Impacts of trypanosomiasis on African agriculture

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Abstract

African animal trypanosomiasis constrains agricultural production in areas of Africa that hold the continent's greatest potential for expanded agricultural production. Compared to animals kept in trypanosomiasis free areas, animals kept in areas of moderate risk of trypanosomiasis have lower calving rates, lower milk yields, higher rates of calf mortality, and require more frequent treatment with preventive and curative doses of trypanocidal drugs. At the herd level, trypanosomiasis reduces milk offtake, live animal offtake and the work efficiency of oxen used for cultivation. Herds of trypanosusceptible livestock can be devastated by sudden exposure to high levels of trypanosomiasis risk.

Trypanosomiasis also affects where people live, the way they manage their livestock and the number of animals that they keep. In the tsetse-infested areas as a whole, trypanosomiasis reduces the offtake of meat and milk by at least 50%. And by generally constraining farmers from the overall benefits of livestock to farming -- less efficient nutrient cycling, less access to animal traction, lower income from milk and meat sales, less access to liquid capital -- trypanosomiasis reduces yields, area cultivated, and the efficiency of resource allocation. It is estimated that a 50% increase in the livestock population would increase the total value of agricultural production by 10%.

The potential benefits of trypanosomiasis control thus appear to be highest in areas where there is good potential for integrating livestock into profitable and sustainable mixed crop-livestock farming systems. This conclusion has clear implications for the development and implementation of the Action Plan for the Programme Against African Trypanosomiasis.

1. Introduction

Tsetse-transmitted trypanosomiasis is one of the most ubiquitous and important constraints to agricultural development in the sub-humid and humid zones of Africa. Kuzoe (1991) estimated that about 50 million people are at risk of contracting African human trypanosomiasis. Reid et al. (forthcoming) estimate that about 46 million cattle are at risk of contracting tsetse-transmitted trypanosomiasis in an area of about 8.7 million km^{2}. Winrock (1992) judge that the sub-humid zone and wetter portions of the semi-arid zone -- areas in which the greatest numbers of cattle are at risk of contracting the disease -- hold the continent's greatest potential for expansion of agricultural output.

For the perceived importance of trypanosomiasis, relatively little information has been compiled about the direct or indirect impacts of the disease or its control. Trypanosomiasis has direct impacts on livestock productivity, livestock management and human settlement; through those direct impacts, the disease has indirect impacts on crop agriculture and human welfare. Changes in livestock management, human settlement and crop agriculture also result in changes in land use, vegetation cover, the environment and human welfare. And all of these have implications for resource use patterns, investments in natural capital (e.g. planting of tree, shrubs and herbaceous legumes, construction and maintenance of conservation structures), social institutions that govern resource use (formal and informal conventions, norms and rules) and, once again, human welfare. Reid (1997) reviews the current state of knowledge about the impacts of trypanosomiasis control on land use and the environment. This paper reviews the state of knowledge about the impacts of African animal trypanosomiasis on livestock productivity, livestock management and human settlement, the impacts of those changes on crop production, and the impacts of changes in livestock production, livestock management, settlement and crop production on the value of agricultural production. Impacts are considered at the herd, household, regional, national and continental scales of resolution.

This paper focuses on African animal trypanosomiasis and its impacts. This is not to deny the importance of human trypanosomiasis. Indeed, while Kuzoe (1991) estimated that there were about 20-25,000 new cases of human trypanosomiasis per year in the 1980s, it is estimated in 1995 that at least 300,000 persons were infected (Ekwanzala, 1995). Recent estimates also put the number of infections at about 300,000 (P. Cattand, presentation to PAAT meeting, Harare, Zimbabwe, September 1998). The prevalence of African human trypanosomiasis has become particularly high in areas experiencing large-scale migration or where medical systems have failed (e.g. Sudan, Democratic Republic of Congo, Angola). The impact of human trypanosomiasis on agriculture has been poorly studied because it is difficult to assess in areas where civil strife are occurring and where it would be difficult to separate the effect of the disease from other factors that contribute to its spread.

Because of poor surveillance and diagnosis, most of the people who have contracted Human African Trypanosomiasis in the 1990s suffered for extended periods and will eventually die of the disease. This reduces the productivity of people with the disease, family members who care for the ill, and the millions of rural residents who fear that they might also contract the disease. Unfortunately, however, there is little evidence available on these impacts. What is known is what it would cost to implement an effective surveillance and treatment programme. The drugs used to treat positive cases of human trypanosomiasis with the most widely available treatment regime cost about \$100 per person and the cost of active surveillance regimes is about US\$ 0.90 per person per year. The cost of the drugs used to treat 300,000 cases per year would thus be about \$30 million per year. An effective active surveillance programme would need to cover 70 percent of the 55 million people at risk and thus would cost about \$35 million per year.

2. Organizing framework

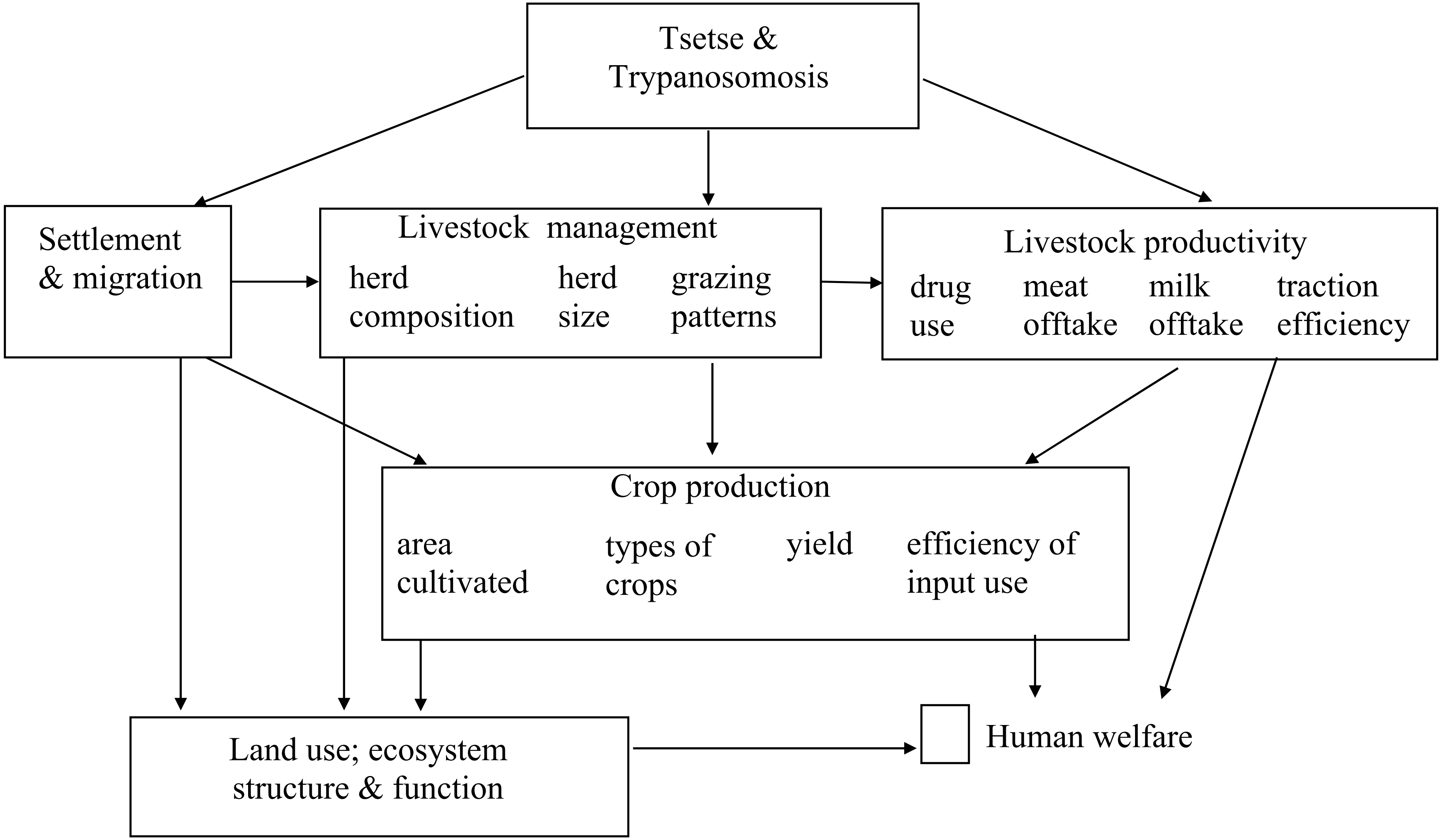
The organizing framework used in this paper generally adopts the distinction between the direct and indirect impacts suggested by Putt et al. (1980). Here direct impacts are aggregated into three groups: impacts on livestock productivity, impacts on migration and settlement, and impacts on livestock management. Indirect impacts are aggregated into four groups: crop production, land use, ecosystem structure and function, and human welfare. Evidence is presented on the all of the direct impacts, the indirect impacts on crop production and some of the impacts on human welfare. Figure 1 illustrates these impacts and the relationships that are assumed to produce them.

The term 'trypanosomiasis' is here used to represent the risk of African animal trypanosomiasis: the components of risk are the pathogenicity of the trypanosomes, the percentage of tsetse infected with trypanosomes, the apparent density of the different tsetse species and the percentage of blood meals taken from livestock. Both trypanosomiasis and livestock productivity can be measured at the animal, herd or household, region, nation or continent levels. At the animal level livestock productivity it is measured by parasitaemia status, packed cell volume, weight gain, reproductive performance, lactation offtake and mortality. At more aggregate levels, livestock productivity is measured in terms of outputs of meat, milk, animal traction and inputs of preventive and curative treatments of trypanocidal drugs.

Trypanosomiasis also has direct impacts on livestock management, particularly (1) the number of livestock kept by farmers, (2) the breed and species composition of the livestock herd, and (3) the way that livestock are grazed. The first and second of these direct impacts could be measured at all scales from the farm to the continent. Unfortunately livestock population data, especially detailed data about breeds, has proven to be difficult to obtain at the national or continental levels.

Trypanosomiasis also has direct impacts on human migration and settlement. Some of these impacts are measurable at the continental level, for example, the different density of livestock resident in tsetse-free and tsetse-infested areas of the African continent. Other impacts are only measurable at the farm or regional level, for example, when villages are built on plateaus rather than along river courses. It is important to note, however, that the influence of trypanosomiasis is often confounded since there are large overlaps between the distribution of tsetse, other livestock health problems (e.g. ticks, tick-associated diseases) and human diseases (e.g. Human African trypanosomiasis, malaria, river blindness). The focus in this paper is on the household and regional levels.

Figure 1: Conceptual framework of the impacts of tsetse and trypanosomosis



The most important indirect impact of trypanosomiasis on crop production is through the availability and health of animals that provide animal traction. Additional traction capacity can allow farmers to expand the area that they cultivate, increase yields of existing crops, grow a different mix of crops, or allocate labour, land and fertilizer more efficiently. Other ways that livestock and crop production interact include: 1) competition between livestock and crops for the available land; 2) production of crop residues for livestock feed; 3) transfer and cycling of nutrients through livestock; and 4) diversification of farmers' income sources. These relationships can be evaluated at a variety of spatial scales, from the farm to the continent.

