Annex 6 Practical Application of GIS

Programme Against African Trypanosomosis

Options For Tsetse Fly Eradication in the Moist Savannah Zone of West Africa:

Technical and Economic Feasibility Study, Phase 1

Practical application of GIS for the identification and selection of control areas in West Africa.

Dr. Guy Hendrickx, AVIA-GIS

March 2001

ANNEX 6 PRACTICAL APPLICATION OF GIS FOR THE IDENTIFICATION AND SELECTION OF CONTROL AREAS IN WEST AFRICA.

Dr. Guy Hendrickx, AVIA-GIS

Introduction

This paper builds further on the Geneva and Rome-Vienna workshops where past applications of GIS for priority setting were presented and some principles underlying the present paper were adopted.

Decision support framework

Figure 1 details the approach adopted in this paper. It highlights the different steps towards data driven decision support for selecting priority areas for tsetse eradication in West Africa. These differ significantly from previously developed models which aimed at defining priority areas for sustainable trypanosomosis control.

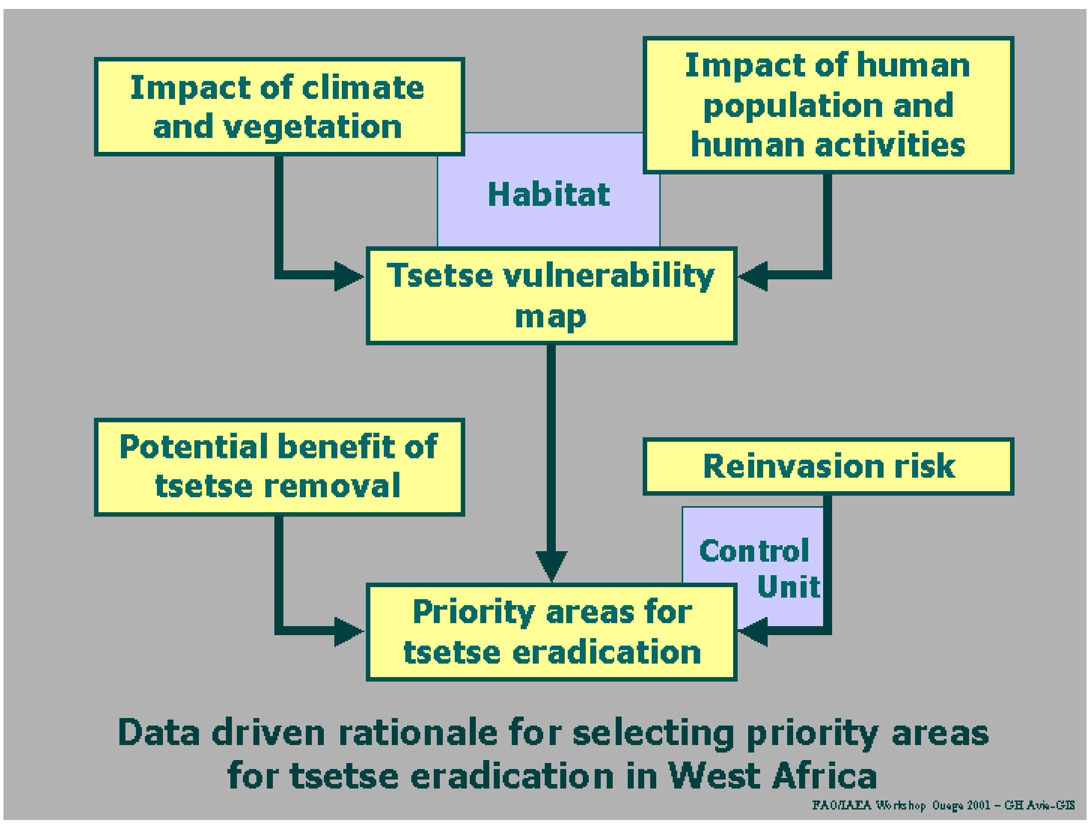

Fig 1 Decision support towards priority setting

Trypanosomosis control aims at sustained suppression of the disease and / or the vector. Therefore decision-making will be mainly anthropocentric, i.e. daily farmers inputs and participation are the key stone of success for any operation (socio-economics of trypanosomosis control).

