ISSN 1020-7163

PAAT TECHNICAL AND SCIENTIFIC SERIES 6

LONG-TERM TSETSE AND TRYPANOSOMIASIS MANAGEMENT OPTIONS IN WEST AFRICA

A PAAT INFORMATION SERVICE PUBLICATION

PAAT TECHNICAL AND SCIENTIFIC SERIES 6

LONG-TERM TSETSE AND TRYPANOSOMIASIS MANAGEMENT OPTIONS IN WEST AFRICA

Guy Hendrickx
Avia-GIS
Zoersel, Belgium
Stéphane de la Rocque
International Cooperation Centre
of Agricultural Research for Development
Montpellier, France
and
Raffaele C. Mattioli
FAO Animal Health Service

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS
Rome, 2004

ISBN 92-5-105118-6

Abstract

Tsetse-transmitted animal trypanosomiasis is a complex disease that directly and indirectly has an impact on Africa's crop and livestock agriculture. Over the past decade awareness of this fact has generated a drive and political will towards solving the problem at the continental scale. In this paper the authors use state-of-the-art spatial tools to study how, for West Africa, the variety of agro-ecological settings may have an impact on decision support towards that goal.

First, the authors describe an approach towards selecting priority areas for area-wide tsetse and trypanosomiasis (T&T) control, based on the mapping of:

- dominant livestock systems with particular emphasis on the integration of livestock and crop agriculture towards mixed farming practices;
- tsetse ecology bands linked to the geoclimatic settings prevailing in West Africa – a northern dry band with fragmented tsetse populations and a southern humid band where tsetse are widespread.

Priority areas are identified in the northern band of the tsetse belt where:

- tsetse populations are fragmented (and therefore vulnerable) or confined only to suitable vegetation along main river courses;
- fly reinvasion risk is minimal due to land pressure and adverse climatic conditions for tsetse;
- mixed farming predominates and an improved integration of crop and livestock agriculture may yield the highest benefits.

Second, three case studies are discussed: the Togo national study (FAO project GCP-TOG-013-BEL), and two studies in Burkina Faso – the Sideradougou pastoral area (Centre de Coopération Internationale en Recherche Agronomique pour le Développement [CIRAD]–Centre International de Recherche-Développement sur l'Élevage en Zone Subhumide [CIRDES]) project) and the Mouhoun

river basin (FAO project GCP-RAF-347-BEL). These three studies aimed at developing decision-support tools for the planning and implementation of integrated T&T control, based on holistic data sets on the spatial epidemiology of T&T (vectors, pathogens, hosts) and the impact of T&T on people, their environment and their livestock production systems. The studies are complementary, and therefore highly relevant to this paper, with regard to:

- the geoclimatic settings covered – in Togo a transect through humid to semi-humid West Africa, and in Burkina Faso from semi-humid to dry;
- the scale at which the studies were conducted – in Togo at the national level, and in Burkina Faso on the Mouhoun river at the river-basin level, and in the Sideradougou pastoral area at the village level.

It is clear from the results of the case studies that any decision support towards T&T management in West Africa must consider the fact that the epidemiology of tsetse-transmitted trypanosomiasis varies with varying climatic settings and land-use patterns. Therefore, the sustainable management of this major threat to animal health will have to be systematic, stepwise and pragmatic. Based on the experience gained in Togo and Burkina Faso a list of the data inputs needed to achieve such a high level of integration is given in Figure 15 (page 45).

It is concluded that an integrated T&T management approach relies on the quality of an extensive list of field data (vector, pathogen, host, livestock system, agro-ecological setting) and the detailed knowledge of geo-epidemiological patterns. We must remain cautious when making choices and avoid being lured into choosing overly simple solutions for complex problems.

Although in West Africa elimination of the fly and the disease may be achievable in the drier parts at the northern limits of the tsetse belt, several crucial assumptions remain to be validated through field research. These include investigations on fly fragmentation, population isolation and fly dispersion (e.g. Mouhoun model).

In the more humid parts, the most viable option remains an integrated approach combining:

- vector suppression in epidemiological hot spots (e.g. Sideradougou model), and
- disease management at the herd level through the strategic use of trypanocides and/or genetic improvement of local trypanotolerant breeds (e.g. Togo model).

Contents

Acknowledgements

The authors are very grateful to Jan Slingenbergh, FAO senior animal health officer, and Dominique Cuisance, CIRAD senior researcher, who were a permanent source of inspiration, not only during the writing of this paper, but mainly during the implementation phases of the various projects discussed in this paper.

The Togo data were collected within the framework of the Belgium-funded FAO projects GCP-TOG-013-BEL and GCP-RAF-347-BEL. The authors are very grateful for the scientific and technical back-up and the administrative support of K. Adoméfa, P. Bastiaensen, B. Bauer, D. Bradley, R. De Deken, M. Denke, N. Doumandji, B. Hursey, Z. Issifou, T.B. Kagnaya, Ph. Marchot, J. Mortelmans, A. Napala, D.J. Rogers, S.M. Touré and J. Vercruysse. Fieldwork was conducted by teams led by K. Agrignan, A. Aliti, K. Amedji, D. Batawui, A. Body, M. Chambaud, B. Dao, A. Hévon, B.T. Kadjassi, J.D. Keita, T. Komlani, N'T. Kouagou, L. Lakougnon, P. Lanwi, T. Lémou, D. Ouatara, K. Somanin and S. Yacnambé.

In Burkina Faso data on the Mouhoun river system were collected within the framework of the Belgium-funded FAO project GCP-RAF-347-BEL and complemented by data originating from recent work conducted by CIRDES teams and from the archive of Dr Issa Tamboura. Fieldwork on the Mouhoun river system (FAO project) was conducted by a team led by Issa Tamboura with the assistance of Zerbo L. Pierre, Daro Boukari, Sanou Tidiany and Sanou Siaka. The project also benefited from the technical input from Zowinde Koudougou.

The Sideradougou work benefited from inputs from M. Arnaud, X. Augusseau, Z. Bengaly F. Borne, G. Cuny, M. Desquesnes, G. De Wispelaere, S. Dray, C. Gauthier, S. Guillobez, V. Freyon, B. Geoffroy, L. Guerrini, I. Kabore, A. Lalba, T. Lefrançois, M. Lesnoff, M. Lounis, C. Meallet, N. Meftah, J.F. Michel, V. Michel, S. Ouédraogo, M. Passouant, L. Petiteau, I. Sidibé, P. Solano and I. Touré.

Much of the West African geographic information systems (GIS) work on livestock systems analysis, tsetse ecology bands and the selection of area-wide priority areas was conducted during a series of FAO/International Atomic Energy Agency (IAEA)-funded and PAAT workshops in Addis Ababa, Geneva, Rome and Vienna and was further refined for the purpose of this paper. This work benefited from many contributors including: A. Bado, D. Bourn, L. Budd, B. Dao, U. Feldman, R. Kastens, Z. Koudougou, C. Mahama, C. Mebrate, N. Okhoya, A. Serdebeogo, I. Tamboura and W. Wint.

Acronyms

AU	African Union (formerly the Organization of African Unity)
AW-IPM	area-wide integrated pest management
CIESIN	Center for International Earth Science Information Network
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CIRDES	Centre International de Recherche-Développement sur L'Élevage en Zone Subhumide
ELISA	enzyme-linked immunosorbent assay
FAO	Food and Agriculture Organization of the United Nations
GIS	geographic information systems
IAEA	International Atomic Energy Agency
IIASA	International Institute for Applied Systems Analysis
IBAR	Interafrican Bureau for Animal Resources
ILRI	International Livestock Research Institute, Kenya and Ethiopia
ISCTRC	International Scientific Council for Trypanosomiasis Research and Control
LEAD	Livestock, Environment and Development
OAU	Organization of African Unity
PAAT	Programme Against African Trypanosomiasis
PATTEC	Pan-African Tsetse and Trypanosomiasis Eradication Campaign
PAAT-IS	PAAT Information Service

PCR	polymerase chain reaction
PCV	packed cell volume
T&T	tsetse and trypanosomiasis
WHO	World Health Organization

Chapter 1
Introduction

Over the past decade decision-makers have been increasingly aware that tsetse-transmitted trypanosomiasis should be considered not only as a disease directly impacting human and animal health, but also as a problem that profoundly affects African agriculture and the livelihood of rural populations. The presence of the disease influences where people decide to live, how they manage their livestock and the extension and intensification of crop and livestock agriculture integration. It thus becomes clear that the only way to achieve sustainable development results in disease-affected areas is by addressing the tsetse and trypanosomiasis (T&T) problem from a multidisciplinary perspective and in the context of improved and sustainable rural development, and not merely as a human and animal health problem alone.

In 1997 the Programme Against African Trypanosomiasis (PAAT) was created. PAAT is a forum, comprising the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), the African Union (formerly the Organization of African Unity)/Interafrican Bureau for Animal Resources (AU/IBAR) and other international, regional and national stakeholders. It seeks to assist in the development and implementation of international policies, strategies and guiding principles for integrated multidisciplinary intervention approaches.[1]

More recently, in 2000 at Lomé, Togo, and in 2001 at Lusaka, Zambia, decisions were made by the African Heads of State and Government confirming the political will to control and

---

[1] PAAT Web site, http://www.fao.org/ag/againfo/programmes/en/paat/home.html

eventually eradicate tsetse flies from the African continent. These decisions clearly claim African ownership and responsibility for the elimination of this African problem (OAU, 2002). As a follow-up, AU formally launched the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) in October 2001 during the 26th meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), held in Ouagadougou, Burkina Faso. PATTEC's major challenge ahead is to mobilize the necessary human, financial and material resources to achieve eventually the elimination of the tsetse fly from Africa.

During a workshop held in Rome in May 2002, PAAT and PATTEC harmonized their views on, inter alia, the concept of area-wide integrated pest management (AW-IPM). A set of criteria/ guidelines for selection of priority areas and joint international action for T&T intervention was agreed. Additionally, two earlier identified areas were validated against these criteria and sequential steps in project implementation were defined (FAO, 2002). The first project area is located in the Ethiopian Southern Rift Valley system and the other area in the common Burkina Faso–Mali "cotton belt" zone in West Africa.

The AW-IPM concept, based on data-driven decision-making, has profited greatly from the development of geographical information systems (GIS) – tools that allow the spatial analysis of data in a multidisciplinary manner. In addition to the establishment of countrywide multidisciplinary databases (e.g. PAAT-Information System [PAAT-IS], Gilbert et al., 2001), results obtained in West (de la Rocque, 1997; Hendrickx, 1999), East (Erkelens et al., 2000) and southern Africa (Doran and Van den Bossche, 2000; Robinson, 1998; Robinson et al., 2002) during the 1990s have greatly contributed towards the implementation of an AW-IPM approach for T&T intervention programmes.

The aim of this paper is to collate, analyse and discuss available information with a view to:

- comprehend better the forces driving integrated livestock–agricultural development in West Africa;

- understand how trypanosomiasis impacts livestock–agricultural production systems; and
- elaborate on options for integration of landscape dynamics and related fly habitat change with strategies for T&T interventions with the scope of planning field livestock–agricultural development programmes.

Chapter 2

Systems analysis, a spatial approach

From the introduction it is clear that understanding existing animal production systems is a keystone of any decision-support system. Therefore, the initial step undertaken was to produce a spatial inventory of livestock production systems prevailing in West Africa within their respective ecogeographical settings. Underlined system dynamics are discussed by comparing spatial patterns with recognized livestock production systems.[2]

CLIMATE, LIVESTOCK AND AGRICULTURE

In any given ecogeographical setting the occurrence and development of livestock production systems can be described by three main factors: human population density, crop agriculture intensity and livestock density (FAO, 1997). While population maps at a useful resolution and at continental scale already existed (e.g. Center for International Earth Science Information Network [CIESIN]),[3] only recently has a continental 5-km grid data set, including satellite-derived cropping[4] intensity and cattle distribution layers, been developed and made widely available (PAAT-IS).[5] The availability of such data layers allows the study of distribution patterns of single and combined variables at a subnational scale. The patterns observed and trends derived may prove invaluable for the understanding of

---

[2] Livestock and Environment Toolbox, FAO-LEAD, http://lead.virtualcentre.org/en/dec/toolbox

[3] Found at http://www.ciesin.org

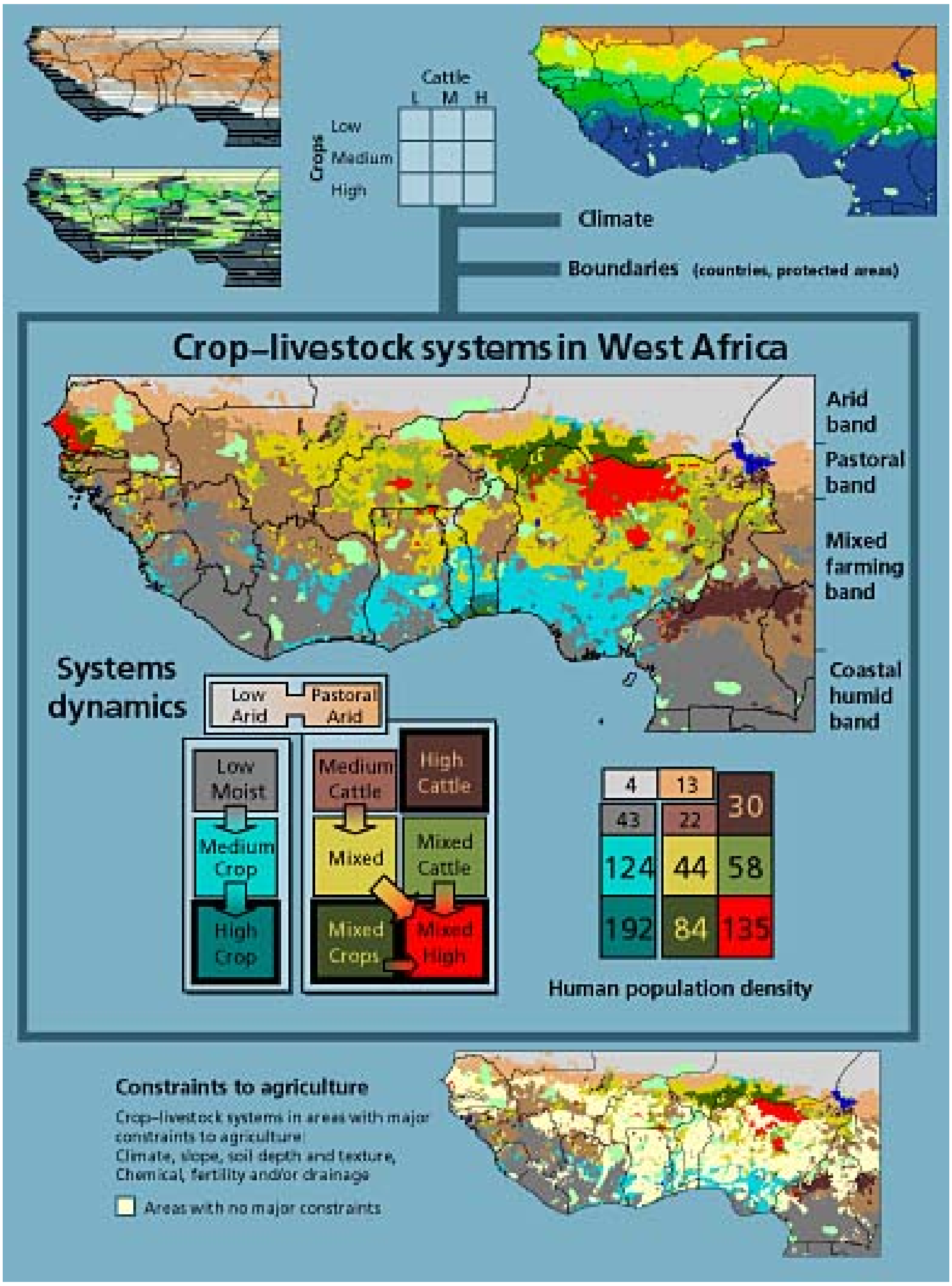
[4] Training data used to produce satellite-derived cropping-intensity prediction are mainly based on cereal crops and often do not include tree crops and tubercles. Therefore this layer is referred to as cereal cropping

[5] Found at http://www.fao.org/ag/againfo/programmes/en/PAAT/home.html

FIGURE 1

Crop–livestock systems in West Africa

Observed crop–livestock systems patterns (central map) clearly show centripetal mixed farming aggregations around development poles. From east to west – Kano and Jos Plateau in Nigeria, Ougadougou in Burkina Faso and Dakar in Senegal. This is confirmed when comparing average population density numbers for each mixed farming type. See Box 1 for background information.



occurring and current drifts of livestock production systems and for the planning of adequate pest management.

