for *Brucella* spp., *B. ovis* and *C. burnetii*; and a competitive ELISA for *B. melitensis* and RVF. Then questionnaires were administered regarding NZD risk factors. The economic impact of brucellosis on milk, meat and hide productions were calculated for Côte d'Ivoire using a stochastic projection matrix model which simulated the demographic growth and compared cattle productions with and without brucellosis. Regarding cross-border control of livestock movements and diseases, thirteen focus group discussions with mobile pastoralists, agropastoralists and farmers as well as eleven key-informant interviews with animal health professionals and livestock movement supporting agencies were conducted. Additionally, cross-sectional serological surveys on brucellosis and Q fever in humans (n = 76), cattle, sheep and goats (n = 537) in slaughterhouses along pastoral corridors in northern Côte d'Ivoire and Abidjan were also performed.

Main results: The seroprevalence of *Brucella* spp. adjusted for clustering was 4.6% in cattle, 0% in sheep and goats and 5.3% in humans. In cattle, age, mixed-herding with other livestock species and having joint hygromas were significant predictors. The seroprevalence of Q fever was 13.9%, 9.4% and 12.4% in cattle, sheep and goats, respectively. The seroprevalence of RVF was 3.9% in cattle, 2.4% in sheep and 0% in goats. Abortion was a significant predictor of seropositivity in ewes. About 4% of the cattle had antibodies against both Q fever and RVF. The Ivorian cattle population was simulated and estimated to be about 1,885,123 and 1,906,961 with and without the disease in 2015, respectively. An overall intrinsic growth rate of 1.8% and 17.4% meat offtake rate were derived. The cumulated net present cost attributable to brucellosis infection was estimated at FCFA 14,455 x 10^6 (95% CI: 6,278–22,906). The incremental live cattle asset value was projected to FCFA 3,826 x 10^6 (95% CI: 1–7,6) in 2015. Regarding cross-border livestock mobility, key-informant interviews and group discussions identified almost 30,000 cattle from 200 mobile pastoralists involved each year in uncontrolled cross-border movements between Mali, Côte d'Ivoire and Burkina Faso. TADs such as Contagious Bovine Pleuropneumonia (CBPP), Foot-and-Mouth Disease (FMD), tuberculosis, lumpy skin disease, pasteurellosis, brucellosis and Blackleg were ranked to be the most important diseases in cattle whereas "*peste des petits ruminants*" (PPR) was the only disease reported in sheep and goats. Lack of veterinary staff and transportation means in veterinary services, poor cross-border veterinary collaboration and harmonization of disease control activities were the main constraints to controlling their spread. The study identified over-arching themes regarding the challenges and needs for cross-border control of TADs and movements and established a program for the harmonization of disease control activities in the three countries.

Conclusions: Our results provide updated epidemiological and economic descriptions of NZDs in Côte d'Ivoire. The research identified key diseases, areas of increased livestock movements, corridors/routes, and needs for cross-border control of movements and diseases in the Sudano-Guinean savanna. Cross-border collaboration should be promoted for the implementation of an effective and durable control. There is an urgent need for cost-effectiveness studies to complement our economic impact estimations as well as studies to better explore and understand the added value of cross-border cross-sectoral collaboration and coordination regarding feasible movement and disease control.

1. General Introduction

1.1. Neglected zoonotic diseases in the world

Zoonoses/zoonotic diseases derive from infections transmitted from domesticated vertebrate and wild animals to people (WHO 2015b). They account for more than half of pathogens known to infect humans and 75% of all emerging infectious diseases in the past decades (Taylor et al. 2001). Neglected zoonotic diseases (NZDs) are those zoonoses that are less prioritized and inadequately addressed by national and regional health policies, particularly in resource-limited countries (WHO 2015a). Unlike emerging zoonoses, NZDs attract less international attention; therefore, they are usually under-reported and underdiagnosed in endemic areas (Maudlin et al. 2009). They are primarily occupational diseases, affecting livestock producers, meat workers and veterinarians through the direct contact with infected animals and their products (King 2011) or through direct contact with pets such as rabies.

Nevertheless, zoonotic pathogens in contaminated foodstuffs contribute to food-borne infections leading to diseases in consumers. Efforts to control and eliminate them in animal reservoirs have gained prominence in developed countries (Ehizibolo 2011). In developing countries, the fast-growing demand for livestock products in urban areas led to the intensification of peri-urban livestock production as well as increased close contact between humans and animals. As such, NZDs are more prevalent in low-income countries where effective animal diseases surveillance systems and food safety are lacking (Zinsstag et al. 2007). NZDs in resource-limited communities reinforce poverty by negatively impacting human and animal health and productivity, thereby constituting major barriers to poverty reduction and economic growth (WHO 2006b).

1.2. Neglected zoonotic diseases in developing countries

Globally, there are between 500 and 900 million poor animal breeders who, besides living in close contact with their animals, have about 70% income dependence on livestock for their livelihood (Ashley et al. 1999). Almost 20% of human illnesses and deaths among these poor communities are due to zoonoses or diseases that recently spread over from animals to people (ILRI 2012). Bovine tuberculosis, brucellosis, rabies, anthrax, cysticercosis, echinococcosis, Q fever, zoonotic trypanosomiasis, and cutaneous leishmaniasis are examples of important NZDs for which there is an increasing advocacy for control (Welburn et al. 2015). RVF should also be considered a NZD, given its major threat for human and animal health.

Several studies demonstrated the impact of NZDs on national economies through their negative impact on public health and livestock production costs (Tschopp et al. 2013;

Zinsstag et al. 2007; Mangen et al. 2002; Domenech et al. 1982). Almost 60% of all reported anthrax cases in humans occurred in developing countries. However, illness and sudden death due to the disease in livestock is largely ignored. From the age stratified incidence rates, up to 30% - 50% of human rabies cases occurred in children under 15 years in Africa and Asia (WHO 2006b). Additionally, human mortality from dog rabies was estimated to be 59,000 deaths with about 3.7 million disability-adjusted life years (DALYs) and USD 8.6 billion economic losses each year (Hampson et al. 2015). Müller et al. (2013) found a low (1.4%) global occurrence of zoonotic tuberculosis among human tuberculosis cases. However, this finding may underestimate the real burden of the disease, since 60% of the human population live in settings where livestock undergo only limited tuberculosis control and where humans and bovine tuberculosis are not differentiated (Cosivi et al. 1998). Although brucellosis has been eliminated in high-income countries, it still causes an estimated annual 500,000 human cases worldwide (Seleem et al. 2010). Globally, there are between 1.5 and 2.4 million new cases of leishmaniasis, with almost 70,000 deaths annually (WHO 2010). Large outbreaks of RVF caused significant economic losses amongst African herds, with abortions (rates ranging from 80–100%); and deaths (25–35% in sheep and 10–20% in cattle) (Abd el-Rahim et al. 1999; Coetzer 1982). Epidemics in Egypt (1976), Mauritania (1987), East Africa (2006–2007) and Sudan (2007–2008) led to several hundred fatal cases in humans (WHO 2007a, b; Jouan et al. 1988; Meegan et al. 1979). Epidemiology of Q fever in Africa is poorly understood; however, Vanderburg et al. (2014) found that this zoonosis accounted for 2–9% of febrile illness hospitalizations and 1–3% of infective human endocarditis cases.

NZDs are primarily maintained in the animal reservoirs, but are transmitted to humans through professional exposure, behavioral and cultural habits. Hence, for the majority of zoonoses, their control and elimination are possible by interventions that vigorously target animal reservoirs as well as their interactions with humans. Given the ‘shared risk’ for human and animal health in a common socio-ecological system, a *One Health* approach is the key factor for effective disease control at the human-animal interface (Zinsstag et al. 2015). This concept has been endorsed as a cross-sector collaboration between human health, animal health, ecology, sociology, and economics, together with their related institutions – working locally, nationally, and globally – to reach optimal health for people, animals, plants and the environment (King 2008; Frank 2008).

At Swiss TPH, this definition is considered not yet sufficient. Fostered collaboration between the sectors has to lead to an added value in terms of better health and well-being for humans and animals, financial savings and enhanced environmental services when compared to traditional single-sector approaches (Zinsstag et al. 2015). An integrated approach is most likely to minimize human exposure in addition to reduce public health costs. For example, Schelling et al. (2005) showed reduction in costs, improved access to health services, and a more cost-effective diseases control in Sahelian pastoralist zones where limited resources and poor diagnostic means and diseases surveillance existed. Furthermore, several studies have shown that in rabies endemic areas, it is more cost-effective to prevent human rabies cases by dog vaccination combined with post-exposure treatment of dog-bite patients than post-exposure prophylaxis alone in humans (Zinsstag et al. 2009; Bögel & Meslin 1990). Similarly, brucellosis control by vaccination in livestock was more profitable and cost-saving for the agricultural and public health sectors if the cost of vaccination were shared between all sectors in proportion to their benefits (Roth et al. 2003).

The scope of the One Health approach to zoonoses control has been expanded to the Ecosystem Health approach, which considers ecosystem sustainability and linkages between Ecosystem change and human and animal health (Costanza & Mageau 1999; Rapport et al. 1999). Ecosystem Health, in turn, was extended to Ecosystem Approaches to Health (EcoHealth), which explores health in socio-ecological systems through transdisciplinary dialogue between science and society (Waltner-Toews & Kay 2005). However, besides the socio-economic added values of One Health and all of its logical extensions, coordination of human and veterinary medical professionals is almost always critical and challenging in resource limited countries where public health, veterinary, agricultural and environmental ministries rarely cooperate (Kaneene et al. 2014).

1.2.1. Brucellosis in developing countries

Brucellosis is designated as one of the neglected, under-detected and underreported zoonotic diseases, but with serious public health relevance in poor communities and medically underserved areas (WHO 2006b). It is caused by *Brucella* spp., a facultative intracellular Gram negative cocco-bacillus, non-spore-forming and non-capsulated bacteria. Seven *Brucella* species are currently found in terrestrial animals: *B. abortus, B. suis, B. melitensis, B. ovis, B. canis, B. microti, B. neotomae,* and *B. microti*. *Brucella* strains are named based on the host animals preferentially infected (Atluri et al. 2011; Scholz et al. 2009; Verger et al.

1987). As such, in domestic animals, *B. abortus* is adapted to cattle, *B. suis* to pigs, *B. melitensis* to sheep and goats, *B. ovis* to sheep, and *B. canis* to dogs. However, cross-species transmission of different *Brucella* species in livestock are evidenced in areas where intermixing of cattle, sheep and goats is common. *B. melitensis, B. abortus* and *B. suis* are called "classic *Brucella*", and are subdivided into biovars according to their biochemical characteristics and/or reaction to the monospecific A (*abortus*) and M (*melitensis*) sera. *B. melitensis*, *B. abortus*, and *B. suis* are subdivided into biovars 1–3, 1–7 and 1–5, respectively (Atluri et al. 2011). A systematic review on *Brucella* species and strains in the West African region found *B. abortus* to be the most prevalent species in cattle (Sanogo et al. 2013). Its biovars 1, 2, 3, 4, 6 and intermediate biovar 3/6 were the most frequent in Western Africa. *B. melitensis* was not associate with cattle brucellosis in this part of Africa (Sanogo et al. 2013); however, in Northern, Central and Eastern Africa there are descriptions of *B. abortus* in small ruminants (e.g. Nigeria) and B. *melitensis* in cattle (e.g., Egypt) (Ducrotoy et al. 2015).

In animal reservoirs, *Brucella* spp. target the reproductive tract including the placenta, mammary glands, and epididymis. The transmission between animals occurs particularly via the discharge of highly contaminated abortion and/or birth materials that contaminate the environment and lead to aerosol infections, for example, in the night pens. Alternatively, transmission can occur through milk, genital secretion and semen (Atluri et al. 2011; Carvalho Neta et al. 2010; Xavier et al. 2009). Zoonotic transmission occurs through close contact with infected animals, abortions/birth materials, consumption of uncooked milk/milk products, and other contaminated animal products. Specific occupational groups such as veterinarians, herdsmen, farmers, meat sellers and slaughterhouses workers are at higher risk than the other populations. Brucellosis infection in humans is associated with febrile disease (in about 80% of patients), but is often difficult to diagnose clinically (because undulant and sub-febrile phases) and particularly in malaria endemic countries cannot be differentiated clinically from other febrile-causing diseases. Other unspecific and debilitating symptoms are arthralgia, myalgia and back pain, epididymo-orchitis (Dean et al. 2012). *B. melitensis* is the most pathogenic *Brucella* for humans, followed in descending order by *B. suis*, *B abortus* and *B. canis* (Acha & Szyfres, 2003).

In sub-Saharan Africa, brucellosis incidence is often high in pastoral and livestock-crop systems and directly proportional to herd size. The epidemiology of the disease in sheep and goats is poorly understood in the region, because they are too often neglected by studies focusing on cattle alone. In semi-arid areas of the continent, the exposure in cattle is almost always greater than 5% (range 4.8–41%) (McDermott & Arimi 2002). Infections in cattle herds resulted in up to 40% abortions of pregnant females, 11% reduction in milk production, 35% meat losses in infected animals, 10% perinatal mortality in calves from infected cows and 15% reduction in calving rate (Mangen et al. 2002; Wilson 1986; Domenech et al. 1982).

In endemic countries, the most common serological surveillance methods are based on the detection of antibodies against *Brucella* spp. These serological tests include the Rose Bengal Plate Test (RBPT), Complement Fixation Test (CFT), Fluorescence Polarization Assay (FPA), Serum Agglutination Test (SAT) and Enzyme-linked Immunosorbent Assay (ELISA) (Gwida et al. 2010). A serological antigen detection test was recently developed at the Swiss TPH and first results with field sera are encouraging (Silbereisen et al. 2015). Molecular assays have also been developed to differentiate *Brucella* species, and assess genetic diversity and epidemiologically-linked cases of infection using strain-specific targets, particularly the repetitive element IS711 (Whatmore 2009). Hence, a PCR assay named AMOS (from "*abortus-melitensis-ovis-suis*") was developed to differentiate most *Brucella* species (Bricker & Halling 1995). Assays were further improved to include the vaccine strains S19 and RB51 for distinguishing between field and vaccine strains (Bricker et al. 2003; Bricker & Halling 1995). A multiple locus variable number tandem repeats analysis (MLVA-15), which uses 15 microsatellite markers with high identification and discriminatory power, was developed to complement or substitute classical biotyping (Flèche et al. 2006). However, isolation of *Brucella* spp. from biological materials remains the gold standard and is needed for the molecular typing, but is rather rarely done given the needs for high biosafety standards.

Mass vaccination of livestock is the approach of choice in regions with high brucellosis prevalence, extensive livestock production and/or pastoralism (Seleem et al. 2010). *B. abortus* strain 19 (S19) and strain RB51 are the most used vaccines for immunization against bovine brucellosis. Unlike S19, RB51 does not induce the formation of antibodies against "O" polysaccharide; therefore, it does not interfere with the routine diagnostic serology test (Moriyón et al. 2004). Thus, RB51 can distinguish post-vaccinal immunity from natural infection in cattle, although its efficacy is controversial (Cardena et al. 2009). *B. melitensis* strain Rev.1 is widely used for subcutaneous or conjunctival vaccination in ovine and caprine susceptible populations; however, this vaccine may induce abortions in pregnant animals. In addition, Rev.1 induces post-vaccinal antibodies that are similar as in infected animals

(Blasco 1997). Up to date, *B. melitensis* Rev. 1 vaccine has not been fully assessed for its use in cattle. *B. abortus* vaccines do not confer effective protection against *B. melitensis* infection, meaning that *B. melitensis* infection in cattle will be a serious problem even in areas where cattle is vaccinated (Gwida et al. 2010), for example in Kyrgyzstan (Kasymbekov et al. 2013). Although brucellosis is controlled in animals through vaccination, no satisfactory vaccine is available for humans. Current human treatment regimens involve the use of two or more antibiotics in order to avoid relapses and drug resistance. The following combination therapies are used: doxycycline-rifampicin, doxycycline-streptomycin, doxycycline-gentamycin and quinolones-rifampicin (Yousefi-Nooraie et al. 2012).

1.2.2. Q fever in developing countries

Except for Antarctica and New Zealand, Q fever is a zoonosis spread worldwide. It is caused by *Coxiella burnetii*, an obligate intracellular Gram negative bacterium (Maurin & Raoult 1999). *C. burnetii* is able to survive in the environment and contaminated materials in a spore-like state for months to years (Porten et al. 2006). The pathogen is recognized as a potential agent of bioterrorism, thus the Center for Disease Control and Prevention (CDC) classify it as a Category B agent (Honarmand 2012). Q fever has been reported in sheep, goats, cattle, dogs, cats, birds and rodents. High-risk groups include, but are not limited to: farmers, agropastoralists, veterinarians, lab workers and meat workers. The transmission from animals to animal is done through contact with abortion/birth products and ticks (Vanderburg et al. 2014). The disease is transmitted to humans via contact with contaminated dairy products, urines, feces, wool, semen, environmental dust and aerosolised particles, and abortion/birth materials (Vanderburg et al. 2014). The inhalation of aerosols contaminated with Q fever led to infections of the common population far (up to 2,000 metres) away from infected dairy goat herds in the Netherlands (Schimmer et al. 2010). In Chad, Q fever seropositivity was associated camel keeping (Schelling et al. 2003).

C. burnetii displays antigenic variation at the level of its lipopolysaccharide (LPS), to appear in an infectious phase I and less infectious phase II (Porten et al. 2006). IgM and/or IgG anti-phase II antibodies are predominant in the acute phase of the disease, whilst elevating anti-phase I IgG antibodies are characteristic for chronic infections (Maurin & Raoult 1999). The three serologic techniques used to detect these antibodies include: the indirect immunofluorescence (IIF) (method of choice), complement fixation, and ELISA (comparable performance to IIF). Although often asymptomatic, Q fever infection in livestock may induce up to 3–80% late-term abortions and stillbirths (Marrie 2007). In humans, the disease is mild or asymptomatic in 60% of cases and chronic in less than 5% of patients (Honarmand 2012; Courcoul et al. 2011). Common symptoms of acute human Q fever are flu-like illness, dry cough, atypical pneumonia, fever, headache, joint pain, and muscle pains. The chronic form may manifest endocarditis, vascular infection, osteoarticular infections, chronic fatigue syndrome (Angelakis & Raoult 2010). Acute human cases are treated using doxycycline as the first line treatment, whilst a combination of doxycycline and hydroxychloroquine is recommended for chronic infections (Honarmand 2012).

Q fever is often under-diagnosed and under-reported in Africa, where it is clinically misdiagnosed and treated as malaria. Consequently, its true incidence is unknown, and its epidemiology is not well-studied (Vanderburg et al. 2014; Eibach et al. 2012; Kobbe et al. 2008). However, the rare studies on Q fever in sub-Sahara found 10% seroprevalence in children in Niger, 44% in Nigeria, 1% in nomadic pastoralists in Chad, 14% in Central African Republic and 39% in Zimbabwe (Nakouné et al. 2004; Schelling et al. 2003; Julvez et al. 1997; Kelly et al. 1993; Blondeau et al. 1990).

Vaccination in infected livestock herds may be a helpful tool for reducing exposure in humans. Both Phase I and phase II vaccines are available (Lisák 1989). The phase I vaccine is used to prevent abortions and infertility and to reduce bacterial shedding in milk, feces and urine (Arricau-Bouvery et al. 2005). Corpuscular vaccines are also available for immuno-prophylaxis of domestic animals. Vaccination is successful only when animals have been vaccinated as non-infected young (i.e., calves and lambs) (Lisák 1989). Integrated Q fever control in livestock and high risk human groups and the environment coupled with public health education on routes of infection serve as an effective strategy to control the disease in poor communities (Honarmand 2012; Boni et al. 1998).

1.2.3. Rift Valley fever in developing countries

Rift Valley fever (RVF) is an acute viral zoonotic disease of domestic ruminants (sheep, goats and cattle) and humans. It is caused by a virus that belongs to the genus *Phlebovirus* in the *Bunyaviridae* family (Daubney et al. 1931). The disease is widespread in numerous African countries where several major outbreaks occurred including South Africa (2010), Madagascar (1990–1991, 2008), Egypt (1977–1978, 1993, 2003), southern Mauritania (1987, 2010, 2012), Kenya (1997, 1998, 2006, 2007), Tanzania (2007), Somalia (2007) and Sudan (2006–2007)

(Sow et al. 2014; Jäckel et al. 2013; Hassan et al. 2011; Adam et al. 2010; Sissoko et al. 2009; Faye et al. 2007; Woods et al. 2002; Jouan et al. 1988; Imam et al. 1979). Six mosquito genera (*Aedes, Culex, Mansonia, Anopheles, Coquillettidia* and *Eretmapodites*) including about 40 species were described as naturally infected by the RVF virus (FAO 2008; EFSA 2005). Mosquitoes in these genera acquire the infection by biting infected vertebrate animals; however, only the subgenera *Neomelaniconion* of *Aedes* and *Culex of Culex* were shown to maintain the RVF virus (Chevalier et al. 2011; Pepin et al. 2010). It seems that in the course of an epidemic certain vectors are more important in initial spread and others for maintained infections. These mosquitoes have the ability to transmit RVF virus transovarially (FAO 2008) and thus infected eggs (often dormant for years) are the main reservoir of the virus.

In Eastern and Southern Africa, *Culex poicilipes, Cx. tritaeniorhynchus, Cx. Antennatus, Aedes circumluteolus, Ae. palpalis, Ae. Lineatopennis, Ae cumminsii, Ae. Mcintoshi, Mansonia Africana*, and *Anopheles* spp. are the main known vectors of RFV (Ratovonjato et al. 2011). In West Africa, *Aedes vexans*, *Ae ochraceus* and *Ae dalzieli* are the only enzootic flood-water mosquitoes proven to transmit the disease (Fontenille et al. 1998). *Aedes* spp. females lay their infected eggs on the muddy banks of ponds or temporary water points. The virus then persists in the eggs from few days to several years during inter-epidemic periods (Chevalier 2013). Heavy rainfall and flooding lead to a rapid and massive hatch of eggs and breeding of larvae into adult mosquitoes (Linthicum et al. 1988). In contrast to *Aedes, Culex* eggs cannot survive desiccation, and require permanent water bodies in order to develop and hatch (Beaty & Marquardt 1996). The implications of these differences in the biology of vectors are that heavy rainfall and flooding are associated with RVF outbreaks in Eastern and Southern Africa while epidemics in Western Africa can occur during years of rainfall deficit (Ndione & Kébé 2002; Linthicum et al. 1999; Fontenille et al. 1998; Linthicum & James 1985).

Theoretically, the direct transmission between ruminants via contact with viraemic fluids is described but never demonstrated (Chevalier et al. 2011). Thus, livestock and wild ruminants are primarily infected via mosquitoes. RVF induces significant abortion rates (up to 100%) and acute deaths amongst lambs and calves (rates up to 90%) (Faye et al. 2007). Sheep are known to be more susceptible than goats, which are again more susceptible than cattle and camels (Chevalier 2013). In humans, the virus is transmitted by mosquito bites, aerosols and viraemic animal products, and abortion/birth materials (Breiman et al. 2010). RVF infection in humans is usually mild, associated with moderate influenza-like illness, biphasic fever, headache, dizziness, retro-orbital pain, chills, anorexia, myalgia and arthralgia. Severe complications (usually around 5% or less of all cases) include hemorrhagic disease, jaundice, and meningoencephalitis. Death occurs in less than 2% of patients with severe RVF (Faye et al. 2007). Strain MVP12 is a potential RVF vaccine used to protect humans, however, it has teratogenic side effects (Gowen et al. 2015). Veterinary attenuated vaccines (strain Smithburn, reassortant R566) and inactivated vaccines exist, but they were shown to induce abortions and congenital abnormalities in domestic ruminants (Breiman et al. 2010). Mass vaccinations once an epidemic started is often too late to have a significant result because badly organized, no time to differentiate already infected animals and bad acceptance by livestock owners because due to the hurry also pregnant females are vaccinated and eventually abort. Besides abortions and mortalities, RVF infection leads to important market restriction of livestock trade.

However, RVF epidemiology is lesser understood in endemic than epidemic areas. The exchanges of RVF virus strains between geographic regions and its introduction from Sudan to Egypt, from the Horn of Africa to the Arabian Peninsula, created disease potentials in naive countries (Durand et al. 2003; Shoemaker et al. 2002; Abd el-Rahim et al. 1999). The lack of effective RVF vaccines and the paucity of commercially available diagnostic assays interfere with disease control (Breiman et al. 2010).

Regional control of the zoonosis requires the identification of livestock migration routes within African regions and between Africa and other continents (Faye et al. 2007). Additionally, understanding the distribution of mosquito vectors as well as the impact of climate change on the population and ecology of *Aedes* spp. and *Culex* spp. are crucial (Chevalier et al. 2011). Key public health actions, in addition to those listed for brucellosis and Q fever, include mosquito protective measures such as vector control strategies that target immature and adult mosquitoes in risk areas.

1.3. Pastoral resources and cross-border livestock movements in the Sudano-Guinean savanna of Western Africa

In Africa, extensive livestock production is the most viable, suitable and dominant agricultural system. In the continent, about 50 million mobile pastoralists and up to 200 million agropastoralists conduct complex webs of livestock movements to benefit from rangeland ill-suited to other land use systems (De Jode 2009). They migrate annually over variable distances from the Sahelian zone to access the wetland pastoral resources in the Sudano-Guinean savanna. Common drivers of movements include access to grazing resources and water bodies, access to market places, fear of farmer-pastoralists conflicts and livestock diseases. Furthermore, livestock movements are perceived by pastoralists and shown by science as a mean for maintaining sustainable ecological equilibrium between natural resources, animals and people (Koocheki & Gliessman 2005). Cattle migrations are conducted through corridors that allow them to move between areas with lower population densities and agricultural activities (Moritz et al. 2013). In contrast to Northern Africa such as Algeria, where 80% of livestock migration is motorized, movements within and from the Sahel towards the south are mainly conducted on foot (Abiola et al. 2005).