Human welfare, like ecosystem structure and function, has several distinct dimensions, each of which can be measured in different ways. Here we focus on economic measures of human welfare. At the household level, income, expenditures and profits are commonly-used economic measures of welfare. At the national level, economic surplus and gross domestic product are appropriate measures.

There are a number of important relationships that are not depicted in Figure 1. For example, the level of trypanosomiasis risk appears to be independent of the other variables depicted. But in fact, trypanosomiasis risk to domesticated livestock depends upon the density of tsetse, the species of tsetse, the trypanosome infection rates in tsetse, the pathogenicity of the trypanosomes, and the proportion of blood meals taken from domesticated livestock by tsetse. Each of these variables depend in turn upon factors that are variable and subject to human manipulation. For example, tsetse density is influenced by altitude, vegetation, the availability of suitable host animals, and the effectiveness of deliberate tsetse control measures (Leak, 1999). There may be important bio-physical feedback effects, therefore, between livestock management, livestock productivity, land use and trypanosomiasis.

The following sections review some of the available evidence on the relationships outlined in Figure 1. Section 3 focuses on the direct impacts of trypanosomiasis risk on livestock productivity. Section 4 focuses on livestock management. Section 5 focuses on human migration and settlement. Section 6 focuses on crop production. Section 7 is a discussion and conclusion. And Section 8 presents a number of implications for policy and programme design.

3. Impacts of trypanosomiasis on productivity

3.1 *Impacts on animal productivity*

Four different approaches have been taken in studies of the impacts of trypanosomiasis on animal productivity. The first approach involves the longitudinal monitoring of the infection status, health and productivity of animals raised under a particular production system in an area of known trypanosomiasis risk. Animals are grouped by the number of times they are detected parasitaemic and productivity parameters are compared for groups detected parasitaemic different numbers of times. An advantage of this approach is its accuracy; a disadvantage is its cost since large numbers of animals must be monitored every month for a number of years. The second approach is to monitor the health and productivity of cattle herds kept in nearby areas of lower and higher levels of trypanosomiasis risk during the same time period. This case-control approach has been used to evaluate the success of tsetse control trials (e.g. Ahmedin and Hugh-Jones, 1995). An advantage is that the productivity indicators are measured for entire herds rather than for individual animals. A disadvantage is that differences in management and local environmental conditions may confound the effects of the disease. The third approach is to monitor the health and productivity of particular cattle herds before and after an intervention that reduces the incidence of trypanosomiasis. This approach generates results with less management bias, but greater environmental bias.

Tables 1, 2, 3 and 4 summarize a number of studies that have used one of these three research approaches. The results suggest that the largest and most consistent impacts of trypanosomiasis are on birth rates and mortality of young animals. The general implication is that the incidence of trypanosomiasis: (i) reduces calving rates by 1-12% in tolerant breeds of

Table 1: Summary of studies of the impacts of trypanosomosis infection on productivity of trypanotolerant cattle

Authors	Location	production system	animal type	tsetse species	Type of analysis	Findings
Agyemang et al. (1990; 1993)	Gambia	Traction, meat & milk, low inputs	tolerant cattle	m.submoritans, palpalis	comparison by parasitaemia (110-226 records)	0 times 1 or more calving rate 63% 56% 6 mos.milk offtake 176kg 140kg
Feron et al. (1987)	Zaire	Specialized meat, high health inputs	tolerant cattle	Tabaniformis (fusca)	across-site comparison (36 mos on 600 records)	low risk high risk calving rate 86% 74% cow weight 330kg 296kg
ITC (1997)	Gambia	Traction, meat & milk, low inputs	tolerant cattle	m.submorsitans, palpalis gambiensis	comparison by parasitaemia (461 births)	0 times 1 or more calf mortality 8% 15% lactation offtake 260kg 236kg
Thorpe et al. (1987)	southern Togo	Specialized meat, low inputs	tolerant cattle	palpalis	comparison by parasitaemia (145 animals)	0 times 1 or more calving rate 92% 81%
Thorpe et al. (1987)	northern Côte d'Ivoire	Milk & meat, moderate inputs	tolerant & susceptible cattle	palpalis, tachinoides	comparison by parasitaemia (82 animals)	0 times 1 or more calving rate 78% 71%
Thorpe et al. (1987);	Zaire	Specialized meat, moderate inputs	tolerant cattle	tabaniformis (fusca)	comparison by times parasitaemic (188 animals)	0 times 1 or more calving rate 75% 67%
Trail et al. (1991)	Zaire	Specialized meat, moderate inputs	tolerant cattle	Tabainiformis (fusca)	comparison by times parasitaemic (146 animals)	below ave above ave calving rate 88% 76% weaning weight 138kg 135kg

Table 2: Impacts of trypanosomosis on productivity of trypanosusceptible and mixed breeds of cattle

Authors	Location	Prod. system	animal type	tsetse species	Type of analysis	Findings
Ahmedin and Hugh-Jones, 1995; Slingenbergh, 1992	south-west Ethiopia	Traction, milk & meat, moderate inputs	susceptible cattle	m.submorsitans, tachinoides (palpalis)	cross-site comparison (recall data for 62 herds)	low risk high risk calving rate 80% 60% abortion rate 2% 10% crude mortality rate 3% 17%
Camus (1981)	Côte d'Ivoire	Milk & meat, moderate inputs	comparison of cattle breeds	palpalis, tachinoides	across-herd comparison	not infected infected calving rate - Baoule 45 43 - N'Dama 40 41 - N'Dama x Baoule 41 44 - Zebu x Baoule 47 41 calf mortality - Baoule 12 19 - N'Dama 9 13 - N'Dama x Baoule 5 10 - Zebu x Baoule 12 21
Camus (1995)	Cote d'Ivoire	Milk & meat, moderate inputs	mixture of breeds	palpalis, tachinoides	before & after regime of preventive drug treatment	before after calf mortality rate 35% 17%
Fox et al. (1993)	Tanzania	Specialized meat, high inputs	susceptible cattle	morsitans, pallidipes, brevipalpis austeni	ave. 3 years before and 1 year after tsetse control	before after calving rate 58% 77% weining weights 124kg 145kg calf mortality rate 14% 5%
Gemechu et al. (1997)	southern Ethiopia	Traction, milk & meat, low inputs	susceptible cattle	pallidipes	before and after tsetse control, recall data from 7-15 farmers	before after crude mortality rate 16% 5% calf mortality rate 58% 8% abortion rate 20% 2%
Rowlands et al. (1995)	southern Ethiopia	[Traction, milk & meat, low inputs	susceptible cattle	pallidipes, fuscipes	comparison by proportion of times parasitaemic (320 animals over 3 yrs)	0 14-50% 60-100% calving rate 81% 78% 72% 1st calving age 40mo 41mo 44mo

Table 3: Impacts of trypanosomosis on productivity of sheep and goats

Authors	Location	Production system	animal type	tsetse species	Type of analysis	Findings
Bealby et al. (1996)	Zambia	Specialized meat, low inputs	susceptible goats	m. submorsitans, pallidipes	comparison of Samorin and Bereneil treatment groups	Samorin Berenil kidding rate 88% 69% birth weight (kg) 1.85 1.69
ITC (1997)	Gambia	Specialized meat, low inputs	tolerant sheep	m.submorsitans, palpalis gambiensis	comparison by times parasitaemic in regression (100 animals)	0 times 1 or more weight gain no effect mortality no effect lambing rate 141% 103%
ITC (1997)	Gambia	Specialized meat, low inputs	tolerant goats	m.submorsitans palpalis gambiensis	comparison by times parasitaemic in regression (200 animals)	0 times 1 or more weight gain no effect kidding rate 129% 92%
Thorpe et al. (1987)	southern Togo	Specialized meat, low inputs	tolerant sheep	Palpalis	comparison by times parasitaemic (152 animals)	0 times 1 or more lambing rate 147% 143%
Thorpe et al. (1987)	northern Côte d'Ivoire	Specialized meat, moderate inputs	tolerant sheep	palpalis, tachinoides	comparison by times parasitaemic (181 animals)	0 times 1 or more lambing rate 160% 141%

Table 4: Summary of analyses of the herd-level productivity impacts of trypanosomiasis

Author(s)	Location	production system	Method	results			
Brandl (1988)	Southern Burkina Faso	Meat & milk, moderate inputs	Ex ante assessment of SIT tsetse control; parameters from Camus 1981 and ILCA, 1979	Total over 10 years	low	medium	high
				milk offtake	- 9%	- 27%	- 38%
				animal offtake	- 5%	- 14%	- 31%
				annual herd growth	- 1.1%	- 3.7%	- 4.1%
Kristjanson et al. (submitted)	Ethiopia	Traction, meat & milk, moderate inputs	Analysis of Ghibe productivity data, steady-state herd	Total over 10 years	Tryps control	No tryps	
				Milk offtake	-10%	-37%	
				Animal offtake	-22%	-25%	
				annual herd growth	0%	-5.9%	
University of Berlin (1993)	Northern Côte d'Ivoire	Traction, meat & milk and meat and milk; moderate inputs	Ex ante assessment of tsetse control by traps; parameters based on Sodepra and other West African studies	Total over 10 years	sedentary	transhumant	
				milk offtake	-12%	-8%	
				animal offtake	-4%	-10%	
				annual herd growth	-1.5	-2.1%	
				traction days	-23%		

cattle and by 11-20% in susceptible breeds; and (ii) increases calf mortality by 0-10% in tolerant breeds of cattle and by 10-20% in susceptible breeds of cattle. Two studies from The Gambia indicate that trypanosomiasis reduces milk offtake from trypanotolerant cattle by 10-26%. Studies on trypanotolerant sheep and goats also indicate that the main impacts of trypanosomiasis are on lambing rates (reduced by 4-38%) and kidding rates (reduced by 37%).

All of these approaches usually involve the administration of curative doses of trypanocidal drugs to animals that are parasitaemic and / or anaemic. The result is that the comparisons are actually between a drug therapy regime, usually applied quite rigorously, and a combination of drug therapy and tsetse control. But in fact, most African smallholders do not have access to the veterinary supplies and services necessary to implement such effective drug treatment regimes. Most studies therefore generate results that are precise and accurate, but not indicative of farmers' actual practices.

One way to assess the actual impacts of trypanosomiasis is to ask a large sample of farmers' to estimate productivity parameters for their herds before trypanosomiasis control, then ask them to estimate the same productivity parameters after a period of effective control. Table 5 summarizes such a study by Kamuanga et al. (1999a). A sample of livestock owners in the Yalé Province of Burkina Faso were interviewed before and after tsetse control was implemented in their area. All of the livestock owners were Fulani pastoralists who had recently settled in the area with their Zebu cattle. The results indicate that the majority (87%) of respondents recognised that there was a substantial reduction in the number of cattle dying due to trypanosomiasis. Livestock owners estimated that the overall mortality rate in their herds was 63% in 1993/4, prior to control, and 7% in 1996/7, after control. Differences in mortality before and after tsetse control were similar for all age-sex cohorts of animals. The small standard deviations around the mean values indicate a great deal of consistency on opinion among respondents. This approach can be implemented at low cost. It can be a cost-effective approach to impact assessment.