Decision-making towards selecting priority areas can be carried out at a national or sub-national level where restricted priority areas are selected according to potential costs and benefits. The relative location in the fly belt of selected areas is of lesser importance.

Vector eradication on the other hand is a political decision which aims at permanently removing a major constraint, in this case tsetse as a vector of African Animal Trypanosomosis and Human Sleeping Sickness. Independently of peoples' will to participate, areas have to be selected on a data driven basis. The key stone here is technical feasibility.

Since the success of the actual eradication campaign will highly depend on the technology used, chosen technologies will have to be carried out by professional teams to guarantee quality and speed. Therefore community participation can focus on disease management (basic animal health and production *sensu largo*) and land-use topics.

Here decision-making is highly dependant on concerted action between countries involved. Large scale areas have to be selected according to the feasibility of tsetse eradication, starting from the easiest parts at the distribution limits of the fly and systematically working towards more complex types of habitat.

Climate in West Africa

A typical feature of the climate in West Africa is its band-like pattern. From North to South the climate changes from arid to moist. Subsequent natural land cover layers include : Desert, Grassland, Grassland savannah, Woodland savannah and Evergreen vegetation such as tropical rainforests and mangrove in coastal areas.

This can be visualised with a variety of data layers. Examples include:

1. Rainfall normal: a ground measured variable rainfall,

2. Vegetation index: a remotely sensed variable,

3. Length of growing period: a derived compound variable (Fig.2).

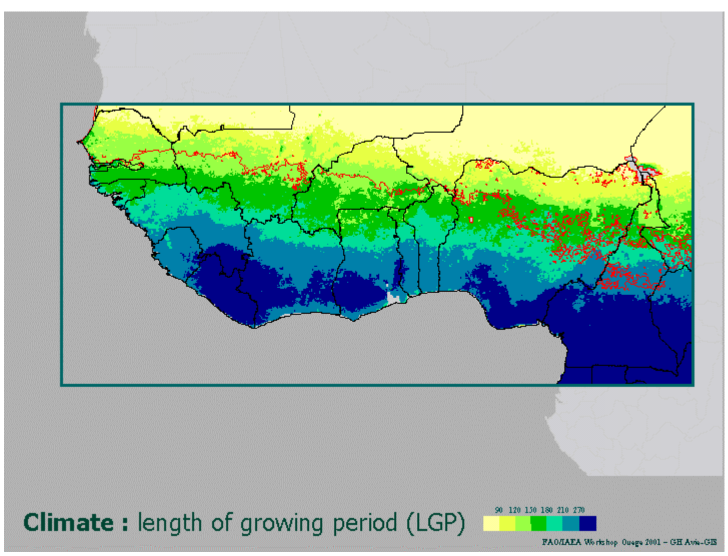

Fig 2 Length of growing period

The length of growing period is the period of vegetation activity in days per year of a specific crop. The layer shown here is a 5km resolution mainly satellite derived spatial prediction of a standard LGP map compiled by FAO (www.fao.org). See PAAT-IS for more details.

Classes limits are (days): <90 / 90-120 / 120-150 / 150-180 / 180-210 / 210-270 / >270

Tsetse distribution in West Africa

In recent years an attempt was made to update ageing tsetse distribution maps. A series of « Potential Range Maps » per tsetse group and per species and, when applicable, per sub-species where produced by the TALA research group Oxford at a 5 km resolution. Predictions are based on data extracted from the Ford and Katondo maps, updated with the most recent field observations where available.

As for any distribution map tsetse are not expected to be uniformly distributed throughout their potential habitat. Due to a combination of circumstances they might even be absent from substantial parts of it.

Maps included in the PAAT-GIS are:

1. Presence/Absence map for all tsetse species combined,

2. *Glossina palpalis sp. (gambiensis* and *palpalis)* and *Glossina tachinoides* : the two most important riverine tsetse species of West Africa,3. *Glossina morsitans submorsitans* : the most important savannah tsetse in West Africa.

Tsetse ecology

Two major factors will affect the viability of tsetse : climate and human activity. The effect of climate (and vegetation) on the ecology of tsetse has been studied since the 1930's and is best illustrated by the work of Nash (1937) and Buxton (1955).