In Western Africa, cross-border livestock movements within and between member countries of the Economic Community of West African States (ECOWAS) are crucial to livestock production. In this region, seasonal livestock flows from Sahelian countries towards countries along the coast can be separated into three main corridors: the "East-Central corridor" where animals migrate from Mali and Burkina Faso towards Côte d'Ivoire, Ghana, Togo and Benin; the "Nigeria corridor" where livestock are trekked from Niger, Chad, Sudan, Central African Republic, Mali and Burkina Faso to Nigeria, Cameroon, Benin and Togo; and the "Western seaboard corridor", where animals move from Mauritania and Mali towards Senegal, Gambia and Guinea Bissau (Abiola et al. 2005).

Mobile pastoralism and trade are the two main drivers of livestock movements in Western Africa. Mobile pastoralism, being regular seasonal back-and-forth migrations between a permanent homestead and wetland pastoral resources, can be divided into cross-border and internal mobile pastoralism (Otte & Chilonda 2003). These migrations last on average three to seven months depending on the host country. Commonly in Western Africa, young male family members or hired herders undertake these journeys with the livestock. Movements for international trade purposes gained massive potential in the region, as they allow national economies to benefit from tremendous taxes on livestock trade. For example, the official cross-border livestock trade is worth in excess of USD 150 million and the potential for expansion is even greater (De Jode 2009). In Mali where there are more than large 300 livestock markets, animal export earnings were as high as FCFA 28 billion, corresponding to about USD 46 million at that time (Ministère de l'Agriculture du Mali 2003). In Mauritania, livestock trade contributes up to 70% of the total agricultural Gross Domestic Product (GDP) (De Jode 2009) and the contribution is comparable for other countries of the region, perhaps with the exception of Côte d'Ivoire (Hatfield & Davies 2006).

Challenges to mobile pastoralism and international livestock trade include their contribution to the regional spread of transboundary animal diseases, of which 40% are zoonotic diseases (Molla & Delil 2014). Furthermore, agriculture is an important means of livelihood, whose expansion to due population growth is in direct competition with mobile pastoralism and all forms of extensive livestock movement in the semi-arid areas. Additionally, there has been increasing pressure on rangelands, water bodies and corridors due to climate change, demographic growth and land use for mining activities (Moritz 2008). Nevertheless, countries within the ECOWAS area have been supportive of cross-border livestock movements and have guaranteed land-use rights and open access to common-pool grazing resources. Several national and regional movement supporting policies such as pastoral codes and bilateral agreements were elaborated to control disease spread and mitigate conflicts. Mobile pastoralists and traders were required to carry the international certificate of mobile pastoralism, cattle vaccination certificate, zoo-sanitary certificate and evidence of local and international tax payments. However, since the last two decades, cross-border corridors have considerably changed in Western Africa and uncontrolled movements of livestock became a potential threat for regional spread of transboundary diseases. This also because countries have set up more restrictive protective rules of cross-border pastoralism, but that are in conflict with the original ECOWAS agreement.

1.4. Overview of livestock production and health systems in Côte d’Ivoire

1.4.1. Livestock production in Côte d’Ivoire

Côte d’Ivoire has three main agro-ecological zones: rainforest zone (or Guinean domain) in the south, humid grass savanna zone (or Sudano-Guinean domain) in the north, and the transition forest-savanna zone in the center. About 90% of the Ivorian population is engaged fully or partially in agriculture, forestry and livestock rearing (Ounissi 2008). The national economy relies strongly on cash-crop production, which includes mainly cocoa, coffee, timber, palm oil, bananas, pineapples, cassava, yams and sugar. The agriculture sector comprised about 40% of the country's Gross Domestic Product (GDP) (MIRAH-DPP 2012).

Livestock production is a sub-sector of agriculture, which contributes up to 5% and 2% in the agricultural and total GDP in Côte d’Ivoire, respectively (OECD 2008). Approximately 1,449,000 cattle; 1,537,000 sheep; 1,200,000 goats; 346,000 pigs and 31 million poultry were found nationwide in 2005 (MIRAH-DPP 2012). Animal breeding is mainly practiced in the humid and dry grass savanna in the north (where 85% of livestock exist) and the transition forest-savanna zone in the center (where 15% of livestock are found) (MIRAH 2003). The national breeds of trypanotolerant cattle consist of "*Baoulé*", "*N'Dama*", "*Lagune*" and their cross-breeds. These animals are kept under extensive grazing in mixed crop-livestock farming, in traditional dairy and market-oriented production systems. Sheep are mainly of the Djallonké breed, while goats are of the West African Dwarf or Guinea type. Few Sahelian sheep and goats are also found in the south. Small ruminants are particularly integrated in the cropping system, with crop residues used as feed for them while they deliver field fertilizer.

The Sahelian droughts of 1972–1973 prompted the Ivorian government to improve domestic livestock production by creating a national livestock development agency (*Societé de Développement des Productions Animales*-SODEPRA) in the 1980s. Education and training of animal health professionals and agropastoralists in “modern” animal husbandry was provided. Several large-scale cattle-fattening ranches were created in Korhogo, Bouaké and Abidjan (Diallo 1995; Handloff 1988). Artificial insemination and crossbreeding activities between local hardy, adapted and trypanotolerant cattle and Sahelian breeds (i.e. *Zébus maures, Zébus peulhs*) were conducted on 86% and 40% of the cattle population in the north and center, respectively. In parallel with the genetic improvement, several programs for intensified production of forage and fodder crops were launched to support the cattle feeding system. Rotational grazing on pastures with rich leguminosa and forage such as *Stylosanthes* *guianensis*, *Brachiaria brizantha* and *Brachiaria ruziziensis* and the use of concentrate (i.e., cottonseed, rice bran, and sugar cane) were promoted. Thus, a more northern (western) model system of livestock grazing was introduced.

SODEPRA collapsed after a structural adjustment program in 1993 and was replaced by another governmental agency named ANADER, which stands for "*Agence Nationale d'Appui au Développement Rural*". Since its inception, ANADER's livestock production strategies have been criticized by local agropastoralists (Diallo 1995; Camus 1995). A consequence of this failure is that domestic supply in cattle and small ruminants' meat is still insufficient, and covers only between 30% and 70% of the national demand. Thus, the country remains a major importer of live ruminants and meat products from Western and Southern Africa, Western Europe and Argentina. Imports of live cattle and cattle meat from Mali and Burkina Faso and Argentina accounted for FCFA 34 billion and FCFA 5 billion in 2003, respectively – meaning USD 55 million and USD 8 million at that time (Diakate 2011). The two political and armed conflicts in 2002 and 2010 also contributed to reducing importantly livestock population in the country.

1.4.2. Animal health systems and major diseases in ruminants

The Ministry of Animal and Fisheries Resources in Côte d'Ivoire is organized around ten divisions, including the Directorate of veterinary services (DSV). DSV is in charge of both animal health and veterinary public health, and is divided into six branches: (i) Animal health and production, (ii) Quality and veterinary public health, (iii) Regulation and zoo-sanitary information, (iv) Veterinary pharmacy and drugs, (v) Animal health improvement program and veterinary public health, and (vi) Trainings and communication.

The Animal health and production branch comprises nineteen regional offices, which are further divided into 58 departmental offices. Almost 174 sub-prefectural offices are subdivisions of the departmental offices. Within departments, a substantial part of animal health activities is supported by private veterinary enterprises. Several hundred-subcontracted animal health surveillance officers act as interfaces between the public and private veterinarians and agropastoralists. They provide basic animal and public health information in villages (MIRAH 2003). Several projects with livestock development programs such as *Projet d'Appui au Développement de l'Elevage en Côte d'Ivoire* (PADECI); *Projet d'Amélioration de la Santé Animale et de l'Hygiène Publique Vétérinaire* (PASA-HPV) and *Projet de*

Gestion Intégrée des Ranchs et Stations (PROGIRS) are conducted in close collaboration with the DSV.

The privatization of the veterinary profession in Côte d'Ivoire transformed the veterinary service delivery into an intensified community-based animal health delivery system. Private veterinarians have created more market-focused incentives for interventions. For example, Fulani agropastoralists who acquired vaccination technics progressively were converted into community animal health providers. Mass vaccinations and prophylactic treatments against key diseases were conducted in the 1990s via contracts with private vaccination agents (mandatory veterinarians), who were mostly ex-agents of the SODEPRA. Major diseases in Ivorian cattle herds included contagious bovine pleuropneumonia (CBPP), Foot-and-Mouth Disease (FMD), trypanosomiasis, tuberculosis, brucellosis, lumpy skin disease, tick-borne diseases, anthrax and pasteurellosis. In small ruminants, *peste des petits ruminants* (PPR) and sheep and goat pox were predominantly found. Regarding their control, national annual mass-vaccination campaigns against CBPP, pasteurellosis, anthrax and brucellosis were regularly performed in the 1990s. Vaccines were then fully subsidized by the government (Camus 1995); CBPP and brucellosis vaccines cost at the time approximately CFA 250 and CFA 85 per vaccine, respectively. Anthelminthic and trypanosomiasis treatments and tick prevention measures were provided. The control of transboundary diseases included surveillance, movement control, quarantine and vaccination of livestock in high risk areas. However, currently, public and animal health sectors are significantly deteriorated nationwide. Public and private veterinary services and the national veterinary laboratory (LANADA) were virtually absent since 2007. DSV, together with ANADER and LANADA tried to improve livestock health status through centralized programs that were often mass interventions. However, these projects were unsatisfactory due to the many underlying problems associated owing mainly to the lack of (private) veterinarians operating in rural areas, who were given the mandate, but the rural areas rarely profitable for them (Schelling et al. 2015a), and the accessibility of the vaccines and drugs. Current development of the market of informal and substandard veterinary products (mainly antibiotics and anti-parasitics) limit adherence of agropastoralists to DSV extended programs.

1.4.3. Human health system and major diseases

The Ivorian healthcare system comprises a public and private sector. Human health in both sectors is importantly influenced by Western medicine and health system models, but also by West African traditional medicines.

The public healthcare sector is organized according to a pyramid scheme. It is divided into three levels: (i) the primary level consist of sanitary institutions of first contacts, ESPC (i.e., rural and urban dispensaries and health centers, maternity wards, specialized urban health centers and clinics), (ii) the secondary level comprises health facilities used for the first reference (general hospitals, regional hospitals, specialized hospitals), (iii) the tertiary level is composed of health facilities used for the second reference (university hospitals, specialized national institutes) (Ouattara et al. 2013). The private health sector is divided into polyclinics, clinics, medical offices, private nursing homes, dental offices and private pharmacies. The public and private sectors are interconnected in the way that most doctors and nurses in the public sector also operate in private health facilities.

Regarding traditional medicines, many Ivorians use them (such herbal doctors and traditional healers) to treat a variety of diseases. These medicines are often recommended as therapies in people with low incomes and as second treatment option for patients who are refractory to modern medicines (Koné et al. 2004).

The healthcare system in Côte d’Ivoire was paralyzed by the two wars in 2002 and 2010 when almost 85% of all health workers stopped working in 80% of the health facilities. Additionally, the infrastructure and administration for drug and vaccine supplies collapsed. They became military camps. Epidemiological surveillance, routine vaccinations and ante-natal consultations were interrupted (Cissé 2011).

Currently, with the assistance of several international partners (e.g., the European Union, United Nations International Children's Emergency Fund, and the European Community Humanitarian Office), 90% of the health centers in the country are being rehabilitated. At present, almost 75% of the population can have access to healthcare in less than one hour's walking distance (Cissé 2011). Numerous infectious disease control programs are again conducted with active control and surveillance of malaria, HIV and other reproductive diseases, tuberculosis, cancers, diphtheria, tetanus, hepatitis B, polio, yellow fever, pertussis (whooping cough), *Haemophilus influenzae* type B and measles. Regarding zoonotic diseases, except from tuberculosis and rabies, they are not part of the priority diseases on the list of Ministère de la Santé et de la Lutte contre le Sida (Tiembré et al. 2011).

1.4.4. Neglected zoonotic diseases in Côte d'Ivoire

Côte d'Ivoire, as one of many poor countries, is experiencing a re-emergence of neglected zoonotic pathogens, partly resulting from the collapse of human and animal health systems during the armed conflicts (Cutler et al. 2010). The literature provides only limited information on the epidemiology, impacts, and burden of NZDs in people and animals. By visiting the World Animal Health Information Database (WAHID) interface of the OIE, in the period between 2005 and 2015, NZDs reported in livestock (but with no case numbers) were rabies, brucellosis, Q fever, RVF, anthrax and bovine tuberculosis (OIE 2015). In the same period in humans, dog rabies and anthrax were frequently – albeit still rarely – reported zoonoses to OIE.

1.4.4.1. Brucellosis

Most of brucellosis information in Côte d'Ivoire found in the literature are outdated. These studies were conducted between 1971–1984 and a more recent literature review on brucellosis in cattle, but largely referring to same old literature (Sanogo et al. 2012; Camus 1984, 1980; Pilo-Moron et al. 1979; Gidel et al. 1976; Boenhel 1971). For example, in 1971 60% of milk products sold in the local markets in northern Côte d'Ivoire were contaminated with *Brucella* spp. (Boenhel 1971). *B. abortus* biovar 1, 3 and 6 were associated with infections in the south, center, north and southeastern Côte d'Ivoire (Sanogo et al. 2013; Pilo-Moron et al. 1979). A study on cattle brucellosis in 2005 found 10% seropositivity (Sanogo et al. 2012). No brucellosis diagnostics were identified in the health services in the country, and patients with febrile disease rarely undergo confirmatory testing for the brucellosis, which partly explains the under-reporting and the lack of brucellosis incidence estimates.

1.4.4.2. Q fever

The public health importance of Q fever is unknown in the country. It was reported to the OIE for the last time in 1996 (OIE 2015). However, a seroprevalence of 8.3% was found in herding dogs with close contact to small ruminants (Boni et al. 1998).

1.4.4.3. Rift Valley fever (RVF)

Although RVF virus was isolated in mosquitoes, bats, ticks and livestock in several neighboring countries, little is known about the viral zoonoses in Côte d’Ivoire (Fontenille et al. 1998). The last study on the disease in livestock was conducted in 1992 when 7% exposure was found in sheep (Formenty et al. 1992).

1.5. Identified research gaps

The literature review on NZDs and cross-border livestock movements in Western Africa in addition to preliminary discussion with health and veterinary practitioners in Côte d'Ivoire showed the following knowledge gaps:

(i) Lack of updated epidemiological data

The persistence of NZDs in the region is partly due to poor understanding of their occurrence, prevailing pathogenic strains, animal reservoirs, transmission dynamics and risk factors. A deeper and updated epidemiological knowledge is required for identification of appropriate control strategies and for engaging the decision-makers in control (McDermott & Arimi 2002). Not only serology studies were outdated, there were neither well characterized zoonotic pathogens to further confirm serology and for molecular epidemiology.

(ii) Lack of cross-sectoral collaboration between human and animal sectors regarding the control of NZDs

In most resource-limited countries where human and animal health institutions operate virtually disconnected, the applicability of the One Health concept is challenging if no further information on potential benefits for closer cooperation is available. For example, tuberculosis and human rabies represent "shared risks" for humans and animals, however, their national control programs in Côte d'Ivoire are conducted in a mono-sectoral approach under the umbrella of the Ministry of Health. Addressing NZDs requires collaborative, cross-sectoral efforts and a multidisciplinary approach to take into account complexities of the ecosystems where both humans and animals reservoir coexist and are part of (WHO 2015b).

(iii) Lack of data on the health and economic impacts of NZDs and the cost-effectiveness of their joint control of human and animal health ministries

The incidence of NZDs are as high in people and animals as their impact on local and national economies (WHO 2012). Assessing the impact and the cross-sectoral benefit attributable to animal and public health sectors in the scenario of integrated control is needed (Zinsstag et al. 2007).

(iv) Strengthening of veterinary systems regarding so far uncontrolled livestock movements and spread of diseases

Political conflicts, cross-border pastoralism and livestock trade are common drivers of uncontrolled animal movements within the ECOWAS zone where veterinary services are often weak. The risk of regional disease spread is henceforth high in Western Africa (Dean, et al. 2013). Early warning, detection and response by improved veterinary systems are crucial to the control and prevention of disease spread. This includes improvement of infrastructures, transportation means, new diagnosis tools such as rapid diagnosis, and expansion of community-based movement control, and particularly of cross-border communication.

(v) Absence of cross-border and regional collaboration regarding the control of diseases

Cross-border and regional collaboration with regards to the control of highly epidemic transboundary diseases is promoted by the OIE (FAO and OIE 2012). However, this regional partnership needs to be reinforced in order to implement more coherent animal movements control strategies. This will further strengthen veterinary services and mitigate the spread of transboundary animal diseases, while not threatening livestock cross-border movements and trade that are central to the countries' economies.

2. Aim and Objectives

2.1. Aim

The aim of this PhD is to contribute to the understanding of the epidemiology of neglected zoonoses in people and livestock as well as to assess their economic impacts to make recommendations for regional control strategies in West Africa for both veterinary and public health systems.

2.2. Specific objectives

The following three specific objectives were addressed:

1. Epidemiology of brucellosis, Q fever and RVF at the human and livestock interface in northern Côte d'Ivoire:
    - To generate epidemiological data on the occurrence, transmission, risk factors, animal reservoirs and causative strains of brucellosis, Q fever and RVF in humans and livestock in northern Côte d'Ivoire
    - To compare different brucellosis serological screening tests in the context of Côte d'Ivoire

2. Pastoralism and transboundary animal diseases in the Sudano-Guinean savanna region of West Africa: towards an integrated cross-border and regional control:
    - To describe and quantify the importance of cross-border livestock movements in the Sudano-Guinean zone
    - To describe the exposure and risk factors of brucellosis and Q fever in abattoirs along mobile pastoralist corridors in Côte d'Ivoire and compare it with the exposure in non-pastoral areas of Abidjan
    - To make recommendations for integrated and synchronized cross-border diseases control strategies

3. Economic impact of cattle brucellosis in Côte d'Ivoire:
    - To estimate total loss of cattle productions attributable to brucellosis

3. Study Sites and Populations

Côte d'Ivoire is a West African country (geographic coordinates: 6.9°N, 5.3°W), bordering the Atlantic Ocean in the south, Ghana in the east, Mali in the north, Burkina Faso in north-east, and Liberia and Guinea Conakry in the west (Figure 3.1). During the last census in 2014, it had a population about 23,295,302 (RGPH 2014). Abidjan and Yamoussoukro are the economic and political capitals, respectively. The Ivorian population consists of more than 60 ethnic groups, which are grouped into seven clusters: Akan, Krou, Lagoon, Nuclear-Mande, Peripheral-Mande, Senoufo and Lobi. 60% are animists, 20% Muslims and 19% are Christians. The country's national GDP was USD 33.74 billion in 2014. The adult literacy rate is almost 50% nationwide. The life expectancy at birth is 56 years. Annual birth and death rates of 29.25 births/1,000 inhabitants and 9.67 deaths/1,000, respectively, are reported (PNUD 2015; The World Bank 2015).

The field study sites were Korhogo and Niakaramandougou or Niakara in northern Côte d'Ivoire (Figure 3.1). Korhogo (9°53N, 6°49W) is the regional capital and a city in the savanna district and the Poro region. Niakaramandougou (8°66°N, 5°28°W) is a department in the district of Vallée de Bandama and the Hambôl region. The climate is warm and dry (November to March), hot and dry (March to May), and hot and wet (June to October). The average annual temperature is 26° C and average rainfall is 1,243 mm, whereby the latter shows high inter-annual variance. The vegetation is dry and humid savanna (Le Guen 2004). Sénoufo and Tagwana were the most important sedentary ethnic groups in both study sites. Their main activity was agriculture, whereas their animals were kept by herdsmen of Fulani ethnicity (Diallo 1995). The population was estimated at 286,000 in Korhogo and 30,000 in Niakaramandougou, according to the 2014 census. Northern Côte d'Ivoire is characterized by extensive grazing in mixed crop-livestock farming, traditional dairy and market-oriented livestock production systems. A cattle population of almost 400,000 and 150,0000 were found in 2012 in Korhogo and Niakaramandougou, respectively (personal communication, Regional Veterinary Office, Korhogo). Most cross-border livestock movements found in the area are explained by the existence of rich wetland pastoral resources and water bodies as well as a relatively low density of tsetse flies.

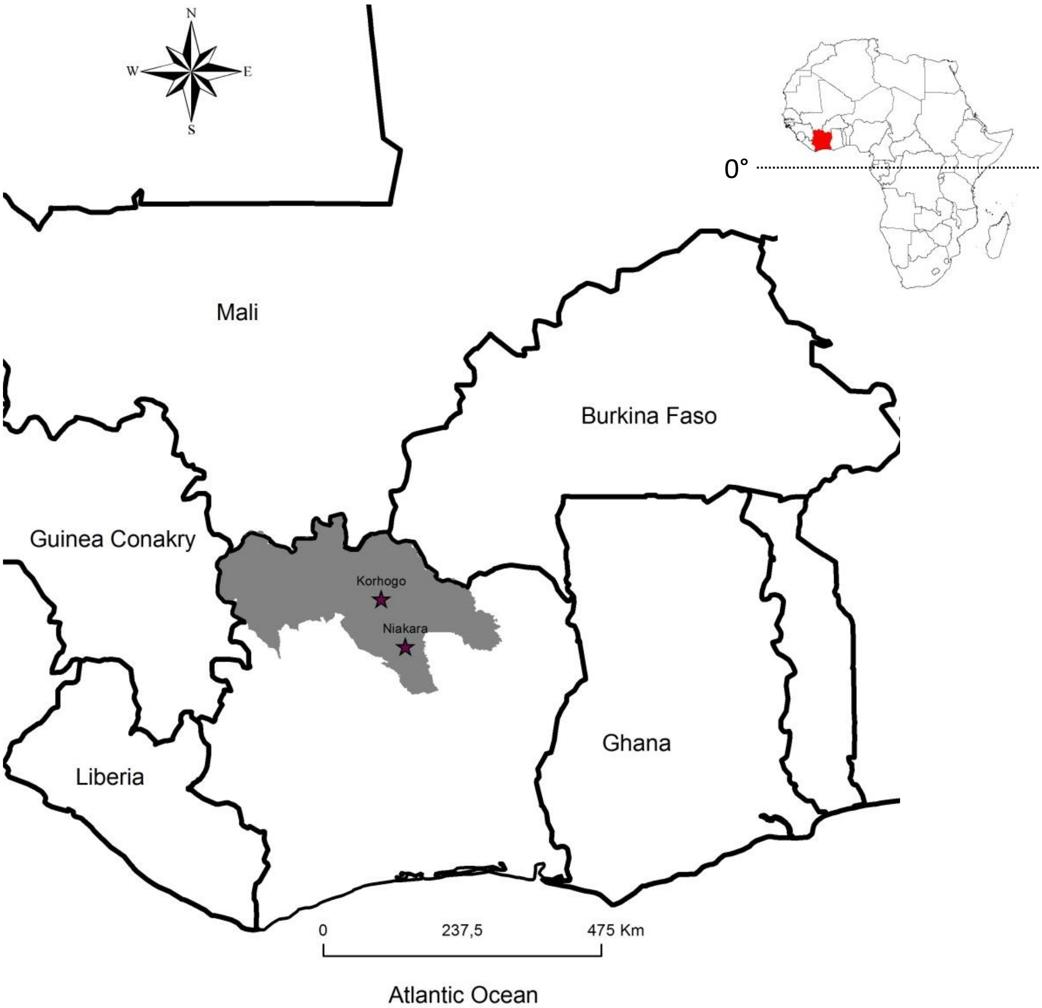

Figure 3.1: Map of the main study sites in northern Côte d'Ivoire (shaded in gray). The neighboring countries of Côte d'Ivoire in West Africa are Mali, Burkina Faso, Ghana, Liberia and Guinea Conakry.

4. Research Partnerships

This PhD project was a collaborative work between the Swiss Tropical and Public Health Institute, the University of Basel, the Institute of Veterinary Bacteriology in Bern and several Ivorian partners, including the Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS), LANADA, Ministère de la Santé et de la Lutte contre le Sida, Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, Ministère de la Production Animale et des ressources Halieutiques.

Since 1951, the CSRS has developed from a laboratory run by Swiss experts into a research institution currently led by Africans under the perspective of north-south research partnership. The goal of CSRS is the improvement of human, animal and environmental health by research, training and service delivery. The CSRS is one of the leading research institutes in sub-Sahara due to its multidisciplinary and multicultural staff including epidemiologist, nutritionist, veterinarians, geographers, statisticians, biologists, ecologist and administrative professionals (Bonfoh et al. 2011).

The PhD started within "National Competence Center for Research – NCCR North-South" program as part of the Research Project (RP) 10, which explored the issues of mobility and access to health care and social services in Africa and Asia. The NCRR North-South was jointly funded from 2001 to 2013 by the Swiss Agency for Development and Cooperation (SDC) and the Swiss National Science Foundation (SNSF).

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5. Epidemiology of brucellosis, Q fever and Rift Valley fever at the human and livestock interface in northern Côte d'Ivoire

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5.1. Abstract

Northern Côte d'Ivoire is the main livestock breeding zone and has the highest livestock cross-border movements in Côte d'Ivoire. The aim of this study was to provide updated epidemiological data on three neglected zoonotic diseases, namely brucellosis, Q fever and Rift Valley Fever (RVF). A three-stage cross-sectional cluster survey in livestock and humans between 2012 and 2014 in a random selection of 63 villages and a sample of 633 cattle, 622 small ruminants and 88 people was conducted. Questionnaires to capture risk factors and performed serological tests including the Rose Bengal Plate Test (RBPT), *Brucella* spp. indirect and competitive ELISAs, *Coxiella burnetii* indirect ELISA and RVF competitive ELISA were administered. The human seroprevalence for *Brucella* spp. was 5.3%. RBPT-positive small ruminants tested negative by the indirect ELISA. The seroprevalence of *Brucella* spp. in cattle adjusted for clustering was 4.6%. Cattle aged 5–8 years had higher odds of seropositivity (OR=3.5) than those aged ≤ 4 years. Seropositivity in cattle was associated with having joint hygromas (OR = 9), sharing the pastures with small ruminants (OR = 5.8), and contact with pastoralist herds (OR = 11.3). The seroprevalence of Q fever was 13.9% in cattle, 9.4% in sheep and 12.4% in goats. The seroprevalence of RVF was 3.9% in cattle, 2.4% in sheep and 0% in goats. Seropositive ewes had greater odds (OR = 4.7) of abortion than seronegative ones. In cattle, a shorter distance between the night pens and nearest permanent water bodies was a protective factor (OR = 0.1). The study showed that the exposure to the three zoonoses is rather low in northern Côte d'Ivoire. Within a One Health approach, cost-benefit and cost-effectiveness of control measures should be assessed for an integrated control.