Table 5. Percentage reduction in mortality as perceived By pastoralists (1993-1997), Sissili ZAP, Burkina Faso (Percent dying of trypanosomiasis and related diseases)

Age-sex cohort	1993/94 (s.d.)	1996/97 (s.d.)	% Reduction
Male calves (0-1 year)	64.9 (20.7)	8.7 (8.4)	56.2
Female calves (0-1 year)	63.3 (21.2)	7.3 (8.2)	55.9
Young males (1-2 years)	60.8 (18.5)	6.9 (8.9)	53.9
Young females (1-2 years)	58.1 (18.3)	6.1 (7.9)	52.0
Males (2-3 years)	60.6 (19.7)	6.7 (8.9)	54.0
Females (2-3 years)	58.1 (20.0)	5.9 (8.2)	52.2
Adult males (> 3 years)	69.9 (24.0)	7.2 (8.5)	62.7
Cows (> 3 years)	70.8 (21.4)	10.0 (7.5)	60.8
Oxen (> 3 years)	61.0 (34.4)	5.4 (8.6)	55.6
Overall	63.1	7.1	56.0

Source: Kamuanga et al., 1999a.

3.2 *Impacts of trypanosomiasis incidence on herd productivity*

Herd simulation models are tools for aggregating herd parameters into measures of livestock capital and overall offtake of live animals and milk. Upton (1989, p. 159) describes the herd simulation approach as follows: "The essential idea is that herd size at date t+1 (Xt+1) must equal herd size at date t (Xt) plus births (at rate b) minus moralities (at rate m) and net offtake (at rate u). Thus:

$$Xt+1 = (1+b-m)Xt - uXt.$$

This relationship may be expressed in more detail if the herd is subdivided into age/sex cohorts, and age-specific mortalities and offtakes are applied (Upton, 1989, p. 159)." Herd simulation models currently in use include the Livestock Productivity Efficiency Calculator (Pan Livestock Services, 1991) and the ILCA Bio-Economic Herd Simulation Model (von Kaufmann et al., 1991).

Two studies have used herd simulation models to evaluate the benefits and costs of tsetse control. Brandl (1988) conducted an assessment of the potential benefits and costs of tsetse eradication through use of the Sterile Insect Technique in the Sideradougou area of southern Burkina Faso. He predicted that the cattle population in the Sideradougou area would increase at about 0.9% per year without tsetse control and between 2 and 5% per year with tsetse control (depending upon the prior severity of trypanosomiasis in the area). With that herd growth, it is estimated that trypanosomiasis reduces milk offtake by 9 to 38% and animal offtake by 5 to 31%.

The University of Berlin (1993) study was undertaken to assess the benefits of tsetse control by traps in northern Côte d'Ivoire. Impacts on the two main production systems -- sedentary and transhumant -- were evaluated separately. The authors predicted that without tsetse control the populations of sedentary and transhumant cattle in northern Cöte d'Ivoire would increase at average annual rates of 10.4% and 9.2% respectively, while with tsetse control those populations would increase at rates of 11.9% and 11.3%. With those assumptions, trypanosomiasis reduces milk offtake by 12% in the sedentary herds and 8% in the transhumant herds; it would reduce animal offtake by 4% in sedentary herds and 10% in transhumant herds.

3.3 *Impacts of trypanosomiasis on animal traction productivity*

Previously unpublished data collected by ILRI in the Ghibe Valley of Ethiopia provide an opportunity to evaluate the effects of trypanosomiasis incidence on the productivity of oxen used for traction. In 1995, data were collected from all 4,985 households resident in an area of successful tsetse control and from a sample of 191 households resident in nearby areas that had not had successful tsetse control. Tsetse control in this case resulted from the coordinated use of pourons by individual farmers (Leak et al., 1995; Swallow et al., 1995).

Average area cultivated was plotted against number of oxen owned for three groups of households: households outside of the tsetse control area; households in the tsetse control area that did use pourons; households in the tsetse control area that did not pourons. The results are plotted in Figure 2. For the no control group, the relationship between number of oxen and area cultivated is linear, with an intercept of 0 and a slope of 0.5. For the group of users in the control area, the linear function has an intercept of 1 and a slope of 0.8. For the

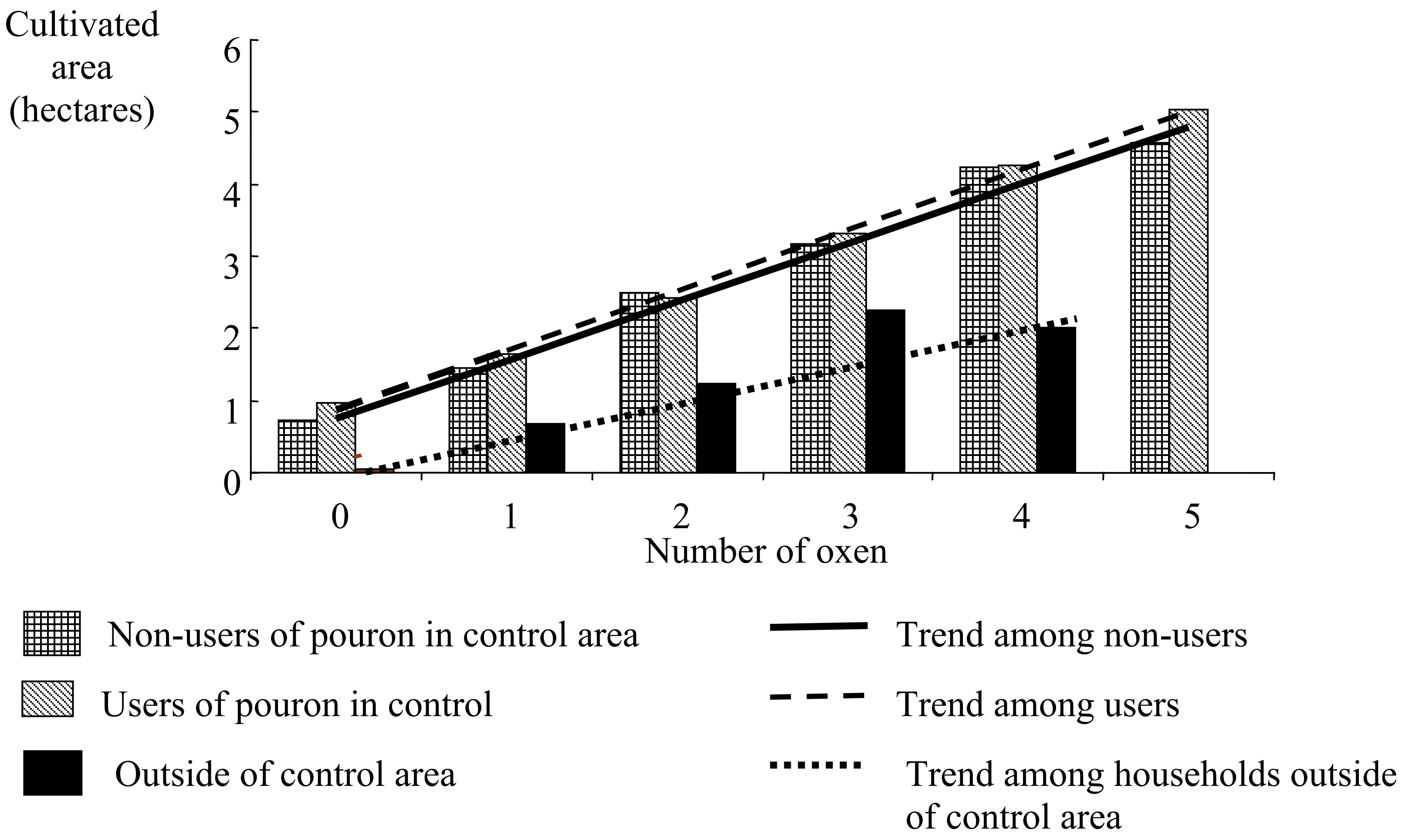


Figure 2: Pouron use and ox power cultivation,
Ghibe Valley of Ethiopia (Source: unpublished ILRI data)

group of non-users in the control area, the linear function has an intercept of 0.7 and a slope of 0.8. In other words, households outside of the control that did not own oxen were not able to cultivate any land using animal traction. One can infer that the other cattle owned by the household were not capable of pulling ploughs and that they did not have access to their neighbours' oxen. For each ox that those households owned, they were able to cultivate 0.5 additional hectares. Households within the tsetse control area that did not own oxen were able to cultivate up to a hectare of land, using either their other livestock (cows, bulls, heifers, donkeys) or their neighbours' animals. For each additional ox that they owned, they were able to cultivate an additional 0.8 hectares of land. Comparison of the two slopes provides a measure of the relative inefficiency of oxen in the two areas: oxen in the high risk area were 38% less efficient than oxen in the low risk area.

3.4 *Impacts of trypanosomiasis on trypanocidal drug use*

Geerts and Holmes (1998) estimate that about 35 million doses of trypanocidal drugs are administered each year in Africa. At an average purchase price of $1 per dose, this means that African farmers are spending $35 million per year on trypanocidal drugs. The large majority of those treatments are likely given to cattle. Assuming that each animal treated was given 2 treatments per year, 17.5 million cattle were treated each year out of a total of 46 million cattle at risk. This implies that two-thirds of the cattle raised under trypanosomiasis risk were not given treatments of trypanocidal drugs.

Evidence from Northern Cote d'Ivoire and southern Burkina Faso suggests that farmers' use of trypanocidal drugs depends most upon: (1) the breeds of cattle that they raise, (2) whether or not they practice transhumance, (3) their knowledge of the disease and its treatment, and (4) their ability to pay. A study conducted by ILRI and the Ministere de l'Agriculture et des Ressources Animales in Cote d'Ivoire shows that livestock owners' use of prophylactic treatments of trypanocidal drugs depended upon whether or not they took their animals on seasonal transhumance and the breed composition of their herds. All households that undertook seasonal transhumance into the forest zone reported using prophylactic treatments. Of households that did not undertake transhumance, 29% with only trypanotolerant cattle used prophylactic treatments, while 66% of households with some zebu used prophylactic treatments.

There is surprising evidence from both West Africa and Southern Africa that trypanosomiasis risk is not an important determinant of the use of trypanocidal drugs. In the Yale province of southern Burkina Faso, Kamuanga et al. (1999a) found that livestock owners spent more money on trypanocidal drugs in 1997 than in 1994, despite a major decrease in trypanosomiasis risk in the area. Two possible reasons for the low initial level of trypanocidal drug use are that the pastoralists who settled in this area of high trypanosomiasis risk were: (1) unfamiliar with the disease and (2) impoverished by the losses that the disease caused.

In eastern Zambia, Van den Bossche et al. (1999) examined the use of trypanocidal drugs in two nearby areas, one with a moderate-to-high level of trypanosomiasis risk and one with a very low level of risk. They found that livestock owners in both areas preferred to administer curative rather than prophylactic treatments of trypanocidal drugs, with most treatments given to oxen and cows. Most treatments were given to clinically sick animals, not necessarily to animals infected with trypanosomes. The average rate of treatment in both areas was 1.5 treatments per year (Van den Bossche et al, 1999, p. 2).