A study jointly initiated by FAO and IAEA aimed, inter alia, at analysing these patterns for West Africa (Hendrickx, 2001). Results obtained are summarized in Figure 1 and some methodological aspects are discussed in Box 1. The analysis revealed a set of distinct patterns (Figure 1, central map):

- Low cereal and low cattle density systems are found in two distinct bands: the dry northern (light grey), and the humid southern and coastal area (dark grey). While in the north climate is a major constraint for crop agriculture, in the humid south perennial crops and forest areas dominate (e.g. Liberia, Côte d'Ivoire), and a higher incidence of diseases impairs economic livestock keeping.
- In addition to forest areas (dark grey) the southern coastal band is further characterized by crop(cereal)-dominated systems ranging from medium to high intensity (light and dark blue). In these areas relatively few cattle are found. These systems cover most of the southern parts of Ghana, Togo, Benin and Nigeria.
- Mixed systems (yellow, where both crops and cattle coexist) are mainly focused around high-intensity farming areas (red) in the medium to high cropping intensity band: the Jos Plateau and close-settled zone of Nigeria, southern Niger, central Burkina Faso (Ouagadougou area) and the Dakar area in western Senegal. Around these zones distinct patches of either crops or cattle-dominated mixed systems are also present. The former in southern Niger (dark green, high-surface/low-yield mixed crop systems) and the latter more scattered in Nigeria and Burkina Faso (light green).
- Cattle-dominated systems with low cropping levels (brown) are found at the fringes of the mixed systems in the medium band. In the dryer areas they correspond to traditional pastoral zones (light brown northern band) while towards the south, in the more humid zones, stocking rates have greatly increased after

BOX 1
Spatial definition of livestock production systems:
some methodological aspects

1. Five-km raster data layers for agriculture intensity (mainly cereals, no data on tree crops and tubers included) and livestock density were reclassed in three classes (high, medium, low) based on expert knowledge.
2. Both data layers were overlayed (cross-tabulation principle) using commercial GIS software (Idrisi 32) and unique values were given to newly created classes, thus defining livestock production system categories, e.g. category medium cattle AND medium crops = mixed.
3. Based on the length of vegetation growing period, the northern pastoral band was defined.
4. Livestock production system categories were further grouped according to the emerging patterns and agro-ecological setting:
   - Northern arid and pastoral band
   - Central mixed farming band
   - Southern humid crop band
5. Average human population densities were calculated per livestock production system category to contribute to the system dynamics analysis.
6. The occurrence of a known set of physical constraints (International Institute for Applied Systems Analysis [IIASA]) was estimated per livestock production system category.

the dry periods of the 1970s and 1980s. Most of those areas have now also been freed from onchocerciasis, further increasing the incoming flux of farmers. Typical “front pioneer” areas are (a) southern Mali, southern Burkina Faso and northern Côte d’Ivoire, (b) northwestern Ghana and (c) northeastern Benin. It is interesting to note that in the Niger the pastoral band (light brown) is disrupted by high-surface/low-yield mixed crop systems.

- A distinct high-density livestock system is situated in the Alameda and Camilla Plateaus of Cameroon and Nigeria. Large parts of these areas, though under siege, are tsetse free.

As described above, the different livestock production system categories are not randomly scattered but a distinct north–south band-like pattern emerges. The given average population density figures per production system further highlight an overall human-induced dynamic pattern of higher intensity linked to higher density (Figure 1, arrows). These findings can now be compared with livestock production systems as described in the LEAD (Livestock, Environment and Development initiative of FAO) toolbox (Box 2). It is important to note that these systems rarely occur in a separate fashion, but overlap in expanse.

- Northern zero agriculture band (15 percent of the total land area): a low-intensity grazing system in arid areas where climate is the limiting factor for agriculture. An extensive cattle production system predominates; the agro-ecological setting governs seasonal livestock movements (transhumance) towards pastures (north and/or south). Population densities are low and no increase is expected. No tsetse are found in these arid conditions. Livestock is trypanosusceptible (Zebu cattle) and may be in contact with tsetse during southern transhumance. Pastoralists protect cattle using trypanopreventive drugs.
- Northern pastoral band (8 percent): a traditional pastoral system dominates with possibility for some cropping. In southern Niger a large proportion of farmland is brought into the cultivation cycle, disrupting traditional pastoral movement patterns and possibly posing a major environmental hazard. In addition, crop agriculturists acquired cattle for draught power during the droughts of the 1970s and 1980s and they compete with pastoral systems. Except for the southern fringes, no tsetse are present. Pastoralists protect cattle using trypanopreventive drugs.
- Mixed farming band (49 percent): complex, highly dynamic mixed systems with further population increase, around well-established centripetal development poles, result in higher

BOX 2
FAO–LEAD livestock production systems classification

A set of livestock production systems is described per agro-ecozone in Figure 1 on page 6. Dominant West African systems are summarized below.

1. Grazing systems: highly dependent on the natural productivity of grasslands.
   a. Mobile systems
      - Arid: nomadic or pastoral communities respond with mobility to environmental variability.
      - Semi-arid: pastoralists must have access to communal pastures along the circuit of transhumance. Though agreements are concluded for resource sharing leading to mutual benefits, conflicts may occur.
      - •. Subhumid and humid: in these zones the majority of livestock owners are sedentary. The remaining mobile pastoralists mainly use natural resources in remote areas with low population density.

   b. Sedentary systems: as an adaptation to prevailing conditions pastoralists can move to mixed farming and abandon transhumance but remain by profession livestock farmers.
      - Semi-arid: sedentary livestock farmers earning most of their income from livestock and giving more attention to livestock than to crops. Agreements are made with other agriculturists but crop encroachment disrupts pastoral areas and limits access to water.
      - •. Subhumid and humid: as a result of population pressure and increased disease risk sedentary grazing is less common. Mostly found in regions where the population pressure is high or increasing. Part of the livestock is owned by outsiders.
2. Mixed systems: conducted by households where crops and livestock are more or less integrated components of one single farming system.

a. Mixed communal grazing: communal grazing areas are the principal feed resource base for livestock, crop residues are grazed and animals are kept in a kraal at night. Farmers remain crop farmers by profession. The principal production objective is to keep livestock as a savings account and to produce milk. Most cattle are kept in village herds.
b. Mixed systems using crop residues: crop residues are collected and conserved to feed livestock on the farm. Part of the year livestock are still grazed on communal areas. The composition of herds by species and animal type may be changed – more draught animals, relatively more goats, sheep grazing fallow and productive cattle on farms.

agricultural intensity. The proportion of mobile grazing livestock farmers decreases southwards and towards higher-intensity poles where a higher proportion of livestock is managed by crop agriculturists. Mobile and sedentary livestock owners contribute, de facto, to improved mixed farming practices (agreements with crop and mixed farming agriculturists). Cattle are mainly herded on communal lands. Crop residue (cotton grains, groundnuts) supplementation is practised at different levels of intensity. Tsetse are present throughout the area. Traditional ways to control disease include the widespread use of trypanotolerant cattle and pasture management with limited opportunities for the development of sound mixed farming practices. The development of agriculture around populated places gradually encroached tsetse habitat allowing for increased numbers of cross-bred cattle to survive. This led eventually to the introduction of new breeds, such as the Borgou in Benin, and the development of mixed farming. The droughts of the 1970s and 1980s forced a significant number of trypanosusceptible cattle to enter this area. Cattle survival is only possible with intensive use of curative trypanocidal drugs. Cross-breeding of trypanotolerant and trypanosusceptible cattle is increasingly practised.

- Coastal crop band (28 percent): crop-dominated systems in the humid south where population pressures are already high except in the forest zones. Here, small-scale and multispecies mixed systems prevail locally (chickens, pigs, small ruminants, trypanotolerant breeds, draught animals). Disease pressure is high and cattle densities are low. No major increases in cattle number are expected as a consequence of tsetse clearance. The capital cities of the coastal countries are located in this band creating opportunities for the development of semi-intensive and intensive (zero grazing) peri-urban livestock systems.

MAJOR PHYSICAL CONSTRAINTS TO AGRICULTURE

One step further in understanding the evolving livestock production systems and the integration of cattle and crop agriculture, should the tsete and trypanosomiasis constraint be removed, could be achieved by analysing the potential environmental risks of a further intensification. Based on a joint IIASA(International Institute for Applied Systems Analysis)–FAO data set (FAO/IIASA, 2000), major climatic and physical obstacles to agricultural activity were mapped (IAEA, 2002). When combined with agriculture intensity, such data layers help highlight areas where soil degradation is a major risk at the regional level.

Results obtained are summarized in Table 1 and areas where physical factors are major impairments to crop agriculture development are depicted in Figure 1, bottom map. In general more than one-third (38 percent) of the total land area in West Africa copes with some form of major physical constraint to agriculture. Poor soil fertility is the most common problem (more than 25 percent) further stressing the urgent need for improved mixed farming practices in the entire area.

In conclusion, the farming systems' analysis briefly outlined above revealed an important set of patterns. Livestock production systems appear not to be scattered but distributed in a band-like pattern throughout West Africa. The general agro-ecological setting, including climate and vegetation, appears to be the driving

TABLE 1
Percentage areas with major constraints per crop–livestock system

System	Slope	Soil texture	Soil depth	Chemical	Fertility	Drainage	Any physical constraint
	1.5%*	8.5%*	7.1*%	4.5*%	26.4*%	6%*	37.9%*
Southern crop band							
Moist perennial	1.8	1.3	3.6	2.4	75.3	4.3	78.7
Crops medium	1.6	4.7	6.1	4.5	49.4	8.1	56.1
Crops high	3.0	11.3	4.7	7.4	29.5	19.0	53.2
Pastoral arid plains							
Arid/semi-arid	0.2	31.3	15.6	13.6	15.8	15.7	40.1
Pastoral arid	0.4	18.9	9.5	12.1	12.3	11.8	34.3
Cattle systems							
Cattle medium	2.7	8.5	14.6	2.0	37.8	4.3	54.3
Cattle high	7.0	6.8	8.2	5.6	47.8	8.6	63.6
Mixed systems							
Mixed	1.6	9.8	7.2	4.5	18.6	5.8	35.7
Mixed cattle	3.2	10.0	9.3	5.3	19.3	10.5	42.6
Mixed crops	1.3	11.2	2.3	6.1	8.0	5.4	28.1
High intensity	2.7	6.0	4.7	5.6	20.2	5.5	34.4

* percentages mentioned in top row indicate total land area percent affected by respective constraint in West Africa

force behind this. The described analysis, i.e. spatial distribution patterns and levels of human density and livestock–agriculture intensity, contributes to a better understanding of the dynamics of production systems. Historically, livestock and crop agriculturists have developed different strategies to address the tsetse problem, for example, herd management and use of trypanotolerant domestic breeds together with trypanotolerant and trypanosusceptible crosses. Crop encroachment on tsetse habitat in areas of higher crop intensity and the widespread use of trypanocidal drugs allowed for influx of trypanosusceptible breeds in the semi-arid and subhumid agro-ecozones. Trypanotolerant livestock breeds are still the dominant breeds in the more humid agro-ecozone. These different agro-ecological settings should be duly considered in designing T&T control strategies.

Chapter 3

Tsetse ecology bands, a north–south gradient

The effect of climate and vegetation on tsetse ecology has been studied in detail since the 1930s (e.g. Nash, 1937; Buxton, 1955; Ford, 1963). In West Africa, as depicted in Figure 2, a series of climatic bands follow a north–south gradient ranging over less than 2 000 km from extreme arid (Sahara desert) to tropical rainforest and humid coastal conditions (Golfe de Guinée). The various tsetse species are adapted to different ecoclimatic conditions and this north–south climatic gradient affects their distribution dynamics and seasonal fluctuations that vary from:

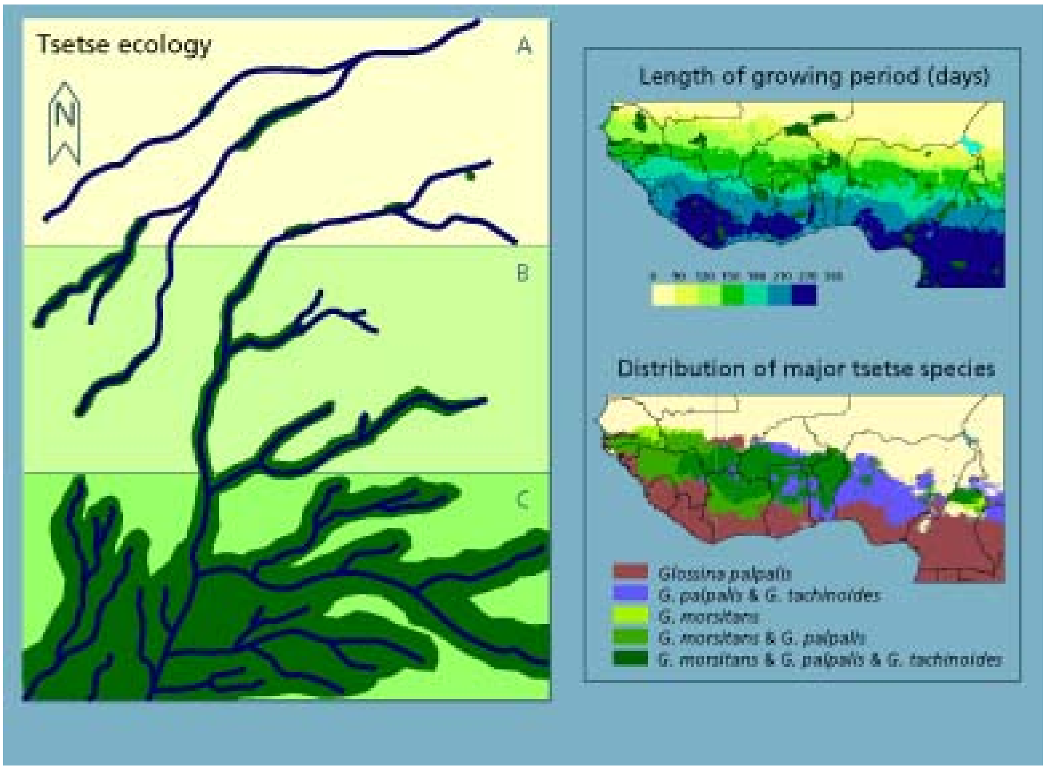
- heterogeneous to homogenous distribution patterns – fragmented to linear to widespread;
- restricted to riparian vegetation (forest galleries) to present in tree savannah valleys.