Keywords: Côte d'Ivoire; human; livestock; brucellosis; Q fever; Rift Valley fever

5.2. Introduction

Zoonotic diseases arise from infections transmitted from vertebrate animals to humans or vice versa. Neglected zoonotic diseases (NZDs) are not adequately addressed by health systems nationally and internationally (WHO 2015a,b). Brucellosis, Q fever and Rift Valley Fever (RVF) are NZDs that have been largely eliminated in industrialized countries, but under-diagnosed and under-reported in resource-poor countries (WHO 2015a).

Brucellosis is caused by *Brucella* spp. with *B. melitensis* being assigned to small ruminants and *B. abortus* to cattle. *B. suis*, *B. ovis* and *B. canis* are mainly associated with pigs, sheep and dog brucellosis, respectively (Seleem et al. 2010). In sub-Saharan Africa, the exposure to the disease is highest in pastoral and agro-pastoral systems where the seroprevalence in cattle is commonly greater than 5% and decreases as herd size decreases (McDermott & Arimi 2002). A few bacteriological studies have demonstrated the existence of *B. abortus* in cattle and sheep, but evidence for *B. melitensis* in small ruminants of West Africa is unclear (Ducrotoy et al. 2014). Q fever is caused by *Coxiella burnetii*, an obligate intracellular gram-negative bacterium (Maurin & Raoult 1999). It has been reported all over the African continent with the highest seroprevalences occurring in sub-Sahara and in West Africa, where it induces significant production losses (Vanderburg et al. 2014). The exposure to Q fever was also shown to be higher in pastoral systems than in other communities (Mazeri et al. 2012). RVF is caused by a *Phlebovirus* in the family of *Bunyaviridae* (Daubney et al. 1931). The disease is widespread in sub-Saharan Africa and in Egypt, from where several outbreaks have been reported (Caminade et al. 2014; El Mamy et al. 2011; WHO 2007a, b; Abd el-Rahim et al. 1999). Mosquitoes of the genera *Aedes* and *Culex* uptake RVF virus by biting infected vertebrate animals and further transmit it transovarially and infect livestock and humans (Diallo et al. 2000; Fontenille et al. 1995; Meegan & Bailey 1988). In contrast to East and South Africa, where epizootic outbreaks are observed after heavy rainfalls and flooding, in West Africa outbreaks can occur during years of rainfall deficit (Caminade et al. 2014; Fontenille et al. 1998). The three NZDs are transmitted to humans through consumption of uncooked dairy products, contact with infected animals and contaminated carcasses or abortion materials. Additionally, humans and animals can be infected with *C. burnetii* through aerosols and ticks (Vanderburg et al. 2014; Franco et al. 2007). The most common symptoms of the three zoonoses in livestock are abortions and weak newborns; whilst in humans, nonspecific febrile diseases, headache, musculoskeletal pains, malaise and body wasting are found (Vanderburg et al. 2014; Dean et al. 2012; WHO 2007a,b). Test and slaughter are a suitable control approach in countries with animal tracking systems and low prevalences, but are not feasible in resource-poor countries due to the mobile pastoral systems and lack of proper compensation of herders. In endemic areas, control and elimination is almost only possible by interventions that simultaneously assess animal reservoirs and interactions with humans in a One Health perspective (Zinsstag et al. 2007; Roth et al. 2003). This assessment should lead to concerted efforts against several zoonoses and non-zoonotic infections, bringing together human and animal health professionals who can share the delivery infrastructure (Schelling et al. 2003). Furthermore, the identification of a cost-effective intervention requires representative quantitative data from both human health and livestock production systems; however, this is hardly available for any neglected zoonosis in resource-poor countries (Zinsstag et al. 2007; Bogel & Meslin 1990).

Northern Côte d'Ivoire, due to its rich grazing resources and water bodies, is the main livestock breeding zone in the country. Cross-border mobile pastoralists from Sahelian neighboring countries are also found in the area each year from November to April (SARA 1999; Diallo 1995). However, no animal disease control program has been in place for the last 20 years and veterinary services have not been efficient since the armed conflicts in 2002 and 2010 (Yabouaffo Honoré, personal communication). Studies on brucellosis in the northern part were conducted between 1971-1984, where it was shown that up to 60% of milk products sold in the local markets were contaminated with *Brucella* spp. (Camus 1984, 1980; Pilo-Moron et al. 1979; Gidel et al. 1976; Böenhel 1971). Q fever was studied for the last time in 1996 (Boni et al. 1998). The last study on RVF was conducted in 1992 where 7% exposure was found in sheep (Formenty et al. 1992). This study aimed at generating updated epidemiological data on the three diseases for a better understanding of seroprevalences and transmission in northern Côte d'Ivoire. The study also looked into the discrepancies of different brucellosis serological test results. Information on seroprevalences and major risk factors are useful to assess the economic impact of the three zoonoses on human health and animal production, and for the identification of suitable prevention and control options in Côte d'Ivoire.

5.3. Materials and methods

Ethical considerations

Approval was obtained from the National Ethics Committee of the Ministère de la Santé et de la Lutte contre le Sida of Côte d'Ivoire (N°71/MSLS/CNER-dkn) and the Direction Générale de Recherche Scientifique et de l'Innovation Technologique du Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (N° 089/MESRS/DGRSIT/KYS/tm). The study was also approved by the Ethics Commission of the Cantons of Basel-Stadt and Basel-Land (ref. 146/10). District health and village authorities, study participants and parents/guardians of minor participants (< 18 years) were informed about the objectives and procedures of the study as well as the potential risks and benefits. A written or oral informed consent was asked from all participants and livestock owners or herders. In case of illiteracy, a thumb imprint was recorded, witnessed and signed by a literate acquaintance of the participant. Questionnaires were administered confidentially, and participants knew that the participation was voluntary, and they could withdraw from the study at any time without further obligation. All information, samples and results were coded and treated confidentially.

Study sites and populations

The field study's sites were Korhogo and Niakaramandougou also called Niakara in northern Côte d'Ivoire (Figure 5.1). Korhogo is the regional capital and a city in the savanna district and the Poro region. Niakara is a department in the district of Vallée de Bandama and the Hambôl region. The climate is warm and dry (November to March), hot and dry (March to May), and hot and wet (June to October). The vegetation is dry and wet savanna used by extensive livestock grazing systems and crop farming. In 2014, a population of almost 760'000 was found in Korhogo (RGPH 2014). About 60% of this population lived in rural areas with income from agro-pastoral activities (RGPH 2014). In 2000, more than 60% of the national cattle population was found in northern Côte d'Ivoire (Le Guen 2004). Cross-border pastoralism is practiced by Fulani herdsmen, who are based in Mali or in Burkina Faso but migrate seasonally with their livestock during the dry season towards Korhogo and Niakara to access pastures, water points and markets. Additionally, internal pastoralism is practiced by herders from one district/region to another northern Ivorian one.

The study populations consisted of all ruminants and livestock-keeping settled or mobile households in the study sites. Sénoufo and Tagwana were the most important sedentary ethnic groups in Korhogo and Niakara, respectively. Their cattle were kept by Fulani shepherds into cattle herds owned by several persons (Diallo 1995). The night pens were usually several kilometres away from the villages. In Korhogo, up to 15% of the cattle herds were mixed with small ruminants and on average a village consisted of five cattle, three sheep and three goat herds. In contrast to Korhogo, in Niakara, cattle herds consisted almost always of more than 50 animals and intermixing between different livestock species was less practiced (Boubacary Barry, personal communication).

Cluster sample size calculation

The sample size calculation was based on the expected seroprevalence of human and livestock brucellosis as the main zoonosis under examination. Considering that the study areas did not vaccinate against brucellosis in the last 20 years, it was assumed that brucellosis has an apparent seroprevalence of 5% and 1% in cattle and small ruminants, respectively (McDermott and Arimi 2002). The design effect (D) was derived from the formula $\mathrm{D} = 1 + (\mathrm{b} - 1)*\mathrm{ICC}$; where b is the number of animals sampled per cluster and ICC is the intra-cluster (intra-village) correlation coefficient (Bennett et al. 1991). It was used an ICC of 0.1 for human and animal brucellosis (Newcombe 2001; Otte & Gumm 1997). Assuming a design effect of 1.9 and using the logit Wald method by Newcombe (2001), the authors calculated a required sample size of 630 cattle in 63 clusters (villages) to have an estimate between 3% to 8% (95% confidence interval). For sheep and goats, the respective 95% confidence interval would then be between 0.4% and 2.7% with the same number of sheep and goats together and assuming a design effect of 1.6. A seroprevalence of 3% was assumed for humans. Aiming for a 95% confidence interval of 1% to 9%, the authors obtained a required sample size of 145 people from 29 villages (the design effect was 1.4). As for Q fever and RVF in livestock, it was assumed that they share common epidemiologic patterns with brucellosis; therefore, the above sample sizes were considered to be large enough for the estimation of seroprevalences.

Sampling

Three cross-sectional studies in humans and livestock using random three-stage cluster sampling were conducted. The selection of villages (1st stage) was done with 63 random geographical coordinates that were visualised with MapInfo Professional® 7.0.Scp. Using a GPS, the 63 villages closest to each coordinate were visited. If a village was not able to participate due to not meeting inclusion criteria or declination to participate, the closest village in the northern direction was contacted. Using this approach, in May to July 2012 and May to December 2013, a total of 47 villages were enrolled in Korhogo. From March to June

2014, 16 villages were enrolled in Niakara. Thus, in total 63 villages were enrolled in the study.

Livestock

In each of the 63 villages, a list of all livestock owners willing to participate and having a minimum of 5 ruminants was established. A random drawing of a cattle, sheep and goat herd owner (2^{nd} stage) was conducted per village. Within a herd, 5–10 animals (3^{rd} stage) were randomly selected using the sampling interval which is the total herd size of animals > 5 months divided by the number of animals to be sampled per herd. Within a herd, the first animal to be selected was the closest to the direction of a pen that was spun. In total, 473 cattle, 331 sheep and 135 goats were sampled in the 63 villages.

Furthermore, sera samples were collected at three slaughterhouses in Korhogo from the period of July 2013 to May 2014. A total of 150 cattle and 209 small ruminants' sera were screened for antibodies against brucellosis. Slaughter animals were selected based on a systematic random technique, where the first ten animals slaughtered were sampled. The abattoir samples were included in the current manuscript for brucellosis serological test comparisons, but not for seroprevalence estimation. Adding these samples increased the sample size used for comparison of serological results and allowed to get kappa estimates with narrower confidence intervals (i.e., more precise estimates).

Households and participants

Eighteen (18) of the 63 villages that were sampled livestock were randomly drawn (1^{st} stage) for human brucellosis serosurvey. In each of these villages the field team conducted a random drawing of two (2) households (i.e., a Fulani and a non-Fulani household) amongst all households keeping livestock and willing to participate (2^{nd} stage). In each of the two households, 2–3 persons older than 5 years of age were randomly drawn from a list of all household members willing to participate (3^{rd} stage). Thus, a total of 88 persons were enrolled in the 18 villages. Venous blood samples were collected after a general physical examination from a nurse.

Figure 5.1: Map of the study sites (shaded are the region of Korhogo and the department of Niakara). The neighboring countries of Côte d'Ivoire in West Africa are Mali, Burkina Faso, Ghana, Liberia and Guinea Conakry.

Questionnaire administration and sample processing

A herd management questionnaire including questions on main risk factors of infection of livestock with *Brucella* spp., *C. burnetii* and RVF virus was filled out for people in charge of livestock rearing. It included questions related to livestock health status, number of abortions during the last birthing season, herd vaccination status, proximity of permanent watering bodies, herd mixing practices, animal purchases, and infestations by insects/ticks. Individual animal demographic data such as sex, age, history of abortion and breed were also collected. Knowledge and risk factors related to zoonoses were assessed with participants by querying them on the consumption of raw dairy products, obstetric practices, and exposure to livestock products. Information on gender, age, profession, and symptoms of brucellosis was recorded for humans. The questionnaire was designed in French and pretested.

Blood samples were collected by venipuncture in 5 ml VacutainerND tubes, where clots were formed at ambient temperature. They were transported at +4°C to the regional veterinary laboratory of Korhogo (LANADA) for centrifugation at 5,000 rpm for ten minutes and kept in 2 ml labeled EppendorfND tubes. Slaughterhouse animal blood was collected filling in the vacutainers with the first blood drawn at bleeding.

Brucellosis, Q fever and RVF serological analysis

For brucellosis serology in animals, all sera samples were screened by the Rose Bengal plate-agglutination Test (RBPT). In cattle, a proportion of 30 µl of serum and 30 µl of antigen (*B. abortus strain S 99,* Bio-RadND) were mixed (WHO 2006a). After a 4-minute rotation, agglutination was recorded as follows: 0 (negative), 1 (doubtful), 2 (moderately positive), 3 (strongly positive). *B. abortus* indirect IgG enzyme-linked immunosorbend assays -ELISA (CHEKIT – BrucellosisND) was used for all livestock sera. In addition, a *B. melitensis* competitive ELISA (COMPELISA – KITND) and the *B. ovis* indirect ELISA CHEKIT were used on RBPT-positive and a random selection of RBPT-negative sera. RBPT in sheep and goats was performed by mixing 75 µl of serum and 25 µl of antigen (Blasco et al. 1994). Similarly, indirect and competitive ELISAs were performed on small ruminants RBPT-positive and negative sera. Indirect IgG ELISA (CHEKIT-Q feverND) for Q fever and competitive ELISA (ID ScreenND RVF) for RVF serology in animals was also performed. For human brucellosis, the RBPT was done by mixing a serum: reagent ratio of 1:1 during 8 minutes (Diaz et al. 2011). Indirect IgM/IgG/IgA ELISA (Serion ELISA classic, Virion\Serion) was used in addition for all human sera.

Data analysis

Data was entered twice into Access 2010 (Microsoft, USA) and compared using Epi-Info™, version 3.5.1 (Centers for Disease Control and Prevention, CDC, USA). The analysis was performed using STATA 12.0 (StataCorp LP, USA). The apparent seroprevalences of brucellosis, Q fever and RVF in cattle, sheep, goats and humans were determined using a Generalized Estimating Equation (GEE) model which was adjusted for clustering within villages (Condon et al. 2004; Schukken et al. 2003; Liang & Zeger 1986). Associations between the individual-level seropositivity in cattle, sheep and goats and potential risk factors were assessed using logistic regression models which were also adjusted for clustering within villages (Homish et al. 2010; Sheu 2000). The univariate analysis was first performed for all animal demographic data (e.g., age, sex, history of abortion and breed) in order to identify significant predictors of seropositivity. The selection of these predictors was done based on the Wald test, retaining covariates with $p \leq 0.2$. All the significant predictors were then pooled into multivariate logistic regression models, additionally adjusted for age and sex (which were biologically important covariates) and for clustering within villages. A backward stepwise selection was then performed based on the Wald test. A predictor was excluded from the final multivariate model when the p-value for its association with seropositivity was ≥ 0.05. Confounders were variables whose exclusion altered the logarithmized odds ratios of other covariates by more than 25% (van Engelen et al. 2014). For humans, univariate analyses were conducted to assess associations between seropositivity and human demographic data (e.g., age, sex, and ethnicity). It was also assessed whether livestock seropositivity was a predictor of seropositivity in people. Where data were too sparse, comparisons were done using Fisher's exact test. Due to the small sample size (n = 88) in humans, a multivariate analysis was not done. The agreements between brucellosis serological tests were assessed by performing a kappa statistic (McHugh 2012; Cohen 1960).

5.4. Results

Descriptive analyses in livestock and humans

Cattle, sheep and goat sampled were of Sahelian Zebu crossbreeds, Djallonké and Grassland Dwarf Goat breeds, respectively. Almost 15% (50/364) of cows, 20% (49/261) of ewes and 20% (23/122) of nanny goats were reported to have aborted. Herd-level history of abortions during the last birthing season was almost 80 % in all species – in cattle (38/46), sheep (31/39) and goat (17/22) herds. During the year prior to the interviews, at least one new animal was introduced into 40% of cattle and sheep herds. Almost 80% of cattle (n = 473) and sheep (n = 331) and 90% of goats (n = 135) were females. Cattle and small ruminants had a median age of 5 and 2.5 years, respectively. About 80% of the participants (n = 88) were men and 16% of them under 15 years old. Minor participants were mostly (11/14) sampled in Fulani households. Eighty-five per cent of the participants were of Fulani ethnicity, of which almost 80% (59/75) were men. Ninety percent of the participants had heard of brucellosis, of which 30% (21/79) knew of its possible transmission to humans (Table 5.1). Overall, 80% (70/88) of participants consumed raw milk. Almost 60% (38/63) of people interviewed reported relapsing fever (Table 5.1). In contrast to brucellosis, participants did not hear of Q fever and its risk factors; however, 85% (17/20) of herdsmen mentioned that ticks were able to transmit diseases to livestock (Table 5.1).

Table 5.1: Knowledge, risk factors and symptoms of brucellosis, Q fever and RVF in humans in northern Côte d'Ivoire.

Category		Fulani n	Fulani Yes (%)	Non-Fulani n	Non-Fulani Yes (%)
Brucellosis					
Brucellosis awareness		75	66 (88%)	13	13 (100%)
Transmission to human[a]		66	20 (30%)	13	1 (7.7%)
Raw milk consumption		75	58 (77%)	13	12 (92%)
Traditional fermented milk consumption[a]		8	3 (37.5%)	0	0 (0%)
Obstetric practices in cows[a]		30	27 (90%)	3	3 (100%)
Obstetric practices in small ruminants[a]		23	0 (0%)	2	0 (100%)
Handling abortion materials[a]	Unprotected contact	38	12 (31.6%)	1	0 (0%)
	Protected contact	38	26 (68%)	1	100 (100%)
	No contact	38	0 (0%)	1	0 (0%)
Removal of abortion materials[a]	On the pasture	34	19 (55.9%)	1	0 (0%)
	In water points	34	15 (44%)	1	100 (100%)
	Burying	34	0 (0%)	1	0 (0%)
Reported symptoms	Relapsing fever[a]	52	29 (55.8%)	11	9 (81.8%)
	Muscle pain[a]	18	15 (83%)	2	1 (50%)
	Arthralgia[a]	29	21 (72%)	3	3 (100%)
	Back pain[a]	22	18 (81.8%)	1	1 (100%)
	Headache[a]	60	41 (68%)	12	10 (83%)
Q fever[b]					
Q fever awareness		75	0 (0%)	13	0 (0%)
Tick infestations in cattle herds[a]		26	24 (92%)	-	-
Possible transmission of diseases from ticks to livestock[a]		20	17 (85%)	-	-
RVF[b]					
RVF awareness		75	0 (0%)	13	0 (0%)
Livestock disturbance by mosquitoes and flies[a]		25	23 (92%)	-	-

[a]Number of respondents differs from the number of participants because the question was not included in the questionnaire during all the surveys or missing answers

[b]Symptoms of human Q fever and RVF were not asked

Brucellosis seropositivity in livestock and humans

The overall apparent seroprevalence of brucellosis by indirect IgG ELISA was 4.6% (95% CI 2–10.6) in cattle and 0% in small ruminants (Figure 5.2). The seropositivity in cattle was significantly higher in Niakara (10.5%, 95% CI 4.7–22) than in Korhogo (1.3%, 95% CI 0.4–3.9). Brucellosis indirect IgG ELISA and RBPT had moderate agreement (kappa value = 0.58) in cattle. However, about 50% (20/39) of cattle positive by indirect IgG ELISA were RBPT-negative. Almost 80% (24/31) of cattle positive by indirect IgG ELISA were confirmed by competitive ELISA with an agreement of 65% (Table 5.2). There was a poor agreement (kappa value < 0.2) between brucellosis indirect IgG ELISA and RBPT in small ruminants (Table 5.2). In total, 30 sheep and 6 goats were RBPT-positive, but negative by the indirect IgG ELISA. Only one RBPT positive goat tested positive by *B. ovis* indirect IgG ELISA, while 1 and 3 sheep were also positive by *B. melitensis* competitive and *B. ovis* indirect IgG ELISAs, respectively.

In humans, 2 of 19 households had seropositive members by indirect IgM/IgG/IgA ELISA. Four young (21–27 years old) men (two Fulani from the same household and two non-Fulani participants) from Niakara were seropositive with an overall apparent seroprevalence of 5.3% (95 % CI 1.6–15.9) (Figure 5.2). Brucellosis indirect ELISA and RBPT had perfect agreement (kappa value = 1) in humans. Seropositive people had high levels of *Brucella* specific IgG/IgA antibodies. None of them remained RBPT-positive after sequential serum dilutions in the RBPT.

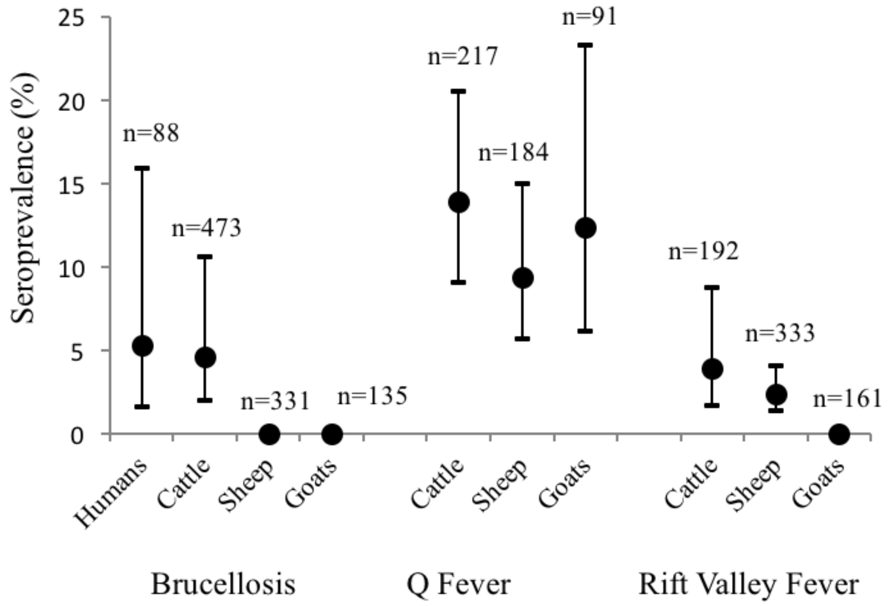

Figure 5.2: Apparent seroprevalences (with 95% confidence intervals, adjusted for clustering) of brucellosis, Q fever and RVF in humans, cattle, sheep and goats in northern Côte d'Ivoire.

Table 5.2: Brucellosis serological tests comparisons and kappa statistics for livestock sera in northern Côte d'Ivoire.

	RBPT	iELISA *B. abortus*		Agreement	cELISA		Agreement	iELISA *B. ovis*	
		Pos	Neg		Pos	Neg		Pos	Neg
Cattle	Pos	19	4	Moderate	17	4	Moderate	3	16
	Neg	20	535		29	210		0	5
Sheep	Pos	0	30	-	1	33	-	3	32
	Neg	0	331		8	112		4	43
Goats	Pos	0	6	-	0	6	-	1	5
	Neg	0	262		5	74		0	25

	iELISA *B. abortus*	cELISA		Agreement	iELISA *B. ovis*		Agreement
		Pos	Neg		Pos	Neg	
Cattle	Pos	24	7	Substantial	2	14	-
	Neg	13	166		1	5	
Sheep	Pos	0	0	-	0	0	-
	Neg	11	196		7	59	
Goats	Pos	0	0	-	0	0	-
	Neg	5	77		1	28	

Kappa = 0.01–0.20: poor agreement; 0.21–0.40: fair agreement

0.41–0.60: moderate agreement; 0.61–0.80: substantial agreement

0.81–1.00: perfect agreement; agreement worse than chance

Potential risk factors and symptoms of brucellosis in livestock and humans

Table 5.3 summarizes risk factors associated with brucellosis seropositivity in univariate and multivariate analyses. On average, a 20% increase in the odds of seropositivity was observed for each additional year of life in cattle (OR = 1.2; 95% CI 1.1–1.3). Animals of 5–8 years were more likely to be seropositive than those < 5 years (OR = 3.5; 95% CI 1.5–8.2). The seropositivity was significantly correlated to having hygromas in cattle (OR = 9; 95% CI 1.3–59). History of abortion in cows was not associated with seropositivity; however, 15% (4/27) of brucellosis seropositive cows (≥ 3.5 years) had abortions. Seropositive cattle had 6 times higher odds (OR = 5.8, 95% CI 2.2–15.4) of sharing pastures with small ruminants than seronegative ones. Compared to cattle originating from Korhogo, the odds of seropositivity were higher in Niakara (OR = 8.2; 95% CI 2.1–31.5). In the univariate analysis, seropositive cattle were more likely (OR = 11.3; 95% CI 3.3–38.1) to have spent more than six months per year sharing pastures with pastoralist herds or trade cattle. No associations were observed between the sero-status in humans and the risk factors and symptoms of brucellosis.

Q fever seropositivity and risk factors in livestock

A total of 492 random animal sera from 51 villages were screened. Individual level apparent seroprevalence of Q fever was 13.9% (95% CI 9.1–20.5) in cattle, 9.4% (95% CI 5.7–15) in sheep and 12.4% (95% CI 6.2–23.3) in goats (Figure 5.2). In Korhogo, the apparent seroprevalence of the disease was 15.1% (95% CI 9.9–22.3), 8.2% (95% CI 4.7–14) and 12.4% (95% CI 6.2–23.3) in cattle, sheep and goats, respectively. In Niakara the seroprevalence was 4.6% (95% CI 0.6–26.2) in cattle, 20.3% (95% CI 17.1–24) in sheep and 0% in goats. Almost 60% (30/51) of villages and 50% (42/95) of herds had at least one Q fever seropositive animal. Compared to sheep originating from Korhogo, the odds of seropositivity were higher in Niakara (OR = 4.2; 95% CI 2–8.4) (Table 5.3).