4. Impacts of trypanosomiasis risk on livestock management

4.1 *Impacts of trypanosomiasis risk on animal numbers*

a) *Farm-level studies.* Table 6 presents data on the numbers of livestock held by households residing in contiguous areas of low, medium and high trypanosomiasis risk in The Gambia. The first result to note is that average herd size, expressed in terms of tropical livestock units, was lowest in the high risk area, twice as high in the medium risk areas, and four times as high in the low risk area. The numbers of herd cattle and horses follow similar trends across the 4 areas. The second result to note is that there is no statistical relationship between the numbers of draft cattle, donkeys, sheep and goats and the level of trypanosomiasis risk. The differential effect of trypanosomiasis risk on the different types of livestock is likely due to differences in animal management rather than degree of susceptibility to trypanosomiasis. Most draft cattle, sheep, goats, horses and donkeys are kept within the village areas, while herd cattle are grazed in closer proximity to the areas of highest tsetse challenge (Mugalla et al., 1999).

Doran and Van den Bossche (1999) report the results of a similar study conducted in nearby areas with zero and medium-to-high trypanosomiasis risk. There was a significant difference between the number of cattle per owner in the tsetse-free and tsetse-infested areas, with an average of 49.0 cattle per owner in the tsetse-free area and 32.4 cattle per owner in the tsetse-infested area. There were no significant differences between the two areas in the number of goats per owner. As in The Gambia, farmers in the tsetse-infested area owned a significantly higher proportion of oxen.

Table 6 Relation between level of trypanosomosis risk and numbers of animals owned, Central River Division, The Gambia.

Type of animal	Levels of tsetse challenge				All areas
	Low risk (L. Fulladu West)	Medium risk (Bansang North Bank)	Medium risk (Bansang South Bank)	High (Niamina East)	
	Average number of animals per household (standard deviation)				
Herd cattle	27.3 (120.6)	9.9 (18.2)δ	10.3 (18.7)δ	3.0 (7.2)	13.7 (65.5)
Draft cattle	1.1 (1.8)	1.2 (1.8)	2.0 (2.3)αβδ	0.9 (1.3)	1.3 (1.9)
Horses	1.2 (1.4)βδ	0.6 (1.1)δ	1.0 (1.6)δ	0.1 (0.3)	0.8 (1.3)
Donkeys	0.9 (1.0)	0.9 (1.1)	0.8 (1.2)	1.1 (1.1)	0.9 (1.1)
Sheep	5.1 (6.7)	4.8 (5.9)	5.1 (4.8)	4.6 (6.1)	4.9 (5.9)
Goats	5.9 (6.0)	5.6 (5.3)	5.7 (6.2)	4.9 (4.2)	5.6 (5.6)
Tropical livestock units	25.8 (97.7)	11.2 (16.1)δ	12.6 (17.3)δ	5.1 (6.8)	14.5 (53.4)

β=Greater than Medium 1 at P<0.01 δ=Greater than High at P<0.01
α=Greater than Low at P<0.01
1 Tropical Livestock Unit = 10 sheep = 10 goats = 1.25 donkey = 1.25 bovine = 1 horse
Source: Mugalla et al. (1997).

b) Country-level studies. Studies of the relationship between tsetse infestation and cattle density have been conducted for two of the African countries that have the largest cattle populations, Ethiopia and Nigeria. Bourn (1978) showed that cattle density is positively related to human population density, rainfall, altitude and the presence or absence of tsetse. Tsetse-infested areas generally supported much lower cattle densities than tsetse-infested areas. Wint

(1999) is following up Bourn's (1978) study of Ethiopia, with the results reported on the PAAT web page (www.fao.org/paat). Wint identifies areas whose livestock populations have been constrained by between 1 and 50 head per square kilometer. The greatest increases are expected in areas adjacent to tsetse-free areas, for example, in the Ghibe Valley discussed in section 3.3 above (Figure 3).

(*c*) *Continental-level studies*. Jahnke et al. (1987) compared the density of cattle in tsetse-infested and non-infested areas of the sub-humid and humid zones. In the sub-humid zone the average livestock density was 9.9 Tropical Livestock Units (TLUs) per km^2 in the non-infested areas and 6.2 TLUs / km^2 in the infested areas (37% less). In the humid zone the average livestock density was 9.3 TLUs / km^2 in the non-infested areas and 2.8 TLUs / km^2 in the infested areas (70% less).

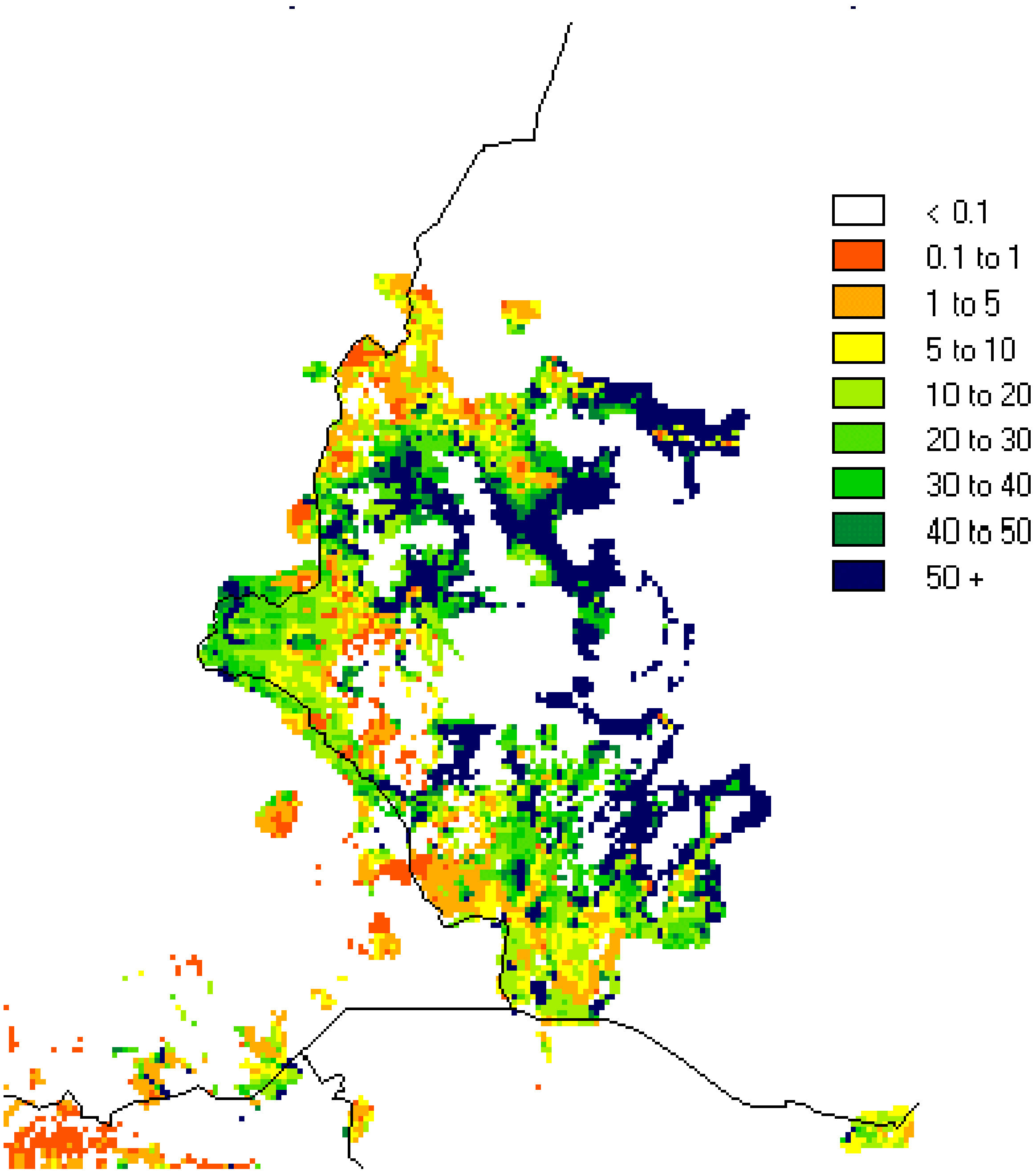
Kristjanson et al. (1999) combined an economic surplus model, a herd simulation model and geographic information systems (GIS) to examine the costs of trypanosomiasis and the potential benefits of its control in terms of meat and milk production. First, they used GIS to overlay the ILRI cattle density data layer, the Ford and Katondo tsetse distribution data layer (Lessard et al., 1990), and a map of agroecological zones to estimate the number and density of cattle raised under trypanosomiasis risk by agroecological zone and tsetse status. The results presented in Table 7 show that the tsetse-infested parts of the arid zone have much higher cattle density than the tsetse-free parts. This is expected since the only tsetse found in the arid zone are along rivers where human and livestock populations are also high. In all of the other zones, cattle density is highest in the tsetse-free areas. In the semi-arid zone the average density was 12.3 head / km2 in the non-infested areas and 10.6 head / km2 in the infested areas (14% less). In the sub-humid zone the average was 8.4 head / km2

Table 7: Number and density of cattle in tsetse-free and tsetse-infested areas of sub-Saharan Africa by region and agro-ecological zone.

Region & agro-ecological zone	Total cattle (million)	Cattle in tsetse-infested areas (million)	% in tsetse-infested areas	Density in infested areas (cattle / km2)	Density in tsetse-free areas Cattle /km2)
Southern Africa					
Arid	4.9	0.1	2	3.4	2.8
Semi-arid	10.1	1.3	13	2.4	8.0
Sub-humid	7.1	0.8	11	1.1	6.0
Humid	0.1	0.0	19	0.3	3.1
Highlands	6.1	0.1	1	6.5	8.6
Total / mean	28.4	2.2	8	2.7	5.7
Eastern Africa					
Arid	15.5	1.5	10	13.7	5.4
Semi-arid	17.9	5.1	28	23.7	16.9
Sub-humid	10.2	6.2	61	9.9	13.7
Humid	0.9	0.6	66	7.9	8.6
Highlands	31.7	8.0	25	21.5	34.5
Total / mean	76.2	21.3	28	15.3	15.8
West Africa					
Arid	6.2	0.0	0	9.7	1.6
Semi-arid	18.1	6.9	38	11.3	13.3
Sub-humid	11.6	10.0	86	9.2	18.5
Humid	1.1	1.1	94	1.5	6.9
Highlands	0.0	0	100	13.2	0.0
Total / mean	37.1	18.0	48	9.0	8.1
Central Africa					
Arid	0.0	0.0	0	0.0	13.6
Semi-arid	1.1	0.2	15	4.3	27.3
Sub-humid	2.9	2.4	82	3.0	8.3
Humid	3.6	3.5	96	1.1	4.9
Highlands	0.5	0.3	55	3.2	14.5
Total / mean	8.2	6.3	77	2.3	13.7
SS Africa					
Arid	26.6	1.6	6	11.8	3.0
Semi-arid	47.2	13.5	29	10.6	12.3
Sub-humid	31.8	19.4	61	6.1	8.4
Humid	5.7	5.2	91	1.3	5.6
Highlands	38.3	8.4	22	17.3	21.4
Total / mean	149.8	47.8	32	5.3	7.2

Source: Kristjanson et al., 1999.