In the north (A), arid conditions prevent fly spread. Locally riparian vegetation constitutes suitable niches for localized, well-demarcated pockets of tsetse populations. Outside these favourable microclimates tsetse hardly survive and it would appear that there are no links between pockets (i.e. there are no population exchanges or population migratory fluxes) except occasionally and in spatially limited neighbouring areas during the rainy season.

In the intermediary band (B), climatic conditions and vegetation become gradually more suitable. Distinct fly pockets tend to merge and tsetse distribution patterns become more linear along main streams. Tsetse populations still remain concentrated in pockets during the dry season, but during the rains flies spread over larger parts of the river systems including important tributaries and savannah buffers.

FIGURE 2
Hypothetical north–south tsetse ecology gradient in West Africa, linked to climatic bands

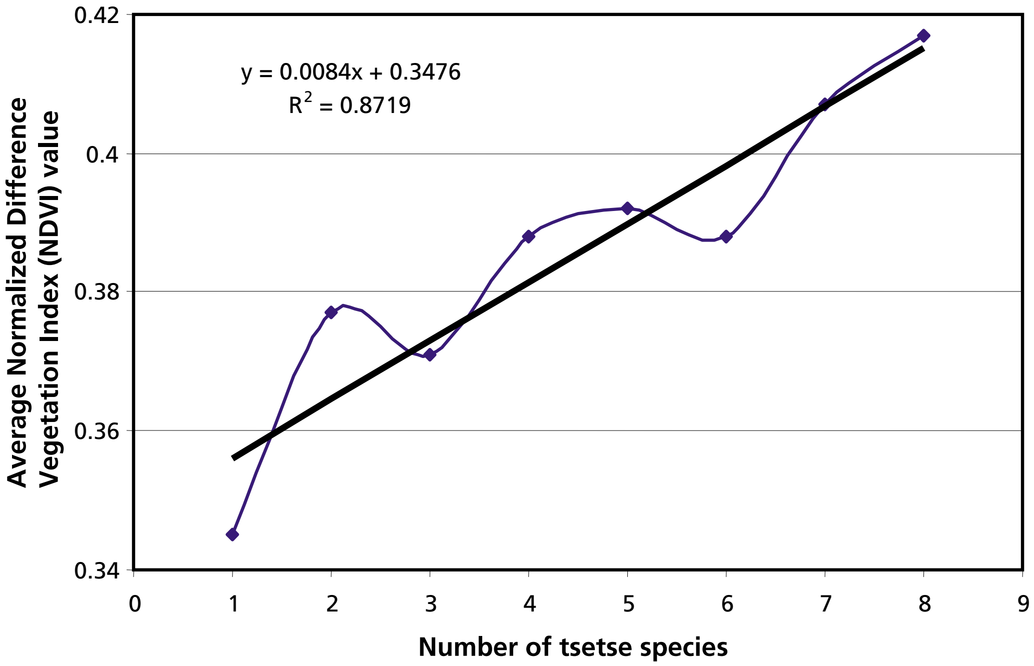
The maps on the right show length of growing period layers, i.e. number of vegetative days per year, as a surrogate for prevailing ecoclimatic conditions. The distribution of the three main tsetse species present in the dry northern band is also given.



In the humid south (C), there are no climatic limitations to fly distribution. Flies are no longer restricted to river systems but are also present in surrounding humid woodlands and forests. Seasonal variation has a greater affect on fly numbers than actual spatial distribution patterns.

In the more humid parts of West Africa, the wide range of favourable climatic conditions (rainfall, humidity and temperature) and the ubiquitous availability of water favour a great variety of suitable tsetse habitats. Though it has been shown that minimal changes in climatic data sets may influence both tsetse distribution limits (Rogers, Hay and Packer, 1996) and abundance (Hendrickx et al., 2001b), tsetse tend to be more widespread when compared to the

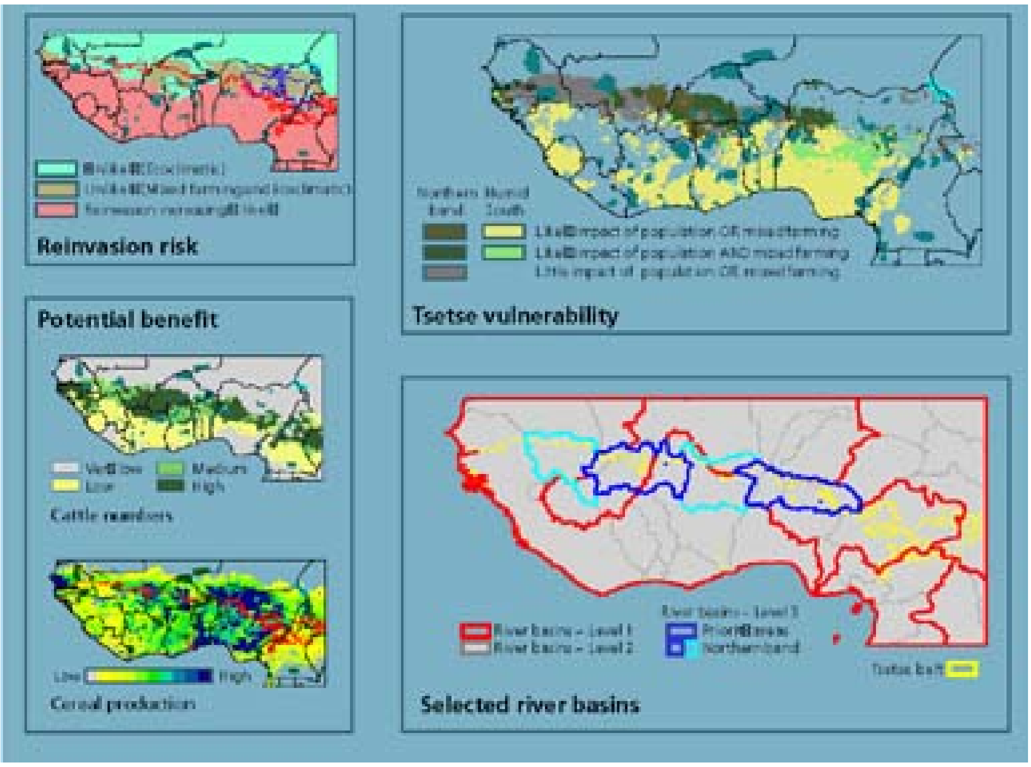
FIGURE 3
Relationship between vegetation and number of tsetse species
(sub-Saharan Africa)
A strong positive correlation between increasing vegetation activity and biodiversity is shown.



dry northern part. In the latter area the presence of tsetse, within their distribution range, is more markedly restricted to suitable vegetation patches and by seasonal vegetation changes. In addition, the number of tsetse species (biodiversity) tends to increase with more luxuriant vegetation conditions (see Figure 3).

Furthermore, these favourable conditions, combined with the impact of agricultural activities and the number of tsetse species involved, make the dynamics of various fly populations complex. Savannah and forest flies are more sensitive to encroachment of their habitat by agricultural activities, like fuelwood gathering, as well as the reduction of natural host populations because of poaching (Nash, 1948). With regard to riparian species, it has been shown in Togo (see case study reported in Chapter 4) that while in the northern part of the country higher agricultural density activity contributes to reduce significantly the presence and abundance of Glossina tachinoides, in

FIGURE 4
FAO–IAEA desk study to select priority areas for area-wide vector eradication in West Africa
See Box 3 for additional information



the humid south, at comparable levels of agriculture intensity, G. palpalis palpalis is far less affected (Hendrickx et al., 1999a).

In turn, human activities including crop and livestock agriculture may create new habitats favouring the persistence of peridomestic fly populations that are difficult to detect and may act as major foci for both human and animal trypanosomiasis. Fly populations may also be preserved locally in protected holy forests (Hendrickx et al., 1999a) and in areas where the soil structure is not suitable for agriculture (de la Rocque, 1997) thus maintaining epidemiological hot spots (see the case study reported on page 35).

Different settings between humid southern and dry northern West Africa call for an adapted approach. While area-wide vector and disease management may be part of the answer in the north, in the

BOX 3
Selection of areas for area-wide vector removal (FAO–IAEA desk study)

Tsetse vulnerability

Climate: tsetse populations are likely to be more fragmented and easier to remove permanently in the northern dry band. In addition, reinvasion is less likely because gaps of adverse conditions prevent fly dispersal. For this study the limit of this “dry band” was empirically set to a Length of Growing Period (LGP) of 170 days.

Human population and land-use pressure: with increasing human population, the number of natural tsetse hosts will drop and an increasing amount of the fly’s habitat will be cleared through cultivation and fuelwood consumption. As a result tsetse populations are expected to drop and/or previously continuous distributions may become fragmented. This was modelled by overlapping areas of (i) expected high human population impact (Reid et al., 2000) and (ii) predicted high cropping intensity and livestock densities (PAAT-IS). It is important to mention that agricultural practices might create new habitat types, especially for riparian tsetse. Nevertheless such habitats are expected to be relatively isolated and therefore vulnerable once identified.

Reinvasion risk

Reinvasion pressure in at least part of the northern band of the fly belt is likely to be low due to: (i) vector populations being restricted to isolated pockets in an otherwise marginal habitat, (ii) interrupted linear vector distribution patterns due to habitat restrictions and (iii) reduction of reinvasion pressure due to high land-use pressure.

Historically, similar conditions have occurred in northeastern Nigeria where flies were removed from a large area, and even without barriers reinvasion has been very limited; human-induced activities and land pressure de facto prevented reinvasion (Bourn et al., 2001).

Fly reinvasion risk was modelled for West Africa based on observed climatic and mixed farming patterns of the Nigerian cleared areas.

Potential benefit

- Cereal production: FAO–IIASA data.
- Livestock production: potential impact on livestock numbers should tsetse be removed (PAAT-IS).

Selected river basins

River basins were identified as "vector control" units. River basin clusters within areas of high tsetse vulnerability, low reinvasion risk and high benefit were earmarked as priority areas for area-wide vector eradication.

south more complex situations may need more integrated answers. This viewpoint was adopted in an FAO–IAEA-funded desk study aiming at identifying priority areas for trypanosomiasis management. A summary of results obtained in the study is shown in Figure 4. This desk study was based on a set of assumptions (see Box 3). Area-wide vector suppression eventually leading to elimination should focus on areas where:

- tsetse are most "vulnerable" at the fringe of their distribution limits;
- reinvasion risk is minimal and/or manageable;
- potential benefit is maximal.

Chapter 4
Case studies

In the past decade a series of relevant field studies were conducted that contribute to the understanding of West African fly ecology and spatial epidemiological patterns: the Togo national study, the study of the Sideradougou pastoral area in Burkina Faso and the Mouhoun river basin study in Burkina Faso.

TOGO

The Togo study was conducted during the 1990s as part of a Belgium-funded FAO trypanosomiasis control project (GCP-TOG-013-BEL). The holistic approach developed to collate field data on flies, disease and cattle at a 0.125 degree resolution across the country provides us with a unique data set for analysis (Figure 5). Published results include an analysis of fly distribution patterns (Napala et al., 1995; Hendrickx et al., 1999a), the study of the spatial epidemiology of trypanosomiasis in the wider sense (Hendrickx et al., 1999b), the mapping of trypanotolerant breeds (Hendrickx et al., 1996; Dao, 1998) and the use of remote sensing to contribute to the reduction of field surveys for tsetse (Hendrickx et al., 2001b) and trypanosomiasis (Hendrickx et al., 2000). Based on these results a georeferenced decision-support methodology for trypanosomiasis management was developed (Hendrickx et al., 1997, 1999b, 1999c; Hendrickx, 1999).

Spatial epidemiology

The traditional response to trypanosomiasis in West Africa has been trypanotolerance (Hoste et al., 1988; Hoste, 1992) and grazing management allowing cattle raising without the need for constant or regular veterinary care in tsetse-infested areas. Results

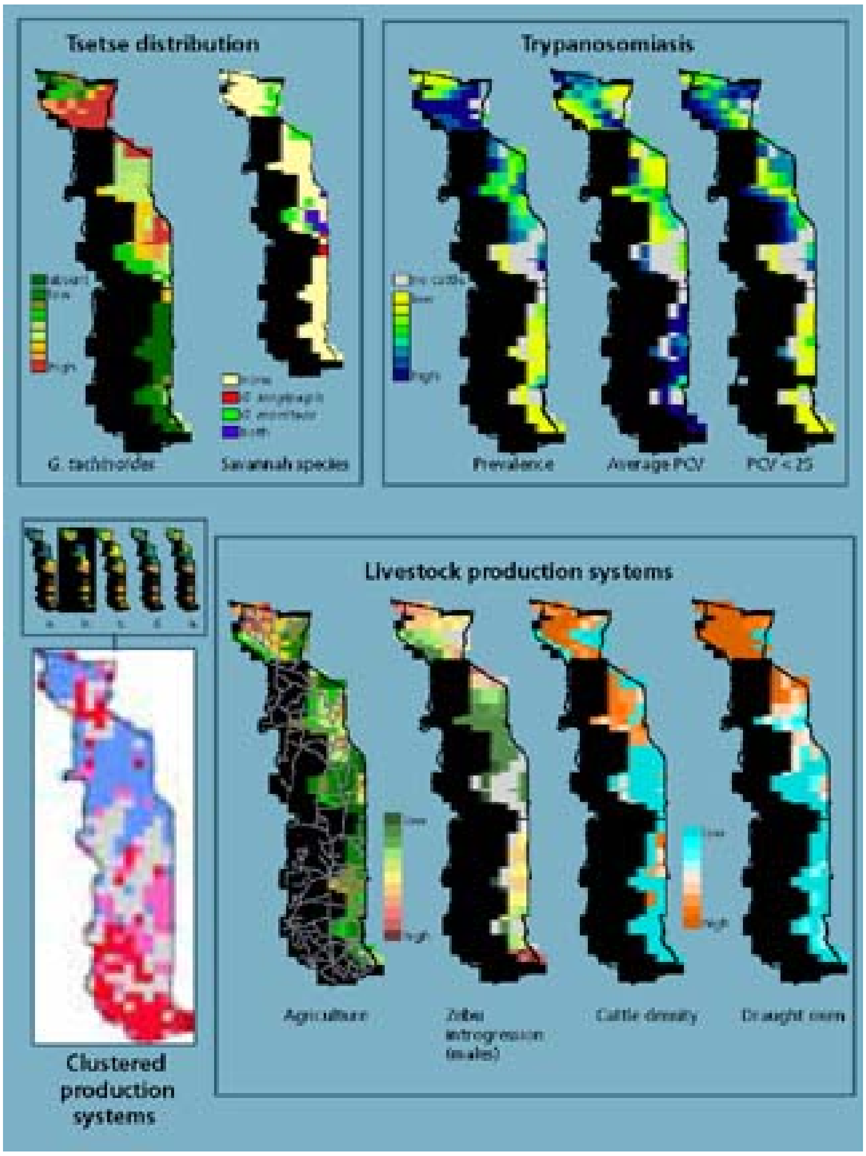
FIGURE 5

Summary of Togo data set

Tsetse distribution: Examples given are the abundance of G. tachinoides and presence of G. m. submorsitans and G. longipalpis. Not depicted: G. palpalis palpalis follows a mirror abundance pattern compared with G. tachinoides and both forest species, G. fusca and G. medicorum, are present in suitable vegetation patches within the distribution range of G longipalpis.