Rift Valley fever (RVF) seropositivity and risk factors in livestock

A total of 686 randomly selected animal sera were tested for anti-RVF virus antibodies. All tested goats were seronegative, while the seroprevalence in cattle and sheep was 3.9% (95% CI 1.7–8.8) and 2.4% (95% CI 1.4–4.1), respectively (Figure 5.2). Korhogo recorded the highest seroprevalences with 5.1% (95% CI 1.95–12.6) in cattle and 4.4% (95% CI 3.7–5.3) in sheep. In Niakara, 1.3% (95% CI 0.2–8.2) of cattle and 2.1% (95% CI 0.6–7.6) of sheep were RVF-seropositive. Seropositive sheep were all from different herds and less than 1% (1/78) of rams had antibodies against RVF virus. Cattle from night pens located < 8 km from permanent water bodies had lower odds of exposure to RVF than those farther away (≥ 8 km)

(OR = 0.1; 95% CI 0.02–0.7) (Table 5.3). Ewes with a history of abortion were more likely to be RVF-seropositive than seronegative ewes (OR = 4.7; 95% CI 1.02–21.3). In contrast to sheep, 3% (2/59) of cattle had antibodies against both *Coxiella burnetii* and RVF virus.

Table 5.3: Risk factors associated with livestock brucellosis, Q fever and RVF seropositivity by *Brucella* spp. and *C. burnetii* indirect ELISAs and competitive RVF ELISA, respectively.

Predictors / Categories	Number (% sero-positive)	Odds Ratio (95% CI) Univariate analysis	Adjusted for age, sex, study site[b]
Brucellosis			
Cattle			
Age			
≤ 5 months–4 years	196 (3%)	1	1
5–8 years	184 (9.8%)	4.2 (1.2–14.9)	3.5 (1.5–8.2)
> 9 years	88 (9%)	4.5 (0.7–29.7)	4.1 (0.9–18.7)
Hygromas			
No	190 (1%)	1	1
Yes	91 (23%)	14.7 (2.7–81)	9 (1.3–59)
Cattle grazing with small ruminants			
No	437 (5.7%)	1	1
Yes	29 (24%)	5.9 (1.4–24.9)	5.8 (2.2–15.4)
Contact with pastoralist herds			
< 6 months	62 (4.8%)	1	1
≥ 6 months	16 (37.5%)	11.3 (3.3–38.1)	[c]
Study site			
Korhogo	223 (1.4%)	1	1
Niakara	250 (11.6%)	8.3 (2–32.9)	8.2 (2.1–31.5)
Q fever			
Sheep			
Study site			
Korhogo	172 (7.6%)	1	1
Niakara	12 (25%)	3.8 (2–7.5)	4.2 (2–8.4)
RVF			
Cattle			
Distance to nearest water body			
≥ 8 km	49 (10.2)	1	1
< 8 km	143 (1.4%)	0.1 (0.02–0.7)	[c]
Sheep			
History of abortion in sheep[a]			
No	211 (1.4%)	1	1
Yes	42 (7.1%)	4.7 (1.02–21.3)	4.3 (1–18.9)
Sheep grazing with cattle			
No	278 (1.4%)	1	1
Yes	40 (5%)	3.1 (1.1–9)	[c]

[a]Excluding young ewes < 1.5 years old

[b]The multivariate model was adjusted to age, sex and study site

[c]The variable was dropped in the backward stepwise selection

5.5. Discussion

The present study provided updated epidemiological data on brucellosis, Q fever and RVF for a better understanding of the occurrence and transmission in northern Côte d'Ivoire. The findings showed that the seroprevalences of the three NZDs were within or below the expected ranges of the West African region as found in the literature (Nanyingi et al. 2015; Vanderburg et al. 2014; McDermott & Arimi 2002; Gonzalez et al. 1992).

Brucellosis seroprevalence in humans and cattle in the study indicated that the disease is endemic, but at a low level of transmission. In cattle, a higher age was a risk factor for seropositivity to *Brucella* spp. This finding is in agreement with the study of Sanogo et al. (2012) also conducted in Côte d'Ivoire and with many other brucellosis surveys (Dean et al. 2013; Sanogo et al. 2012; McDermott & Arimi 2002). Cattle sampled in our study were predominantly cows, which were kept in the herds longer than bulls. This herd management system likely increased the risk of long term exposure of cows to *Brucella* spp. when compared to bulls and young cattle.

Joint hygromas was a strong predictor of brucellosis seropositivity, which is in line with previous studies on the continent (McDermott & Arimi 2002; Akakpo 1987; Chantal & Ferney 1976). Fulani herdsmen in northern Côte d'Ivoire stated that *"there are two types of cattle brucellosis in the area: one type called "abortive Bakaalè" causes late term abortions without joint hygromas; the other type is the so called "dried Bakaalè" which induces hygromas without abortion"*. To the best of our knowledge, there was no published evidence to support this statement.

Niakara offered wider rangelands and concentrated cattle herds from different regions of Mali and Burkina Faso, where zoonoses are a relevant public health concern, as described by previous studies (Coulibaly & Yameogo 2000; Tounkara et al. 1994). The frequent contacts between the local cattle and these highly extensive pastoral systems might explain the increased exposure to *Brucella* spp. in livestock sampled in Niakara when compared to Korhogo.

The serosurveys were conducted from 2012 to 2014 during all seasons (rainy, dry and cold-dry seasons). However, when the data was stratified by study sites, the authors found no variability in exposure to brucellosis between years and seasons. Possibly, there might have been other spatial and temporal risk factors that were not captured due to the cross-sectional nature of the study.

Almost all studies on livestock brucellosis in West Africa have been conducted in cattle that were perceived as the major reservoir of *Brucella* spp. Thus, the epidemiology of the disease remained unknown in small ruminants in the region (Ducrotoy et al. 2015). *B. melitensis* was assigned to small ruminants and has been reported from North, East and Central Africa. Given the high mobility of people and livestock within and between regions in Africa, an explanation why it would not occur in West African small ruminants is warranted to be interesting. Although small ruminants were seronegative in our study sites, there might be a possible cross-species contamination with *Brucella* spp. from cattle to sheep and goats through the frequent intermixing of livestock species, as discussed by Gumaa et al. (2014). Further bacteriology studies are urgently needed to isolate *Brucella* spp. from small ruminants in the region and to shed more light on the inconclusive serology findings.

In humans, participation was voluntary, and participants were those in contact with livestock and animal products. Therefore, if the human brucellosis seropositivity was to be extrapolated this would likely lead to an over-estimation for the whole population of northern Côte d'Ivoire. The fact that no significant symptom was found in humans may be due to the diagnostic challenges in our study areas which are also malaria-endemic areas (D'Acremont et al. 2010) or simply because the positive samples were too few (n=4). The West African *B. abortus* strains may also be less virulent since, also in Togo, lower than expected human symptoms and seropositivity were found despite substantial seropositivity in cattle (Dean et al. 2013a). The increased titers of *Brucella* spp. specific IgG / IgA antibodies in seropositive people indicated a longer past exposure. However, other clinical conditions or the presence of rheumatoid factor may also cause increased IgG / IgA antibodies leading to cross-reaction in humans (Solís García del Pozo et al. 2014; Nielsen & Yu 2010).

Raw milk consumption, which was found higher, but not significantly related to brucellosis seropositivity, was shown by previous studies to be a risk factor of the disease (Gidel et al. 1976). Fulani herdsmen in the study sites stated that "*boiling of milk for consumption by a Fulani family will decrease the number of cows in the herd owned by this family*". However, it seemed that drinking raw milk was not the main route of exposure to brucellosis in herders. Seropositivity in adult men alone may indicate rather direct exposure with infected cattle and birth/abortion materials of cattle rather than through contaminated cattle product consumption; this is in line with the study of Bonfoh et al. (2012). Still, women were seronegative in the study; despite that they did obstetric practices in small ruminants.

Almost 50% of the respondents in our study had disposed of abortion materials in publicly used water bodies (i.e. agro-pastoral dams and rivers). Nevertheless, Krauth et al. (2015) found that more than 60% of people in northern Côte d'Ivoire were in direct contact with unsafe water, which is consumed without any processing by almost 30% of the population. Thus, sampling of publicly used water bodies in northern Côte d'Ivoire and assessing level of contamination with *Brucella* spp. as well as other pathogenic micro-organisms might be a prominent future health research topic.

As for brucellosis serology, to comparing test outcomes was not planned. Given that RBPT and ELISAs were not validated in the sub-Saharan context and because of the contradictory results already seen in northern Togo, test comparisons to highlight the discrepancy between the RBPT and the ELISAs (OIE 2009; WHO 2006a) and particularly to find more indications on the status of small ruminants were performed. It was found that competitive and indirect ELISAs had substantial agreements in cattle. However, more than half of the cattle positive by both ELISA tests seemed to be misclassified as false negative by RBPT. Thus, the seroprevalence in cattle decreased from 4.6% (by indirect ELISA, n = 473) to 1.8% (by RBPT, n = 633). The fact that 36 RBPT-seropositive small ruminants were all seronegative in the indirect ELISA and only very few seropositive in the competitive ELISA (Table 5.2) suggest that they were probably false positive, as described by prior studies (Dean et al. 2013a; Nielsen & Yu 2010). Using in addition a *B. ovis* indirect ELISA did not shed further light in the discrepancy of RBPT seropositivity and ELISA seronegativity. Therefore, the study used *B. abortus* indirect ELISA seropositivity as the outcome for risk factor analysis.

As for Q fever, tick infestations of livestock were not recorded during the first two serosurveys and no association was seen in the few remaining data. Herdsmen viewed ticks, tick-borne diseases and resistance to acaricides to be a problem. Q fever seemed to play a minor role in abortion compared to brucellosis in an older study by Domenech et al. (1985). It was revealed that abortions were reported in most of the herds, but were not significantly associated with Q fever and brucellosis seropositivity. Probably other factors induced those abortions; reference is made to poor nutrition and drought as well as diseases such as contagious bovine pleuropneumonia, Foot-and-Mouth Disease, and trypanosomiasis, which are also endemic in northern Côte d'Ivoire.

The findings on RVF suggest that there is a circulation of RVF virus in Côte d'Ivoire, even though no history of outbreaks was reported in the country since more than 20 years (Formenty et al. 1992). The higher seropositivity in cattle followed by sheep may be explained by the fact that the most attractive bait of the mosquito vectors is cattle rather than sheep (Tantely et al. 2013). Thus, cattle sharing the pastures with sheep may increase the exposure in sheep with further exposure of goats, given that sheep and goat are intermixed in the villages.

Studies in sub-Sahara have hypothesized that "proximity to permanent water bodies was exposing humans and livestock to RVF" (Pourrut et al. 2010; Clements et al. 2007). The assumed explanation was that the nearest water bodies were a sheltered habitat for mosquitoes, and hence favored the mosquito spread to the nearest dwellings and cattle night pens. In this study, the night pens were located between 2.5 and 29 km to a river bed/dam which flooded during the rainy season. The median distance to nearest permanent water point was about 8 km, and this distance was used for binary classification (< 8 km and ≥ 8 km) in the RVF risk factor analysis. It was found that having night pens closer to permanent water bodies was protective against exposure to RVF. This finding was also reported in the region, where it was argued that a substantial part of RVF viral transmission was carried out by crepuscular and nocturnal mosquito vectors (Chevalier et al. 2011; Beaty & Marquardt 1996). The optimal 'active flight' distance for both *Culex* and *Aedes* around their breeding sites is considered to be within a radius of 1 km (EFSA AHAW Panel 2005). The minimum distance to nearest permanent water bodies (2.5 km) in this study was out of this optimal "active" distance. The finding suggested that RVF mosquito vector species in the study sites might rather use temporary water points for breeding sites in the vicinity of the night pens compared to larger permanent water bodies. Additionally, it was hypothesized that in northern Côte d'Ivoire, the exposure of livestock to RVF by mosquito bites occurred in the night pens. Further studies to explore temporary water bodies surrounding the night pens and include them in RVF risk factor analysis are needed.

The results of the study suggested that brucellosis was likely endemic with a low-level transmission in the north. Once the high risk and endemic areas are identified in Côte d'Ivoire, and feasibility and cost-benefit of control is shown, the disease may be controlled through mass vaccination in cattle, as discussed in prior studies in sub-Saharan Africa (Ducrotoy et al. 2015; Seleem et al. 2010; WHO 2006a, b; McDermott & Arimi 2002). RBPT may be the most affordable screening test to be used in the control of brucellosis in resource-limited countries. However, unacceptable false positive rates found in tests among small ruminants, recurrent disadvantages. Thus, an alternative to increase its sensitivity and specificity in sub-Saharan Africa may be the use of the so called "modified RBPT" on sequential serum dilutions (Gumaa et al. 2014; Nielsen & Yu 2010; Blasco et al. 1994). The combination of RBPT and indirect/competitive ELISA can also increase the testing sensitivity, detecting IgG and IgM produced during early acute and chronic phases of brucellosis. Further studies on the identification of appropriate test cut-off values in small ruminants are needed in the region (McDermott & Arimi 2002). This can only be done with a reference bank of West African true (culture-confirmed) positive and negative sera (in tests and by herd history).

RVF serosurveys and animal vaccination are probably the best tools to control the disease and prevent outbreaks (Bird & Nichol 2012; Breiman et al. 2010). However, there is no information on possible cost-benefit of a vaccination and the availability of RVF vaccines. Therefore, further studies on these issues will be of immense benefit for human and animal health.

Tick control may reduce livestock exposure to *C. burnetii* and other tick-borne diseases. Being aware of transmission of diseases by ticks, many herders already applied tick control using acaricides commercialized in the informal sector that, according to them, are not effective against local tick species. For more systematic control of Q fever, cost-benefit would also need to be assessed, and also strengthening veterinary services may contribute to better harmonize the access to and utilization of quality vaccines/products.

Community based public health education campaigns by joint human and animal health professionals through various information channels (radio stations, television) concerning boiling of milk, safe handling of livestock and animal products, coupled with appropriate obstetric manipulations and disposal of abortion materials should be disseminated to reduce the exposure to zoonoses in humans.

5.6. Conclusion

The integrated human and animal seroepidemiology study on brucellosis, Q fever and RVF strengthened understanding by providing updated information on the transmission, risk factors and animal reservoirs of the three zoonoses in northern Côte d'Ivoire. The seroprevalences in humans and livestock were rather low and within the seroprevalence ranges of the West African region. Nevertheless, a public outreach on the possible routes of transmission may further reduce the exposure. Further One Health studies are needed in other parts of the country and the region to better understand the epidemiology and to define suitable control options. Further studies on the cross-sectoral economics of brucellosis, Q fever and RVF in both veterinary and public health sectors will better guide authorities in their decision to engage in control. No country alone in the West African region could control a disease given the high cross-border and internal mobility of people and livestock; therefore, a regional collaboration is needed for more effective zoonoses control.

5.7. Acknowledgements

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6. Mobile pastoralism and transboundary animal diseases in the Sudano-Guinean savanna region: Towards an integrated cross-border control

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Working Paper

6.1. Abstract

The Sudano-Guinean savanna region borders northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso. The cross-border region has uncontrolled mobile pastoralism and livestock trade which increases the risk of spread of transboundary animal diseases (TADs) including zoonoses. The objectives of the present study were to collect epidemiological information on major TADs and cross-border livestock movements and to design a harmonized control plan for the three countries. The field team conducted thirteen focus group discussions with mobile pastoralists, agropastoralists and farmers and eleven key-informant interviews with animal health professionals and livestock movement supporting agents. It was conducted cross-sectional serological surveys on brucellosis and Q fever in humans (n = 76) and cattle, sheep and goats (n = 537) in three slaughterhouses along pastoral corridors in northern Côte d’Ivoire and Abidjan. Brucellosis and Q fever seropositivities were significantly higher in slaughter cattle in northern Côte d’Ivoire (6.7% and 17%, respectively) than in Abidjan (1.3% and 5.6%, respectively). The exposure to brucellosis in meat workers in northern Côte d’Ivoire was 6.6%. About 30,000 cattle in 200 cross-border pastoralist herds arrived each year in northern Côte d’Ivoire. Contagious bovine pleuropneumonia (CBPP), Foot-and-Mouth Disease (FMD), tuberculosis, lumpy skin disease, pasteurellosis, brucellosis and Blackleg were ranked to be the most important diseases in cattle, whereas *peste des petits ruminants* PPR was the only disease reported in sheep and goats. Lack of veterinary staff and transportation means in veterinary services, poor cross-border veterinary collaboration and synchronization of diseases control activities were main constraints to diseases control. A harmonized cross-border mass vaccination campaign against priority infectious diseases should be conducted at the beginning of rainy season (mid-May to June). The study identified overarching themes regarding the challenges and needs for cross-border control of TADs. Cross-border collaboration should be promoted for the implementation of an effective control. Studies on economic impact of major TADs and the cost-benefit of their control in West Africa are needed to further discuss feasible regional control.

Keywords: Transboundary animal diseases, cross-border control, savanna region, cross-border pastoralism, slaughterhouse.

6.2. Introduction

Livestock production is an integral part of agriculture. Most of the resource-limited countries rely heavily on livestock's contribution to agricultural GDP. An extensive livestock grazing system is the most appropriate land use system in the African arid and semi-arid lands because it is adaptable to the highly variable environment and zones where crop fields cannot be sustained. Mobile pastoralists live in dry and remote areas where livelihoods depend on the knowledge of the surrounding ecosystem and on the well-being of the livestock, which provides more than 50% of their income (Koocheki & Gliessman 2005; Otte & Chilonda 2003). Transhumance is a common type of mobile pastoralism in Africa with regular seasonal back-and-forth movements from a permanent homestead and often between summer or rainy season and winter or dry season pastures (Otte & Chilonda 2003). In sub-Saharan Africa, mobile pastoralists share a traditional ethos of open and free access to common-pool grazing resources and water points – regardless of nationality or socio-economic and cultural status (Moritz et al. 2013). Natural resource dependence (mainly pastures, more than water), conflicts and access to market places have traditionally been drivers of livestock mobility (Brottem et al. 2014a, b). Cross-border livestock movements, frequent in Africa given the centuries-old practice of mobile pastoralism, is described to be associated with the spread of "highly contagious epidemic animal diseases with significant economic and food security concerns, known as transboundary animal diseases -TADs" (Dean et al. 2013b; Cheneau et al. 1999). TADs are highly contagious livestock diseases or important zoonoses. Besides the resulting public health risks, TADs' impact can vary from reduced animal productivity and restricted market access to the elimination of entire herds (FAO & OIE 2012). In addition, highly contagious TADs have the potential to spread rapidly around the globe such as pathogenic avian influence or within larger regions such as Foot-and-Mouth Disease. Therefore, controlling them at the source is a shared interest within infected countries and between infected and uninfected ones. FAO's Emergency Prevention System (EMPRES) for animal health focuses on the following TADs: Foot-and-Mouth Disease (FMD), contagious bovine pleuropneumonia (CBPP), sheep and goat pox, *"peste des petits ruminants*-PPR", highly pathogenic avian influenza, RVF, Newcastle disease, brucellosis, Q fever, African and classical swine fever, and equine encephalitidies (FAO 2015).

The global control of TADs can only be achieved if there is good national and regional governance of animal health systems and operational veterinary services as well as collaboration between the key-stakeholders. However, sub-Saharan countries are at different levels of managing TADs depending on their socio-economic development, priorities of their livestock production sectors and their policy-makers' commitment.

In West Africa, Fulani mobile pastoralists move variable distances from the Sudano-Sahelian zone to the Sudano-Guinean savanna, with a great number of them heading towards the savanna rangeland of northern Côte d'Ivoire, Togo, Benin, Ghana, and Nigeria. They face challenging livestock breeding conditions that are characterized by livestock diseases and farmer-pastoralist conflicts (Moritz 2006). Fulani and M'boro are the most important groups whose way of life is mobile pastoralism, but there are also others such as Arabs. In the region, there are supporting policies for mobile pastoralism and legislative tools such as pastoral codes and bilateral agreements. Given the economic importance of livestock movements in the region, these were established to support and harmonize pastoralism as well as to defend and secure land rights of mobile pastoralists (IUCN 2011). Decisions A/DEC.5/10/98 and C/REG.3/01/03 of the Economic Community of West African States (ECOWAS) in 1998 and 2003, respectively, provided a regional framework to facilitate cross-border transhumance with the adoption of the International Transhumance Certificate. Nevertheless, implementation of these policies and laws is inadequate since pastoralists cannot move freely between countries. Furthermore, adapted local and cross-border control guidelines for TADs are unavailable in the region (Inter-Réseaux Développement Rural 2012).

Regarding Côte d'Ivoire, the government has been supportive of livestock movements across borders in the 1980s by creating a national livestock development agency (Societé de Développement des Productions Animales – SODEPRA) for securing continued and cheap supply of live animals and animal products in the country (Diallo 1995). In the early 1990s much more cross-border pastoralism and within-country movements occurred in Côte d'Ivoire, Mali and Burkina Faso. However, since the collapse of SODEPRA 20 years ago, no animal disease control program is in place and veterinary services have not been operational since the armed conflict in Côte d'Ivoire in 2002.

The current study aims at better understanding the epidemiology of major TADs and making recommendations on working towards appropriate cross-border control strategies in the savanna region.

6.3. Materials and methods

Ethical considerations

This research was part of a large study on zoonoses in the savanna region in northern Côte d'Ivoire, and was approved by the National Ethics Committee of the Ministère de la Santé et de la Lutte contre le Sida of Côte d'Ivoire (N°71/MSLS/CNER-dkn) and the Direction Générale de Recherche Scientifique et de l'Innovation Technologique du Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (N° 089/MESRS/DGRSIT/KYS/tm). An earlier approval was received from the Ethics Commission of the Cantons of Basel-Stadt and Basel-Land (ref. 146/10). Prior to enrolment of participants, information on the study, brucellosis and Q fever and TADs was provided in the local language (*Malinké*). A written or oral informed consent was asked from all participants in the abattoirs, focus groups discussions and interviews. In case of illiteracy, a thumb print was recorded, witnessed and signed by a literate acquaintance of the participant. Questionnaires for abattoir workers were administered confidentially and in privacy. Participants knew that their personal information was kept anonymous and they could withdraw from the study without further obligation. Blood sampling of people and livestock was done from a nurse and a veterinarian, respectively.

Study region and period

In October to December 2013, livestock cross-border entry points and transhumance corridors were visited in the areas of Niélé, Ouangolodougou, Pôgô, Tengréla, Niakaramandougou and Korhogo in the savanna district (northern Côte d'Ivoire), in Zégoua and Kadiana in the Region of Sikasso (southern Mali) and Banfora and Niangoloko in the Comoe province (southwestern Burkina Faso). The region studied was the Sudano-Guinean savanna region of West Africa (Figure 6.1). The study period corresponded to the time of the year when mobile pastoralists were most frequent in the region. From July 2013 to May 2014, four main abattoirs (those with the largest numbers of abattoir workers and daily slaughtered animals in Côte d'Ivoire) were enrolled in the city of Korhogo in the north and Abidjan, the capital city, in the south.

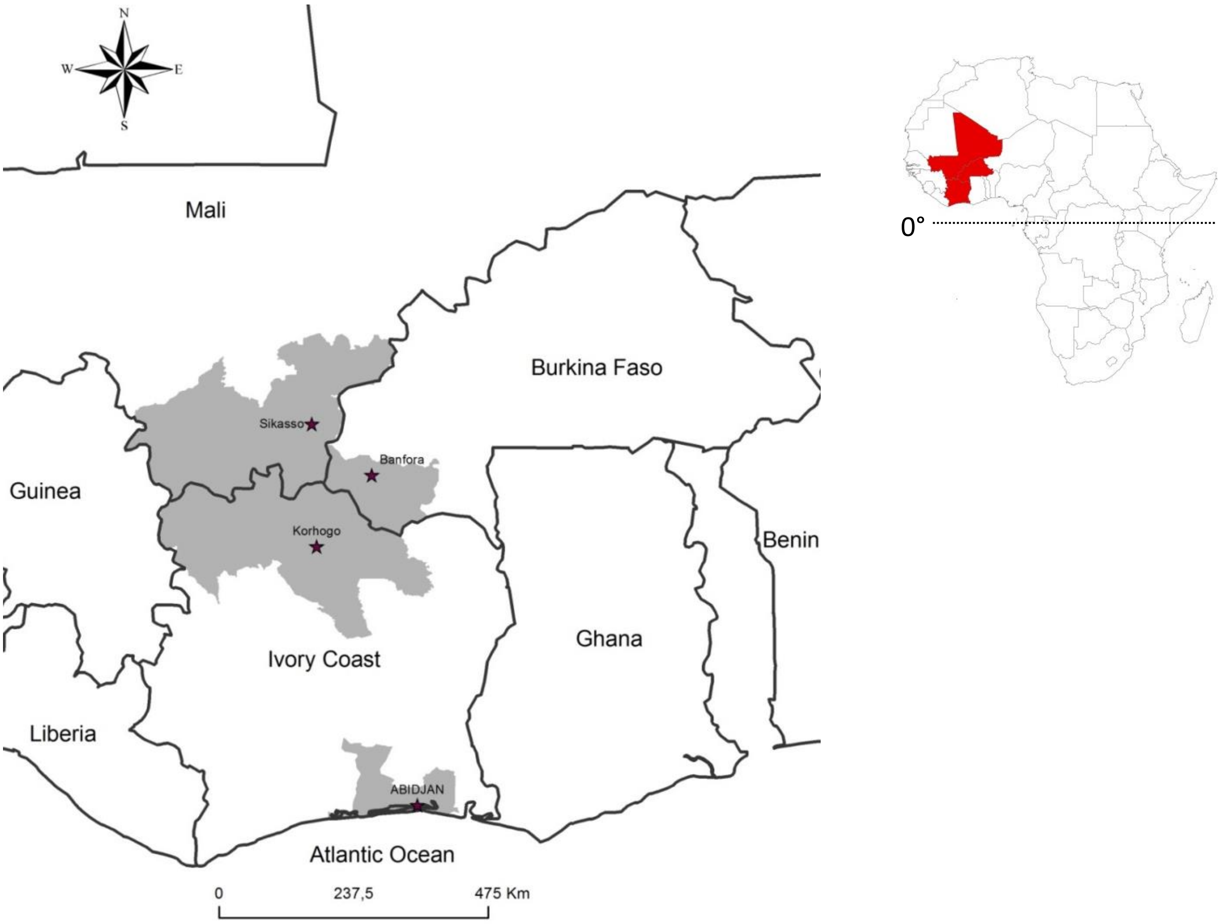

Figure 6.1: Map of the district of Abidjan and the Sudano-Guinean savanna region (shaded in gray) with the names of district capitals.