Figure 3: Predicted increase in cattle density with removal of economically-important species of tsetse in tsetse-infested areas of Ethiopia



Source: Wint (1999) from PAAT web page (www.fao.org/paat) in the non-infested areas and 6.1 / km2 in the infested areas (27% less). In the humid zone the average was 5.6 head / km2 in the non-infested areas and 1.3 head / km2 in the infested areas (77% less). And in the highland zone, the average was 21.4 head / km2 in the non-infested areas and 17.3 head / km2 in the infested areas (19% less). Differences between the non-infested and infested areas appear to be greatest in southern and central Africa and lowest in East Africa.

Kristjanson et al. (1999) then used a herd simulation model to estimate the milk offtake and meat offtake that are produced by cattle in tsetse-free areas compared to cattle kept in tsetse-infested areas. The results show that the tsetse-free area produces 83% more milk and 97% more meat per unit land area than the tsetse-infested area. The reductions in milk and meat result in lower welfare for producers who earn less income from the production of meat and milk and consumers who consume less of those products. Together, consumers and producers lose a total of $1,338 million per year.

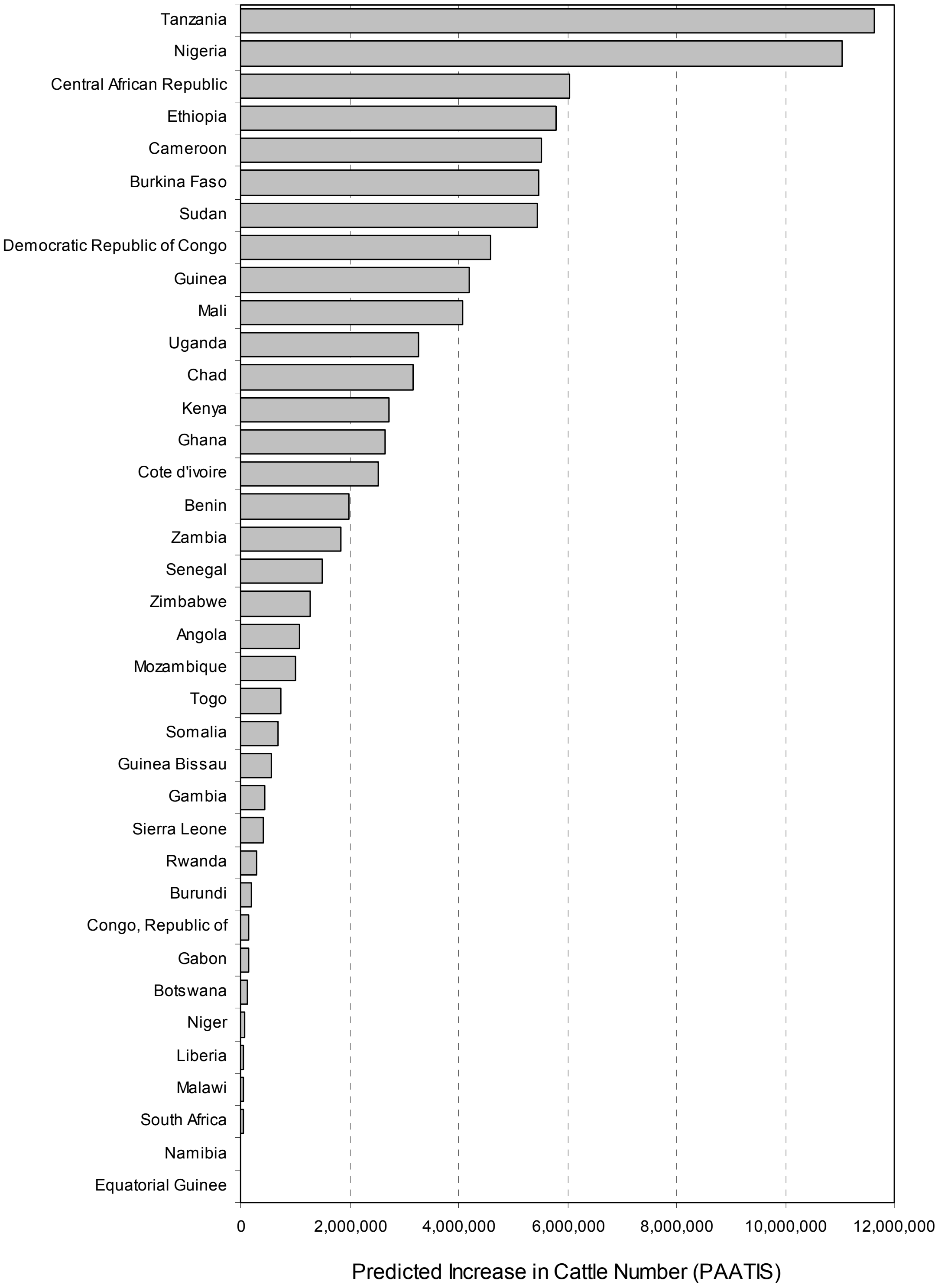
Gilbert et al. (1999) have also predicted increases in cattle density for the African continent as a whole using the coarse-resolution spatial data (pixels of approximately 5 square kilometres) available through the PAAT Information System. Geo-referenced data from 12,000 points located across the African continent were used to estimate statistical relationships that can be used to predict cattle density and cultivation intensity on the basis of a number of explanatory variables, especially rainfall, temperature, vapour pressure deficit, vegetation cover, elevation, potential evapotranspiration, length of growing period, human population, and the number of tsetse species present. Statistical relationships were estimated for a number of ecozones occurring in each country. The resulting equations were then used to predict cattle densities with and without the presence of tsetse. The results, summarized in Figures 4 and 5, indicate that there now are about 172 million head of cattle kept in the 37 countries that have some level of tsetse infestation, of which 44.7 million are within the area of tsetse infestation. Without the presence of tsetse, there would be approximately 90 million more cattle. Effectively, therefore, they suggest a 200% increase in actual numbers. The greatest increase in numbers would be in Tanzania, Nigeria, Central African Republic, Ethiopia, Cameroon and Burkina Faso. Again, cattle densities are predicted to increase by between 1 and 50 head per square kilometre. Increases of 50 head or more are expected in areas adjacent to tsetse-free areas, for example in Tanzania, Ethiopia, Nigeria and Burkina Faso.

4.2 *Impacts of trypanosomiasis risk on grazing and seasonal migration*

a) Village-scale studies: Wacher et al. (1994) undertook a detailed quantitative study of farmers' grazing management relative to the distribution of tsetse in an area of low to moderate tsetse challenge in The Gambia. Cattle grazing was generally focused on the village, while tsetse were concentrated in a woodland area to the north of the village. Only during the wet season, when crops were planted in the fields around the village, were cattle grazed in an area of relatively high tsetse density. There was large variation among herds in the degree of exposure to tsetse throughout the year.

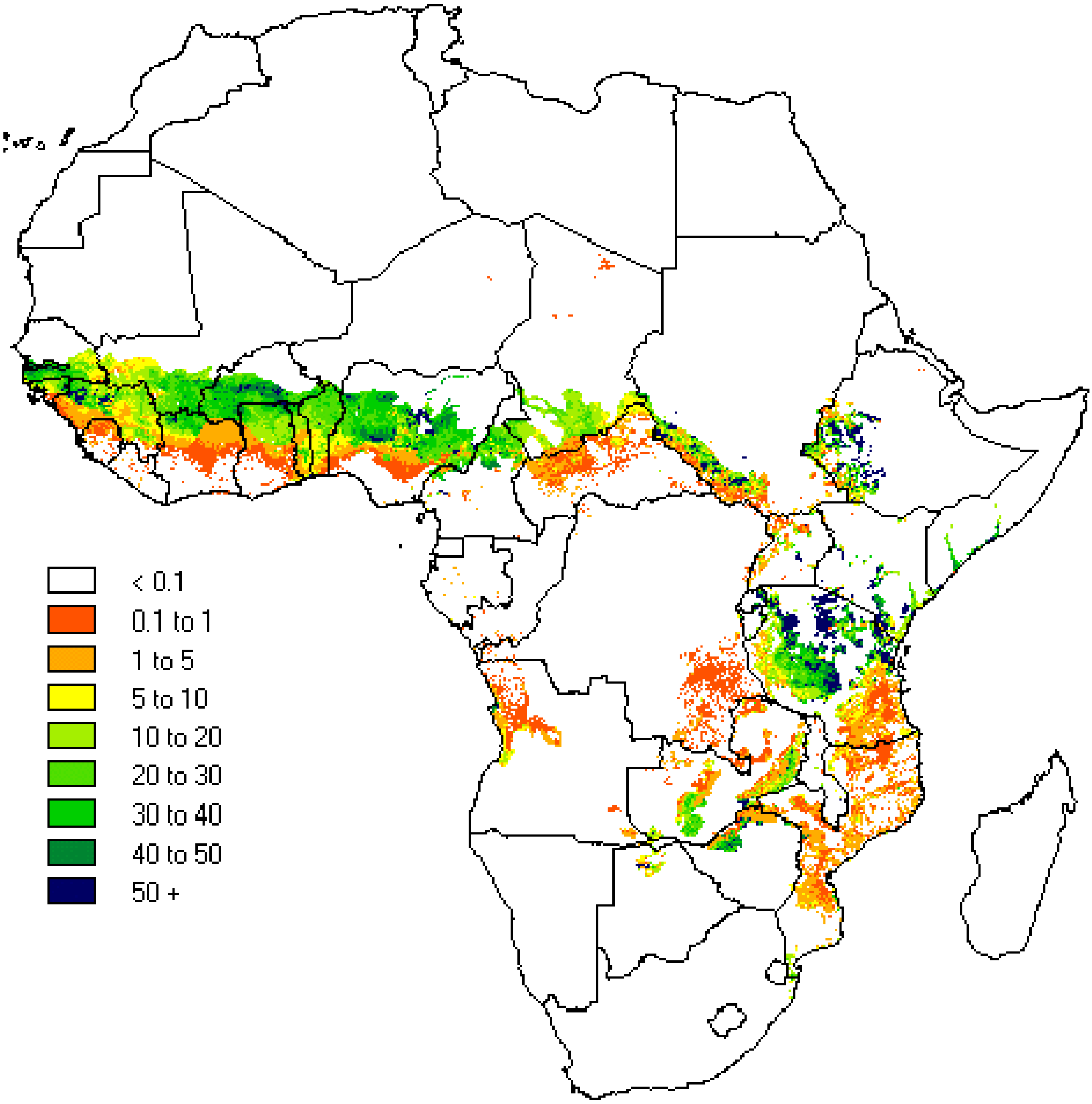
In the Ghibe Valley of Ethiopia, ILRI has monitored the grazing patterns of 11 cattle herds since 1993, less than two years after a tsetse control trial had started and within a few months of the time that tsetse were suppressed to less than 10% of their pre-trial level. The herds that were followed all began as collective village herds, with animals housed in corrals at each household at night, then brought together into collective herds each morning. The herds that were monitored were selected from adjacent villages within a relatively densely populated portion of the tsetse control area measuring about 50 km^2. Arndt (1995) and Arndt (1996) analysed the herd monitoring data to evaluate how grazing patterns changed as the intensity of land use increased with tsetse control. GIS techniques were used to estimate the size and configuration of the grazing area of each herd. Additional information was obtained through 19 group interviews convened with groups of farmers in the 9 villages within the study area. The findings suggest that four related processes unfolded as a result of successful reduction of trypanosomiasis risk in the study area: (i) initial expansion of grazing areas toward the rivers due to the reduction in problems with tsetse, then reduction of grazing areas closer to villages as more and more of the land was brought into cultivation; (ii) splitting of collective herds as the intensification of cultivation made wet-season grazing more scarce and