Bovine trypanosomiasis: The combined prevalence of Trypanosoma vivax, T. congolense and T. brucei; the average herd packed cell volume (PCV), a measure of anaemia (a major symptom of trypanosomiasis); the percentage of anaemic animals = cattle with a PCV below 25.

Livestock production systems: Left-hand map: cluster analysis showing in blue a rural traditional system, in red a market-oriented system and in pink intermediary systems. The latter was obtained by unsupervised clustering of the five variables depicted in the top maps: (a) cattle numbers, (b) cattle per herd, (c) owners per herd, (d) percentage of rural owners, (e) percentage of rural owners being agriculturists. Right-hand maps: agriculture intensity – percentage of land in the cultivation cycle; Zebu genes introgression – percentage of reproductive males with a Zebu phenotype; cattle density; draft oxen density.



discussed in the Togo spatial epidemiological study (Hendrickx et al., 1999b) suggested that trypanotolerant taurine cattle did indeed make a contribution towards reducing the impact of the disease in Togo, but this still did not enable farmers to exploit fully the production potential of their cattle. The presence of tsetse in the country remained a major obstacle to cattle raising and particularly constrained mixed farming development and intensification (Figure 6a and b). As a comparison, data from outside the tsetse belt (Mali, the Niger, Nigeria, the Sudan and Chad) show a very strong positive relationship between sedentary cattle densities and agriculture intensity levels (Wint and Bourn, 1994).

Also of particular relevance was the fact that riparian tsetse appeared to be less susceptible to crop encroachment in the humid south (1 300 mm annual rainfall), i.e. densities of G. p. palpalis remained high and unrelated to cropping intensity levels, while 600 km up-country in the dry northern part of Togo (1 000 mm annual rainfall) G. tachinoides densities dropped with increasing cropping intensity levels.

Livestock production systems

The distribution of animal husbandry systems was analysed (Figure 5). Obtained spatial patterns revealed two major systems (Hendrickx et al., 1999b): (i) a traditional extensive village system, prevailing in the northern half of the country, where cattle owned by a group or family are a patrimony for future generations. This system may or may not include the presence of draught oxen, and (ii) a semi-modern, more market-oriented system where ownership is often individual (civil servants, traders) and savings are invested in cattle. This analysis did not include the seasonal presence of transhumance cattle herds.

Interestingly, the difference between the two systems also depends on the proportion of trypanotolerant taurine cattle out of total cattle. There was a higher proportion of taurine cattle in the traditional rural system while cross-bred were more numerous in the market-oriented system. This difference between the data sets was

FIGURE 6A
PCV and cattle density

PCV categories are: <25 (n=9), 25–26 (n=14), 26–27 (n=29), 27–28 (n=63), 28–29 (n=23), >29 (n=7). Significance: R=0.972, n=6, p=0.0012.

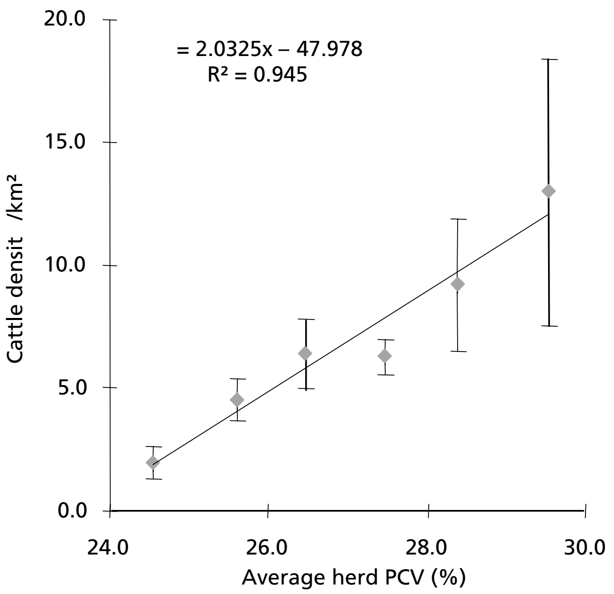
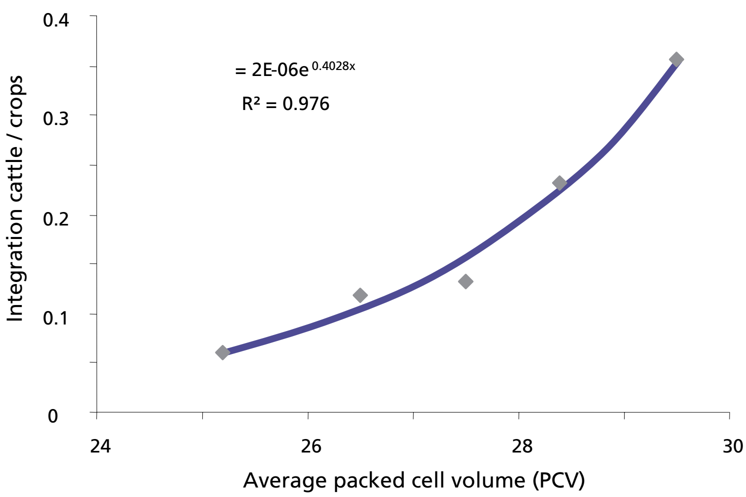


FIGURE 6B
PCV and the integration of cattle and crops

PCV categories are the same as in as Figure 6a. The association between crop agriculture and cattle is defined as the slope from the linear regression of agriculture against cattle density per PCV category. Agriculture is expressed as the percentage of land cultivated as digitized from maps derived from aerial photographs (UNDP, 1984). Regressions are (from low to high PCV): (1) y = 0.0602x + 1.4335 (R^2=0.135, p<0.01), (2) y = 0.1188x + 1.387 (R^2=0.097, p<0.01), (3) y = 0.1324x + 0.2756 (R^2=0.215, p<0.001), (4) y = 0.2323x – 2.3546 (R^2=0.1512, p<0.01), (5) y = 0.3566x + 3.5711 (R^2=0.3687, NS).



particularly true for bulls, highlighting distinct purpose-oriented livestock management strategies and different levels of risk taking, i.e. the risk of diluting trypanotolerance in a tsetse-infested area, once given access to veterinary inputs.

Decision-support systems

The results summarized above clearly stress the fact that trypanosomiasis management should not simply be regarded as a stand-alone animal health problem. Any control measure should be adapted to the animal husbandry system, and integrated into the wider perspective of the improvement of basic animal health and production, including the use of trypanotolerant breeds, and the integration of livestock and crop agriculture.

Hence the developed decision-support system integrates these various aspects (Hendrickx et al., 1997, 1999c; Hendrickx, 1999). A first model was developed to set priorities for trypanosomiasis management (Figure 7 top maps), i.e. veterinary follow-up of valuable cattle in rural systems (e.g. draught oxen) and of market-oriented (mainly cross-bred) herds. The resulting map (Output 1) highlighted areas where improved animal health follow-up should be of major concern. The second model looked at priorities to boost mixed farming practices (Figure 7 bottom maps) and is mainly relevant for rural systems. The resulting map (Output 2) highlighted areas where removal of existing disease constraints, in which trypanosomiasis prevails, might benefit most the development of mixed farming practices. Finally, particular care should be taken with regard to environmentally fragile areas, i.e. areas where the level of soil degradation is such that the further development of livestock activities, should trypanosomiasis control be a success, may result in irreversible environmental damage.

This problem was addressed during a pilot study (Van Camp, Biesemans and De Wulf, 1999; Van Camp et al., 2002) conducted in two areas in the northern part of Togo (Figure 8). Using a data set derived from ground validated satellite imagery (Landsat TM) and other physical land-resource databases, a mathematical model based

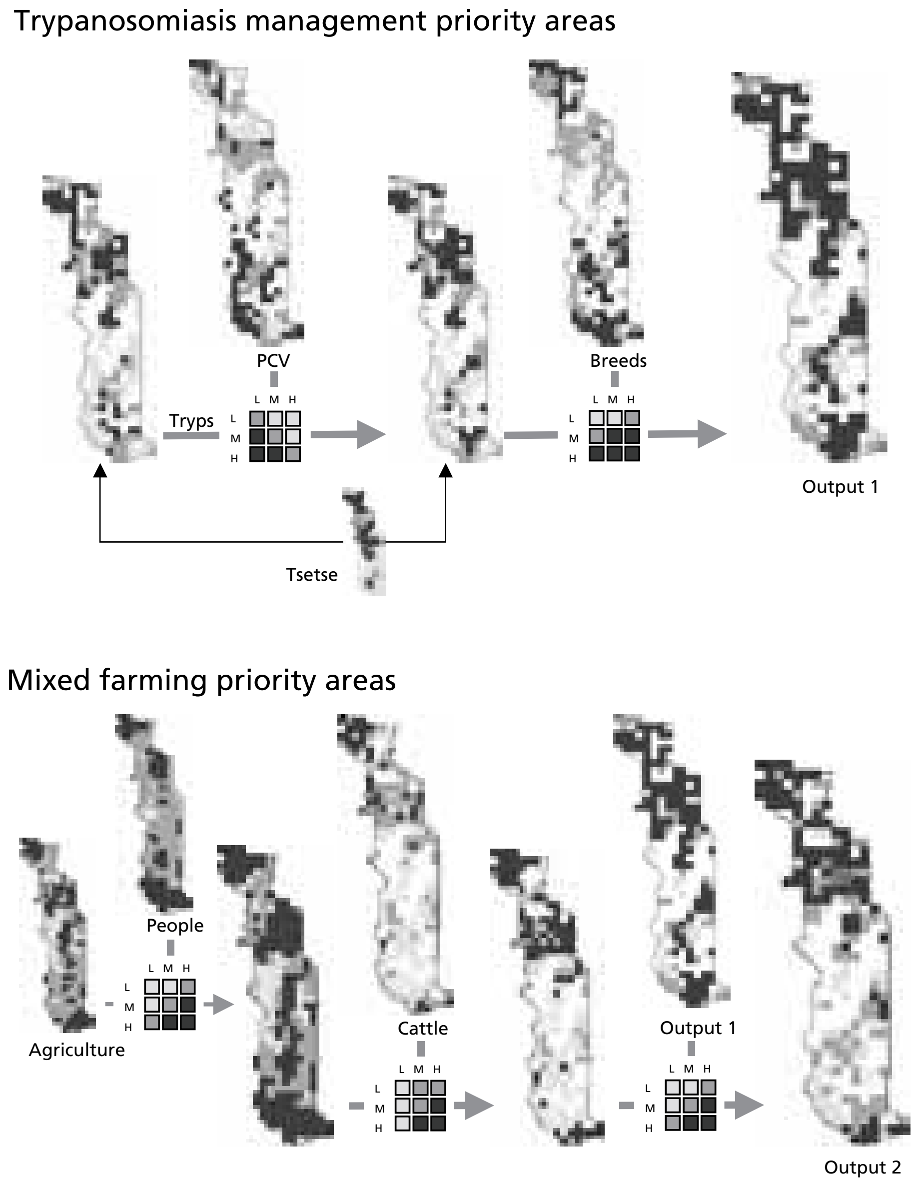
FIGURE 7

Example of a developed data-driven decision-support GIS

In the first set of maps priorities are set for trypanosomiasis management. First, spatial data about trypanosomiasis and anaemia are cross-tabulated pixel by pixel to produce a new map depicting basic animal health conditions. This map is then corrected for breed factor (trypanotolerance) to produce Output 1, a measure of need (i.e. priority areas) for veterinary follow-up per pixel. This information is applicable to individual market-oriented herders willing to invest in herd and/or individual treatment schemes.

The second set of maps shows priority setting for T&T control depending on farming systems. First, mixed farming systems are identified by combining spatial data on population density, agriculture intensity and cattle densities. This map is cross-tabulated with the output of the previous model to highlight priority areas for T&T control in mixed farming areas, where the cost–benefit ratio is expected to be highest (Output 2).

See Hendrickx (1999) for more information.



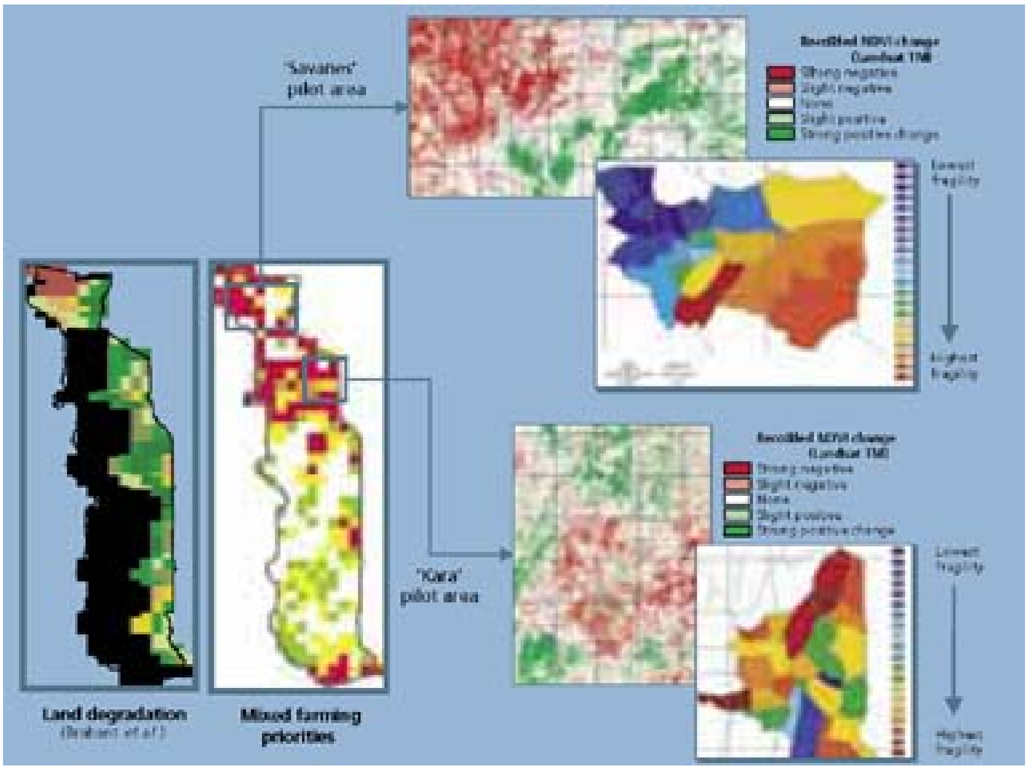
on fuzzy relational computation was developed. As a result cantons, the smallest administrative unit, chosen as “application units”, could be ranked according to their environmental fragility (Figure 8), further refining the decision-making process. It is important to highlight here that the interpretation of results of this type may not always be as straightforward as it appears. “High environmental fragility” does not necessarily mean, “refrain from control of trypanosomiasis”. On the contrary, it may suggest, “improve the integration of livestock and crop agriculture towards environmentally more sustainable practices”. Sustainable practices include sound trypanosomiasis management.

These various results provided evidence of the importance of planning adapted T&T control activities at a national level (Hendrickx et al., 1997; Napala et al., 1999; Batawui, 1999; Kouagou et al., 2000; Hendrickx, Batawui and De Deken, 2002; Bastiaensen et al., 2003; Batawui et al., 2003).