Interviews and focus group discussions

The two field investigators (Mr. Y. B. Kanouté and Mr. B. G. Gragnon) were of veterinary background and bilingual in French and “Malinké”, one of the most predominant languages in the region. Interview and focus group discussion (FGD) guides were designed in French but translated and pretested in Malinké by the team. Team members had previous training and experience with qualitative and quantitative data collection. In the pastoral areas, the team was supported by local veterinary services, village chiefs and field guides for identifying and engaging in discussion with mobile pastoralists, agropastoralists, farmers, and livestock movement supporting agents. Convenient meeting sites and time were defined with participants. Meetings took place in veterinary services and homes of village chiefs. Each focus group discussion involved a minimum of five participants (i.e., agropastoralists, mobile pastoralist and farmers). Retrospective information on livestock species, animal diseases and cross-border pastoralism was recorded. When participants and key-informants provided syndromes rather than specific (local) names of diseases, interviewers further asked to identify the corresponding diseases. Key-informant interviews were conducted with local authorities from departmental animal health services, veterinarians at cross-border livestock entry points and livestock transport agencies. Interviews and discussions were transcribed into French and analyzed to identify overarching themes and issues reported by interviewees in responses to open-ended questions. These themes were further discussed and their overall number of mentioning in the discussions and interviews were registered. Discussions continued until no new aspects came up on the topics discussed. Moderators reviewed transcripts for accuracy and discussed issues that emerged.

Simple ranking

Interviewees in group discussions were asked to identify major diseases using their local names which were mostly based on clinic symptoms and recognized by animal health professionals, mobile pastoralists and agropastoralists. These diseases were ranked based on their economic impacts (mortality, weight loss, reduced-milk production and abortions) over a one-year period prior to the study. Interviewees were asked to discuss the ranking and reach a group decision on ranks or to give a final rank set by the majority of interviewees. Any opposite statements were further discussed until group consent was reached. It was derived the overall median rank (from 1 = "most important" to 9 = "least important") for each disease (Catley et al. 2009).

Pairwise ranking

Participants in group discussions were asked to compare the relative importance of each livestock disease to other diseases one-by-one. During each pairwise comparison a score of one point to the disease found to be more relevant than the other was given. The total score was calculated for each disease. The overall median scores (with 10^{th} and 90^{th} percentiles) of each disease were ranked (Catley et al. 2012).

Seasonal calendars

Focus group participants' perceptions on the seasonal patterns of key livestock diseases as well as cross-border movements were registered. The information was visualized in a seasonal calendar where the ordered local seasons of the year were cross-tabulated with the diseases. Participants were asked to give scores from absence (0) to highly frequent (3) (Catley et al. 2002). The score given by the majority of interviewees was recorded. For each disease, the overall median score was calculated for each season of the year and plotted as bar charts.

Participatory mapping

Mapping of pastoral corridors and trade routes was conducted with mobile pastoralists, agropastoralists, livestock movement supporting agents and veterinarians in Côte d'Ivoire, Mali and Burkina Faso using a pretested approach. Four grid points with known coordinates were marked on preprinted, paper maps. During interviews and focus group discussions, participants were first introduced to landmarks on the map. They were then asked to plot spatial data with markers of different color. A series of questions was used to animate the drawing of key features such as water bodies, corridors and routes, livestock entry points, key departments and villages in areas of transhumance. Participants were also asked to map points such as water points that could be visited and coordinates taken with a GPS (Garmin eTrex GPS™). The paper maps were then photographed, geo-referenced with the known coordinates of at least three points and further processed in MapInfo Professional® 7.0.Scp and ArcGIS® 10.2.1 by adding different layers with different information.

Blood sampling and questionnaires in slaughterhouses

Random drawing of names from a bag of slaughterhouse workers (e.g., butchers, meat and fried blood sellers) willing to participate in the study was done in Korhogo. Participants were questioned about brucellosis symptoms, consumption of raw milk, and contact with contaminated livestock products. Venous blood was collected from participants in 5 ml Vacutainer[ND] tubes after a general physical examination from a nurse.

Slaughter animals sampled were the first ten animals slaughtered after a first one that was drawn with a random number. Animal blood samples were collected filling in 5 ml Vacutainer[ND] with the first blood drawn at bleeding. A data sheet for animals with (estimated) age, breed, sex, tick infestation and origin was filled in. Samples were transported on ice and processed at the regional veterinary laboratory in Korhogo and the "Centre Suisse de Recherches Scientifiques" in Abidjan.

B. abortus (CHEKIT Brucellosis[ND]) and *C. burnetii* (CHEKIT Q fever) indirect IgG enzyme-linked immunosorbent assays (ELISAs) were used to screen livestock sera. The indirect IgM/IgG/IgA ELISA (Serion ELISA classic[ND]) was performed for brucellosis antibodies in humans.

Data analysis

Data was double entered into Access 2010 (Microsoft, USA) and compared using Epi-Info^{TM}, version 3.5.1 (Centers for Disease Control and Prevention, CDC, USA). The analysis was performed using STATA 12.0 (StataCorp LP, USA). Qualitative data on livestock diseases and pastoral movements were semi-quantified and analyzed with non-parametric statistical tests to calculate median scores and 10th and 90th percentiles. Associations between brucellosis and Q fever seropositivity and risk factors were assessed using logistic regression. Univariate logistic regression was used to identify significant covariates. The selection of these predictors was done based on the Wald test, retaining covariates with $p \leq 0.2$. All significant predictors were then pooled into multivariate logistic regression models, additionally adjusted for age and sex (which were biologically important covariates) and the study sites. A backward stepwise selection was then performed based on the Wald test. A predictor was excluded from the final multivariate model when the p-value for its association with seropositivity was ≥ 0.05. When data were too sparse, comparisons were done using Fisher's exact test. Due to the small sample size ($n = 76$) in humans, the multivariate analysis was not possible.

6.4. Results

Interviews and focus group discussions

Simple and pair-wise ranking

In total, the field team conducted 13 focus group discussions (2 FGDs with farmers and agropastoralists in southern Mali; 2 FGDs with farmers and agropastoralists in southwestern Burkina Faso; 9 FGDs with farmers, agropastoralists and mobile pastoralists in Côte d'Ivoire). Eleven key-informant interviews (2 veterinarians and 1 livestock movement supporting agent in Mali; 2 veterinarians in Burkina Faso; 4 veterinarians and 2 livestock movement supporting agents in Côte d'Ivoire) were also conducted. Rearing of cattle rather than small ruminants was perceived by the majority of participants to be more important for the livelihoods of breeders. Neither sheep nor goats were considered to be convenient for live animal cross-border movements. Tables 6.1 and 6.2 summarize major livestock diseases and their local names in "Malinké". In terms of order of highest to lowest scores, these were contagious bovine pleuropneumonia (CBPP) also called "*fôko fôko*" (which is described as lung disease from the air), Foot-and-Mouth Disease (FMD) or "*sâfa*" (which refers to contagious sores around the mouth and udders), bovine tuberculosis called "*sôko sôko*" (which was described by participants as weight loss and chronic cough in cattle), lumpy skin disease or "*kru-kru*" (which is described as large nodules on the skin), pasteurellosis named "Tienjil" (described as swelling under the neck and dyspnea with nasal discharge), brucellosis or "*Baakâlè*" (described as joint hygromas and/or repetitive late term abortions in cows and herdsman's fever), blackleg or "*Boni*" (described as disease caused by "bad spirit" from the savanna; it was associated with crepitant swellings and sudden death) and trypanosomiasis "*sumaya-fiin*" (described as "black malaria" in cattle, referring to fever, anemia and jaundice) (Table 6.1 and 6.2). In small ruminants, *peste des petits ruminants* (PPR) was the most important (and indeed the only small ruminant) disease reported by the interviewees. PPR disease was quite endemic in the country, but in the few years prior to the interviews, it induced severe diarrhea, ulcerations in the mouth, ocular and nasal discharges, which caused mortalities of sheep and goats in the villages.

Pairwise ranking, assumed to be more objective than simple ranking approach because based on pairwise comparisons, showed a slight difference in the orders of FMD, tuberculosis, pasteurellosis and brucellosis. Q fever and RVF were unknown to agropastoralists and pastoralists; thus, they were not reported. Ranking results were later cross-checked by animal health professionals, who were more in favor of the pairwise ranking results. However, they found trypanosomiasis to be the second most important disease after CBPP because of the multiple resistances to the existing trypanocidal drugs.

Table 6.1: Simple ranking of reported livestock diseases in the savanna region of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso from December 2012 to December 2013.

Median rank	Livestock diseases	Local names	Number of reports of diseases during discussions
	Cattle		
1	CBPP	*Fôko-fôko*	13
2	Tuberculosis	*Sôko-sôko*	11
3	FMD	*Sâfâ*	11
4	Lumpy skin disease	*Kru-kru*	6
5	Brucellosis	*Baakâlè*	7
6	Pasteurellosis	*Tienjil*	7
7	Blackleg	*Boni*	9
8	Trypanosomiasis	*Sumaya-fiin*	10
9	Tick infestations	*Tètè*	2
	Sheep and goats		
1	PPR		11

Table 6.2: Pairwise ranking (median score with 10th and 90th percentiles) of reported livestock diseases in the savanna region of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso from December 2012 to December 2013.

Rank	Livestock diseases	Local names	Median Score (10^{th} - 90^{th} percentiles)	Number of reports of diseases
	Cattle			
1	CBPP	*Fôko-fôko*	4 (1 - 9)	13
2	FMD	*Sâfâ*	4 (0 - 7)	13
3	Tuberculosis	*Sôko-sôko*	3 (0 - 7)	13
4	Lumpy skin disease	*Kru-kru*	3 (0 - 6)	6
5	Pasteurellosis	*Tienjil*	2 (0 - 8)	7
6	Brucellosis	*Baakâlè*	1 (0 - 5)	13
7	Blackleg	*Boni*	1 (0 - 5)	13
8	Trypanosomiasis	*Sumaya-fiin*	1 (0 - 5)	13
9	Tick infestations	*Tètè*	0 (0 - 0)	13
	Sheep and goats			
1	PPR			13

Seasonal occurrence of major livestock diseases

Interviewees in the three countries reported that the rainy season lasted from mid-May to September with the main rains from mid-July to August. The cold dry season was extended from October to January. The hot dry season lasted from February to mid-May. Livestock cross-border movements were driven by seasonal variations in pastures and water resources, which were explained by variations in rainfall. At the end of the rainy season, mobile pastoralists from Mali and Burkina Faso started movements further south towards northern Côte d'Ivoire where they stayed the whole dry season until the next seeding period.

In general, all priority diseases identified above had seasonal patterns (Figure 6.2). In cattle, CBPP was reported to occur throughout the year, but at a higher rate during the cold-dry and dry seasons. Trypanosomiasis was considered to be an endemic disease with the highest case frequency during the cold-dry season. FMD and lumpy skin disease were reported to induce increased mortalities during cold-dry and rainy seasons. Abortions reported by interviewees and related to brucellosis were more frequent during the rainy season (May–September). Tick infestations increased steeply during the rainy and cold-dry seasons. The occurrence of pasteurellosis was distributed more evenly with similar frequencies in all three seasons. Tuberculosis and blackleg seemed to be less prevalent during the rainy season. However, veterinarians in Korhogo reported that tuberculosis cases were distributed more evenly throughout the year, with on average two positive carcasses per day at the abattoir of Korhogo, where about 50–150 cattle were daily slaughtered. PPR was found in sheep and goats during the dry and cold-dry seasons (Figure 6.2).

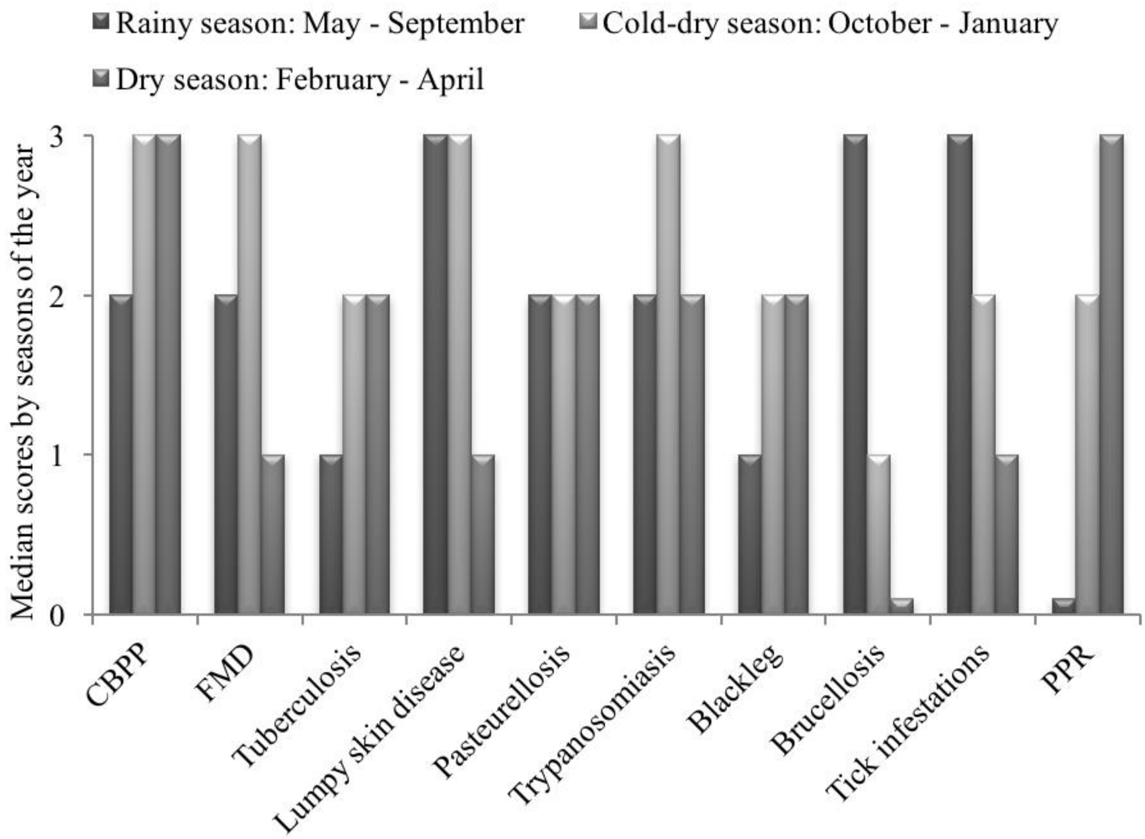

Figure 6.2: Reported seasonal occurrence of major livestock diseases in the savanna region of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso from December 2012 to December 2013.

Cross-border pastoralism and livestock trade between Côte d'Ivoire, Mali and Burkina Faso

Key-informants reported that livestock cross-border movements towards northern Côte d'Ivoire were more common since the Sahelian droughts in the 1960s and 1970s than earlier. Three main modes of livestock movements were used by mobile pastoralists and livestock traders, namely, trekking, trucking and railing. Each year, pastoralists trekked their cattle from Mali and Burkina Faso to the rich wetland pastoral resources in northern Côte d'Ivoire. These animals were in groups from 100 to 150 animals and driven over a distance of 400–900 kilometers from the regions of Mopti and Sikasso (in Mali) to Niélé, Tengréla, Séguela, Korhogo and Niakara (in northern Côte d'Ivoire). The pastoralists and traders from the areas of Ouayigouha, Pô, Pouytenga, Banfora and Niangoloko (in Burkina Faso) moved to northern

Côte d'Ivoire (in Ouangolodougou, Ferkessédougou, Korhogo and Niakaramandougou, Dabakala) over a distance of 200–700 kilometers. Figure 6.3 shows a participatory map of reported cross-border pastoralist corridors and areas of increased livestock movements as well as livestock trade routes between the three countries. Note that these corridors changed over the years due to the expansion of agricultural land use, farmer-pastoralist conflicts and environmental changes.

Regarding livestock trade, trucking was the most used mean of transportation between Mali and Côte d'Ivoire. Thirty to 50 cattle and 100–150 small ruminants were transported from the center and southern regions of Mali towards Côte d'Ivoire (Niakaramandougou, Bouaké, Diombokro, Soubré, Agboville, Abidjan and San-Pédro) from one trader at a time (Figure 6.3). Since the civil wars, the most used transport for live animals between Burkina Faso and Côte d'Ivoire was the transnational railway line (*SiTARAiL*), running from Ouagadougou to Abidjan. Cross-border livestock movements were facilitated by livestock movement supporting agencies called "*agences de convoyage du bétail*". These agents dealt with every transportation requirement, including export taxes and negotiations with officials and – in cases of farmer-pastoralist conflict – also with farmers. The agreements between traders or pastoralists and these agents were taken before the transport.

Between 2005 and 2010, livestock movement supporting agencies at the borders recorded an annual entry of almost 2,500 trucks transporting 90,000 Malian cattle and 80,000 small ruminants towards Côte d'Ivoire. In 2011 and 2012, about 17,000 cattle heads from 115 Malian mobile pastoralists herds crossed the borders towards northern Côte d'Ivoire (personal communication, Mr. Merépé Togo, 2013). In the same period, approximately 9,000 cattle from 60 mobile Fulani pastoralist herds from Burkina Faso headed towards Ouangolodougou and Ferkessédougou in northern Côte d'Ivoire. During the same two years period, 75,000 cattle and 200,000 small ruminants were shipped by the railway line from Burkina Faso. All of these live animals did not undergo cross-border zoo-sanitary controls because Ivorian veterinary border services were missing from 2010 to 2012 due to the post-electoral crisis. Interviewees highlighted that live animals imported to Côte d'Ivoire were primarily intended for slaughter but also for restocking local Ivorian herds. Thus, uncontrolled cross-border movements were perceived to pose zoonotic risks for the Ivorian population as well as a threat of other disease spread (personal communication, Gomah Diomandé, 2013).

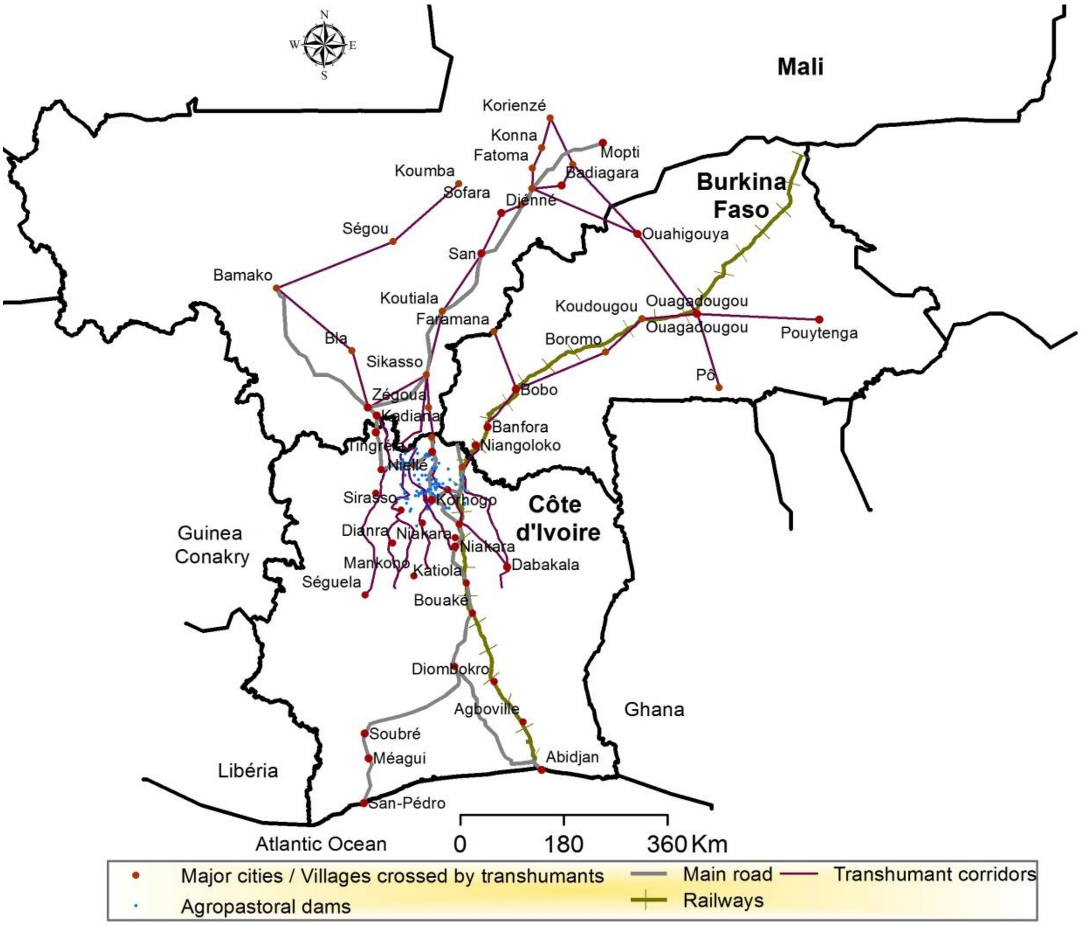

Figure 6.3: Participatory map of livestock trade routes and pastoralist corridors, and areas of increased livestock movements in Côte d'Ivoire, Mali and Burkina Faso as reported and described by interviewees between December 2012 and December 2013.

Challenges of control of mobile pastoralism and livestock trade in the savanna region

Cross-border movements of livestock were found to be the most important animal production system in northern Côte d'Ivoire. They allowed effective access to rangelands and livestock markets. However, farmers and agropastoralists from northern Côte d'Ivoire perceived mobile pastoralism to disseminate diseases and promote contact between infectious Malian and Burkinabé cattle and susceptible Ivorian herds at grassing sites and watering points. Additionally, farmers interviewed in all the three countries were opposed to livestock movements as it was a source of crop damage and farmer-pastoralist conflicts. The following statement was reported from four farmers in southern Mali and northern Côte d'Ivoire: "*Whenever mobile pastoralists crossed our villages, our animals started to develop Fôko-fôko*". Furthermore, local animal breeders opposed cross-border movements because they flooded Ivorian markets with cheaper live animals.

Mobile pastoralists reported that mobility was essential for access to pastures and water as well as for sustainable management of rangelands because it avoided overgrazing. They found that farmer-pastoralist conflicts were based on recalled much earlier crop damage events. These escalated and became established ethnic and socio-cultural conflicts. For example, the following statement was recorded from Burkinabé and Malian pastoralists: "*Mobile pastoralists have problems during movements because local farmers hate pastoralists; they always want you to pay for crop damages you did not cause, but rather happened a long time ago*". Furthermore, cross-border pastoralists were requested to pay multiple "illegal unofficial taxes" during movements from their home countries to northern Côte d'Ivoire. A Malian pastoralist reported: "*Pastoralists hide in the savanna because they are always victims of unusual taxes payments*". They requested authorities to protect pastoral corridors without agricultural activities. They have perceived such corridors to be the only solution to mitigate conflicts, but also for official movement control.

Animal health professionals in the three countries recognized the economic impacts of transboundary and zoonotic diseases. They have perceived cross-border control in the region as an urgent need. Additionally, Ivorian animal health professionals thought of CBPP, FMD, bovine tuberculosis and lumpy skin disease as being imported from Mali and Burkina Faso. They mentioned that livestock traders, in contrast to mobile pastoralists, usually requested zoo-sanitary and veterinary certificates and paid local and international taxes. Their current challenge was the reduced access to mobile pastoralists who mostly used informal corridors to move within the savanna and bypassed cross-border controls (personal communication, Mahamadou Traoré & Bakary Malé, 2013). Along the informal corridors, pastoralists were directed from the electric high-tension pylons to the Ivorian borders. Once across the border, they spread into the savanna. Figure 6.3 shows their points of destination in the northern Côte d'Ivoire (Korhogo, Sirasso, Dikodougou, Niakaramandougou, Tafiéré, Dabakala, Boundiali, Séguéla, Mankono and Tingréla), where they stayed each year almost six months from November to April and pretended to be Ivorian agropastoralists to avoid control. Their destinations were about 300 kilometers from the border entry points.

Figure 6.4 shows the reported needs of key-informants from the animal health sector. The veterinarians struggled with the vastness of rangelands and remote entry points. More veterinary staff and transportation means were the most important needs raised by border veterinary services. On average during the high season of movements, two veterinarians were found to conduct zoo-sanitary control for 500–700 cattle per week. Due to the lack of transportation means, the control could not be done for trucks or mobile pastoralists who did not pass through the official entry points. The lack of official and well-marked pastoralist corridors was recurrent in discussions. Before the civil war, pastoralists rather took official routes because there were attractive vaccination pens and dip tanks for free treatment against ectoparasites; however, these were destroyed. This fact is reflected in the following statement of a departmental veterinarian in Tengréla, northern Côte d'Ivoire: "*Currently, pastoralists have no interest to pass by veterinarians because they have no vaccines, drugs or diagnostic means for cattle*". Another constraint was the virtual absence of cross-border collaboration.

Livestock movement supporting agents proposed to set up pastoral committees to defend pastoralists' rights and harmonize pastoral regulations such as standardized taxes along pastoral corridors and roads. They also mentioned a need to inform farmers, agropastoralists and other stakeholders about the economic, environmental and socio-culture relevance of pastoralism and livestock cross-border trade.