Figure 4: Predicted increases in cattle populations with removal of all species of tsetse



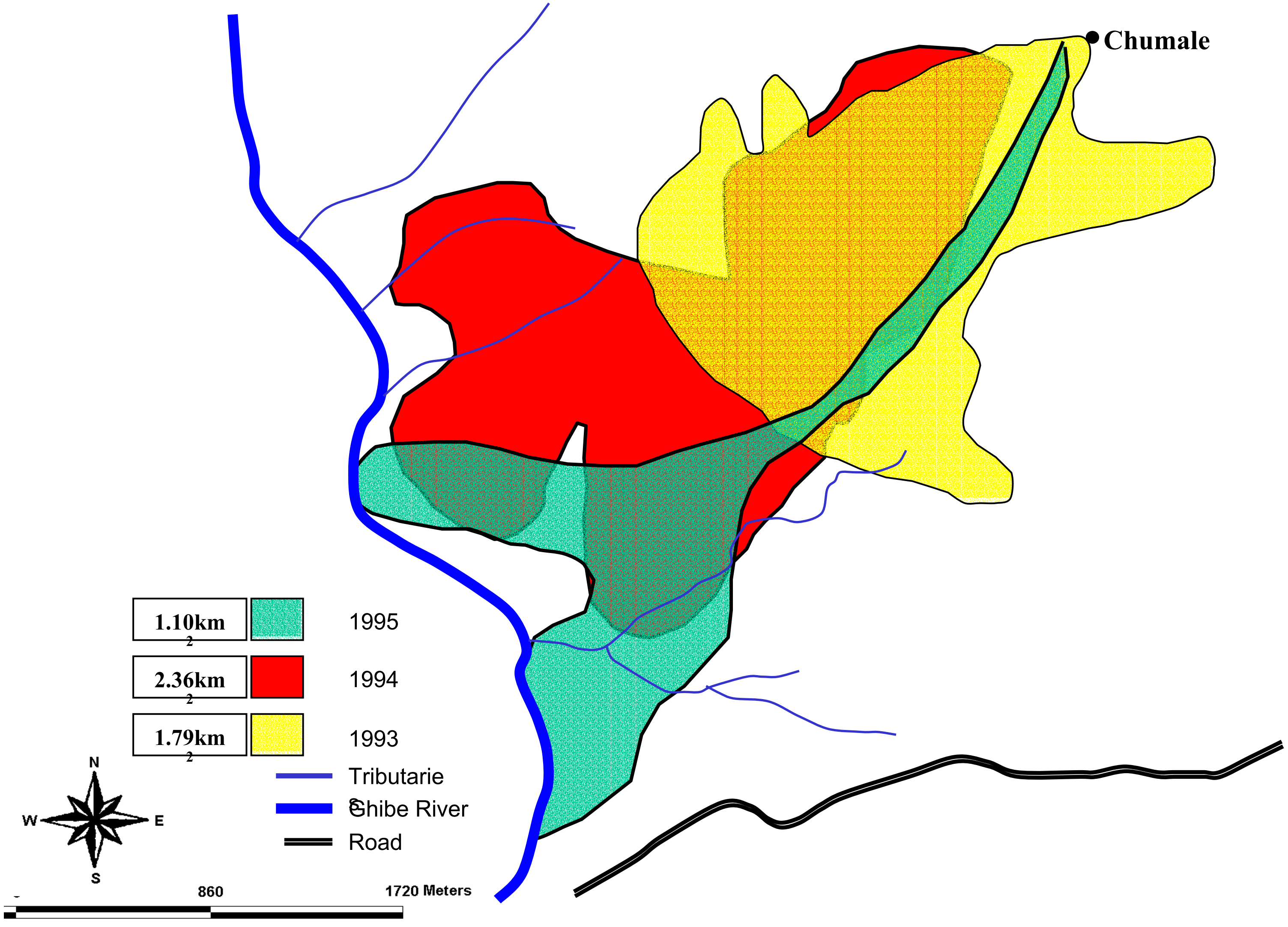
Source: Gilbert et al. (1999)

Figure 5: Predicted increase in cattle density with removal of economically-important species of tsetse across Africa



(Source: Gilbert et al., 1999 as shown in PAAT web page (www.fao.org/paat)

Figure 6: Territorial changes of crop season grazing orbits of the Chumale herd from 1993-1995 (Source: Arndt, 1996)



thus more difficult to manage large herds; (iii) individual farms began to put fences around the grazing areas on their own farms, especially in villages in which collective herds had been split; and (iv) some farmers began to send animals out of the area to more sparsely populated areas (Figure 6).

In 1995-6 a study was undertaken in southern Burkina Faso to evaluate the impacts of an experimental programme of tsetse control undertaken by CIRDES (Centre International de Recherche-Developpement sur l'Elevage en zone Subhumide) and the local farmers. Households in two nearby areas, Satiri and Bekuy, were asked to describe their livestock enterprises and perceptions prior to 1991 and since 1991. Tsetse control began in the Satiri area in November 1987 and was extended to the Bekuy area in 1995, just prior to the survey. Table 8 summarises results on farmers' perceptions of the ease of access to different types of grazing areas at the time of the survey relative to the situation before tsetse control began in Satiri. About 60% of respondents in the Satiri area said that it had become easier to access grazing areas near river valleys, swamps, in natural pastures and in gallery forests. Over 80% of the Bekuy respondents said that the current situation was about the same as it was before tsetse control began in Satiri (Kamuanga et al., 1999b).

Table 8: Farmers' perceptions of ease of access to grazing areas before and after tsetse control, Satiri and Bekuy, southern Burkina Faso (% of households monitored)

	Area of long tsetse control -- Satiri (n = 152)			Area of recent tsetse control -- Bekuy (n = 75)		
Grazing area	easier than 1991	no change since 1991	more difficult than 1991	easier than 1991	no change since 1991	more difficult than 1991
near river valleys	62	20	18	1	83	15
near swamps	59	22	20	3	84	13
Natural pastures	61	20	19	1	87	12
Gallery forests	59	20	21	0	84	16

Source: Kamuanga et al., 1999b.

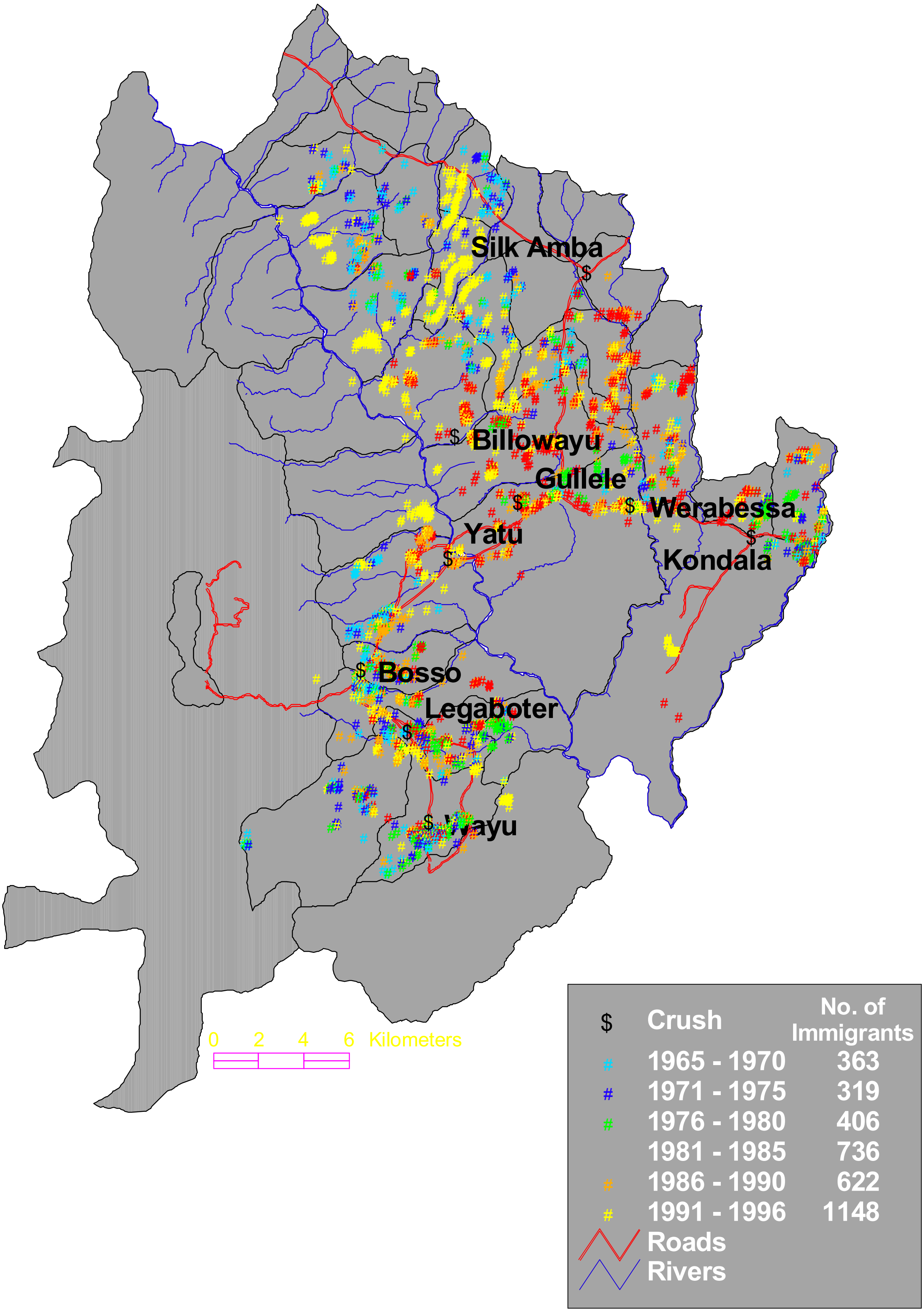
b) National-level and regional-level studies: Bassett (1993) argues that seasonal fluctuations in the density of tsetse has important impacts on grazing patterns and hence on land-use conflicts between Fulani herders and sedentary farmers in northern Côte d'Ivoire. The two dominant species of tsetse in northern Cote d'Ivoire are riverine species (*G. palpalis gambiensis* and *G. tachinoides*) whose populations increase during the rainy season and decline during the dry season. At the height of the rainy season Fulani herders move their cattle away from the major rivers to the upland agricultural areas to avoid tsetse. This results in conflicts between pastoralists and farmers.