- National trypanosomiasis extension campaign
  - Target population (nationwide trypanosomiasis management priorities, Figure 7, top maps): draught oxen, market-oriented herds and advanced village herds.
  - Method: series of posters depicting extension topics such as: (i) tsetse and trypanosomiasis, (ii) diagnostic-driven trypanocidal treatment, (iii) draught oxen and (iv) options for tsetse control (pour-on, insecticide-treated targets). These posters were used as a basis for household discussions led by trained extension workers and/or private veterinarians.
  - Implemented by: private rural veterinarians – self-installed but promoted by the project – as well as official extension workers and existing “barefoot veterinarians”, in areas not covered by private veterinarians.
  - Results obtained: important reduction in trypanosomiasis prevalence, less spectacular results on average herd health.
- Integrated T&T control
  - Target population: selected village clusters in mixed farming priority areas.

FIGURE 8
Togo: Assessment of priority areas for trypanosomiasis control using remote sensing and fuzzy logic

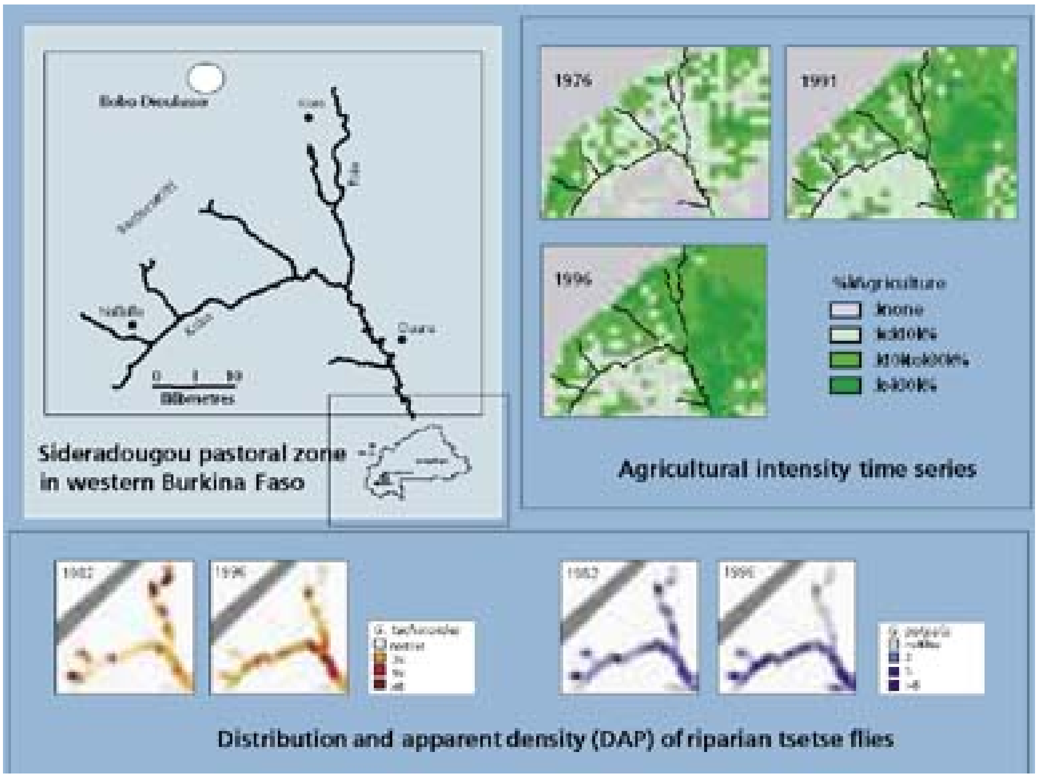
Natural phenomena, like the fragility of the environment, rarely have crisp boundaries and therefore cannot be approached in the classical way with binary logic (fragile or not: 0 or 1). With fuzzy logic, entities are allowed to have a partial membership to a class, which is assigned by membership functions. In the Kara and Savanes experimental regions (northern Togo) a methodology based on this technique was developed to define the fragility of application units and according priority for trypanosomiasis control. The variables per unit were derived from satellite images (see Landsat TM maps below) and physical land resources were stored in a relational database. The attributes were converted to fuzzy values between 0 and 1 (characteristic matrix) depending on the degree of environmental stability enhancement per unit and the units were ranked according to their fragility, yielding state-of-the-art information for decision support (see respective maps of ranked administrative units). See Van Camp, Biesemans and De Wulf, 1999 and Van Camp et al., 2002 for more information.



– Method: community participatory approach combining regular veterinary follow-up and epicutaneous use of insecticide (pour-on technique) scheme.
– Implemented by: community supervised by private and government veterinarians.
– Results obtained: while the application of insecticide on cattle in small village clusters was successful in controlled

FIGURE 9
Sideradougou spatial data set (Part 1)

Map showing the geographical location of the Sideradougou pastoral area in western Burkina Faso. A time series is given showing the evolution of agriculture intensity (percentage of land under cultivation) derived from aerial photography (1976) and Landsat TM satellite imagery (1991 and 1996). Observed riparian tsetse densities are compared for two surveys conducted using identical high intensity trapping techniques, i.e. one biconical trap per 100 m riparian vegetation.The surveys were conducted in 1982 (Cuisance et al., 1984) and 1996 (de la Rocque, 1997).



experimental conditions (Batawui, 1999; Hendrickx, Batawui and De Deken, 2002; Batawui et al., 2003), in practice pour-on schemes required permanent monitoring to compensate for organizational problems at the village level (Bastiaensen, personal communication).

BURKINA FASO – SIDERADOUGOU AGROPASTORAL AREA

The Sideradougou agropastoral area (1 200 km², Figure 9) is situated south of Bobo-Dioulasso in western Burkina Faso, and is representative of the Sudanese ecoclimatic zone, with wooded savannah and bushy riparian gallery along the riverbanks. Because of a significant curve of the isohyets in the medium longitudes of West Africa, and despite comparative latitudes, this area is more humid than northern Togo.

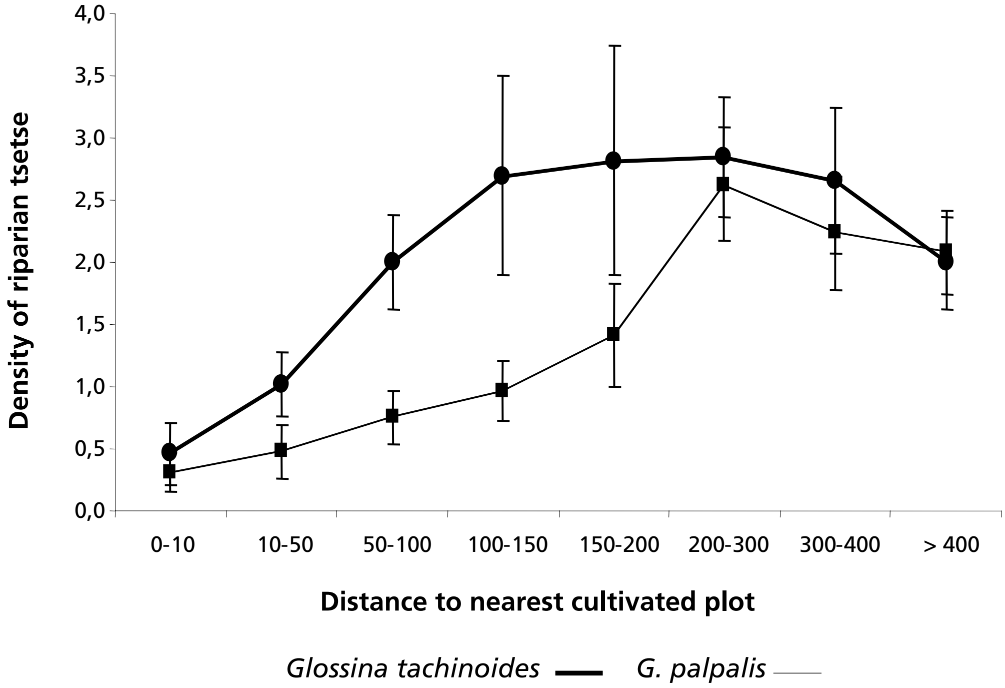
Comparative analysis of remote sensing data showed significant land-use pattern changes over the past 20 years owing to increasing demographic pressure and immigration. This effect was mainly noticed in the eastern part, which is under considerable pressure from agricultural activities (Figure 9) such as cotton growing, a major cash crop. Savannah flies, G. morsitans submorsitans, the most sensitive species to crop encroachment, disappeared from the area and only riparian fly species (e.g. G. p. gambiensis and G. tachinoides) persist. The description of their distribution patterns was the initial objective of the “Sideradougou project” conducted between 1996 and 2000 in collaboration between the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and the Centre International de Recherche-Développement sur l’Élevage en Zone Subhumide (CIRDES) (de la Rocque et al., 2001a).

Change in riparian tsetse distributions with cultivation

The 1996 study was based on an ecological and entomological survey during the dry season. Along 120 km of the major river systems, biconical traps were placed at 100-metre intervals. All the results were integrated in a geographical information system. For each separate trap site, densities of riparian flies were correlated to ecological characteristics of the habitat (vegetation, river beds, water-flow patterns) and the most favourable habitats were identified for each species (de la Rocque, 1997).

Results obtained were compared with results from a similar survey conducted in 1982 (Cuisance et al., 1984) and tsetse distribution and abundance changes were related to environmental changes (de la Rocque et al., 2001b). Briefly, substantial and contrasting differences in tsetse fly distribution and density were observed along the river systems (Figure 9). On the western branch of the Koba river (Nakaka area), populations of both riparian species (G. tachinoides and G. p. gambiensis) were quite similar in terms of density and

FIGURE 10
Correlation between apparent densities (Y axis) of Glossina tachinoides (thick line) and Glossina palpalis gambiensis (thin line) and the distance in metres from the nearest cultivated plot (X axis) in the Sideradougou area, 1996



distribution between 1982 and 1996 whereas on the eastern branch (Ouara area), an increase of more than 2.5 times for G. tachinoides and 1.5 times for G. p. gambiensis occurred. Along the Tole river, G. p. gambiensis had almost disappeared while G. tachinoides was still found, although at reduced densities.

These contrasting tsetse dynamics between the Tole and eastern Koba river systems were surprising, considering both rivers run in areas of similar land-use intensity levels. Analysis revealed that tsetse density reductions were related to cropping distance from watercourses (Figure 10).

This strong link between localized agricultural development and impact on tsetse is not only due to direct human activities (wood cutting, hunting, drawing of water, use of insecticides), but also, and maybe mainly, to indirect impact induced by amplification of rainwater runoff. Land clearance and reduced plant cover exacerbate the effects of rainfall, which rapidly modifies the soil microstructure, renders it less permeable and finally exacerbates runoff (Riou, 1990). This favours riverbank erosion and the uprooting of riverside trees, essential components of riparian tsetse habitats.

This pattern of erosion was observed when the distance between the rivers and the cultivated plots was approximately ten metres. It was particularly marked along the Tole river. The resulting gaps in tree cover reduce the buffer effect played by the vegetation in relation to the drier conditions in the savannah and modify the abiotic conditions within the galleries. These changes in tsetse fly population dynamics as a whole can lead to the local disappearance of a fly species, as was observed with G. p. gambiensis. On the other hand, G. tachinoides seems better suited to forest environments transformed by human activity.

This situation contrasted with the conditions along the eastern branch of the Koba, where the cultivated plots were 300 metres or more from the river. The difference of valley landscape was mainly due to differences in soil characteristics. The Tole drainage system has good soils for cropping that extend close to the river. In contrast, on the Koba river alluvial soil formation, known as “yellow bank soil”, is a capping loamy soil that is difficult to till (Guillobez, 1979). As a consequence of the limited expansion of agriculture nearby the river, the gallery forests were not degraded. In such conditions, if habitat is preserved, increase of human and cattle densities may even favour tsetse presence by increasing feeding opportunities.

In conclusion, studies at various scales are required to forecast correctly tsetse distribution and abundance (Hendrickx et al., 2001a). Global analysis of land use is very useful, especially for the savannah species. For the riparian species, results from the Sideradougou study highlight the importance of local factors measured at high spatial resolution.

Contrasting epidemiological patterns at the herd level

Dissection of tsetse, and polymerase chain reaction (PCR) analysis of the infected organs, showed that infection patterns differ locally

TABLE 2
Epidemiological differences between eastern and western Sideradougou

	Eastern (n=524) (percentage)	Western (n=330) (percentage)
Midgut infections [1]	20.0	65.5
Proboscis infections	64.2	22.7
PCR identification rate	84.2	33.5
Blood meals [2] on ruminants	42.8	21.2
Blood meals on pigs	26.5	29.7
Blood meals on reptiles	16.9	36.4

[1] Parasites were identified using polymerase chain reaction (PCR). The PCR identification rate is the percentage of samples. recognized by the specific PCR primers for the parasites known in the area. Samples that have not been identified are considered as non-pathogenic parasites for cattle, e.g. reptile trypanosome species.
[2] Blood meal analysis was carried out using the enzyme-linked immunosorbent assay (ELISA) method.

(Table 2) (Lefrançois et al., 1998). In areas where agricultural activity density is low (western Sideradougou), tsetse flies frequently feed on wild reptiles (monitor lizards or crocodiles) and rarely carry pathogenic trypanosomes. In areas with more dense agricultural activity (eastern Sideradougou), most flies feed upon cattle and pigs, and are highly infected by pathogenic parasites. Riparian tsetse flies appear to be opportunistic feeders, showing little host preferences and feeding on the most available host. This opportunism governs the interaction between vectors, domestic hosts and parasites. Consequently, entirely different epidemiological patterns may occur in areas only a few kilometres apart (de la Rocque, 1997).