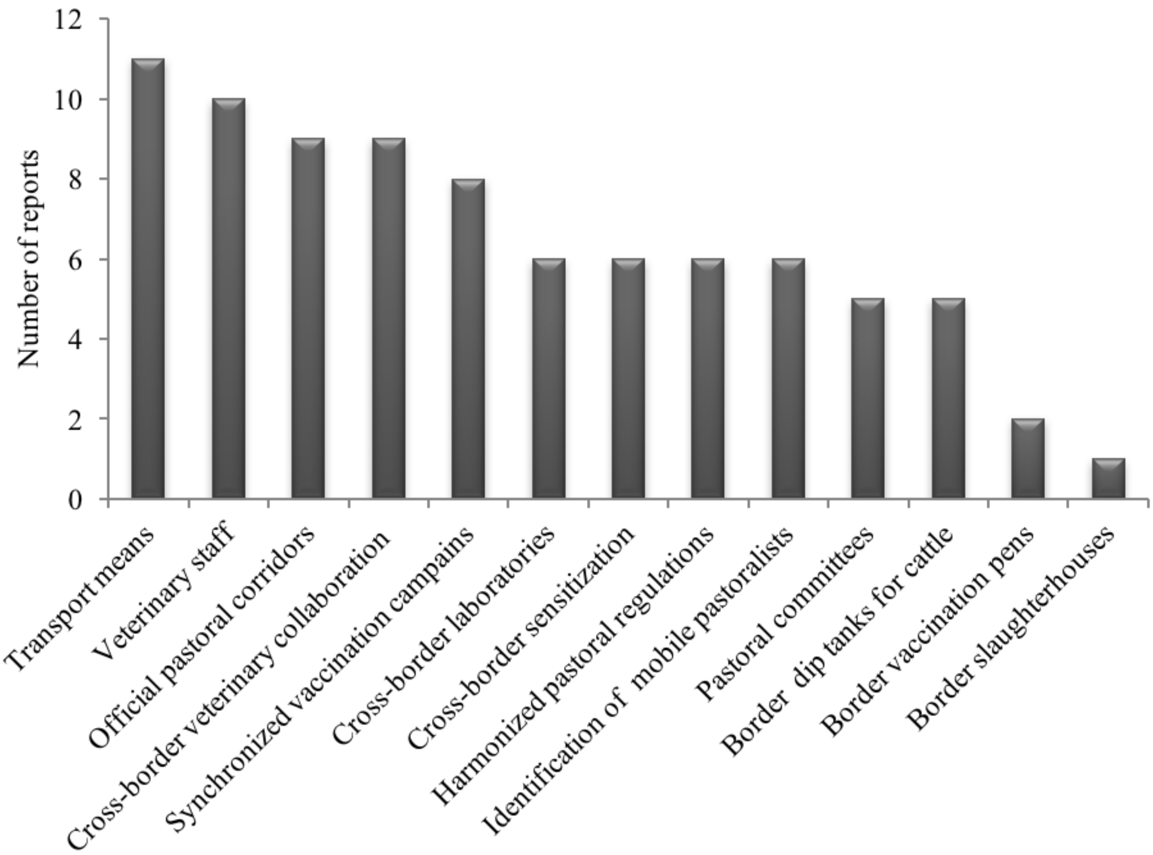

Figure 6.4: Reported challenges and needs of the animal health sector for cross-border control of livestock movements in the Sudano-Guinean savanna of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso.

Challenges and control of livestock diseases in the savanna region

Farmers and agropastoralists reported that the control of TADs requires the restriction of livestock cross-border movements, while supplying local breeders with high quality veterinary products distributed by a higher number of veterinarians operating in rural areas. Pastoralists' recommendations were mainly on proper prophylactic vaccinations and treatments before movements and to avoid intermixing between pastoralist and local cattle.

Animal health professionals in the three countries reported that vaccines were generally available for all major diseases (Table 6.3). However, the vaccination against CBPP was the only mandatory vaccination, but with no real penalty if refused by livestock owners. Few agropastoralists vaccinated their livestock against FMD, pasteurellosis, blackleg or lumpy skin disease, whereas treatments against trypanosomiasis and ticks were common. Veterinarians reported that failure to control TADs was primarily related to pastoralists and agropastoralists' attitudes and beliefs. In northern Côte d'Ivoire, cattle vaccinations upon

CBPP outbreaks induced several mortalities because the vaccine was administered to animals already infected. Thus, CPBB vaccines were believed to transmit the disease. Regarding brucellosis, livestock breeders preferred to remove cows that aborted 2–3 times during their lifespan rather than buying the vaccine. Fulani further stated that vaccines requiring a booster after six months such as vaccines against FMD and pasteurellosis were of low quality. Vaccination campaigns against PPR failed because small ruminants were owned from women who were less involved than men in livestock disease control activities. Veterinarians reported the lack of adequate cold chain facilities for the storage of the vaccines under hot climatic conditions that decreased the quality of most vaccines.

Animal health professionals reported an urgent need for disease control programs and synchronization of cross-border control activities (Figure 6.4). Interviewees developed a disease control plan based on the seasonal occurrence of key diseases, the seasonal pattern of livestock movements, the inter-annual variations in animal's nutritional status, the animal treatment habits of agropastoralists, the availability of animal health workers, vaccines and drugs, and, finally, the duration of immunity/protection of animals (Table 6.3). The proposed control plan should allow cross-border synchronization also because of appropriate timing and time intervals between vaccinations or treatments. As such, an integrated mass vaccination campaigns against CBPP, FMD, pasteurellosis, blackleg and cattle brucellosis should be conducted at the beginning of the rainy season (mid-May to June) (Table 6.4). A booster vaccination for FMD and pasteurellosis should be given six months later in beginning of cold-dry season (October). Given brucellosis vaccination is neglected by agropastoralists, a prophylactic vaccination in heifers only might be appropriate in the study sites. Lumpy skin disease vaccines should be administered from end of dry season (April) to the first rains in May. PPR control should reach lambs and kids ≤ 6 months by a mass vaccination at beginning of the rainy season. Trypanosomiasis preventive and curative chemotherapy in adult animals should be given every second to third month, whereas calves should be treated during high-risk seasons (i.e., cold-dry and dry seasons). Prophylaxis of tuberculosis should target systematic testing of trade cattle at border entry points as well as an active surveillance in abattoirs throughout the year (Table 6.4). Tick control should be conducted the whole year, with particular emphasis during the rainy and cold-dry seasons where tick populations increase steeply.

Table 6.3: Most available vaccines and drugs used against major diseases in local markets of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso.

Major diseases	Causing pathogens	Brand names for vaccines / drug in local markets	Type of vaccine /drug	Booster
CBPP	Bacteria	Perivax T_1SR^{ND}; Perivax T_144^{ND}	Live attenuated vaccines (*Mycoplasma* spp. T_1SR; T_144 strains)	6 months; annual
FMD	Virus	$Aftovax^{ND}$; $Aftovaxpur^{ND}$	Inactivated vaccines (FMD Virus strain SAT 2, 3, O and A)	4–6 months
Pasteurellosis	Bacteria	$Pastovax^{ND}$	Inactivated vaccine (*Pasteurella multocida* types E6 et B6)	6 months
Blackleg	Bacteria	$Symptovax^{ND}$	Inactivated vaccine (*Clostridium chauvoei*)	Annual
Brucellosis	Bacteria	$RB51^{ND}$	*B. abortus,* RB51 strain	Annual
PPR	Virus	$Capripestovax^{ND}$	Live attenuated vaccine (PPR Virus 75/1 LK6, BK2)	Annual
Lumpy skin diseases	Virus	$Nodulovax^{ND}$; $Lumpyvax^{ND}$	Live attenuated vaccine (sheep and goat pox virus)	Annual
Trypanosomiasis	Protozoa	$Berenil^{ND}$/$Trypamidium^{ND}$	Trypanocidals: Diminazene / Isometamidium	2–4 months

Table 6.4: Tentative annual disease control plan for major livestock diseases reported in the savannah region of northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso.

	Diseases	Dry season			Rainy season					Cold-dry season			
		F	M	A	M	J	J	A	S	O	N	D	J
Mass vaccination	CBPP vaccination				xxx	x							
	FMD vaccination			xxx	xxx	x				xxx			
	Pasteurellosis vaccination				xxx	x				xxx			
	Blackleg vaccination				xxx	x							
	Brucellosis vaccination				xxx+	x+							
	PPR vaccination				xxxβ	xxxβ							
	Lumpy skin disease vaccination			xxx	x								
	Trypanosomiasis chemotherapy	o	o	cc	ccc		ccc	ccc		ccc o	ccc o	o	cc o
	Tick infestation	*			*	**	***	***	***	***	***	*	*
	Tuberculosis surveillance	S	S	S	S	S	S	S	S	S	S	S	S

xFrequency of vaccination

+Vaccination in heifers only

βVaccination of lambs and kids ≤ 6 months

cFrequency of trypanosomiasis chemoprophylaxis in adult cattle

oPreventive treatment of calves with trypanocidal drugs

*Number of acaricid spray per month

SActive surveillance in abattoirs and systematic testing of trade cattle at entry points

Brucellosis and Q fever seropositivity and risk factors in livestock and humans in abattoirs along the pastoralist corridors and trade routes

A total of 76 human, 300 cattle and 240 small ruminant sera were collected at three slaughterhouses in Korhogo and the main abattoir of Abidjan were screened for brucellosis and Q fever. Almost 70% (172/256) of cattle tested in abattoirs were bulls. The overall apparent seroprevalence of *Brucella* spp. by indirect IgG ELISA was 3.5% (95% CI 1.6–6.6) in cattle and 0% in small ruminants. Note that so far *B. melitensis* was never isolated from small ruminants in Western Africa. Seropositivity in cattle was significantly higher in Korhogo than Abidjan: 6.7% (95% CI 2.7–13.3) vs. 1.3% (95% CI 0.2–4.7). The overall seroprevalence of Q fever was 8.8% (95% CI 5–14) in slaughter cattle. Cattle sampled in the abattoir of Abidjan were less likely to be exposed to *Brucella* spp. (OR = 0.2; 95% CI 0.04 - 0.92) and *C. burnetii* (OR = 0.3; 95% CI 0.1–0.86) than those sampled in Korhogo (Table 6.5).

Eighty-three per cent (63/76) of interviewed abattoir workers in Korhogo were men. Five male butchers or meat sellers were brucellosis seropositive, leading to an overall seroprevalence of 6.6% (95 % CI 2.2–14.7). Seropositive participants were between 23 and 46 years of age and had a median of 15 years of professional experience. In contrast to people sampled in cattle abattoirs, all participants (28 men out of 76) screened in small ruminant abattoirs were seronegative. However, this difference was not statistically significant, because butchers in small ruminant abattoirs could also intervene in cattle abattoirs and vice-versa. Women (n = 11) selling fried cattle blood products in the local markets were also brucellosis seronegative (non-significant difference when compared to men). They reported to have sold a median of four blood buckets per day (corresponding to approximately 80 liters of blood). Those women with their family members went in and out to collect fresh cattle blood in the abattoir of Korhogo. Blood was allowed to congeal in containers or was partially cooked to accelerate the process before frying.

Raw milk consumption was reported in 36% (25/70) of abattoir workers and was not associated statistically to seropositivity (as was the case for age and gender). Almost half (35/73) of the participants did not know that transmission of livestock diseases (zoonoses) to humans through contact with meat products or by aerosol at slaughter was possible. Furthermore, 70% (40/60) of interviewees said to have slaughtered cattle clinically sick without using protective measures.

Table 6.5: Risk factors of brucellosis and Q fever in livestock sampled in the abattoirs of Korhogo and Abidjan from July 2013 to May 2014.

Diseases / Predictors	Categories	Number (% seropositive)	Odds ratio (95% CI) Univariate analysis	Adjusted for age, sex, study site
Brucellosis				
Cattle				
Sex	Male	173 (2%)	1	1
	Female	83 (6%)	2.7 (0.7–10.4)	0.8 (0.2–4.4)
Age categories	4 years	93 (3%)	1	1
	5–8 years	114 (2%)	0.5 (0.1–3.3)	0.8 (0.1–5.2)
	> 9 years	49 (8%)	2.7 (0.6–12)	2.9 (0.6–14)
Cattle slaughtered in Korhogo		105 (7%)	1	1
Cattle slaughtered in Abidjan		150 (1%)	0.2 (0.04–0.92)	0.2 (0.03–1.4)
Human				
Sex	Women	13(0%)	1	1
	Men	63 (8%)	-	-
Age	≤ 30 years	29 (7%)	1	1
	> 30 years	47 (6%)	0.9 (0.1–5.9)	1.1 (0.2–7.3)
Raw milk consumption	No	45 (9%)	1	1
	Yes	25 (4%)	0.4 (0.05–4)	0.4 (0.04–3.5)
Q fever				
Cattle				
Sex	Male	132 (8%)	1	1
	Female	39 (13%)	1.8 (0.6–5.6)	0.7 (0.2–3)
Age categories	4 years	52 (12%)	1	1
	5–8 years	86 (7%)	0.6 (0.2–1.9)	0.8 (0.2–3)
	> 9 years	33 (9%)	0.8 (0.2–3.3)	0.9 (0.2–3.9)
Cattle slaughtered in Korhogo		47 (17%)	1	1
Cattle slaughtered in Abidjan		124 (6%)	0.3 (0.1–0.86)	0.2 (0.06–0.93)
Infestation by ticks	No	77 (9%)	1	1
	Yes	94 (9%)	0.9 (0.3–2.7)	0.8 (0.3–2.5)

6.5. Discussion

The study found higher brucellosis and Q fever seropositivity in the pastoral area of northern Côte d'Ivoire than in Abidjan. The present study also collected epidemiological information on TADs including zoonoses and cross-border livestock movements between Mali/Burkina Faso and Côte d'Ivoire. In 2012, at least 200 pastoralist herds were estimated to be involved in uncontrolled cross-border movements. National borders are porous regarding livestock movements and, subsequently, so is the risk of disease spread due to the absence of cross-border control measures. However, participants have proposed cross-border control strategies based on their reported needs.

A participatory approach to explore local knowledge of major livestock diseases and cross-border movements by interviews, focus group discussions, ranking, scoring and mapping was used (Catley et al. 2012; Mariner & Roeder 2003). This participatory approach should lead to a transdisciplinary process with key concerned stakeholders (Schelling et al. 2015b). The quality of the data collected using one of these approaches was cross-checked by triangulation, meaning that detailed answers were asked for any specific subjects raised by the interviewees during the discussions. Simple ranking results were reassessed by pairwise ranking and by questioning of livestock health professionals; seasonal calendars were established by agropastoralists and farmers and reassessed by veterinarians (Catley et al. 2012; Denzin 2006; Patton 1999).

The major TADs in the study sites were CBPP, tuberculosis, FMD, lumpy skin disease and brucellosis. Prior studies in the region have assessed livestock production impacts of some of these diseases. For example, Kané (2002) found a prevalence of mainly subclinical CBPP of 10.5% in Mali and 3% in Burkina, whereas a 5 to 10 % mortality rate and 90% decrease in milk production were estimated by Tami et al. (2006). Ellis and Putt (1981) reported that FMD induced 33% reduction in milk production, up to 10% abortion and 20% death among young animals in endemic countries. Lumpy skin disease caused mortalities ranging from 1 to 5%, with a 50% drop in milk production (Hunter & Wallace 2001). The sanitary and wildlife conservation impact of bovine tuberculosis were less known, particularly for low prevalent rural areas than for high prevalent peri-urban dairy production, although a 5% loss of carcass was reported in a study conducted in Ethiopia (Tschopp et al. 2013).

Given the current situation with poor diseases surveillance systems, control efforts should primarily target cross-border livestock control, mass vaccination and public outreach programs. Largely uncontrolled cross-border mobility of livestock was perceived as the greatest risk for the spread of TADs in the study sites. Closer collaboration between authorities and stakeholders from neighboring countries is needed to define safer livestock movement corridors. However, Mali, Burkina Faso and Cote d'Ivoire are currently implementing separate national TADs and movement control approaches with minimal cross-border collaboration, for example, regarding the harmonization of vaccination campaigns. The annual CBPP vaccination campaigns in Burkina Faso and Mali always resulted in low coverage (about 30% in Mali) (Ministère de l'Agriculture du Mali 2003). According to interviewed veterinarians, the low vaccine coverage was mainly explained by the reluctance of mobile pastoralists to pay for the vaccines and stay further away from the border to Côte d'Ivoire during vaccination campaigns. But Mali and Burkina Faso did not conduct their campaigns during the same period of the year. According to pastoralists, shortage of fodder due to loss of land to expanding mining and farming, increased risk of farmer-pastoralist conflicts, and frequent unofficial payments driving them to remoter areas were cited as the major reasons for the failure to vaccinate their animals.

The synchronization of prophylactic disease measures as outlined with stakeholders in this study, coupled with unwavering commitment of governmental and non-governmental actors and data exchange between neighboring countries, will be critical to reach mobile pastoralists with services on either side of a border. Additionally, to increase the effectiveness of control, neighboring countries in the study area should invest more their limited resources to focus on existing parallel cross-border movement zones as mapped in this study. A fostered exchange between veterinary services with livestock movement supporting agencies, who are continuously in contact with pastoralists, should help to localize mobile pastoralists. The same would apply to new joint pastoral and village committees.

Vaccines were available for almost all major diseases; however, their demand was rather low. For example, the PERIVAX T1-SRND vaccine used against CPBB conferred a shorter post-vaccinal immunity with less adverse effects, but a revaccination was needed six months later. To avoid cost of revaccination but also disease cases, Fulani agropastoralists rather used antibiotics to treat CBPP-infected animals. Thus, there was a great need for outreach programs with good information and convincing arguments from animal health ministries to encourage the adherence of agropastoralists, farmers and mobile pastoralists to prophylactic programs. Additionally, efforts should be directed towards the supply of quality veterinary products (e.g., vaccines, drugs) that allow minimal requested coverage for each major disease.

As an alternative to the live animal trade, building refrigerated slaughterhouses in pastoral areas to supply meat-importing countries with frozen safe meat products from pastoralist livestock, as implemented in the pastoral area of Turkana County in Kenya (http://amref.org/news/lomidat-slaughter-house), should be considered. Moreover, the creation of cross-border veterinary laboratories would minimize the time to process biological samples taken from quarantined herds at the borders that were shipped for analysis in capital cities. Such laboratories would also improve diagnostic capacities and diseases surveillance systems including data exchange across borders.

6.6. Conclusion

This study showed that participatory methods and conventional sero-epidemiology studies in Mali, Burkina Faso and Côte d'Ivoire contributed to identifying the need for cross-border control of livestock movements and TADs. Prerequisites for a successful cross-border control identified were cross-border veterinary collaboration, cross-border synchronization of disease control activities, and the strengthening of veterinary services. Further studies on the economic impact of TADs on livestock production and cost-benefit and cost-effectiveness of their control and surveillance strategies are required.

6.7. Acknowledgements

The authors would like to the Ivorian, Burkinabé, and Malian authorities, veterinary services, village chiefs and the study participants for their collaboration. Furthermore, thank you to Dr. Ouattara Issa, Mr. M. Merépé Togo, Mr. Inoussa Sawadogo, Mr. Drissa Coulibaly, Mr. Pierre Dehi, Mr. Bouréima Yalcouyé, Mr. Mahamadou Traoré, Mr. Bakary Malé, Mr. Gomah Diomandé, Mr. Mamadou Koné, Mr. Zhakaria Koné, Mr. F. Datoliban Koné, Mr. Issoufou Ilboubo, Mr. Yacouba Ouédraogo and Mr. Aboubacar Barry for their contributions to the field data collection. Great thanks to Dr. Christian Schindler, Dr. Jan Hattendorf for providing statistical support, Mr. Blaise Amani, Mr. Jean Baptiste Assamoi, Mr. Nestor Kessé Bli, Mr. Tuo Kanigui, Mrs. Emmanuelle Sarah Mara, Mr. Jalil Darkhan, Mrs. Christelle Dassi for their help in serological analyses and data entry. Thank you to Dr. Gokou Sébatien and Mr. Epinza Nicodème for their inputs regarding human brucellosis, and to Mrs. Jennifer Evack for editing the English manuscript.

7. Stochastic Simulation of the Economic Impact of Cattle Brucellosis in Côte d'Ivoire

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7.1. Abstract

The aim of this study was to simulate Ivorian cattle demographic process and the loss of cattle productions attributable to brucellosis over a 10-year (2005–2015) period. A discrete, sex and age-structured stochastic demographic model to simulate cattle population growth and estimate the costs of brucellosis infection, comparing meat, milk and hide production and live cattle asset value with and without the disease scenarios was developed. The cattle population was estimated to be about 1,885,123 and 1,906,961 with and without the disease in 2015, respectively. An overall intrinsic growth rate of 1.8% and 17.4% meat offtake rate were derived. The cumulated net present cost attributable to brucellosis was estimated at FCFA 14,455 x 10^6 (95% CI: 6,278–22,906), which is the equivalent of USD 23,662 x 10^3 (95% CI: 10,276–37,496), at a rate of FCFA 579.7 per USD in 2015. The incremental live cattle asset value was projected to FCFA 3,826 x 10^6 (95% CI: 1–7,623) or USD 6,340 x 10^3 (1,657–12,629) in 2015. These cost estimates were likely due by chance, probably because of the inaccuracy or high variability of input production parameters and prices. This is the first stochastic projection model for the Ivorian cattle, and can be used in future with more accurate and context specific input data for better cost estimations of brucellosis and any other zoonotic disease.

Keywords: Brucellosis, cattle population, loss of production, matrix model, Côte d’Ivoire.

7.2. Introduction

Brucellosis is predominantly a chronic zoonotic disease in livestock, wildlife and humans and is caused by Gram-negative bacteria *Brucella* spp. Bacteria are transmitted to people through the direct contact with infectious animal abortion/birth materials and contaminated products. Though the zoonosis has been eliminated in high-income countries, it induces every year 500,000 human cases worldwide (Seleem 2010). Brucellosis is present in all sub-Saharan countries where it potentially induces major economic losses to livestock production through abortions, lower fertility and fecundity, reduced milk and meat productions, as well as mortality of weak newborns of infected females (McDermott et al. 1987). In contrast to cattle, the epidemiology and economic impacts of brucellosis are less evidenced in small ruminants in Africa (Ducrotoy et al. 2015). Up to date, there is no *B. melitensis* isolate from Western Africa and our working hypothesis is that brucellosis is absent in small ruminants in Côte d'Ivoire.

Mangen et al. (2003) estimated a total additional income potential of USD 86–143 million per year by elimination of brucellosis in sub-Sahara. An older study on the economic significance of brucellosis in Central Africa has estimated up to 6% loss of the gross income per cattle (Domenech et al. 1982). In Western Africa, few older studies have assessed the cost of brucellosis at herd level. In Côte d'Ivoire, Camus (1984) found an annual loss of FCFA 150 million (almost USD 260,000) in brucellosis infected herds due to a 10% decrease in the annual income of cattle breeders. Boenhel (1971) showed that 60% of milk produced in northern Côte d'Ivoire was infected by *Brucella* spp., and thus, would have needed to be boiled or pasteurized before human consumption.

A national brucellosis mass vaccination campaign was launched in 1978 by the Ivorian governmental agency Société de Développement des Productions Animales (SODEPRA). Breeding cows were primarily vaccinated, and in the following years heifers only. This resulted in a 40% reduction in the cattle abortion rates, and an important increase in milk yield in the country (Camus 1995). The last census of the Ivorian livestock population was conducted in 2001, when 1,336,000 cattle were estimated (MIRAH-DPP 2012). The collapse of SODEPRA in 1995 and the first armed conflict in 2002 led to the cessation of livestock diseases control activities, destruction of animal health services and production infrastructure, large numbers of stolen cattle herds that were culled or trekked abroad. Since then, the national supply of milk, meat and hides strongly depends on import (BNETD 2012). This work simulates the Ivorian national cattle demography and the losses in meat, milk and hide productions attributable to cattle brucellosis over a 10-year period (2005–2015). This data can be further used to assess the cost-effectiveness of brucellosis control in Côte d'Ivoire.

7.3. Materials and methods

Ethical considerations

The study was approved by the Ministère de la Santé et de la Lutte contre le Sida (N°71/MSLS/CNER-dkn), and the Direction Générale de Recherche Scientifique et de l'Innovation Technologique du Ministère de l'Enseignement Supérieur et de la Recherche Scientifique in Côte d'Ivoire (N° 089/MESRS/DGRSIT/KYS/tm). Further approval was obtained from the Ethics Commission of the Cantons of Basel-Stadt and Basel-Land (ref. 146/10).

Data collection

A seroprevalence of 4.6% (95% CI 2–10.6) derived from a previous cross-sectional study using a three-stage cluster sampling approach was employed, and 63 village herds in northern Côte d'Ivoire from 2012 to 2014 (Kanouté et al. 2017). The national cattle herd composition and slaughter data were collected from the Regional and Departmental Veterinary Services and the Laboratoire de Recherches Veterinaires (LRK) in northern Côte d'Ivoire. Given the sparse data on cattle production parameters in the country, the literature on extensive livestock production systems in semi-arid sub-Saharan Africa to assemble parameters' values was used – but, where no published parameters for sub-Saharan Africa existed, also from elsewhere (e.g., Kyrgyzstan) (Kasymbekov et al. 2014).

Ivorian national cattle herd composition

In 2005, a total cattle population of 1,449,000 was estimated, and almost 80,000 cattle were slaughtered that year (MIRAH-DPP 2012). Both populations were used in study as the baseline populations. Animals were grouped by sex and age: female and male calves (0 – 1.6 years), heifers and replacement bulls (≥ 1.6–3.6 years), adult bulls and breeding cows (> 3.6 years) (Sokouri et al. 2010; Mangen et al. 2002). Table 7.1 and 7.2 show the national cattle population structure and slaughter data (MIRAH-DPP 2012). The national herds had a preponderance of breeding cows and heifers (almost 50% and 20%, respectively), while slaughter animals were predominantly cows and replacement males (approximately 30% each) and adult bulls (approximately 15%).

Table 7.1: Age and sex structure of the national cattle population (in equilibrium) used for the simulation from 2005–2015.

National cattle herd structure	Population vector (N_t)	Mean proportions of sex and age classes in the population (Eigenvector)
Female calves	167,452	0.1156
Male calves	167,452	0.1156
Heifers	278,460	0.1922
Replacement males	66,242	0.0457
Cows	693,933	0.4789
Bulls	75,457	0.0520
Total	1,449,000	

Table 7.2: Age and sex structure of the slaughter cattle population used for the simulation from 2005–2015.

Structure of slaughter cattle	Population vector (N_t)	Relative proportions of slaughter animals
Female calves slaughter	7,185	0.09
Male calves slaughter	9,700	0.13
Heifers slaughter	3,897	0.05
Replacement males slaughter	20,970	0.27
Cows slaughter	24,478	0.32
Bulls slaughter	11,325	0.15
Total	77,555	

Projection matrix model

A Leslie matrix which is a squared, discrete, sex and age-structured demographic model to project the population dynamics according to Vandermeer and Goldberg (2003) was used, and the cost of brucellosis infection in cattle estimated. The economic evaluation included income losses: decreased milk, meat and hide production in infected herds. Possible socio-economic impacts of the disease on human health as well as other potential indirect costs were not included in this model.