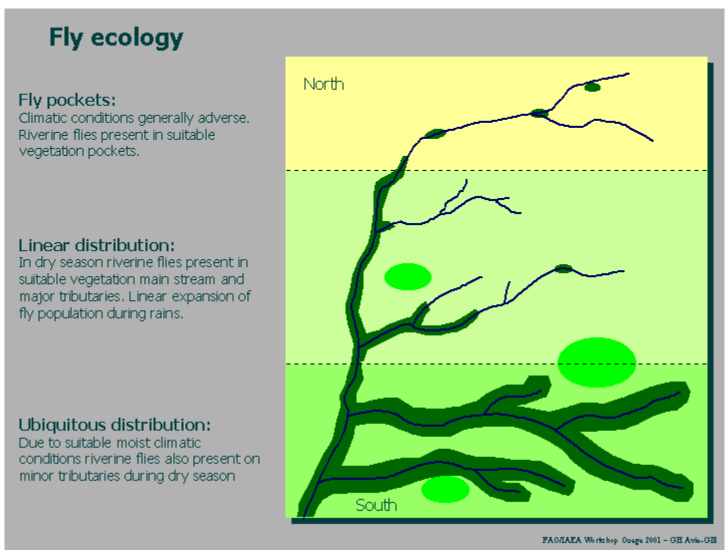

Fig 3 Tsetse ecology bands

Band-like climatic patterns affect fly ecology in West Africa. The identification of such subsequent fly ecology bands is of prime importance to contribute to the development of sustainable area-wide vector management strategies (see also detailed legend in French below[1]).

[1] Légende Figure 3 :

1. Glossines riveraines absentes ou très rares

- In the northern part of the fly belt it is more likely that tsetse could be permanently removed. Populations are expected to be more fragmented. After removal re-invasion is less likely since gaps of adverse conditions prevent fly dispersal.
- In the southern part where tsetse distribution is ubiquitous, high re-invasion pressure is likely to jeopardise permanent fly suppression and/or eradication attempts.
- The separation between « feasible » and « less feasible » is expected to be near the southern border of the linear distribution band (middle band) where the entire river network is not yet populated by tsetse.

From an operational point of view it is important to identify this limit as accurately as possible.

The Burkina Faso data set

During the FAO project, Projet Regional de Lutte contre la Trypanosomose Animale (PLTA), GCP-RAF-347-BEL a series of field surveys were conducted and combined with data from CIRDES. Combined entomological and parasitology field surveys (Fig. 4) allowed the identification of subsequent bands for Western Burkina Faso.

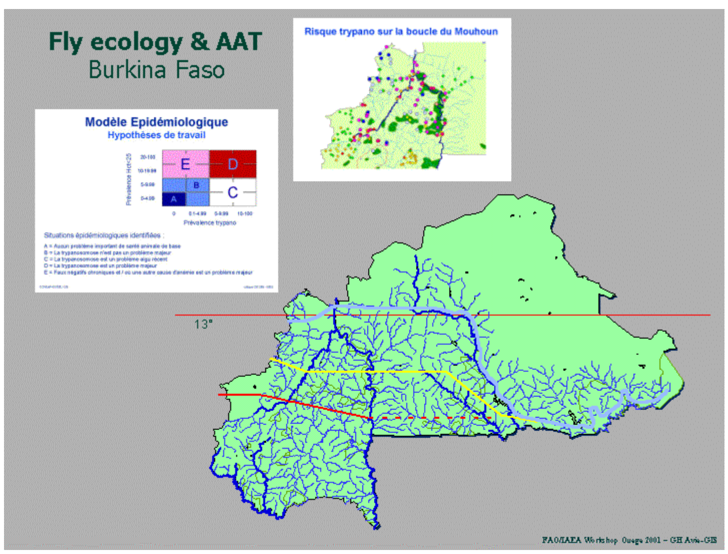

Fig 4 Burkina Faso data set

Fly ecology bands in Western Burkina Faso (legend to figure 4):