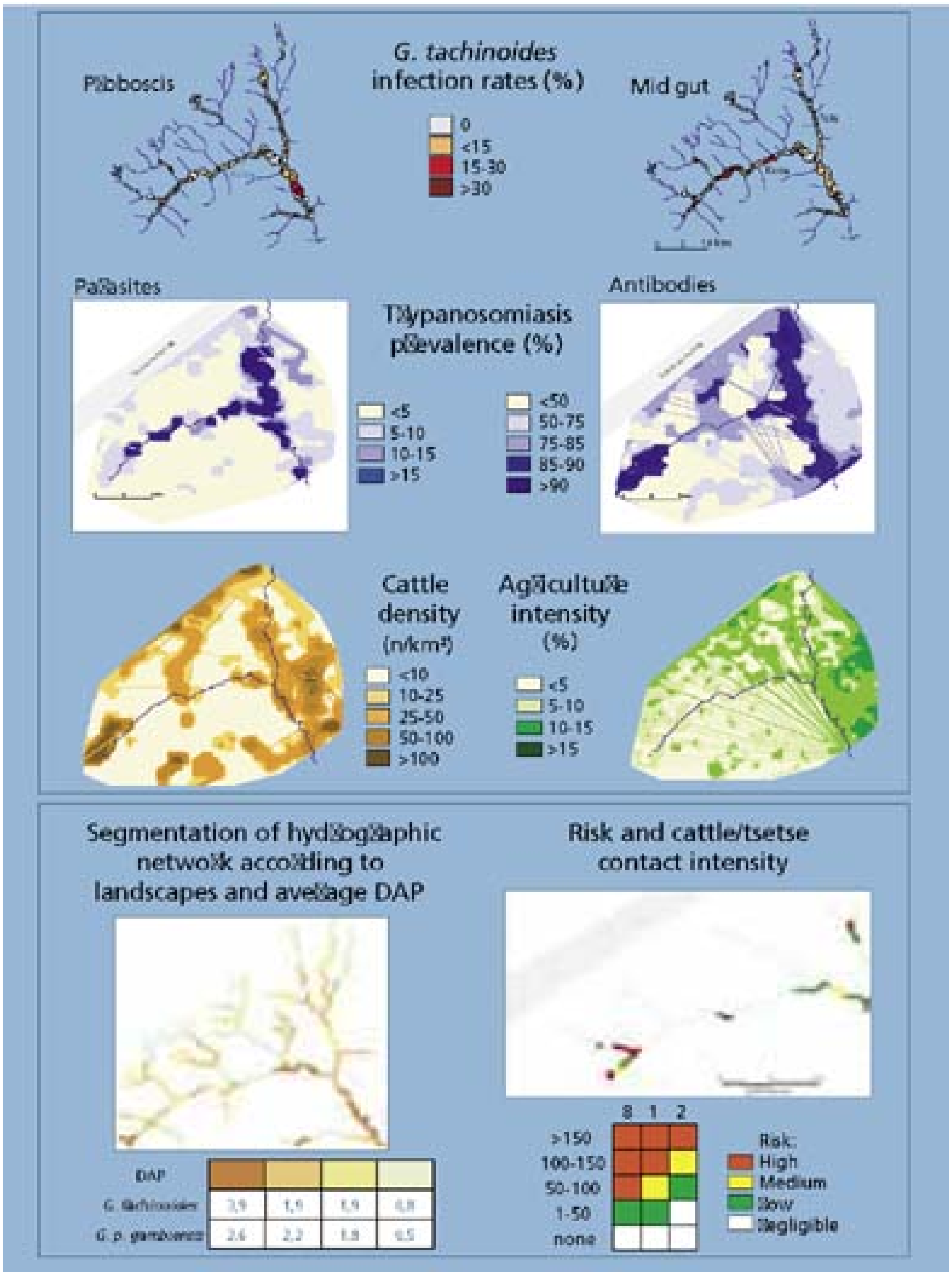
A multidisciplinary approach to risk evaluation

Very different epidemiological situations thus occur on a fine scale. The risk of transmission primarily depends on the intensity of contact between hosts and vectors (de la Rocque et al., 1999). All the factors influencing this contact in time and space have to be considered (Laveissière, Couret and Hervouet, 1986). Some of these factors are related to the physical environment (riparian vegetation, structure of the rivers, geomorphologic profile, distribution and abundance of tsetse flies) and others to human activity (agricultural occupation, breeding systems, pastoral management). Epidemiological hot spots,

FIGURE 11

Sideradougou spatial data set (Part 2)

Chosen spatial epidemiology data about vectors, host and environment are given in the first series of maps. The second series shows how a combination of spatial epidemiology data sets can contribute to highlight risk (epidemiological hot spots), and therefore priority areas at the village level.



i.e. major disease transmission foci areas, might thus only accurately be revealed through a multidisciplinary approach that includes all major components of the agro-ecological and socio-economic systems involved (de la Rocque et al., 2001a).

Towards highlighting epidemiological hot spots

To reveal these epidemiological spots, a model was proposed using GIS and spatial analysis tools.

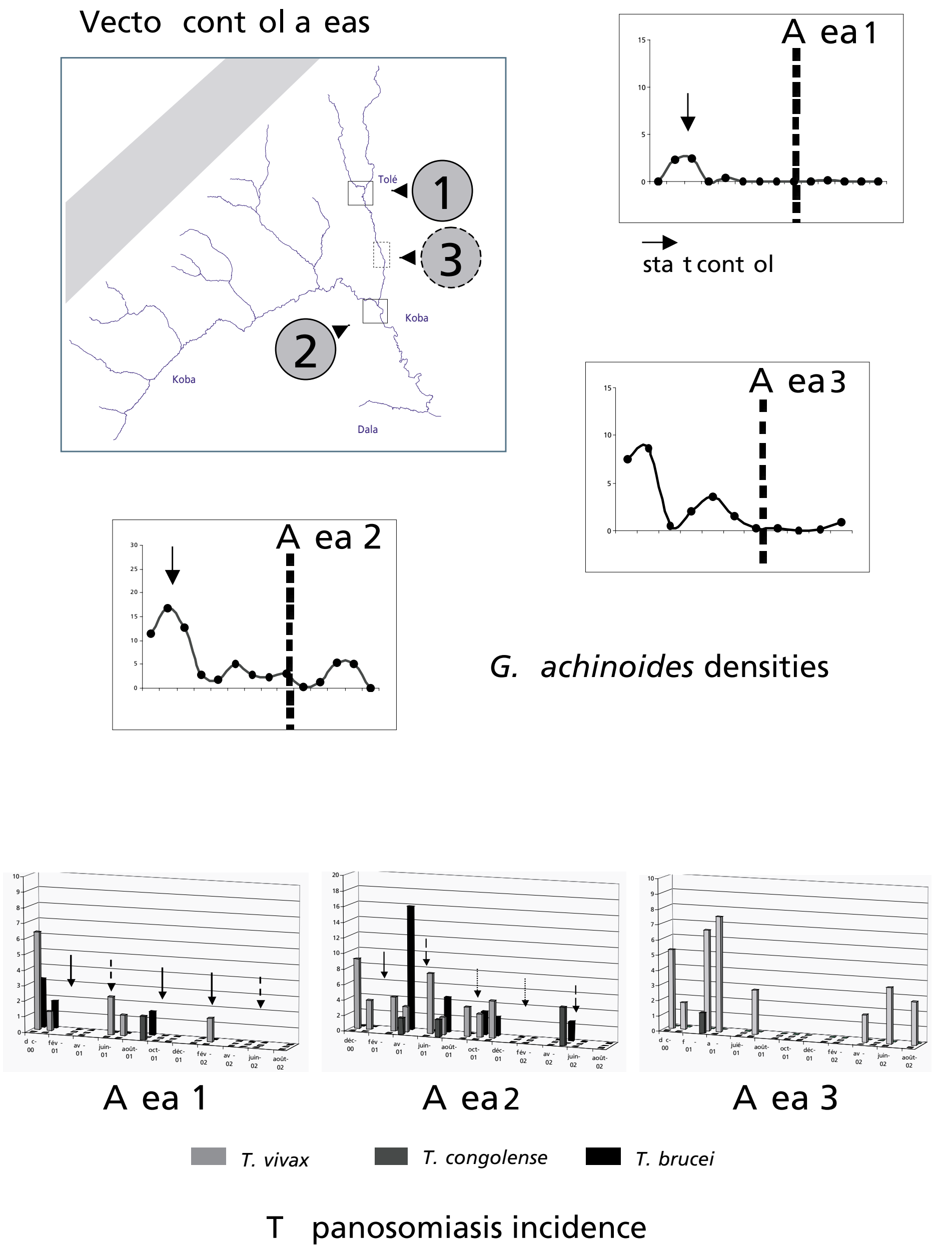
- The most favourable habitats for each of the two species of riparian flies were identified using high-resolution remote sensing data (SPOT XS). However, at this scale forest galleries remain difficult to characterize because their width (from 20 to 40 metres) is often at the limit of the satellite resolution. Therefore a more general approach aiming at landscape recognition within valleys was developed and allowed us to segment the whole river network according to identified valley types. The most suitable landscapes for tsetse were recognized (see Figure 11).
- In parallel, an exhaustive and georeferenced census of all the stockbreeders, agropastoralists and farmer settlements was carried out in the field. Breeding systems were characterized and grazing areas were assigned to each of the settlements (Michel et al., 1999). These areas take into account the various breeding practices and in particular water management. A model was developed to establish a map of spatial distribution of cattle in the area (Figure 11).
- The overlay of tsetse and cattle layers revealed major host–vector interaction sites (i.e. host–vector interface) (Figure 11). It was concluded that, of the 120-km river system prospected in this study, 15 percent of it appears to harbour higher disease transmission risk (de la Rocque et al., 2001a).

The relevance of these results was validated by comparing identified epidemiological hot spots with the PCR dissection results and with parasitological and serological prevalence studies (Figure 11) (Michel et al., 2002). There are significantly more flies infected by the three

FIGURE 12

Sideradougou vector control

Vector control areas and observed Glossina tachinoides densities following integrated T&T control in identified risk areas. In the first site, tsetse densities rapidly dropped below recordable levels. In the second, less fragmented site, though tsetse densities decreased, a low level of tsetse activity persisted. This is probably due to fly inflow from adjacent habitats. More surprisingly, flies also decreased in the intermediate site, where no control was conducted, suggesting a distant impact of control. Control sites, well outside the area under consideration, confirmed that this decrease was not due to climatic reasons. Similar curves were obtained for Glossina palpalis gambiensis. The trypanosomiasis incidence in sentinel herds for each control area is also given. In the three sites, parasitological pressure decreased after a few months of tsetse control. During the second year, infections were sporadic.



species of pathogenic parasites in the red zones. This translates into a four-fold risk increase for cattle living or entering in the red zones.

Vector control in targeted areas

This study revealed that different epidemiological situations occur at the kilometre scale. This diversity is related to the narrow ecological requirements of the riparian flies, which are localized in circumscribed habitats. At this scale the actual rate of vector–host contact appears to be more determinant than fly density alone for risk evaluation.[6] This finding may be of particular benefit with regard to fly control. To test this hypothesis a pilot trial was conducted during the last two years. The aim was to focus control operations only on identified epidemiological hot spots.

The developed control strategy was based on two principles:

- tsetse control aimed at suppression of tsetse populations below the threshold level where parasites cannot circulate thus leading to a significant decrease of infection prevalence in cattle;
- tsetse control was conducted only in identified epidemiological hot spots where rural populations do experience a trypanosomiasis problem, a prerequisite to obtain community involvement and a major factor for reducing costs of an eventual disease control campaign.

Two fly/disease control methods were integrated:

- impregnated targets along the drainage line at intervals of 100 metres, covering 2 or 3 km of the hot spot;
- epicutaneous treatment with pour-on formulations (live bait technique) of sedentary cattle visiting the hot spots daily.

The latter method was used only during the rainy season, when the tick burden is at its peak and may constitute an additional incentive to livestock holders.

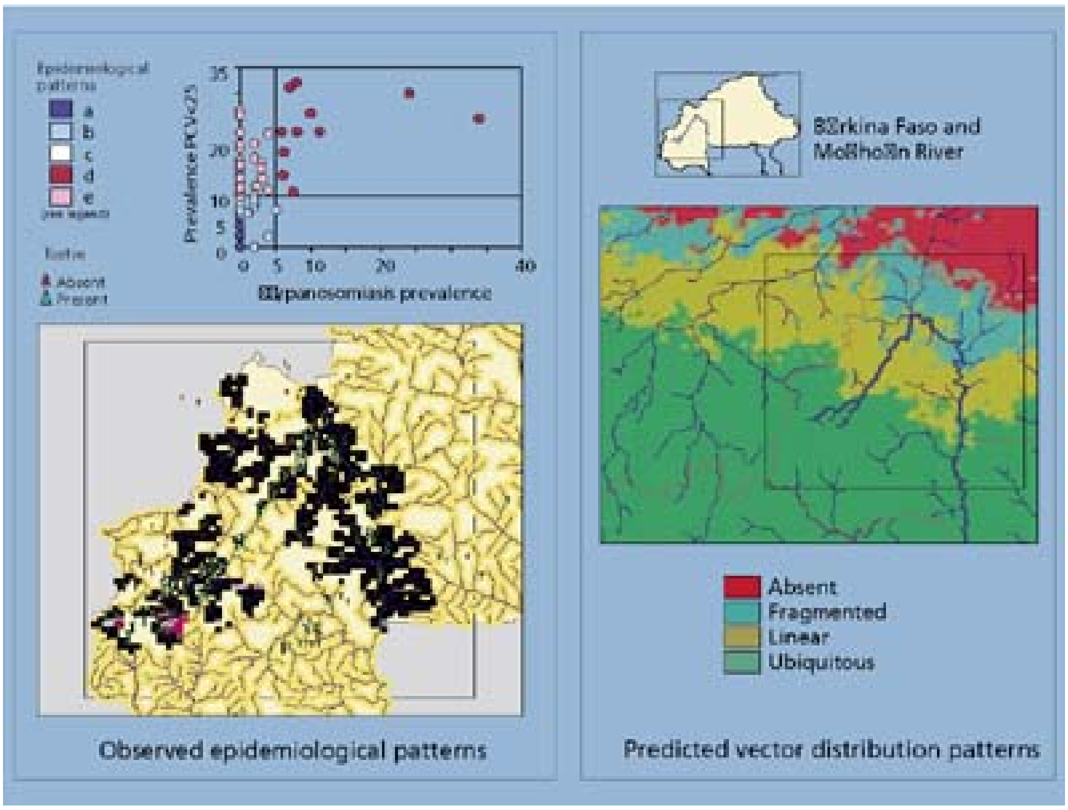
[6] With other species of tsetse flies that have broader ecological requirements, such as flies of the morsitans group, risk is generally related to fly densities. Nevertheless, in the densely cultivated areas of West Africa, these species tend to regress, and the riparian species have an increasing epidemiological importance.

FIGURE 13

Mouhoun spatial epidemiology

Observed epidemiological patterns: A simple model was developed relating observed trypanosomiasis prevalence levels (measured using wet smears of buffy coat) and the prevalence of anaemic animals (individuals with a PCV below 25). By setting class limits for both variables five epidemiological classes were identified (top graph) and depicted on the map: (a) no major animal health problem, (b) trypanosomiasis is no major problem, (c) trypanosomiasis is a recent acute problem (not observed here, class was used to set overall model class limits), (d) trypanosomiasis is a major problem, (e) though trypanosomiasis prevalence is low, a high percentage of individuals have a PCV below 25, which may be due to the presence of false negative or chronic cases with undetectable low parasitaemia, or to other anaemic diseases. The map of epidemiological patterns was obtained by separately interpolating observed field data for trypanosomiasis prevalence and PCV within a 5-km radius around river systems. Results were then cross-tabulated to map the different epidemiological classes. No data were collected in "yellow" areas. Green areas depict observed fly densities. Negative trap sites are shown in red.

Predicted vector distribution patterns: Based on the observed field data along the Mouhoun river system and on a personal communication from Dr Aliti Djiteye and S. Maiga (Laboratoire Vétérinaire, Bamako, Mali) describing fly presence at the level of river basins in Mali, a four-class training set was produced to predict the spatial distribution of riparian fly-ecology patterns (see also Chapter 3): (i) no tsetse flies, (ii) fragmented tsetse population only present in pockets of suitable habitat, (iii) tsetse present in linear habitat of main streams and important tributaries only, (iv) tsetse present on entire river system. Using a set of satellite-derived predictor variables (5 km grid) and discriminant analysis techniques a spatial model was built depicting respective areas covered by each fly-ecology class.



The pilot trial was conducted in two distinct areas (Figure 12). The first site was located in a large forest gallery particularly suitable to tsetse, the second in a small and degraded gallery. A third site, located between the two, was used to evaluate the dispersion of the control effect.

Results were monitored by monthly entomological surveys and parasitological follow-up of sentinel herds. Preliminary results obtained for tsetse densities and trypanosomiasis prevalence (Figure 12) show some significant trends. An additional interesting result is the evolution of the antibody seroprevalence in the sentinel herds of site 1, decreasing from 85 percent to 60 percent in less than one year (data not shown).