The projection model was available as an Excel spread sheet which showed all calculations and used a series of charts to illustrate outputs of modifying various model parameters. It was also linked to the add-in program Ersatz (version 1.3.3, EpiGear International, 2015, Pty Ltd, QLD, Australia) which included variance of the parameters values to shift from deterministic to stochastic Monte Carlo method for analyses of uncertainty. The modeling was based on the hypothesis of exponential growth in the population and the absence of inward and outward migration of cattle. The demographic process and the cattle population vector (N_{t+1}) for each following time step was simulated by multiplying the Leslie Matrix (A) by the age and sex-structured stable population vector (N_t) for the previous time step as according to Vandermeer and Goldberg 2003 (Figure 7.1):

$$N_{t+1} = \begin{bmatrix} F_0 & F_1 & F_2 & F_3 & \cdots & F_s \\ S_0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & S_1 & 0 & 0 & \cdots & 0 \\ 0 & 0 & S_2 & 0 & \cdots & 0 \\ \cdots & & & & & \\ 0 & 0 & 0 & 0 & S_{s-1} & 0 \end{bmatrix} \begin{bmatrix} N_0 \\ N_1 \\ N_2 \\ N_3 \\ \cdots \\ N_S \end{bmatrix}$$

Figure 7.1: Structure of the Leslie matrix (A) and the population vector (N_t).

The first two rows in the Leslie matrix indicate the probability that a cow of any given age will produce a female/male calf (i.e., sex and age-specific fecundity F_s). Note that local Ivorian cattle breeds do not reach sexual maturity before the age of 3.5 years (Sokouri et al. 2010). The rows (below the first two) present the likelihood that an animal of a given age will survive for another year (i.e., age-specific survivorship S_s). The matrix also included the persistence of heifers (i.e., 1–1/years as heifer or 1–1/2) in replacement herds and cows (1–1/years as breeding cow or 1–1/4) and bulls (i.e., 1–1/4) in breeding herds. Table 7.3 shows the parameters and their values used in the Leslie matrix for the simulation of the population growth. To consider uncertainty and variability in the projection matrix, each demographic and production parameters were specified with a PERT (or Beta PERT) distribution according to expert's minimum, maximum and mode (or most likely central value) (Table 7.3). Cattle brucellosis is rarely fatal (i.e., about 1% mortality rate in cows) (Mangen et al. 2002); thus, it was assumed that it induces 15% decrease in the baseline calving rate in seropositive herds according to Bernués et al. (1997). The fertility in brucellosis-infected herds can be written as follow:

$F_i = basline\ ferility * (1 - (0.15 * seroprevalence))$.

A multivariate sensitivity analysis by Monte Carlo simulations to calculate Spearman's rank correlation coefficients (RCC) for model parameters and cattle productivity with and without the disease was performed. The simulations were run for 10,000 iterations to identify the most sensitive parameters and to show how changes in their values could affect the population structure and productivity. To make reliable inferences on model outputs, Monte Carlo errors were assessed via checks for potential lack of convergence in parameter trace plots.

Table 7.3: Cattle productivity and slaughter parameters used, and their distribution for the projection of the Ivorian cattle population.

Productivity parameters (Units)	Mean value	Min	Max	Distribution (Source)
Fertility rate for female calves (Calve*Year^{-1})	0.220	0.219	0.221	Pert^{+} (n.r.^{0})
Fertility rate for male calves (Calve*Year^{-1})	0.220	0.219	0.221	Pert^{+} (n.r.^{0})
Survival female calves (Calve*Year^{-1})	0.876	0.875	0.877	Pert^{+} (n.r.^{0})
Survival male calves (Calve*Year^{-1})	0.841	0.840	0.842	Pert^{+} (n.r.^{0})
Survival heifers (Heifer*Year^{-1})	0.929	0.928	0.930	Pert^{+} (n.r.^{0})
Survival bulls (Bull*Year^{-1})	0.300	0.299	0.301	Pert^{+} (n.r.^{0})
1–1/years in replacement herds as heifer	0.500	0.499	0.501	Pert^{+} (n.r.^{0})
1–1/years in breeding herds as cow	0.683	0.682	0.684	Pert^{+} (n.r.^{0})
1–1/years in breeding herds as bull	0.750	0.749	0.751	Pert^{+} (n.r.^{0})
Slaughter rate for female calves (Calve*Year^{-1})	0.085	0.084	0.086	Pert^{+} (n.r.^{0})
Slaughter rate for male calves (Calve*Year^{-1})	0.100	0.099	0.101	Pert^{+} (n.r.^{0})
Slaughter rate for heifers (Heifer*Year^{-1})	0.040	0.039	0.041	Pert^{+} (n.r.^{0})
Slaughter rate for replacement males (Young male*Year^{-1})	0.400	0.399	0.401	Pert^{+} (n.r.^{0})
Slaughter rate for breeding cows (Cow*Year^{-1})	0.300	0.299	0.301	Pert^{+} (n.r.^{0})
Slaughter rate for breeding bulls (Bull*Year^{-1})	0.200	0.199	0.201	Pert^{+} (n.r.^{0})

* Multiplied by

$^{+}$ Assigned by authors following consultations with veterinary clinicians and other experts

n.r.^{0}: No reference

Economic evaluations of livestock production

It was assumed that the public cost of cattle brucellosis was negligible (since the study did not further consider human health impact); hence, the economic evaluations from the private livestock holders perspective were conducted according to Tschopp et al. (2013). Given limited research data on cattle product values in Côte d'Ivoire specifically and sub-Saharan Africa in general, some values were assigned after consultations with veterinary clinicians and other experts familiar with the cost distributions of these. The annual milk, meat and hide production were calculated in the scenarios without and with brucellosis, adjusting the baseline fertility rate ($\mathrm{F} = 0.220$) to the seroprevalence-dependent reduction in fertility ($F_i = 0.218$). The losses associated with the annual milk production were estimated by multiplying the population of lactating cows with the average yearly milk yield and price per liter (Table 7.4), as according to Roth et al. (2003) and Godet et al. (1981). The annual slaughter value was computed by summing up the products of the sex and age-structured slaughter cattle population with respective average carcass weight and meat price per Kg (Table 7.4). The annual hide production value was obtained by multiplying the total number of hides (i.e., total slaughtered cattle) by the average hide weight and price per Kg. The net present value (NPV) of livestock production was a function of milk, meat and hide production with and without the disease, and was calculated in Microsoft Excel 2010 using the following equation $NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^t}\text{-}Co$; where C_t = cattle production values during the period t; C_o = initial production value; r = discount rate, and t = time period in years. A discount rate of 5% was used to consider the time value of the local currency FCFA and the possible risk or uncertainty of future cash flows, as well as an exchange rate of USD 1.00 = FCFA 512.950 in 2005; and USD 1.00 = FCFA 579.682 in 2015 (http://www.oanda.com/currency/converter). The total production losses were estimated by subtracting the NPV of cattle productivity with brucellosis from the NPV of cattle productivity without brucellosis. A summary statistic of mean values with 95% confidence intervals was tabulated for NPV and the loss of production. The annual asset value of the live animals was estimated by summing up the products of age-structured live cattle populations and the average market prices in each scenario. The cost breakdown calculations were done to assess the individual contribution of milk, meat and hide production that represented the total domestic production value.

Table 7.4. Cattle production parameters and product prices (in FCFA) used for brucellosis economic impacts estimation in 2015.

Variables name (units)	Average	Min	Max	Distribution (Reference)
Carcass weight (kg), female calves	60	50	70	Normal+ (n.r.[0])
Carcass weight (kg), male calves	70	60	80	Normal+ (n.r.[0])
Carcass weight (kg), heifers	100	80	190	Normal+ (BNETD 2012)
Carcass weight (kg), young males	120	110	200	Normal+ (BNETD 2012)
Carcass weight (kg), cows	280	150	360	Normal+ (Mangen et al. 2002)
Carcass weight (kg), bulls	325	200	400	Normal+ (Mangen et al. 2002)
Meat price (FCFA per kg)	2,300	1,400	3,000	Normal+ (BNETD 2012)
Milk yield (liter/cow/year)	600	400	680	Normal+ (Domenech et al. 1982)
Milk price (FCFA per liter)	350	250	400	Normal+ (MIRAH-DPP 2012)
Hide weight (kg/animal)	20	10	25	Normal+ (n.r.[0])
Hide price (FCFA per kg)	800	650	1,000	Normal+ (n.r.[0])
Adult cattle price (FCFA)	210,000	125,000	600,000	Normal+ (BNETD 2012)
Replacement cattle price (FCFA)	125,000	90,000	170,000	Normal+ (BNETD 2012)
Calve price (FCFA)	80,000	60,000	100,000	Normal+ (n.r.[0])
Reduced milk yield in brucellosis infected herds (%)	15	10	25	(Bernués et al. 1997)
Reduced fertility rate in brucellosis infected herds (%)	15			(Bernués et al. 1997; Domenech et al. 1982; Camus 1980)

+ Assigned or adjusted after consultations with veterinary clinicians and other livestock experts

n.r.[0]: No reference

7.4. Results

Demographic dynamic of Ivorian national cattle herds from 2005 to 2015

The simulation projected the cattle population to be 1,885,123 (95% CI: 1,876,483–1,893,484) in the scenario with brucellosis and 1,906,961 (95% CI: 1,894,404–1,919,484) without brucellosis (Figure 7.2). An overall intrinsic population growth rate (i.e., Eigenvalue) of 1.8% and an annual offtake rate of 17.4% for domestic meat production were found. The sensitivity analysis of the projection model showed that the persistence of breeding cows (RCC = 0.78) and heifers (RCC = 0.45) in the herds, fertility rate (RCC = 0.71) and survival of female calves (RCC = 0.27) as well as the survival of heifers (RCC = 0.26) influenced most the population growth.

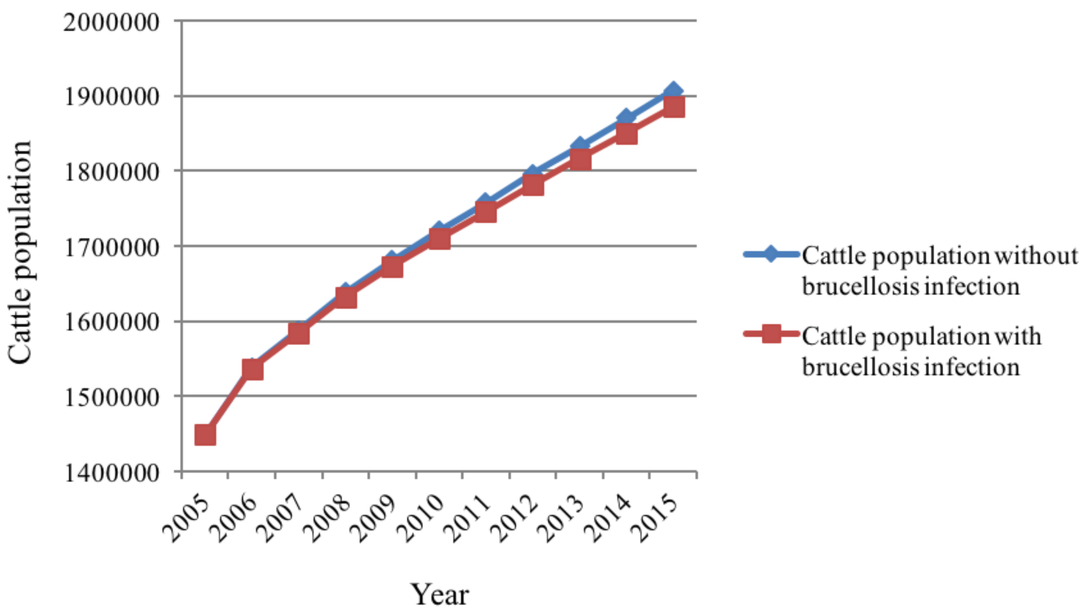

Figure 7.2: Demographic dynamic of the Ivorian cattle population from 2005 to 2015 with and without brucellosis.

Cattle productivity and cost of brucellosis from 2005 to 2015

The total cattle gross production value without brucellosis was FCFA297,482 x 10^6 (i.e. about USD 500,000 x 10^3) and was composed of 72% meat, 26% milk and 2% hide production values in 2015. The net present value (NPV) of these products in the baseline year was FCFA 127,669 x 10^6 (i.e., about USD 224,748 x 10^3). During the 10 years period, the cumulated NPV was estimated at FCFA 2,062,415 x 10^6 (95% CI: 1,536,407–2,217,122) in the scenario with brucellosis, and FCFA 2,076,871 x 10^6 (95% CI: 1,685,643–2,437,478) without brucellosis. The cumulated net present losses caused by brucellosis were FCFA 14,455 x 10^6

(95% CI: 6,278–22,906) which is the equivalent of USD 23,662 x 10^3 (95% CI: 10,276–37,496).

Figure 7.3 shows the growth of the NPV and the cost of brucellosis over the 10-year period of simulation. In the sensitivity analysis, the overall costs of brucellosis were most influenced by the fertility rate for female calves (RCC = 0.41), persistence (RCC = 0.43) and the slaughter rate of breeding cows (RCC = 0.32), persistence (RCC=0.19) and survival of heifers (RCC = 0.17), fertility rate for male calves (RCC = 0.16), and milk prices (RCC = 0.16) as well as meat prices (RCC = 0.16). The overall live cattle asset value was as high as FCFA 359,307 x 10^6 (95% CI: 234,786–545,744) with the disease scenario, and FCFA 364,606 x 10^6 (95% CI: 238,663–554,850) without the disease scenario in 2015. Thus, the simulated difference of the asset value between cattle flock in both scenarios was about FCFA 3,826 x 10^6 (95% CI: 1–7,623) or USD 6,340 x 10^3 (1,657–12,629) in 2015. The overall asset value was most influenced by the market prices of replacement cattle (RCC = 0.9).

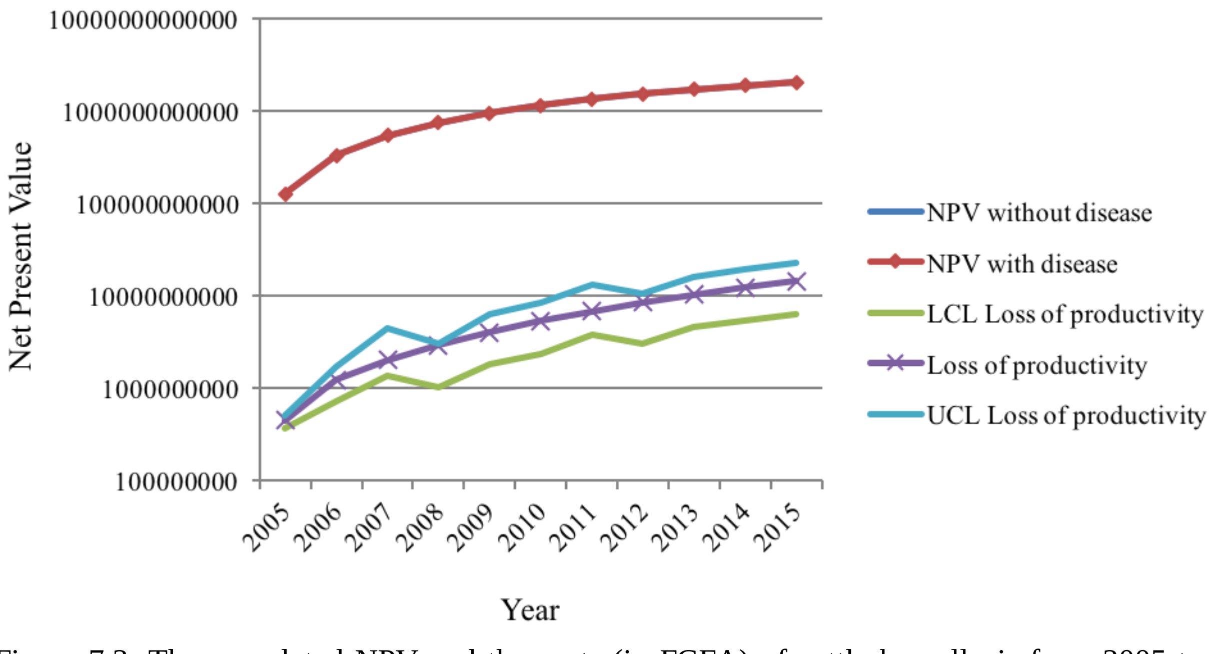

Figure 7.3: The cumulated NPV and the costs (in FCFA) of cattle brucellosis from 2005 to 2015 in Côte d'Ivoire.

7.5. Discussion

To the best of our knowledge, this is the first stochastic simulation of cattle demographics and costs estimates of the cattle production with and without brucellosis in Côte d'Ivoire, and indeed for a West African country. The findings suggest that the cattle population and the costs of brucellosis gradually increase absolutely and relatively in the next years.

Given the lack of official and reliable data on cattle population for the period of simulation, the precision of the estimates about the population growth could not be assessed. Sex and age-stratified stochastic projection would have generated more precise estimates, as it captures essential features of the population growth (Vandermeer & Goldberg 2003). The annual growth rate was reported to be 4% from 1974 to 1995 in the country, but then gradually decreased to 0.14% in 2001 at the beginning of the civil unrest (BNETD 2012). Restoring peace and re-opening Côte d'Ivoire to neighboring countries for cattle import provided a new national cattle population with a growth rate about 2.4% in 2005 (BNETD 2012). Therefore, our estimate of 1.8% annual growth rate over a 10-year period seems realistic, despite that this fixed rate does not reflect alternations of normal and drought years with generally higher mortality rates of cattle in Africa. The 17.4% annual meat offtake rate found was within the range reported in the literature – albeit, still far below the maximum level of offtake at which a livestock population can be maintained (i.e., 40% according to Bouwman (1997)). The persistence and survival of cows and heifers, and the calving rate for female calves were the most influencing parameters in our Leslie matrix, as they maintained the demographic growth (Schärrer et al. 2014). Consequently, the model was sensitive to any change in their values. However, since input data sources were sparse and not always specific to the Ivorian context, there may be aberrations in parameter values which, in turn, might impact the predictions (Upton 1989).

Though the meat products contributed 70% of the overall gross productions values, the sensitivity analysis showed that variations in meat prices had limited influence on the model outcomes when compared to the basic reproduction parameters of fertility, persistence and survival. The confidence intervals of NPV and live cattle asset values with and without the disease overlapped; therefore, the cost estimates were statistically not significantly different. This does not mean that there was not a real cost of brucellosis, but probably shows the rather high variability of demographic and production parameters, as well as market prices. In analogy with endemic cattle tuberculosis at relatively low levels (< 1%) (Tschopp et al. 2013), this study does not preclude the need to control cattle brucellosis in endemic areas in Côte d'Ivoire.

Some of the limitations of this study were that the Leslie matrix considered the Ivorian cattle population to be closed to inward and outward cattle mobility, which is not the case, particularly since the post-electoral armed conflict in 2010 (Kanouté et al. 2017). The model was neither adjusted to co-morbidities and density-dependent factors that can also limit the population growth and productivity, nor to normal and drought years. The demographic projection assumed that animals within the same sex and age classes had the same chance of survival and reproduction (i.e., individual homogeneity). These assumptions have likely influenced the model outputs.

It would be interesting to reassess the population dynamics and the losses of productions due to brucellosis by including the above-mentioned limitations in the stochastic model, as well as an intervention scenario with different achieved vaccination coverages. This will give valuable insight into the more complex cost-effectiveness assessment of brucellosis control in the country. More importantly, a future assessment must include human health costs, and health burden due to uncontrolled brucellosis to assess the societal benefits of brucellosis control in Côte d'Ivoire specifically, and in Western African countries more generally.

7.6. Conclusion

The presented study is the first stochastic demographic model for the Ivorian cattle population and can serve as a backbone for a more detailed cost-effectiveness assessment of brucellosis control at herd and national levels that also includes human health costs. The findings provide stakeholders and decision-makers with evidence-based information about the costs of cattle brucellosis in terms of meat, milk and hide productions, as well as live cattle asset values. The matrix can be used in future with more accurate and context specific input data for better cost estimations of other zoonotic diseases, and for comparable cattle populations in other West African countries. In the future, regional exchange in Western Africa with its high cross-border mobility of cattle should be assessed in total. This should foster regional collaboration in appropriate control plans of brucellosis, of other important zoonoses and transboundary livestock diseases.

7.7. Acknowledgements

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8. Discussions

The aim of this PhD was to contribute to the understanding of the epidemiology of neglected zoonoses in people and livestock and to assess their economic impacts to make recommendations for regional control strategies in West Africa for both veterinary and public health systems. This aim was subdivided into the three main objectives:

(i) Epidemiology of brucellosis, Q fever and RVF at the human and livestock interface in northern Côte d'Ivoire;

(ii) Pastoralism and transboundary animal diseases in the Sudano-Guinean savanna region of West Africa: towards an integrated cross-border and regional control;

(iii) Economic impacts of cattle brucellosis in Côte d'Ivoire.

The results of each individual study are discussed in detail in the respective result chapters. In this section, the overall significance of the thesis is discussed, then the main methodological considerations, followed by innovative contributions of this PhD to NZD epidemiology. It then discusses how these findings can progress from innovation to validation and application for a better control of NZDs and livestock movements. Finally, the limitations of the work are addressed as well as the implications of key findings and general recommendations given.

8.1. Context and overall significance of the thesis

In response to the Sahelian drought in 1970s, central achievements were made by the Ivorian government and the Ministry of Animal Resources to increase national livestock production. From 1970 to 1990, several pastoral infrastructures and livestock movement supporting policies were established to attract and settle mobile pastoralists from abroad who benefited seasonally from the Ivorian wetland pastoral resources (Diallo 1995). Regrettably, the agricultural structural adjustment plan (ASAP) in 1990 resulted into the gradual disengagement of the government from the livestock production sector, the privatization of animal health care, and the dissolution of the governmental livestock production agency (SODEPRA) in 1993 (MIRAH-DPP 2012; BNETD 2012). Drought episodes from 1984–1985, the economic crisis and the devaluation of the FCFA in 1994, and armed conflicts also severely affected animal health and production. These events led to poor disease surveillance and control as well as dysfunctional veterinary services (Coulibaly 2013). Moreover, the north and center of Côte d'Ivoire, where almost 95% of all the cattle and 80% of the small ruminants are found, are areas of uncontrolled north-south cross-border livestock movements (MIRAH-DPP 2012).

The findings of this PhD thesis contribute to the understanding of the occurrence and transmission of three key NZDs at the human and livestock interface in Côte d'Ivoire. For the first time, the cattle demographic process and economic impacts of cattle brucellosis were assessed in the country. The study further elucidates the mechanism and challenges to cross-border livestock movements between Mali, Burkina Faso and Côte d'Ivoire, their possible control strategies in the cross-border area of West African Sudano-Guinean zone. The overall significance of the study is that it has generated broad and updated epidemiological information which can be used by stakeholders and decision-makers from countries bordering the Sudano-Guinean savanna in general and, Côte d'Ivoire in particular for future research and public health interventions. These are essential elements to show the added value of One Health (Zinsstag et al. 2015).

8.2. Methodological considerations

8.2.1. Epidemiology of brucellosis, Q fever and RVF at the human and livestock interface in northern Côte d'Ivoire

Study sites, design and field methodology

Korhogo and Niakara were selected to be the study sites for brucellosis, Q fever and RVF serosurveys as they are important livestock breeding zones with complex webs of livestock cross-border pastoral movements. The low density of tsetse flies and trypanosomiasis occurrence are further factors that favored the increase of livestock production in the study sites. For practical considerations and the lack of updated livestock census data, cross-sectional studies with three-stage cluster sampling approach in 63 villages from 2012 and 2014 were conducted. The intra-cluster correlation coefficient ICC (also called rho) measures the relatedness of individual and animals within and between villages with respect to exposure to a specific disease (Schelling et al. 2015c). Regarding sample size calculation, it was hypothesized that brucellosis was endemic at a low transmission rate and an ICC of 0.1 was used (Newcombe 2001; Otte & Gumm 1997). The underlying assumption behind this ICC close to zero is that brucellosis infected animals are randomly distributed throughout the study population; thus, it would be more appropriate to sample fewer villages and more animals per villages (Salman et al. 2003). However, given the limited number of herds per study village as well as their small size, more villages and fewer animals (i.e., 5–10 cattle, sheep and goats) per village were sampled. Indeed, some selected villages had no ruminants at all and had to be replaced.

In general, the study was well accepted by the local community and participants, as there was a lack of private veterinarians to examine and provide animal health care in rural areas. However, the field team was refused in one village after its traditional authorities were informed about the study objectives and sampling procedure. In their village in 2010, an unrelated research team charged CFA 10,000 per participant for processing blood samples and laboratory fees. This led to an atmosphere of mistrust with respect to field researchers and their adherence to our project on NZDs. Additionally, the traditional authorities, mainly the "chefs de village" and close relatives in three villages, had to be included in the study although they were not selected during the random sampling. Failing to include them would have resulted in the exclusion of their respective villages. In few other villages, the "chefs de village" or villagers had disagreements with Fulani herdsmen; thus, sampling these Fulani and their livestock was not allowed. Furthermore, convincing Sénoufo and Tagwana communities to participate was a recurrent challenge, given that they conceived animal diseases, including zoonoses, to be health risks for Fulani herdsmen but not themselves. Côte d'Ivoire has a generalized HIV epidemic with the highest adult prevalence (about 4%) in Western Africa and an infection rate about 70% in adult people (UNAIDS 2014). Thus, most of the participants were concerned about a possible HIV testing that might have been done without their consent. These examples are practical issues, although addressed in the participants' information, may explain the limited number of enrolled participants and may have affected the randomness of the sampling procedure. Cross-sectional multi-stage cluster sampling can minimize survey costs and control the uncertainty related to estimates, but it can lead to erroneous inferences on the entire population if the study population and/or the clusters are chosen based on biased opinions (Radhakrishna et al. 2009).