1. Light blue line: historical limit *G. tachinoides* (approximately 13° North),

2. En saison sêche les Glossines riveraines sont présentes uniquement sur les cours principaux aux endroits ou la végétation est particulièrement propice. Elles sont absentes ou très rares sur les cours secondaires. Une fois ces lieux de présence de Glossines identifiés leur élimination peut y être entreprise sans risques majeurs de réinvasion.
3. Glossines présentes sur la totalité des cours principaux en saison sêche. Elles sont aussi présentes de façon saisonnière sur les cours secondaires ou en permanence dans des lieux où la végétation y est particulièrement favorable. La lutte doit y être envisagée sur la totalité des cours principaux de façon concertée en partant des zones à plus densités vers les zones à plus forte densité. Les risques de réinvasion augmentent vers le sud en s'approchant de la zone 4. Leur élimination totale reste envisageable en combinant la lutte avec une politique de gestion des terres adéquate.
4. Les Glossines sont présentes sur la totalité des cours principaux et secondaires tant en saison sêche qu'en saison des pluies. La coordination des activités de contrôle y devient fort complexe. Les risques de réinvasion sont présents sur la totalité du réseau hydrographique. Une action concertée ne peut y être envisagée que lorsque les Glossines ont été éliminées dans les zones précédentes et l'installation de barrières de protection y est incontournable.

2. North of yellow line: tsetse present only on main river,

3. North of red line: tsetse also present on main tributaries,

4. South of red line: tsetse present on all tributaries.

West Africa Northern band

West African climate bands and fly ecology bands identified in Burkina Faso allow us to draw a first tentative northern band, empirically set within the <170 LGP zone, where tsetse habitat is marginal and sustainable tsetse suppression may be more successful than in the Southern areas.

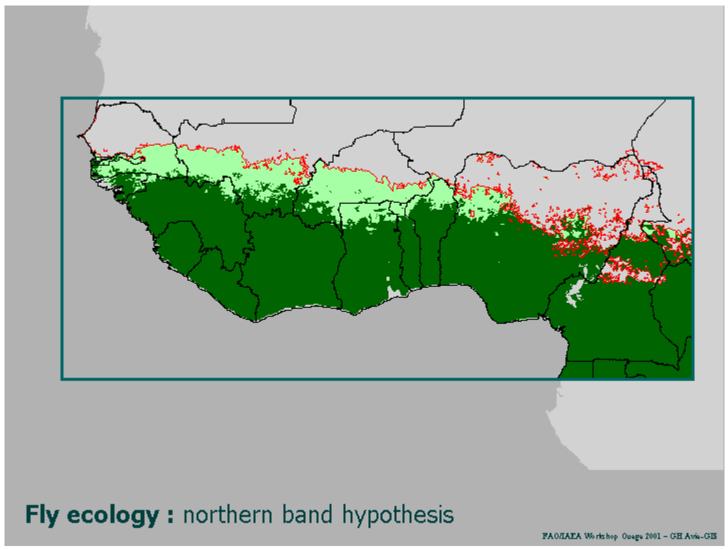

Fig 5 Tentative northern fly ecology band

Legend to Figure 5:

- Red line : northern limit tsetse distribution.
- Light green : area where LGP < 170 days within tsetse limits, marginal habitat likely.
- Dark green : area where LGP > 170 days within tsetse limits.

Tsetse and human population

After climate and vegetation, the second major factor which will influence tsetse ecology is human activity and its impact on the environment. With increasing human populations the number of natural tsetse hosts will drop due to hunting and an increasing part of the land will be cleared through cultivation and due to firewood consumption. As a result tsetse populations will lack both food sources and suitable habitat, and populations will drop.

Based on an extensive literature study R. Reid and colleagues (Reid *et al.*) postulated two scenario's describing the potential impact of human populations on tsetse distribution. Results shown here depict the expected impact of increased human population numbers (year 2040) on present fly distribution limits according to a liberal scenario (lower population densities have an higher impact on tsetse populations) and a conservative scenario (population levels need to be higher prior to impact tsetse distributions significantly).

It is to be noted that this model applies to savannah flies. The authors expect impact of human activity on riverine flies to be less important.