In conclusion, such a targeted vector-control approach appears to be efficient, not for tsetse eradication, but for decreasing tsetse densities below the threshold of significant parasite transmission. Such a result, however, is fragile and supposes permanent effort by the beneficiaries. Socio-economic surveys are actually conducted for an appraisal of the livestock owners' perception with regard to the control interventions and their sustainability. Their willingness to contribute either through labour or through financial participation should allow the creation of local associations charged with the continuation of control activities.

MOUHOUN RIVER BASIN

Following results obtained in both projects described above, activities were extended to drier areas of Burkina Faso, for example the Mouhoun river basin, formerly known as the Black Volta (Figure 13).

Epidemiological patterns at the river-basin level

A series of entomological and protozoological field surveys were conducted during the FAO regional project GCP-RAF-347-BEL, a follow-up of the Togo project GCP-TOG-013-BEL. The aim was to identify epidemiological patterns at the river-basin level. Results are summarized in Figure 13. Data collected by CIRDES teams in the Kenedougou province (joint CIRDES–ILRI–Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwickling [BMZ] project, McDermott, personal communication) and at additional sites along the Mouhoun river (joint CIRAD–CIRDES project, Bouyer, personal communication) are also included.

The adapted methodology for identifying spatial epidemiological patterns is summarized in the legend of Figure 13 (for more details see Tamboura et al., 1999; Hendrickx and Tamboura, 2000; Tamboura, Béré and Hendrickx, 2000). The obtained map of epidemiological patterns shows a distinct trend. Trypanosomiasis mostly constitutes a problem along the main course of the Mouhoun stream from source to downstream. Different epidemiological classes appear not to be scattered randomly but as a rule the problem becomes progressively less “intense” when moving to smaller tributaries. The observed prevalence of trypanosomiasis in cattle drops (from red to pink areas) followed by the percentage of anaemic animals (from light blue to dark blue).

The combination of both parasitaemic data (positive for infection) and data on anaemia (the main occurring symptom in trypanosome-infected animals) has the advantage of correcting for false negative samples, which may be due to the use of the relatively low sensitivity parasitological tests (wet smear – buffy coat – dark ground microscopy [Murray, Murray and McIntyre, 1977]). Interestingly, no areas were found with high parasitaemia and low prevalence of anaemic animals, stressing the link between trypanosomiasis occurrence and presence of anaemic animals in field situations. Nevertheless, other diseases may also cause anaemia and therefore the model may be considered not only as an estimation of the trypanosomiasis problem but also as a measurement of the general health status of the surveyed herds.

Tsetse ecology model

In a further study of the Mouhoun area, tsetse data from various available sources were used to model the spatial distribution in western Burkina Faso and southeastern Mali of the different fly ecology classes already discussed (see Figure 13). For more details on the rationale and approaches used see Hendrickx (2001). General information about discriminant analysis used to build the spatial prediction model is given in Hendrickx (1999).

The results obtained suggest a series of horizontal bands depicting the various fly-ecology classes. Interestingly some important matches can be made with the independently created epidemiological pattern map (Figure 13):

- a widespread trypanosomiasis problem at the "sources du Mouhoun" where riparian tsetse are ubiquitous;
- trypanosomiasis mainly restricted to linear fly distribution areas along the main stream.

Both results were important indicators suggesting pathways for future research towards further understanding epidemiological and fly-ecology patterns in this part of West Africa.

Towards understanding tsetse fragmentation

As may be suggested by the results described above, the "Boucle du Mouhoun" has a series of characteristics that make it particularly suitable as a study area representative of the dry northern part of the West African tsetse belt.

- It is entirely within the fly belt.
- It extends over 180 km from north to south within a rainfall range of 1 300–1 400 mm at the Mouhoun sources, 1 000 mm in the northern part of the river bend and 1 200 mm in the eastern leg.
- It includes a great variety of landscapes and valley profiles including large flood areas in the western ascending leg and highly cultivated areas with protected forest patches in the descending eastern leg.

Within given distribution limits, the distinction between suitable and non-suitable tsetse habitat may depend on apparently minor changes in ruling ecoclimatic settings. In areas where macroclimatic conditions are generally unfavourable, tsetse become highly susceptible to occurring habitat changes, for example, a breach in riparian vegetation continuity may induce rapid changes in tsetse populations. Physiological population fitness indicators such as body size or age group distribution patterns allow for a certain level of quantification of population stress (Rogers and Randolph, 1991). Preliminary results of population studies conducted on several sites by a team from CIRDES suggest that though actual population fragmentation is rarely observed along the Mouhoun main stream, significant age structure differences occur in areas subject to environmental stress (Bouyer, personal communication).

- In its northern part, though macroclimatic conditions appear least favourable (1 000 mm annual rainfall), large patches of riparian forests remain and this natural habitat is protected from human impact resulting in locally abundant healthy tsetse populations.
- Highest habitat stress is recorded in the eastern descending leg. Riparian forests are degraded because of soil erosion. Intensity depends on soil characteristics, slope, water flow intensity and agriculture. Tsetse populations are reduced and show a younger age structure.
- Along the western ascending leg, the main stream is surrounded by natural dams creating flood areas. This has a positive impact on erosion and vegetation is luxuriant. Tsetse populations are abundant with normal age structures.

In contrast, along the Mouhoun tributaries isolated riparian habitat patches separated by several kilometres of cultivated wetlands have been identified using satellite imagery and field surveys. As a next stage, population studies are planned in these areas. These will include genetic studies and modelling of fly dispersal patterns in time and space. Such studies will yield crucial data towards planning sustainable fly suppression and may be the first step towards a removal strategy.

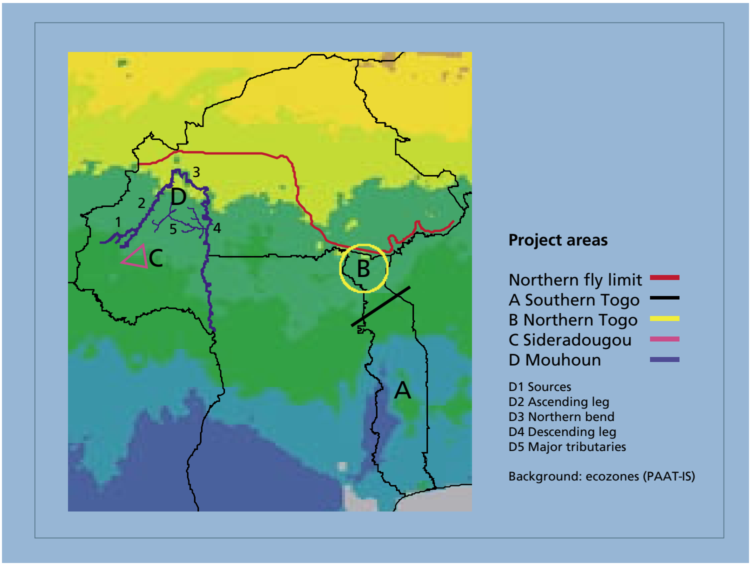
Chapter 5

Towards integrated tsetse and trypanosomiasis management

Evidence gathered in the case studies confirms the band-like gradient suggested in Figure 2; the actual location of the different case studies is given in Figure 14 as compared with West African ecozones.

In most of Togo (Figure 14) drainage systems form an intricate web of favourable riparian tsetse habitats; savannah and forest species only persist in a few well-defined protected areas. The riparian tsetse habitats can hardly be avoided by livestock and appear not to be affected by crop encroachment at current cropping intensity levels. Farmers have responded to this by adopting trypanotolerant breeds. Nevertheless, low cattle numbers and the strong correlation observed between packed (red) cell volume (PCV), i.e. an indicator of the animal health status, and the integration of cattle and agriculture clearly show that these breeds, with little veterinary follow-up in traditional livestock production systems, do survive, although some production losses occur. In market-oriented livestock production systems, i.e. with access to cash and thus to veterinary inputs, livestock owners tend to increase the size of their cattle through cross-breeding trypanotolerant Somba females with trypanosusceptible Zebu bulls. This phenomenon was also observed on a larger scale elsewhere where it resulted in stabilized new cattle genotypes, for example, Borgou in Benin and Ketekou in Nigeria. In the northern part of Togo (Figure 14) climatic conditions are drier and suitable riparian habitats are more readily identifiable within a tropical dry forest landscape, allowing proper herd management practices that avoid contact with the vector. This area coincides with the southern distribution limit of trypanosusceptible Zebu breeds. Crop encroachment had a marked impact on G. tachinoides. As a result of proper management, tsetse

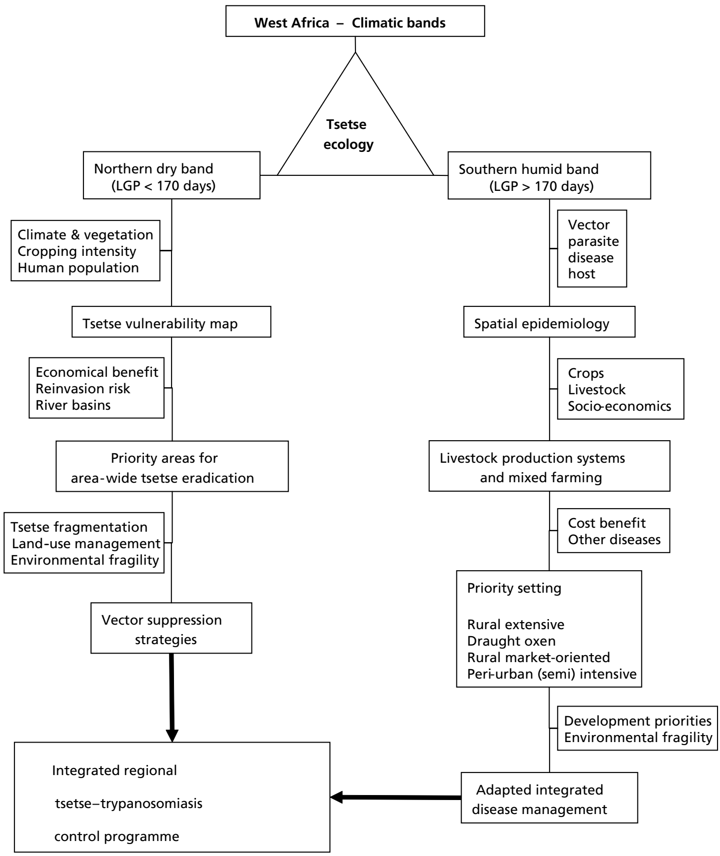
FIGURE 14
Geographical location of reported case studies
Background : West African ecozones derived from remotely sensed data on vegetation and temperature and ground-measured climatic data (source: PAAT-IS).



control was successful and animal health significantly improved at the village level (Batawui et al., 2003).

The Sideradougou pastoral area in Burkina Faso (Figure 14) is more humid than northern Togo. Nevertheless suitable riparian habitats remain relatively easy to identify. Depending on livestock production systems, contact between vector and host may or may not be avoided. This largely depends on the availability of water resources. Different landscapes yield different risk levels identified as epidemiological hot spots. Control measures focusing on these hot spots not only decreased fly density but also disrupted trypanosomiasis transmission in such a way that a significant reduction in disease incidence could be measured. Sustainability largely depends on the organizational capacity of local communities.

FIGURE 15
Summary of data input needs for data-driven decision support
Scenarios for the dryer northern band and more humid southern band of West Africa are summarized.



This includes the concerted choice of control methods (de la Rocque, in preparation).

The Mouhoun river basin (Figure 14) includes a variety of riparian habitat types representative of the dry ecozone at a subregional level. The dominant cattle breeds are trypanosusceptible Zebu and, because

TABLE 3

Vector suppression strategy on the Mouhoun river basin

Mouhoun (see Figure 14)	Fly ecology category	Vector suppression strategy	Needed complementary research
1. Sources	Ubiquitous	Extensive web of drainage lines with suitable habitat. High epidemiological risk. Need for identification and control of epidemiological hot spots (Sideradougou model).	Prior to considering elimination, link and relative isolation from southern river basins must be researched. A crucial factor is to avoid reinvasion downstream.
2. Ascending leg	Linear	No agriculture in valley. Habitat preserved and identified. Important flood zones. Large-scale vector suppression possible.	Monitoring fly population on the main stream and seasonal fluctuations along tributaries.
3. Northern bend	Linear–fragmented	Within circumscribed habitat healthy tsetse populations. Outside harsh climatic conditions preventing reinvasion.	Monitoring fly population.
4. Descending leg	Linear	High anthropogenic pressure from east. Riparian habitat degraded. Stressed tsetse populations with high mortality rates.	Research the possibility of using the high agriculture intensity stretch of the main stream as a barrier to upstream reinvasion.
5. Major tributaries	Linear	Linear habitat in isolated pockets. Various levels of anthropogenic impact.	Identification of fly pockets. Investigate genetic isolation of pockets and dispersion models.

Fly-ecology category: as depicted in prediction output (see Figure 13).

it is a major cotton growing area, crop encroachment is relatively high. Based on field data on disease prevalence and anaemia, a distinct epidemiological pattern was shown; the trypanosomiasis problem was mainly confined along the main stream while low problem levels occurred along less important tributaries. Field data on tsetse allowed modelling of fly-ecology bands depicted in Figure 2.

Any decision support towards tsete and trypanosomiasis management in West Africa must consider the fact that the epidemiology of tsetse-transmitted trypanosomiasis differs with varying climatic settings and land-use patterns. Therefore, the sustainable management of this major threat to animal health will have to be systematic, stepwise and pragmatic. A tentative list of the data inputs needed to achieve such a high level of integration is given in Figure 15.

Although data-driven decision support was successfully implemented in the southern humid band (e.g. Togo case study), this is not yet the case for the northern dry band. Many of the assumptions made during the desk study aiming at selecting priority areas for tsetse eradication have yet to be validated in the selected areas. Based on the experience gained on the Mouhoun river system in Burkina Faso, part of the Mali–Burkina Faso priority area for area-wide vector eradication, an integrated approach including pathways for research is suggested in Table 3.

Chapter 6
Conclusions

It can be concluded that an integrated T&T management approach relies on the quality of an extensive list of field data (vector, pathogen, host, livestock system, agro-ecological setting) and the detailed knowledge of geo-epidemiological patterns. We must remain cautious when making choices and avoid being lured into choosing overly simple solutions for solving complex problems.

Although in West Africa elimination of the fly and the disease may be achievable in the drier parts at the northern limits of the tsetse belt, several crucial assumptions remain to be validated through field research. These include investigations on fly fragmentation, population isolation and fly dispersion (e.g. Mouhoun model).

In the more humid parts, the most viable option remains an integrated approach combining: (i) vector suppression in epidemiological hot spots (e.g. Sideradougou model) and (ii) disease management at the herd level through the strategic use of trypanocides and/or genetic improvement of local trypanotolerant breeds (e.g. Togo model).

References

Bastiaensen, P., Cissé, A., Gnofam, M., Bebay, C.E., Kouagou, N'T., Sonhaye, A., Napala, A. & Hendrickx, G. 2003. Pratique vétérinaire privée rurale au Togo: appréciation socio-économique de sa viabilité. Bulletin of Animal Health and Production in Africa, 49: 96–120.

Batawui, D. 1999. Effet sur les Glossines de l'application séquentielle de l'insecticide (Karate 2.5 ED) sur le bétail par la méthode Electrodyn au Togo. Institut de Médecine Tropicale, Anvers, Belgique. (M.Sc. thesis)

Batawui, K., Bastiaensen, P., Napala, A. & Hendrickx, G. 2003. L'application séquentielle de lambda-cyhalothrine sur le bétail par la méthode ELECTRODYN™. Résultats obtenus au Togo dans le cadre de la lutte contre la TAA. Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux, 55(3): 189–195.