5. Impacts of trypanosomiasis on human settlement and long-term migration

Trypanosomiasis can also be an important constraint on migration and human settlement patterns. There are at least four recent studies that have examined the relationship between trypanosomiasis, migration and settlement. Reid et al. (1999) studied the impacts of an outbreak of trypanosomiasis in the Ghibe Valley of Ethiopia on land use and land cover. The main factor driving changes in land use and land cover was migration – rapid movement of large numbers of people out of the area – and changes in settlement patterns – with many households moving away from the low-laying areas near rivers.

Studies of the impacts of trypanosomiasis control found quite different results in Ethiopia, Burkina Faso and Zimbabwe. In Ethiopia, household censuses were conducted in nearby areas of tsetse control and no tsetse control. The results indicate that over 70% of all household heads reported that they or their parents moved to the area. Movement to the area was highest during the period of tsetse control, 1991-96. More recent migrants settled nearer to the rivers and further from the roads than less recent migrants (Figure 7). This trend is particularly worrying since the riverine forests are a main concentration of biological diversity within the landscape (Reid et al., 1997b).

Figure 7: Immigration into the Ghibe Valley,
Ethiopia, 1965 - 1996



A similar study conducted in the Satiri and Bekuy areas of southern Burkina Faso did not find any evidence of an association between tsetse control and migrants' decisions of when and where to settle. Nearly half of the migrants indicated that they moved into the area to benefit from the availability of good pastures and water; others migrated in to join relatives and gain access plentiful agricultural land. None of the migrants referred to tsetse control as the main motivation for settling in the region (Kamuanga et al., 1999).

A study conducted in Gokwe District in the Zambezi Valley of Zimbabwe found evidence of a positive impact of trypanosomiasis control on migration. Data were collected for about 40 households in each of 12 study sites, with the sites purposively selected to represent different time periods since effective tsetse control. Household data on year of settlement were used to construct profiles of in-migration into the study sites over the period 1963 and 1995. An econometric analysis was then conducted to separate out the impacts of trypanosomiasis control from other factors hypothesized to effect in-migration. The results indicate that, everything else equal, the rate of immigration was more than doubled by the implementation of tsetse control. The establishment of roads and markets also had significant positive impacts on the rate of in-immigration (Govereh, 1999).

Overall it appears that trypanosomiasis can have major impacts on migration and settlement. The most rapid impacts may occur when an outbreak of trypanosomiasis occurs that causes large losses in livestock numbers. Reductions in trypanosomiasis risk have less rapid impacts on in-migration. The case study evidence suggests that the magnitude of the in-migration will depend upon the origin of the control itself. In the Burkina Faso study sites, tsetse control was undertaken in response to an outbreak of trypanosomiasis among a population that had recently been induced to settle in the area. No new migration was prompted in that case. In Ethiopia, tsetse control was undertaken on a more experimental basis, with the Ghibe area chosen somewhat randomly among other possible areas. Some new migration was prompted and the spatial pattern of settlement changed markedly. In the Zambezi Valley of Zimbabwe, tsetse control was done prior to major in-migration into the area. Areas cleared of tsetse became much more attractive to potential immigrants.

6. Indirect impacts on crop agriculture

Changes in livestock productivity, livestock management and migration can all have impacts on crop agriculture. This section reviews previous studies of these relationships and presents some new estimates of the impacts of trypanosomiasis on the value of agricultural production in the countries that are completely infested by tsetse.

6.1 *Impacts of animal traction and migration on crop production*

Studies recently conducted in the Ghibe Valley of Ethiopia and the Zambezi Valley of Zimbabwe suggest that households that migrate into an area of tsetse control can constitute a powerful force for change in agricultural production. The Ghibe Valley study found that the average migrant household owned 78% more oxen and 56% more cattle and cultivated 37% more land than the average long-term resident of the area. Migrants coming into the Ghibe Valley generally have no cattle when they arrive and build up their herds from year to year so that after 3-4 years they have as more cattle as the long-term residents. Unfortunately in the Ghibe area, the cultivated area is expanding toward the Ghibe river, causing livestock grazing to concentrate more and more along the river banks (Kagwanja et al., 1999).

The study conducted in the Zambezi Valley of Zimbabwe also shows large differences between immigrants and people born in the study sites. In 1995 61% of migrants owned cattle, while only 38% of the indigenous residents owned cattle. Forty-seven percent of migrants owned ox teams, compared to 27% for indigenous residents. Migrants owned an average of Z$ 8467 worth of animal traction equipment, compared to Z$ 5015 for indigenous residents. With that extra capacity for animal traction, migrants planted more area to cotton, the main cash crop. While indigenous residents produced slightly higher yields of maize and cotton, they generated lower revenues from crops than migrants. Migrants and indigenous residents who used animal traction generated higher returns to land and labour than households that only used hoes. Migrants that used animal traction generated 45% more income per unit of land and 143% more income per unit of labour than migrants that cultivated with hoes. Indigenous residents that used animal traction generated 25% more income per unit of land and 140% more income per unit of labour than indigenous residents that cultivated with hoes (Govereh, 1999).

6.2 *National and regional studies of the impacts of trypanosomiasis on agricultural land use*

Gilbert et al. (1999) also evaluated the relationship between tsetse presence and the intensity of cultivation. Using the data base of 12,000 geo-referenced data points from around Africa, they estimated statistical relationships between the intensity of cultivation and a number of other variables including the number of economically-important tsetse. The resulting statistical relationships were then used to extrapolate cultivation intensity for the remainder of the African continent. Preliminary attempts to derive the predicted increase in cultivation without tsetse have been produced and the results are presented in Figure 8. It is interesting to note that the largest percentage increases are predicted to occur in the humid and sub-humid regions of West Africa. The analysts involved in this research note that further validation and better quality training data are needed to improve the accuracy of the results (C. Jenner, personal communication, 11/99).

6.3 *More general relationships between livestock and crop agriculture*

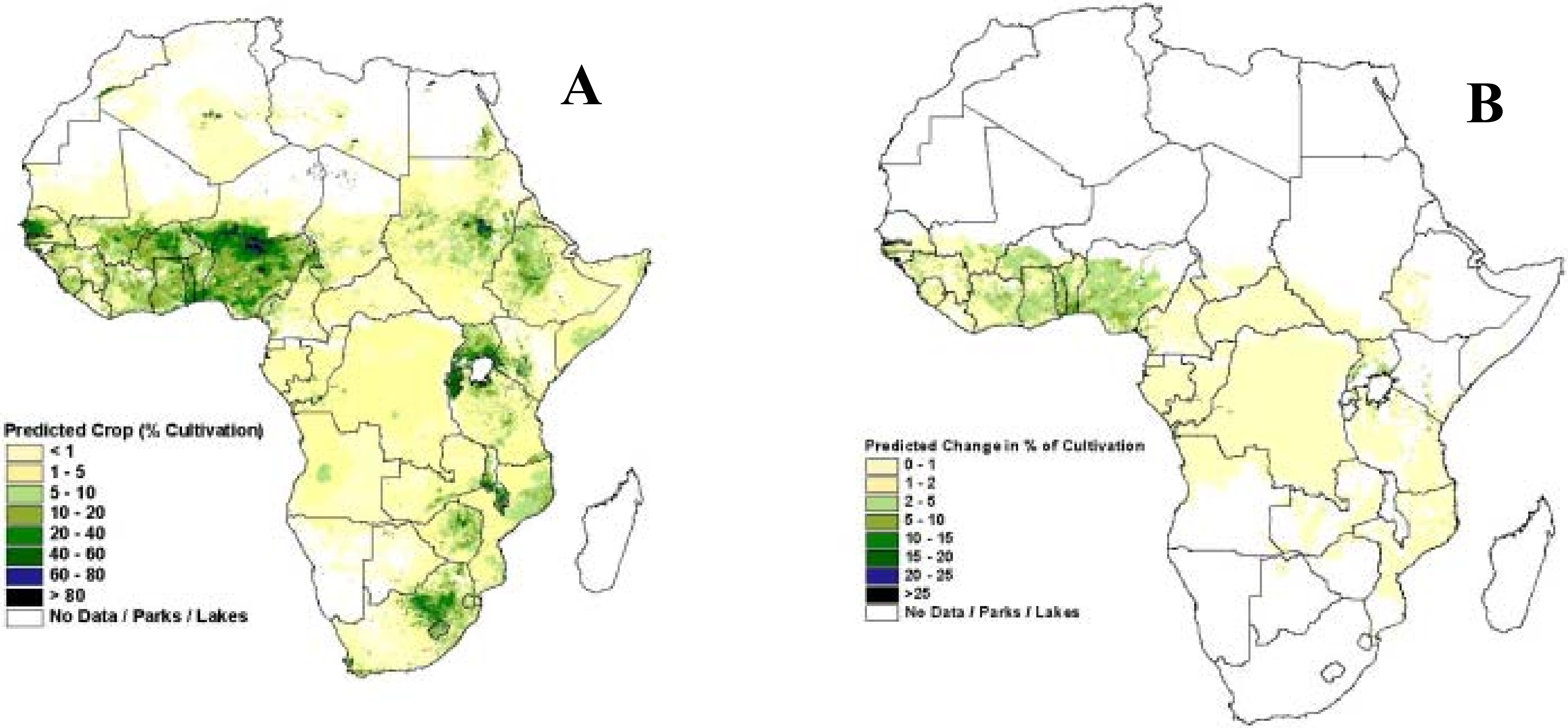
The results obtained in the Ghibe Valley of Ethiopia and the Zambezi Valley of Zimbabwe are consistent with other studies of the relationship between livestock and crop agriculture in sub-Saharan Africa. Steinfeld (1988) related the size of cattle holdings to maize area and maize yield for farms in the semi-arid and sub-humid zones of Zimbabwe. He found strong positive relationships between cattle holdings and area and between cattle holdings and yield. Savadogo et al. (1994, 1996) evaluated the productivity and price responsiveness of farmers that used animal traction, and those that did not use animal traction, in Burkina Faso. Compared to non-traction households, animal-traction households achieved about the same yields per hectare, used the same amount of labour per hectare, and allocated about the same proportions of land to the four crops. However, animal-traction households applied more fertilizer and manure per hectare, were more responsive to the prices of maize and cotton, had higher average and marginal productivities of labour and land, and achieved a more efficient allocation of labour across crops. Productivity differences were particularly large for cotton and maize. The authors hypothesized that the productivity advantage of animal traction households stemmed from their better ability to make use of manure and ability to cultivate better quality soil.