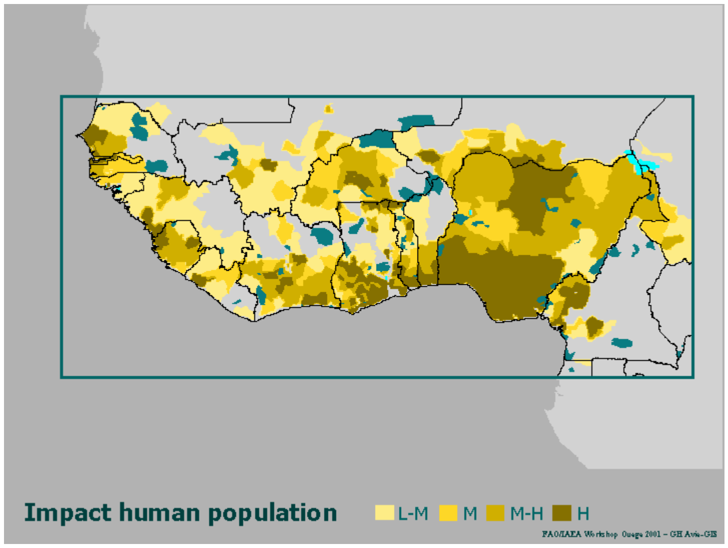

Fig 6 Human population impact classes

In figure 6 both scenarios are combined and new class limits are:

1. < 15 people / km² : Little impact (of human population) on tsetse,
2. 15 – 30 / km² : Low to medium impact,
3. 30 - 40 / km² : Medium impact,
4. 40 – 77 / km² : Medium to high impact,
5. > 77 / km² : High impact.

Population data source : PAAT-IS

Tsetse and agriculture

The impact of human population densities on tsetse habitat is mainly caused through agricultural activities.

Detailed data layers (5 km resolution) of predicted crop agriculture and cattle distributions (see PAAT-IS for more information) are used here to further contribute to highlight areas of major impact of human activity on tsetse populations. Both data layers are reclassed as “high – medium – low” and outputs are overlayed to depict the different mixed farming classes.

Selected class limits for predicted agriculture intensity (% of land in the cultivation cycle) are:

1. < 10 % of land into the cultivation cycle (Low)
2. 10-30 % of land into the cultivation cycle (Medium)
3. >30 % of land into the cultivation cycle (High)

Selected class limits for predicted cattle density (number of cattle per km²) are:

1. < 4 cattle / km² (Low)
2. 4-16 cattle / km² (Medium)
3. > 16 cattle / km² (High)

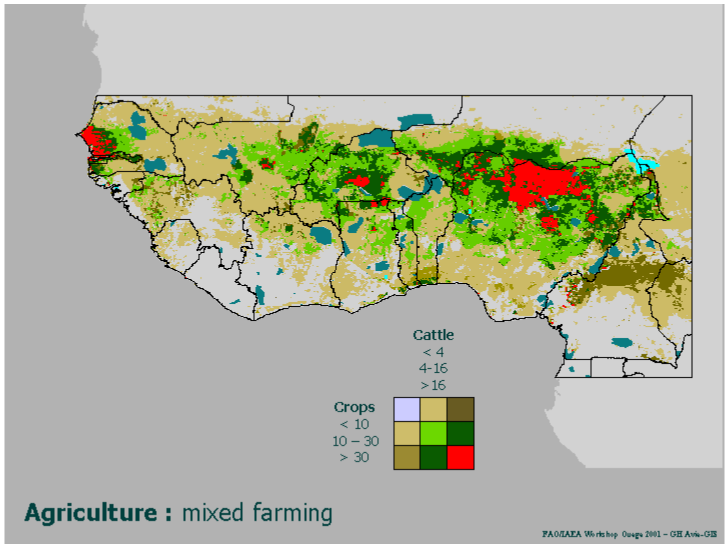

Fig 7 Mixed cattle - crops classes

Figure 7 shows the obtained overlay output. Areas where both cattle and crop agriculture are medium or high (green, red) are of particular relevance since here the impact of agriculture on tsetse populations is likely to be highest.