Bourn, D., Reid, R., Rogers, D., Snow, B., & Wint, W. 2001. Environmental change and the autonomous control of tsetse and trypanosomiasis in sub-Saharan Africa. Environmental Research Group Oxford Limited, Information Press Limited, Oxford, UK. 248 pp.

Buxton, P.A. 1955. The natural history of tsetse flies. An account of the biology of the genus Glossina (Diptera). Memoirs of the London School of Hygiene and Tropical Medicine, 10. London, H.K. Lewis & Co. 739 pp.

Cuisance, D., Politzar, H., Tamboura, I., Merot, P. & Lamarque, G. 1984. Répartition des glossines dans la zone pastorale d'accueil de Sidéradougou, Burkina Faso. Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux, 37: 99–113.

Dao, B. 1998. Trypanosomose et trypanotolérance animale au Togo: contribution du système d'information géographique, à l'étude de l'introgression zébu. Faculté des Sciences et Techniques, Université Cheikh Anta Diop de Dakar, Sénégal. (thesis) de la Rocque, S. 1997. Identification des facteurs discriminants de la présence de glossines dans une zone agro-pastorale du Burkina Faso. Intérêt pour l'évaluation du risque trypanosomien. Université Montpellier II. 162 pp. (Ph.D. thesis)

de la Rocque, S., Bengaly, Z., Michel, J.F., Solano, P., Sidibé, I. & Cuisance, D. 1999. Importance spatiale et temporelle des interfaces bovins-glossines dans la transmission de la trypanosomose animale en Afrique de l'Ouest. Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux, 52(3-4): 215–222.

de la Rocque, S., Michel, J.F., Cuisance, D., De Wispeleare, G., Augusseau, X., Guillobez, S. & Arnaud, M. 2001a. Le risque trypanosomien, une approche globale pour une décision locale. Montpellier, Edition du CIRAD. 152 pp.

de la Rocque, S., Augusseau, X., Guillobez, S., Michel, V., De Wispelaere, G., Bauer, B. & Cuisance, D. 2001b. The changing distribution of two riverine tsetse flies over 15 years in an area increasingly occupied by agriculture in Burkina Faso. Bulletin of Entomological Research, 91(3): 157–166.

Doran, M. & Van den Bossche, P. 2000. SITE Analysis. An appraoch to strategy formulation for tsetse and trypanosomosis control. Bovine trypanosomosis in southern Africa, Vol. 1. Harare, Zimbabwe, Regional Tsetse and Trypanosomosis Control Program for Southern Africa. 74 pp.

Erkelens, A.M., Dwinger, R.H., Bedane, B., Singenbergh, J.H.W. & Wint, W. 2000. Selection of priority areas for tsetse control in Africa; a decision tool using GIS in Didessa Valley, Ethiopia, as a pilot study. In Animal Trypanosomosis: Diagnosis and Epidemiology, pp. 213–236. IAEA, Vienna. Leiden, the Netherlands, Backhuys Publishers.

FAO. 1997. Ecozones, farming systems and priority areas for tsetse control in East, West and southern Africa, consultancy report by W. Wint, D. Rogers and T. Robinson. Prepared by ERGO Ltd and TALA for the FAO Animal Health Division, Rome.

FAO. 2002. Workshop on PAAT-PATTEC Harmonization. 2–3 May 2002, Rome.

FAO/IIASA 2000. Global agro-ecological zones. CD-ROM. Version 1.0. Land and Water Digital Media Series 11. Rome.

Ford, J. 1963. The distribution of the vectors of African pathogenic trypanosomes. Bulletin of the World Health Organization, 28: 653–669.

Gilbert, M., Jenner, C., Pender, J., Rogers, D.J., Slingenbergh, J. & Wint, W. 2001. The development and use of the Programme Against African Trypanosomiasis Information System (PAATIS). In International Scientific Council for Trypanosomiasis Research and Control (ISCTRC) Conference, Mombasa, Kenya, 27 September to 1 October 1999. OUA-STRC

Guillobez, S. 1979. Les milieux vertiques du bassin de la Volta Blanche dans la région de Bagre (Haute Volta). L'Agronomie Tropicale, 34(1): 23–39.

Hendrickx, G. 1999. Georeferenced decision support methodology towards trypanosomosis management in West Africa. State University of Ghent, Veterinary Faculty, Gent, Belgium. (Ph.D. thesis)

Hendrickx, G. 2001. Practical application of GIS for the identification and selection of control areas in West Africa. Lead paper presented at the FAO/IAEA Workshop on Strategic Planning of Area-Wide Tsetse and Trypanosomosis Control in West Africa, Ouagadougou, Burkina Faso, 21–24 May 2001.

Hendrickx, G. & Tamboura, I. 2000. Epidémiologie spatiale de la trypanosomose animale au Burkina Faso, le cas de la boucle du Mouhoun. Colloque International sur les Techniques de l'Information Spatiale et de l'Epidémiologie: Bobo-Dioulasso, Burkina Faso, 7–9 March 2000. CD-ROM.

Hendrickx, G., Batawui, D. & De Deken R. 2002. Electromagnetic forces and tsetse. Electrodyn, a contribution of physics to integrated pest management. Newsletter on Integrated Control of Pathogenic Trypanosomes and their Vectors, No. 6.

Hendrickx, G., Meghen, C., Napala, A., Machugh, D.E., Bradley, D.G. & Dao, B. 1996. Phenotypic designation of Togolese cattle correlate strongly with microsatellite allele frequencies. Animal Genetics, 27(suppl. 2): 21 (Abstract only).

Hendrickx, G., Napala, A., Slingenbergh, J.H. W. & Palmer, H.B. 1997. Facteurs affectant le contrôle de la trypanosomose au Togo. In International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Twenty-third Meeting, Banjul, The Gambia, 1995. pp. 291–294. OUA-STRC

Hendrickx, G., Napala, A., Dao, B., Batawui, D., De Deken, R., Vermeylen, A. & Slingenbergh, J.H.W. 1999a. A systematic approach to area-wide tsetse distribution and abundance maps. Bulletin of Entomological Research, 89: 231–244.

Hendrickx, G., Napala, A., Dao, B., Batawui, D., Bastiaensen, P., De Deken, R., Vermeylen, A., Vercruysse, J. & Slingenbergh, J.H.W. 1999b. The area-wide epidemiology of bovine trypanosomosis and its impact on mixed farming in subhumid West Africa; a case study in Togo. Veterinary Parasitology, 84: 13–31.

Hendrickx, G., Slingenbergh, J., Dao, B., Bastiaensen, P. & Napala, A. 1999c. Systèmes d'Information Géographique (SIG), outils puissants de prise de décision. In International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Twenty-fourth Meeting, Maputo, Mozambique, 1997. OUA-STRC.

Hendrickx, G., Napala, A., Slingenbergh, J.H.W., De Deken, R., Vercruysse, J. & Rogers, D.J. 2000. The spatial patterns of trypanosomosis predicted with the aid of satellite imagery. Parasitology, 120: 121–134.

Hendrickx, G., de La Rocque, S., Reid, R. & Wint, W. 2001a. Spatial trypanosomosis management. From data-layers to decision making. Trends in Parasitology (formerly Parasitology Today), 17: 35–42.

Hendrickx, G., Napala, A., Slingenbergh, J.H.W., De Deken, R. & Rogers, D.J. 2001b. A contribution towards simplifying area-wide tsetse surveys using medium resolution meteorological satellite data. Bulletin of Entomological Research, 91: 333–346.

Hoste, C. 1992. Contribution du bétail trypanotolérant au développement des zones affectées par la trypanosomose animale africaine. Revue Mondiale de Zootechnie, 70-71: 21–29.

Hoste, C., Chalon, E., d'Ieteren, G. & Trail J.C.M. 1988. Le bétail trypanotolérant en Afrique occidentale et centrale. Vol. 3. Bilan d'une décennie. Etude FAO Production et Santé animale, 20/3, Organization des Nations Unies pour l'Alimentation et l'Agriculture, Rome, Italie.

IAEA. 2002. Land use monitoring in selected areas for area-wide tsetse elimination in West Africa. Consultant report by G. Hendrickx, prepared by Avia-GIS for the Joint Division of the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency, Vienna, Austria.

Kouagou, N.T., Bastiaensen, P., Napala, A., Dao, B. & Hendrickx, G. 2000. La lutte contre les trypanosomoses animales et les vétérinaires privés au Togo. Newsletter on Integrated Control of Pathogenic Trypanosomes and their Vectors. 4: 26–28.

Laveissière, C., Couret, D. & Hervouet, J.P. 1986. Localisation et fréquence du contact homme/glossines en secteur forestier de Côte d'Ivoire. 1. Recherche des points épidémiologiquement dangereux dans l'environnement végétal. Cahiers de l'ORSTOM, série Entomologie médicale et Parasitologie, 24: 21–35.

Lefrançois, T., Solano, P. de La Rocque, S., Bengaly, Z., Reifenberg, J.M., Kabore, I. & Cuisance, D. 1998. New epidemiological data on animal trypanosomosis by molecular analysis in the pastoral zone of Sideradougou, Burkina Faso. Molecular Ecology, 7: 897–904.

Michel, J.F., Michel, V., de La Rocque, S., Touré, I. & Richard, D. 1999. Modélisation de l'occupation de l'espace par les bovins. Applications à l'épidémiologie des trypanosomoses animales. Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux, 52(1): 25–33.

Michel, J.F., Dray, S., de La Rocque, S., De Wispelaere, G., Desquesnes, M., Solano, P. & Cuisance, D. 2002. Modelling bovine trypanosomosis spatial distribution by GIS in an agro-pastoral zone of Burkina Faso. Preventive Veterinary Medicine, 56: 5–18.

Murray, M., Murray, P.K. & McIntyre, W.I.M. 1977. An improved parasitological technique for the diagnosis of African trypanosomosis. Transactions of the Royal Society of Tropical Medicine and Hygiene, 71: 325–326.

Napala, A., Hendrickx, G., Vermeilen, A., & Gnagna, K. 1995. Répartition et abondance des Glossines et de la trypanosomiase bovine au Togo. In International Scientific Council for Trypanosomiasis

Research and Control (ISCTRC), Twenty-second Meeting, Kampala, Uganda, 1993. pp. 74–75. OUA-STRC.

Napala, A., Kouagou, N'T., Dao, B., Bastiaensen, P., Slingenbergh, J.H.W. & Hendrickx, G. 1999. Amélioration de la prévalence de la trypanosomose et de la santé bovine à travers la vulgarisation et la participation communautaire à l'échelle nationale: résultats d'une campagne de vulgarisation au Togo. In International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Twenty-fifth Meeting, Mombasa, Kenya. OUA-STRC.

Nash, T.A.M. 1937. Climate, the vital factor in the ecology of Glossina. Bulletin of Entomological Research, 28: 75–127.

Nash, T.A.M. 1948. Tsetse flies in British West Africa. London, His Majesty's Stationery Office (HMSO). 77 pp. 15 maps.

OAU. 2002. Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC). Plan of Action. Addis Ababa, Ethiopia, June 2001. 31 pp.

Reid, R., Kruska, R.L., Deitchmann, U., Thorthon, P.K., & Leak, S.G.A. 2000. Human population growth and the extinction of the tsetse fly. Agriculture, Ecosystems and Environment, 77: 227–236.

Riou, G. 1990. L'eau et les sols dans les géosystèmes tropicaux. Systèmes d'érosion hydrique. Paris, Masson Ed. 217 pp.

Robinson, T. 1998. Geographic Information Systems and the selection of priority areas for control of tsetse-transmitted trypanosomiasis in Africa. Parasitology Today, 14: 457–461.

Robinson, T., Harris, R.S., Hopkins, J.S. & Williams, B.G. 2002. An example of decision support for the trypanosomiasis control using a geographical information system in eastern Zambia. International Journal of Geographical Information Science, 16: 345–360.

Rogers, D.J. & Randolph, S.E. 1991. Mortality rate and population density of tsetse flies correlated with satellite imagery. Nature, 351: 739–741.

Rogers, D.J., Hay, S.I. & Packer, M.J. 1996. Predicting the distribution of tsetse flies in West Africa using temporal, Fourier processed meteorological satellite data. Annals of Tropical Medicine and Parasitology, 90: 225–241.

Tamboura, I., Hendrickx, G., Koudougou, Z. & Béré, A. 1999. Tsétsé et trypanosomose dans la zone cotonnière du Burkina Faso: cartographie des zones à risque. In International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Twenty-fifth Meeting, Mombasa, Kenya. OUA-STRC

Tamboura, I., Béré, A. & Hendrickx, G. 2000. Contrôle de la trypanosomose animale dans les zones libérées de l'onchocercose au Burkina Faso. Colloque International sur les Techniques de l'Information Spatiale et de l'Epidémiologie: Bobo Dioulasso, Burkina Faso, 7–9 March 2000. CD-ROM.

UNDP (United Nations Development Programme). 1984. Atlas du développement regional du Togo. Direction Générale du Plan: Lomé, Togo. 206 pp.

Van Camp, N., Biesemans, J. & De Wulf, R. 1999. Contribution of Spatial Information Techniques in monitoring and supporting a sustainable control of animal trypanosomosis in Togo. In International Scientific Council for Trypanosomosis Research and Control (ISCTRC), Twenty-fifth Conference, Mombasa, Kenya, 27 September to 1 October 1999, poster presentation.

Van Camp, N., Biesemans, J., Hendrickx, G. & De Wulf R. 2002. Integrated pest management and environmental fragility. A contribution of fuzzy logic to decision making. Newsletter on Integrated Control of Pathogenic Trypanosomes and their Vectors. No. 6

Wint, W. & Bourn, D. 1994. Anthropogenic and environmental correlates of livestock distribution in sub-Saharan Africa. Report prepared for the Overseas Development Administration, London. 58 pp.

Tsetse-transmitted animal trypanosomiasis is a complex disease that directly and indirectly has an impact on Africa's crop and livestock agricultural development. In this paper, state-of-the-art spatial tools are applied to study the variety of agro-ecological settings in West Africa with a view to providing decision support to the management of the tsetse and trypanosomiasis (T&T) problem according to the prevailing agro-ecological conditions.

Based on the analytical mapping of dominant livestock systems, land-use patterns, integration of livestock and crop agriculture (mixed farming) and geoclimatic factors affecting tsetse ecology (northern dry band with fragmented tsetse populations and southern humid band where tsetse are widespread), priority areas for T&T intervention were identified. These areas are situated in the northern band of the tsetse belt where:

- tsetse populations are fragmented (and therefore vulnerable) or confined only to suitable vegetation along main river courses;
- fly reinvasion risk is minimal due to land pressure and adverse climatic conditions for tsetse; and
- integration of crop and livestock agriculture prevails.

In these areas, the elimination of the fly and the disease may be achievable and consolidated through the expansion and intensification of mixed farming, leading to maximal yield benefits when expressed in terms of sustainable agriculture and rural development.

The spatial analysis, including spatial epidemiology of T&T (vectors, pathogens, host) and the impact of T&T on people, their environment and their livestock production systems, showed that, in the southern and more humid parts, the most viable option remains an integrated approach combining vector suppression in epidemiological hot spots and disease management at the herd level through the strategic use of trypanocides and/or genetic improvement of local trypanotolerant breeds.

ISBN 92-5-105118-6 ISSN 1020-7163

9 789251 051184

TC/M/Y5342E/1/7.04/1750