6.4 *Livestock and total agricultural production*

Agricultural production functions provide a quantitative assessment of the relationship between inputs and outputs. Thirtle et al. (1995) and Frisvold and Ingram (1995) have estimated agricultural production functions for sub-Saharan Africa that relate country-level stocks of agricultural labour, agricultural land, livestock and other ‘non-conventional’ inputs (irrigation, agricultural research, calorie availability, agricultural export growth, policy variables, weather, disaster) to the total value of agricultural products produced in the country. Thirtle et al. (1995) analysed data for 22 countries for the years 1971 to 1986, while Frisvold and Ingram (1995) analysed data for 28 countries for the years 1973-1985. Thirtle et al. (1995) estimated the elasticity of agricultural production with respect to livestock stock to be 0.23 -- that is, a 1% increase in a country’s stock of livestock was associated with a 0.23% increase in the country’s agricultural output. Frisvold and Ingram (1995) estimated the output elasticity of livestock stock to be 0.19. For the semi-arid, sub-humid and humid tropics, changes in stocks of livestock contributed about 19%, 16%, and 20% of total agricultural output growth between 1973 and 1985.

These estimates of the elasticity of agricultural production with respect to livestock stock can be used to predict how total agricultural production would change with changes in the stock of livestock. Suppose, following the previous discussion, that the presence of trypanosomiasis reduces the total number of livestock in an area by between 25 and 50%. With an output elasticity of 0.2, we can predict that trypanosomiasis would reduce agricultural gross domestic product by between 5% and 10%. For countries that are completely infested by tsetse, we can estimate that trypanosomiasis reduces agricultural output by that amount. Table 9 presents those calculations for 10 African countries that are completely infested with tsetse.

Figure 8: Predicted Percentage Cultivation with all tsetse species (A) and Predicted Change in Percentage Cultivation assuming the removal of all tsetse species (B).



Source: Gilbert et al. (1999).

Table 9: Estimates of the impacts of trypanosomiasis on agricultural gross domestic product for the 10 African countries that are completely infested by tsetse

	Agricultural GDP (USD millions in 1997) **	Impacts of trypanosomiasis with 40% and 80% impacts on total stock of livestock	
		40%	80%
Benin	812	65.0	130.0
Central African Rep.	468	41.2	82.4
Congo, Republic	230	18.4	36.8
Cote d'Ivoire	2768	221.4	442.8
Gabon	380	30.4	60.9
Ghana	3178	254.3	508.5
Guinea	1039	83.2	166.3
Guinea-Bissau	143	11.4	22.9
Sierra Leone	414	33.1	66.2
Togo	512	40.9	81.9
Total for 10 countries	999.1	799.3	1598.6

** World Bank (1999, Table 12, Structure of Output)

Source: Own estimates based on World Bank (1999) measurements of Agricultural Gross Domestic Product, concensus estimates of aggregate impacts of trypanosomosis on livestock numbers and Thirtle et al. (1995) and Frisvold and Ingram (1995) estimates of the output elasticity of livestock stock.

7. Conclusions and Implications

7.1 *Conclusions*

In sum the empirical evidence that has accumulated during the last 10 years supports previous claims that trypanosomiasis is an important constraint on agricultural production in Africa. Trypanosomiasis directly constrains the productivity of cattle, sheep and goats by reducing birth rates, increasing abortion rates, and increasing mortality rates. Mortality rates are particularly high among young animals. Without effective drug therapy, increases in the incidence of trypanosomiasis can devastate herds of trypanosusceptible cattle and the farming systems into which those cattle are integrated. Trypanosomiasis nearly wiped out herds in the Ghibe Valley of Ethiopia in the mid-1980s and in the Yale province of Burkina Faso in the early 1990s.

The existence and severity of trypanosomiasis also shapes farmers' choices about the size and structure of their cattle herds and their use of tsetse habitat for grazing. It is estimated that trypanosomiasis reduces the total population of cattle by 30% - 50% and the production of meat and milk from those cattle by at least 50%. Trypanosomiasis is also one of the factors that constrain the development of specialized dairy enterprises in the sub-humid and humid lowlands of the continent.

Likely more important than its impacts on meat and milk production is its impacts on the development of integrated crop-livestock production systems. There are at least four ways that this happens. First, trypanosomiasis reduces the work efficiency of oxen. Evidence from a case study site in Ethiopia suggests that a team of oxen in a tsetse-infested area is capable of cultivating 40% less land than a team in a tsetse-control area. This relationship needs to be studied in additional study sites. Second, trypanosomiasis reduces the number of oxen that farmers choose to hold. In some situations the reduction is minimal, as in The Gambia. In other situations, cattle and other draft animals are completely excluded from the system. Thirdly, high trypanosomiasis risk can largely exclude species and breeds of livestock that are otherwise well-suited to animal traction. For example, very few West African Zebu cattle or horses are used for traction in the wetter semi-arid and drier sub-humid regions of West Africa. Fourthly, high trypanosomiasis risk reduces the attractiveness of frontier areas for new migrants. When all of the interactions between livestock and crop production are considered, trypanosomiasis may reduce the total value of agricultural production by 5-10%.

Case studies conducted in Zimbabwe and Ethiopia show that tsetse and trypanosomiasis control can make certain areas more attractive to people living in source areas where farms are small and soils are depleted. Large-scale changes in policy or climate will prompt large numbers of people to move from those source areas; successful implementation of tsetse and trypanosomiasis control can make certain areas much more attractive destinations for new migrants. The availability of land, quality of soils, and availability of transportation infrastructure are also important characteristics considered by migrants when they choose when and where to move. On the other hand, case studies conducted in Burkina Faso, Cote d'Ivoire and Kenya show that tsetse control projects can be successful, and perhaps more sustainable, when they react to the needs of long-term residents or new migrants. In those cases the effective implementation of tsetse and trypanosomiasis control may not prompt much new immigration.

Results from case studies in Ethiopia and Zimbabwe show how much new energy and vitality new migrants can bring to a frontier region. In Zimbabwe the first-generation migrants have higher education, raise more livestock, cultivate more crops, and are more efficient in their use of resources than indigenous residents. In Ethiopia, new migrants raise more livestock, cultivate more land and co-operate more effectively than indigenous residents. While they continue to be poorer in some terms, indigenous residents in Zimbabwe continue to hold all of the positions of power and benefit from the active rental market that has developed for oxen.

In-migration has costs, however. New migrants tend to settle at the peripheries of the village landscape. In Ethiopia, new immigrants are settling closer and closer to the riverine areas that are so rich in biological resources. Conflicts between new immigrants and indigenous residents are common. A comparison of the Burkina Faso and Ethiopia case study sites suggests that conflicts will be greatest where people's livelihood strategies and culture are most different. In those cases, land-use conflicts may be very bitter even when land appears to be in plentiful supply.

The impacts of tsetse and trypanosomiasis control on migration depend upon the origins of the control itself. Control undertaken before large-scale migration into an area, as was the case in Zimbabwe, is likely to prompt a significant increase in in-migration, particularly to places where land is available, soil quality is high, and markets are accessible. Migration into those areas is likely to occur in pulses, with in-migration highest after policy and climate changes that reduce the costs of migration, or make migration more attractive compared to staying in source areas. A likely problem in those situations is that tsetse control may be costly and difficult to sustain. On the other hand, tsetse control undertaken after in-migration has occurred, as was done in several sites in southern Burkina Faso and northern Cote d'Ivoire, is unlikely to result in much new in-migration. Tsetse and trypanosomiasis control may be cheaper and easier to sustain in such areas.

7.2 *Implications*

The question taken up in this final section of the paper is: how can an improved understanding of the impacts of trypanosomiasis contribute to more sustained and effective development in tsetse-infested areas? Answers to that question are grouped under three sub-headings: a) research and information needs; b) targeting public investments; and c) appropriate partnerships.

a) Research and information needs. The evidence presented in this paper is gleaned from a small number of studies at the site, nation and continental levels. The small number of systematic case studies that have been conducted, for example, in the Ghibe Valley of Ethiopia, Central River Division of The Gambia, Mushie Ranch in Zaire -- are really only relevant for specific production systems and disease risk situations. There are two fundamental problems with those case studies: (1) they are very expensive; and (2) they fail to represent farmers' actual management practices. Future case studies should focus on production systems that have been understudied in the past (e.g. peri-urban dairy production, donkeys, small ruminants) and should be consistent with farmers' actual practices. A cost-effective way to generate more information about trypanosomiasis impacts would be to make impact assessment a systematic part of monitoring and evaluation of actual disease control interventions. The approach taken by Kamuanga et al. (1997) may be particularly useful in this regard.

New tools for remote sensing and GIS analysis are creating new opportunities for researchers to provide information to those who design trypanosomiasis control policies and programmes. Wint and Bourn (1994), Rogers and Hay (1996), Wint (1998), Hendrickx et al. (1997), Reid et al. (1997a) and especially Gilbert et al. (1999) have generated a great deal of useful spatial information about disease risk and its impacts. Priority should now be given to the assessment of information needs, identification of information gaps, and greater understanding of the usefulness of different types of information to different stakeholders. Who needs to know what? When do they need to know it? What information do they need to make what decisions?

b) Targeting public investments. Some of the principles that should guide public investments in trypanosomiasis control are as follows:

(i) Public investments should complement and not replace private investments. In particular, public agencies should not subsidize the provision of trypanocidal drugs, unless the affected population is unfamiliar with the disease or livestock are an important reservoir of human trypanosomiasis.

(ii) Public programmes of intervention should not be undertaken if there is an acceptable policy change that could achieve the same results. Policies most directly related to trypanosomiasis control include input market policies, veterinary policies and international trade policies. For example, policies that lower the price of trypanocidal drugs reduce incentives for tsetse control.

(iii) Public programmes and policies for trypanosomiasis control should be consistent with other public programmes and policies. It is most important to consider how trypanosomiasis control complements or competes with programmes and policies affecting protected areas, settlement, migration and land use. Trypanosomiasis control is likely to increase pressures for increased in-migration, settlement close to rivers, and exploitation of land near to protected areas. It will often be necessary to consider the trade-offs between development and environmental objectives.

(iv) Public funds should be allocated to maximum social returns per dollar of investment. Returns will be highest where the cost per unit land area is low and the potential benefits high. The results presented in this paper imply that potential benefits are likely to be highest where there is high potential for integration of crops and livestock in mixed farming systems. The potential for mixed farming may be highest in sub-humid areas that are well connected to urban or international markets. The PAAT Plan of Action discusses this principle in more detail (www.fao.org/paat).

c) Appropriate partnerships. There is a need for a compromise between centralized and decentralized planning and implementation of trypanosomiasis control. A centralized approach is useful for prioritizing public interventions at the continental and national levels, for coping with transboundary issues, and for circumstances where livestock owners move their animals over large distances. A centralized approach is also tempting when central agencies have most of the technical information on the disease and its control. On the other hand, decentralized planning is necessary to ensure buy-in from local authorities that are becoming increasingly powerful across much of Africa, for recovering the costs of interventions from potential beneficiaries, and for ensuring that trypanosomiasis control is consistent with local priorities and policies.

The principle of subsidiarity should guide the overall approach to trypanosomiasis control. Implementing this principle means that the individual livestock owners and community groups who benefit most from tsetse control should finance and manage all components of control that they are willing and capable to do. It means that de-centralized government agencies should monitor the disease and vector situation, assess the effectiveness of community interventions, and finance some components of the control operation in areas where the beneficiaries are far removed from the control points. It means that central government agencies should set national priorities for intervention, develop new techniques for control, provide training in the epidemiology and control of trypanosomiasis, align relevant policies and programmes, and negotiate with neighbouring countries.

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