Tsetse vulnerability

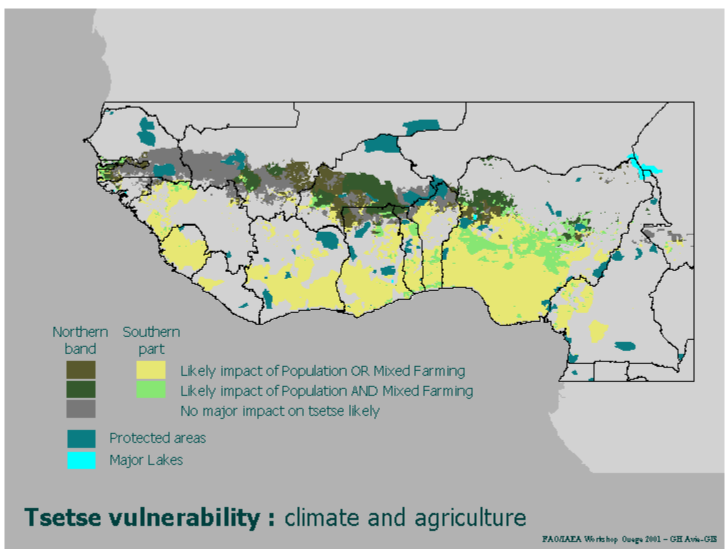

Fig 8 Tsetse vulnerabilty : people - mixed farming

Finally the combined potential effect of climate, human population and human activity on tsetse habitat is modelled by overlaying map outputs depicted in figure 6 and 7.

From a fly suppression (and/or eradication) point of view this impact offers both a direct and indirect advantage:

- Direct advantage: high land pressure will reduce fly populations. Savannah flies are expected to be more affected than riverine flies. Fly distribution is fragmented and once identified fly pockets are more easily dealt with.

- Indirect advantage: the existing high land use pressure will contribute to prevent fly re-invasion following eradication. This affects both riverine and savannah flies.

Figure 8 highlights areas where tsetse populations are most vulnerable to control measures (see legend). The result of this analysis shows two major impact areas.

In Nigeria both mixed farming and human population are likely to influence tsetse, not only in the LGP<170 zone but also in more humid southern parts whilst in Mali-Burkina levels of human population densities and mixed farming are less extreme. There impact appears to be restricted to the LGP<170 zone.

It is also important to mention here that agricultural practices might create new habitat types, especially for riverine tsetse. Nevertheless such habitats should be by definition isolated and therefore vulnerable once identified.

Impact of tsetse removal

Besides external factors affecting fly distribution patterns and increasing vulnerability of tsetse towards control measures, potential benefits have also to be taken into consideration when selecting priority areas for sound vector management.

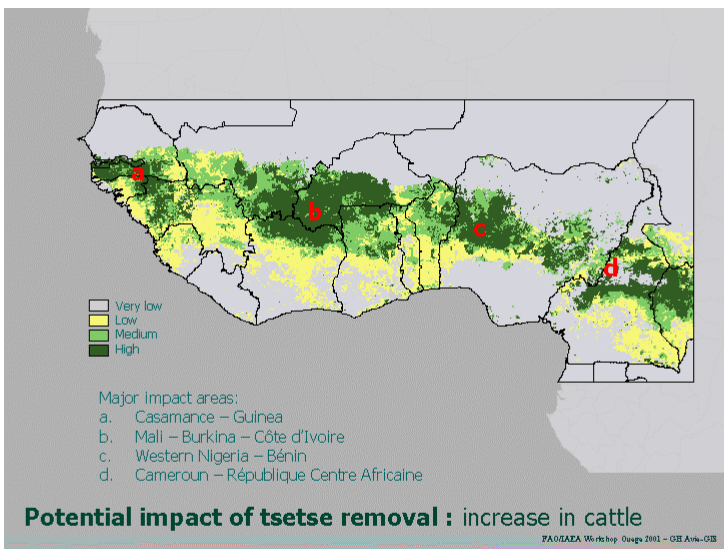

Fig 9 Predicted cattle increase after tsetse removal

Legend to figure 9 :

1. increase of 0-0.1 cattle / km² : Very low
2. 0.1 – 5 / km² : Low
3. 5 – 10 / km² : Medium
4. > 10 / km² : High

Figure 9 shows the predicted increase in cattle densities after removal of tsetse (See PAAT-IS for more details) and currently depicts the best approximation towards mapping the relative potential benefits of tsetse eradication at a 5 km resolution. Four major potential benefit areas are highlighted.

The re-invasion issue

A vital aspect of tsetse eradication is fly re-invasion. Ideally flies should be removed from a completely isolated area with zero re-invasion pressure (e. g. the Island Zanzibar in East Africa). This rarely is the case. On the other hand no example is known of the successful maintenance of a permanent artificial barrier against tsetse after tsetse removal (see also short annotated bibliography on the subject of re-invasion in annex).

Nevertheless in the previous part of this paper it was seen that in the northern band of the fly belt low re-invasion pressure is likely due to :

- Isolated fly pockets in marginal habitat with « near to zero » re-invasion risk,
- Interrupted linear distribution patterns due to high land pressure,
- Reduction of re-invasion pressure due to high land pressure.