Serological methods

Continued improvement of brucellosis diagnostic methods is essential in the African context, where none of the available commercial serological tests are validated in field. In sub-Saharan countries, the status of the herds with respect to *Brucella* spp. infection is hardly known because of the poor epidemiological surveillance system and the neglected status of the disease. Hence, most of the diagnostic tests available have only been validated using European sera samples. Determining the sensitivity and the specificity of these tests in field conditions is challenging and, the performances and shortcomings of one or the other serological test remains a matter of debate and controversy. However, for screening purposes, tests are required to have a high sensitivity and sufficient specificity to detect as many cases as possible, but this goes with an increased rate of false positives. For research purposes, it is more appropriate to use serological tests with high sensitivity followed by a confirmatory test of high specificity to detect IgM and IgG produced in early acute and chronic phases and to minimize false positive results (Dean et al. 2013a; OIE 2009; WHO 2006a). Several studies have highlighted the discrepancy between the rose Bengal plate test (RBPT – one of the most commonly used test) and the ELISAs (Dean et al. 2013a; OIE 2009; WHO 2006a). The standardization of the marketed RBPT reagent and its inability to distinguish serological cross-reactivity between the smooth *Brucella* spp. lipopolysaccharide and *Yersinia enterocolitica O:9* remained a major concern (Corbel 2006). The indirect ELISA, although unable to differentiate between postvaccinal immunity and field infection, is more sensitive than most of the conventional serological tests including RBPT. But, no single brucellosis serological test is suitable for all epidemiological settings (Dean et al. 2013a; WHO 2006a; OIE 2009). In this study, all sera samples were tested using RBPT and about 75% of cattle and small ruminant samples were also tested with *Brucella* spp. indirect ELISA. Given the above-mentioned limitations of the RBPT, indirect ELISA seropositivity as the outcome for risk factor analysis were used – particularly because of possible cross-reactivity to Yersinia of the RBT. All RBT-positive and some negative small ruminant sera with a *B. ovis* ELISA were further tested to see whether ovine brucellosis would explain RBT seropositivity, which it did not. The gold standards for RVF and Q fever serodiagnostics are the virus neutralization test (VNT) and indirect immunofluorescence, respectively. The VNT is laborious, expensive and requires appropriate bio-containment facilities and 5–7 days for completion (Beechler et al. 2015). The competitive and indirect ELISAs performed for both diseases were shown to be highly accurate diagnostic tools (Kim et al. 2012; Fournier et al. 1998; Field et al. 1983).

Cultivation and molecular characterization of Brucella spp.

In order to shed more light on the epidemiology of brucellosis and its inconclusive serology findings in Western Africa, this PhD study also aimed at obtaining *Brucella* spp. cultures to do molecular characterization of prevailing *Brucella* strains circulating in northern Côte d'Ivoire. From 2012 to 2014, a total of 83 specimens (milk, hygromas fluid, genital secretions, lymph nodes and fetus) from cattle (n = 43) and small ruminants (n = 40) were aseptically collected and stored using a non-selective commercially available medium (BD BBL™ Culture Swab™ Plus Amies Gel without Charcoal) and or dry tubes for the purposes of bacterial cultivation and isolation. About 56 specimens (from cattle, n = 16 and small ruminants, n = 40) were also preserved in a lysis buffer medium (2-mercarpethanol + distilled water + Guanidine thiocyanate + Tris-HCl) to inactivate and preserve bacterial DNA. Given that there is currently no laboratory in Côte d'Ivoire with both adequate equipment and training to handle isolation of *Brucella* spp., these materials were shipped to the Institute for Veterinary Bacteriology, Bern, Switzerland. Regrettably, after rather long delays in the shipment of specimens, many specimens were of lesser quality at arrival, and one of two shipments for bacterial cultivation was usable. The cultivation was conducted using *Brucella*-medium agar base (BSA), supplemented with 5% inactivated horse serum and *Brucella* selective antibiotics. The incubation in 5% CO_2 took 10 days at 37° C (Dean et al. 2014). A TaqMan® *Brucella* spp. that utilizes the real-time polymerase chain reaction (PCR) to amplify a target sequence unique to *Brucella* spp. in the inactivated buffered samples was also performed. The cultivation did not result in a bacterial growth on the BSA medium. However, the TaqMan® identified *Brucella* genus in a milk and hygromas sample without further possible species and biovars designation. The two TaqMan® PCR positive cattle were also seropositive by the indirect ELISA and were sampled in two different villages. The success of culture isolation depends on the specimen (quantity and quality), the stage of the infection (acute, latent, chronic), the duration and media used for the storage and isolation as well as the cultured *Brucella* species (Seleem et al. 2010; McDermott and Arimi 2002). The absence of the bacterial growth in the modified *Brucella* selective medium used in our study might be due to the antimicrobials present in this formulation to which some *Brucella* species are sensitive (Vicente et al. 2014). In order to increase the sensitivity of the culture, the OIE (2012) recommends the simultaneous use of other media such as Farell (most selective) and the modified Thayer-Martin media (with greater sensitivity and less selective) for the primary isolation. As described by Dean (2014) in northern Togo, the Taqman PCR, here again, was more sensitive diagnostic method than the bacterial culture. In future, these methods should be available in biosafety laboratories in Western Africa to reduce time of shipment of samples. A reference laboratory in Western Africa with a reference strain and sera bank could also validate serological tests for the West African context.

Field laboratory and technology transfer

The establishment of our project in northern Côte d'Ivoire was an opportunity to train Ivorian laboratory technicians, nurses and students in performing indirect and competitive ELISAs and rose Bengal plate test as well as reading the respective serological test results. Important laboratory supplies, including an ELISA-reader, were transferred to partner Ivorian laboratories. Additionally, the field assistants were trained in questionnaire-based data collection and entry. In Western Africa, there is a lack of field epidemiologists who are also trained in basics of serological testing. Also, one single PhD study can contribute importantly to capacity-building.

Collaboration between human and animal health sectors in Côte d'Ivoire

The simultaneous assessment of the exposure to NZDs in humans and livestock is a One Health approach and the added value is that linkages between human and animal exposure can be faster established (Zinsstag et al. 2015; King 2008). This integrated approach entails cross-sector collaboration between different partners and stakeholders, particularly animal and human health professionals to define common priorities, objectives and responsibilities to address NZDs more strategically. This study explored the level of this cross-sector collaboration between Ivorian human and animal health professionals and their related institutions through informal interviews with key-informants in Abidjan and the north.

In general, except tuberculosis and human rabies, none of the NZDs was part of the national priority diseases in the country. Barriers to cross-sector collaboration included the "single-sector control approach used by the Ministère de la Santé et de la Lutte contre le Sida and Ministère de la Production Animale et des Ressources Halieutiques" in the country. However, in one departmental veterinary office in Tengréla (northern Côte d'Ivoire), veterinarians collaborated with human health professionals from the local office of Institut National d'Hygiène Publique (INHP) in sanitary control of slaughterhouses and the management of dog bites cases. This collaboration at local level may be a channel through which future more structured cross-sector collaborations could be developed as an important step towards the application of the One Health concept in Côte d'Ivoire.

8.2.2. Pastoralism and transboundary animal diseases in the Sudano-Guinean savanna region of Western Africa: towards an integrated cross-border and regional control

The three NZDs addressed in this study were also among the Transboundary Animal Diseases (TADs). The characteristic of TADs is that they cause significant economic and are of public health relevance for considerable number of countries, but particularly those sharing national borders (FAO 2015; Dean et al. 2013b). Their global control is only achieved if there is a harmonized national and regional governance of animal health systems and cross-border collaboration between the key stakeholders (Cheneau et al. 1999). These considerations led to extend the research activities to the Sudano-Guinean savanna region bordering northern Côte d'Ivoire, southern Mali and southwestern Burkina Faso, with its uncontrolled mobile pastoralism and livestock trade that most likely increase the risk of spread of TADs in the region. A participatory approach that was supplemented by questionnaires during the cross-sectional surveys to assess major TADs and mobile pastoralism in the region was used. Dialog between the research team and interviewees from the three countries led to a better understanding of the local ethno-veterinary knowledge and perceptions about possible cross-border control strategies of livestock movements and TADs (Catley et al. 2012; Schwab & Syme 1997). Interviewing, focus group discussions, ranking, scoring and mapping that were used in the study produced reliable data which may better describe key animal health problems than unrelated surveys (Mariner & Roeder 2003; Catley & Wood 2002). Interviewees had valuable knowledge about prevailing TADs and possible control approaches for livestock movements (Schelling et al. 2015b). It was clear that the priorities from a researcher's perspective did not always match those of participants. For instance, brucellosis, Q fever and RVF were priority diseases for the researchers; however, participants were more concerned about CBPP, FMD, tuberculosis and lumpy skin disease, probably because of the high mortality rates and the more conspicuous economic losses they induced each year. Additionally, participants mostly recommended feasible movement control strategies based on field realities and available resources. In order to benefit from a significant support of these local communities, any control activity targeting movements and TADs in the areas would need to consider the recommended priorities and perspectives from the locals (Schelling et al. 2015b). The cross-border field visits and interviews provided an innovative platform for sharing ideas, experiences and needs regarding feasible control actions at international and community-levels. This should be followed with a cross-border cross-sectoral stakeholder meeting where initial results are presented. Such a workshop can better capture the dynamic opinion interactions between different parties, which are also crucial for setting appropriate control strategies. The data triangulation was done to ensure quality and reliability, and the collected data were semi-quantified and analyzed using non-parametric tests and descriptive statistics. However, statistics cannot adjust for potential recall bias. Since the interviewees were given time to discuss and reach group consensus, Kendall's coefficient of concordance between informants' responses (Catley 2006) was not calculated. The study provided an understanding of possible control strategies for TADs and livestock movements (which could be followed up by more in-depth social science studies). The results are most useful to start true dialogue between countries in the Sudano-Guinean savanna region, however, cannot be uncritically applied to other cross-border pastoral settings in Africa.

8.2.3. Economic impact of cattle brucellosis in Côte d'Ivoire

In general, to engage policy-makers and investors effectively, it is important to assess the economic impacts of diseases from households to national and regional levels (McDermott et al. 2013). Numerous studies have shown the substantive socio-economic impacts of brucellosis in industrialized countries; whilst the losses of productions attributable to brucellosis were seldom estimated in sub-Saharan Africa. The extensive and highly mobile livestock production systems in the region and the lack of high quality production parameters are certainly part of the many factors that render such estimations problematic (McDermott et al. 2013; Akakpo et al. 2010; Zinsstag et al. 2007; Bogel & Meslin 1990). However, assessing the economic impact of brucellosis is a crucial step towards the cost-effectiveness evaluation of potential control approaches and the cost-benefit of undertaking an intervention. The annual cost of the disease at herd level was estimated in the 1980s to be about FCFA 150 million (almost USD 260,000) in Côte d'Ivoire (Camus 1984). Since these years, the country remains a major importer of milk, live animals and meat products with about 60–70% of cattle meat imported from Western and Southern Africa, Western Europe and Argentina (Diakate 2011).

This thesis aimed at simulating Ivorian cattle population and the losses of milk, meat and hide productions attributable to brucellosis over 10 years (from 2005–2015). The last census of the Ivorian agricultural sector and livestock population took place in 2001 (MIRAH-DPP 2012). Data for 2005 as the baseline year was used, because it was assumed that the post-electoral armed conflict ended in that year and led to re-opening Côte d'Ivoire to neighboring countries' markets and mobile pastoralist cattle herds from Mali and Burkina Faso (BNETD 2012).

Brucellosis seroprevalence data from our representative cross-sectional survey collected between 2012 and 2014 (Kanouté et al. 2017) was used. The Leslie matrix developed was a useful tool for the stochastic simulation of population growth and costs of brucellosis (Vandermeer & Goldberg 2003). It was determined that very few updated and reliable studies were conducted about livestock production parameters in Western Africa in general and Côte d'Ivoire in particular. Given that the country has been a conflict zone for almost a decade, the few official data available on livestock production and populations had to be taken with precaution. It was also noticed a large variability in live cattle, meat, hide and milk prices throughout the years, seasons and localities. Thus, most of the parameters used were assigned or adjusted by the authors following consultations with veterinary clinicians and other livestock experts familiar with livestock production in semi-arid areas. Finally, a cumulated net present cost of about FCFA 14,455 x 10^6 (or USD 23,662 x 10^3) – an important cost – was found, but the confidence limits of livestock growth and production overlapped between the scenarios with and without brucellosis. This study showed how challenging cost-benefit and cost-effectiveness assessments of diseases in the highly extensive and traditional livestock production systems in sub-Saharan Africa are. The lack of high-quality data still remains a considerable barrier at different levels, which needs to be broken down in order to make a step forward towards public health interventions. The results can be fed in regional discussions on brucellosis and other disease control measures. At a higher regional level, the mobility will play a lesser role, but the cost sharing scenarios of control measures will likely become more challenging.

8.3. Contribution of the PhD to innovation, validation and application

Table 8.1 summarizes the contribution of this PhD study to the strategic core mandate of Swiss TPH, which emphasizes the cycle of innovation, validation and application – and back to innovation.

Contribution to Innovation

The One Health approach used in our study promoted the integration of human and animal health sectors through communication and collaboration in areas where both sectors and related institutions operate virtually disconnected. The joint human and animal health field team was perceived by the participants and local stakeholders as the most innovative approach to medical care for both livestock owner families and their animals. The study generated updated epidemiological data that were most needed for a better understanding of the occurrence and transmission of three important NZDs. The study used a participatory approach in conjunction with serosurveys (qualitative and quantitative methods) to gain local knowledge on key TADs and challenges and needs for the control of livestock movements in the cross-border pastoral areas. The simultaneous use of both methods also provided a shortcut to more costly sampling efforts and allowed to define new hypothesis: regional and cross-border collaborations in zoonoses and TADs are crucial. By conducting cross-border field interviews and focus group discussions, different perspectives with respect to mobile pastoralism and its control options were captured in Mali, Burkina Faso and Côte d'Ivoire. A harmonized disease control plan was designed, which – after validation in an extended regional stakeholder workshop – would be a useful tool for strategic control of NZDs and TADs in the three countries. Further, the study developed the first stochastic model used to simulate cattle population and the cost attributable to cattle brucellosis in Côte d'Ivoire. In addition to cost estimation, such a model is highly appreciated as it guides decision-makers about livestock production goals (e.g., restocking vs. slaughter). This and other new approaches to disease control and One Health are still very scarce in West Africa. This PhD triggered thinking beyond the sectoral comfort zones to find solutions across sectors.

Contribution to Validation and Application

This thesis strongly focused on the inextricable linkages between human and animal health and the added values of the cross-sectoral collaboration between both sectors by applying the One Health concept for an in-depth understanding of the epidemiology of NZDs. Since the last studies on brucellosis in northern Côte d'Ivoire in the 1980s, the present research confirmed the continued presence of *Brucella* spp. in the area. The fact that small ruminants in this study were all brucellosis seronegative in the indirect ELISA (and only few positive in the competitive ELISA) and also negative by culture suggests that *B. melitensis* is currently not circulating in the study sites. This is in favor of the common statement that "*B. melitensis is not found in Western Africa*", but, is not yet a confirmation. Indeed, it is not hard to understand that with the mobility of livestock in Western Africa, and exchange between Northern and Western Africa, *B. melitenisis* would not only be imported once. However, it could also be shown that the longer trade routes are mainly for cattle and more rarely for small ruminants. The serological results reflect the inconclusive past serological findings on livestock brucellosis in Africa and the discrepancies between commercially available diagnostic tests in the African context. As long as there is no reference brucellosis laboratory in West Africa, culture of brucellosis (with all biosafety and material transfer agreement considerations) seems secondary in relation to setting up faster methods such as direct typing, which in addition may be more sensitive but still needs well-trained bacteriologists for proper assessment (Dean et al. 2014). Again, there is an important gap and lack in laboratory capacity in West Africa. The simultaneous use of the participatory approaches and sero-epidemiology led to applicable results that should be further negotiated and validated in a larger use in other Western African cross-border pastoral areas. Together within a One Health approach, these will guide the design of future field research in the study areas. The findings presented on the occurrence and risk factors of NZDs as well as brucellosis economic impact are relevant for future epidemiology studies in Western Africa.

Table 8.1: Contribution of the PhD study to innovation, validation and application.

Objectives	Innovation	Validation	Application
1	Integrated human and animal health research within a One Health perspective to understand the epidemiology of NZDs.	The level of exposure and risk factors of NZDs were determined at the human and livestock interface.	The One Health concept could show linkages and its added value in northern Côte d'Ivoire will further promote the use of the concept in future research.
2	A participatory approach to a questionnaire-based study together with cross-sectional abattoir serosurveys in pastoral and non-pastoral areas in Côte d'Ivoire, Mali and Burkina Faso.	The two approaches together captured the complexity of the issue of cross-border pastoralism and priority trans-boundary animal diseases and identified feasible cross-border control strategies.	The use of the participatory approaches and sero-epidemiology across borders led to applicable results that will guide future negotiations between main stakeholders.
3	The first stochastic projection matrix model developed to simulate the cattle population growth and the cost of cattle brucellosis in Côte d'Ivoire and indeed for a West African country.	The model simulated the estimated economic impacts of brucellosis in the country.	The estimates serve as a backbone for economic impacts and cost-effectiveness assessment of other NZDs at herd and national levels.

8.4. General limitations of the study

The limitations discussed here are the most important ones that can influence the interpretation and the generalizability of our findings to a wider context:

- The One Health approach via a cross-sector collaboration between human health, animal health, ecology, sociology, and economics, together with their related institutions to identify the added value of such collaboration in terms of better health outcome and financial savings has been endorsed. However, the field team did not include a social scientist, or an ecologist who could have added for example by improving the understanding of the ecology of RVF mosquito vectors.
- A series of cross-sectional studies from 2012 to 2014 were performed. From 2012 to 2013, field samplings took place during the end of dry season (April-May) and the whole rainy season (May–August) in the savanna district in Côte d'Ivoire. In 2014, sampling was conducted during the cold-dry season (November–January), the dry season (February–April) and rainy season (June–July) in the savanna district and the district of Vallée de Bandama. No statistically significant variability was found between seasons, years and the study sites, which may not be biologically plausible, given the seasonal pattern of livestock movements and contact networks in the areas of study.
- In the participatory approach the data was based on reported judgment that was not further verified by an epidemiological study but rather by triangulation of data sources. However, for the latter, several potential sources of bias were possible such as exaggeration, selection, recall and selective memory bias.
- The study enrolled fewer human participants than initially planned (for reasons discussed in the sub-chapter 8.2.) which may have led to an overestimate of the true seroprevalence since only those who felt they were concerned by zoonoses participated. By conducting the risk factors analysis using the test results of ELISA (which was intended to be used as confirmatory test) the livestock sample was additionally decreased, leading to wider confidence intervals.
- The lack of reliable and updated epidemiological and official data in the study sites posed an obstacle in the way that the precision of the estimates could not always be cross-checked.

- Cultivation and molecular characterization of prevailing *Brucella* spp. as well as other zoonotic pathogens was not possible, and thus, the identification of prevailing zoonotic pathogens in the study sites is not confirmed by isolates.
- Seropositivity or sero-conversion for one of the examined NZDs does not necessarily mean clinical illness in humans and animals.
- A paucity of adequate health care and diagnostics and preventive services for hard-to-reach communities was common in the study areas, where the understanding of the epidemiology of numerous tropical diseases also remained scattered. However, due to resource constraints, this PhD research did not focus on assessing the co-morbidity and co-infection with multiple zoonoses and major non-zoonotic tropical diseases (e.g., malaria), as well as the impacts, and interrelationship of potential co-infections.
- Socioeconomic and political instability in Cote d'Ivoire led to a decade of civil war, which also resulted in the lack of reliable epidemiological data and dysfunctional veterinary services in the study sites. Given that almost all West African countries have experienced conflicts over the past generation, this study strongly recommends measures that ensure peace and stability in the region. This will ensure well-functioning health systems and sustainable diseases control measures.

8.5. Implications for future research

This thesis made a valuable contribution to the understanding of NZDs and TADs as well as livestock movements and their cross-border control strategies in Western Africa. These further research avenues are proposed:

- Future research on NZDs in Western Africa should be done in the human and livestock health sectors to generate evidences on the disease that can truly make linkages between the two sectors and are not disaggregated by time and geographical zones. A simultaneous assessment with a mixed team seems to be the most straightforward.
- Future studies should identify appropriate One Health design that fit the socio-cultural, economic and political context in Africa at national, regional and global levels. For this, social sciences need to be more closely associated from the very beginning.
- More sampling and laboratory-based studies should lead to the identification of key diseases, disease foci and high risk (pastoral and non-pastoral) areas.

- Setting up of routine and disease-specific surveillance will generate relevant and timely information on livestock movements and diseases for early detection. Surveillance should be integrated in terms of diseases and across health sectors.
- Future studies on the molecular characterization of zoonotic pathogens in general and in particular *Brucella* spp. warrant more insight into the ecology and genetic diversity of the pathogens in Western Africa, and is also relevant for epidemiological linkages and diagnostics.
- Future studies should validate commercial brucellosis serological tests for the West African context and standardize the RBPT reagent. They should identify appropriate test cutoff values in livestock species. This can only be done with a reference bank of West African true (culture-confirmed) positive and negative sera together with herd histories.
- There is a need to inform decision-makers with evidences about the contribution of livestock production to food security and food safety as well as to national economic growth. This also applies to its public health relevance.
- Future studies should assess the socio-economic impacts of NZDs in humans and animals as well as cost-effectiveness and cross-sectoral economics of their control with different achieved vaccination coverages; this will better guide authorities in their decision to engage in control.

8.6. General recommendations

The following recommendations need to be considered:

- Veterinary and public health services need to be strengthened in northern Côte d'Ivoire in particular, and the Sudano-Guinean savanna in general. There are no close-to-patient or herd diagnostics available for major zoonoses in either sector, and both sectors struggle with outreach services.
- Human and animal health policies and programs with respect to zoonoses need to be considered under a multi-sectoral umbrella and cross-sectoral communication initiated and continued.
- Regular cross-border and cross-sectoral meetings are needed to define common priorities, identify feasible control approach and share responsibilities for achieving a successful regional control of NZDs and other TADs.

- Neighboring countries in Western Africa must collaborate in pulling their limited resources together and focus on cross-border high risk zones rather than using separated control approaches with minimal cross-border collaboration.
- Harmonized prophylactic disease measures across-borders and data exchange between neighboring countries needs to be promoted.
- There is a need for defining safer livestock movement corridors and setting-up pastoral committees in the study areas. Also, a fostered exchange between veterinary services with livestock movement-supporting agencies and pastoral committees need to be initiated to mitigate farmer and herders' conflicts and allow official control of movements in Western Africa.
- The creation of cross-border veterinary laboratories would improve diagnostic capacities and diseases surveillance systems not only at the borders but in the whole region.
- Community-based health information joint human and animal health campaigns can be carried out through various information channels such as radio, but likely best through outreach programs that encourage the adherence of agropastoralists, farmers and mobile pastoralists to prophylactic programs. These would increase awareness about the routes of transmission of NZDs and further reduce the various exposures.

9. Conclusion

The epidemiology and economic impacts of NZDs, livestock cross-border movements and TADs were investigated in northern Côte d'Ivoire and in the Sudano-Guinean savanna with southern Mali and north-western Burkina Faso bordering northern Côte d'Ivoire. The study used an overall One Health approach and has combined participatory approaches together with conventional seroepidemiology. The One Health concept was translated into practice by a joint human and animal field team to simultaneously assessment the status of people and their livestock and thus to draw conclusions on linkages and risk factors of zoonoses that could not have been established elsewhere. This thesis provided local decision-makers, stakeholders and community members with updated epidemiological information on NZDs. It assessed the economic impacts of brucellosis, identified key TADs and areas of increased livestock movements, and proposed feasible cross-border control of movements and diseases in the in the Sudano-Guinean savanna zone. The study identified an urgent need for strengthening local veterinary services with regard to prophylactic outreach services, but also for the public health sector to improve patient diagnostics. Future studies should consider the contribution of livestock production to food security and their economic and public health relevance. Given that no country alone can control an infectious disease and no sector alone can mitigate health impacts caused by zoonoses, a regional cross-sectoral collaboration should be promoted, and communication fostered between human and animal health sectors.

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11. Appendices

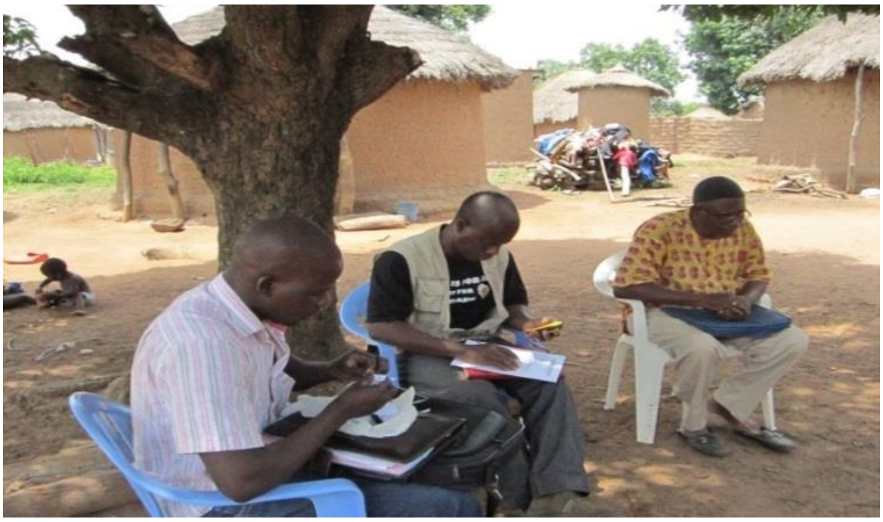
A veterinarian is sampling livestock

A nurse is sampling a herdsman

The field team is meeting traditional authorities in a study village

After finishing sampling the mobile pastoralists in the savanna

Questionnaire administration



Cattle abattoir of Korhogo (northern Côte d'Ivoire)

Cattle to be slaughtered on the next day

Carcasses after a daily slaughter

Collection of fresh cattle blood at the abattoir

School children are buying fried blood

A woman is frying cattle blood in a market in Korhogo

Women are buying fried blood

Visiting veterinarians at the border entry points for trade and pastoralist livestock

Cross-border pastoral infrastructures destroyed during the civil wars in Côte d'Ivoire