In such circumstances, it may be possible to conduct a concerted area-wide eradication campaign. Historically similar conditions have occurred in North-Eastern Nigeria where flies have been removed from vast areas without barriers and with no significant re-invasion to date.

Nigeria case study

Figure 10 depicts the historical distribution limits of G. tachinoides in Nigeria. The red overlay shows the area cleared of tsetse from 1954/55 to 1977/78. No barriers were installed and to date no significant re-invasion occurred in this area.

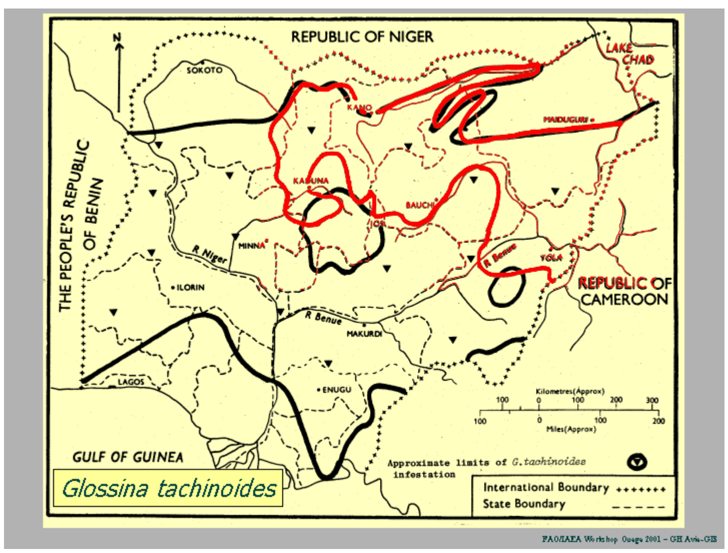

Fig 10 *Glossina tachinoides* in Nigeria

In order to contribute to the characterisation of those cleared areas, within area frequency distribution histograms of the three climatic variables depicted earlier are given together with mean values, standard deviation and mean plus one or two standard deviations. The latter values allow us to define a “minimum threshold set” below which re-invasion is unlikely : i.e. areas where the average NDVI is below 0.3 AND the LGP below 178 days AND rainfall below 1121 mm.

For the same purpose frequency distribution histograms are depicted for human population, cattle densities and cropping intensity. Here a “maximum threshold set” can be identified above which re-invasion may be unlikely : i.e. human population pressures of more than 29 people / km² AND cattle densities of more than nine head / km² AND cropping intensities of more than six percent of the area cultivated.

Both threshold sets are combined in figure 11.

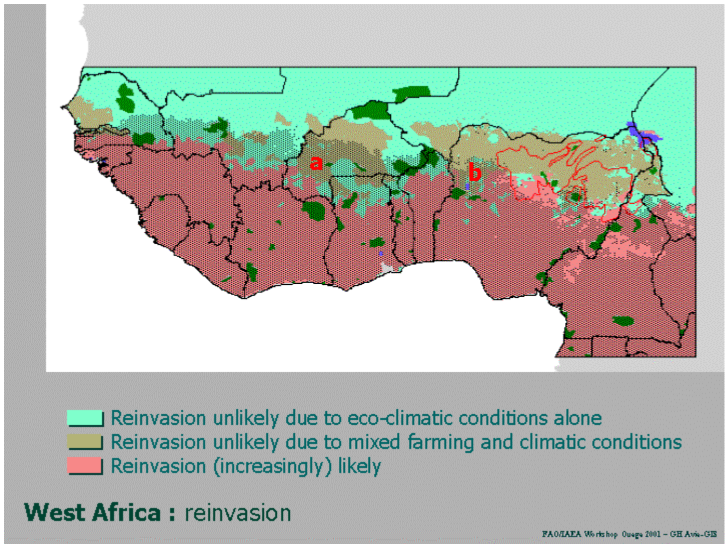

Fig 11 Derived re-invasion risk in West Africa

In areas where climatic conditions alone currently contribute to reduce re-invasion, concerted land use management during and post eradication may be a major tool towards sustained results without the need for costly barriers.

Selection of priority areas

A next step towards selecting priority areas includes the identification of "control units or entities". From a fly ecology point of view, the most suitable unit is the river basin.

River basins can be derived from digital elevation models (DEM), i.e. raster files of altitude measures at a 1 km resolution. Such resolution is detailed enough for the purpose of this study and should also allow planning at the national level. More detailed data may be needed at the local level for proper operational planning.

A processed DEM derived river basin data set for Africa is freely downloadable from the following internet site : http://edcdaac.usgs.gov/gtopo30/hydro/africa.html.

It is important to note here that the principle of fly-ecology layers also applies at the river basins level. Where tsetse distribution is restricted to main rivers and major tributaries and the vegetation along other tributaries is unsuitable, tsetse populations may be relatively isolated with no contacts between adjacent river basins (except where tributaries enter the main river), reducing re-invasion risks.

Figure 12 shows level 4 river basins.

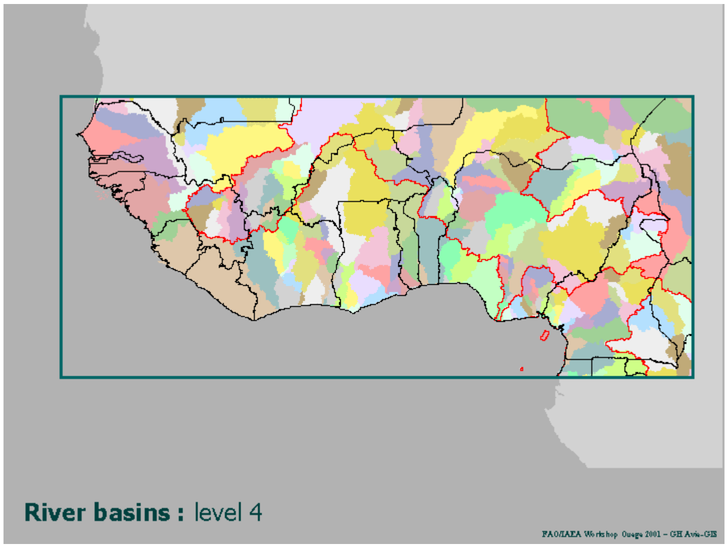

Fig 12 Level four river basins

This layer was used to select priority areas, i.e. river basin clusters, taking into consideration the informa tion gathered above on :

- Vulnerability of tsetse habitat (impact climate/vegetation AND human activities)
- Potential benefits
- Re-invasion risks

The selected river basins are shown in figure 13.

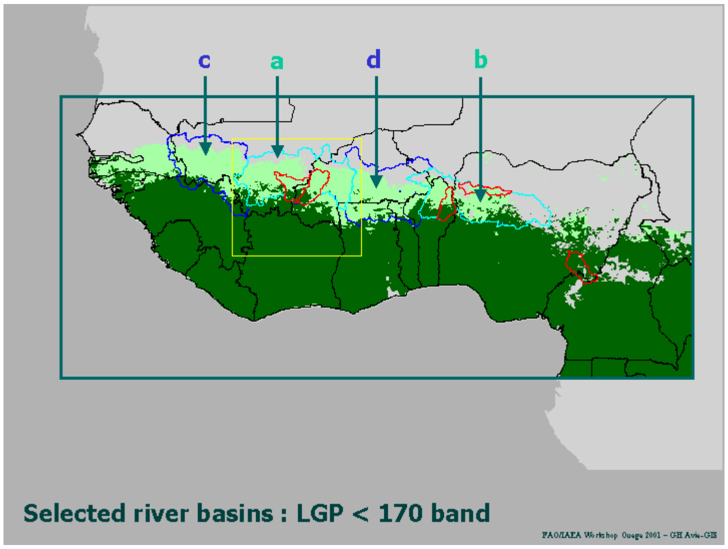

Fig 13 Selected priority areas

Legend figure 13:

1. Area a: Mali-Burkina Faso priority area.
2. Area b: Benin-Nigeria priority area.
3. Area c: Western extension (second level priority area if aim is to clear entire Northern fly band).

4. Area d: Central extension (second level priority area if aim is to clear entire Northern fly band).
5. Red areas: selected river basins for small sized shadow projects discussed in the main report.

The yellow rectangle depicts the area covered in the last part of this report.

Case study: Mali – Burkina Faso priority area (a).

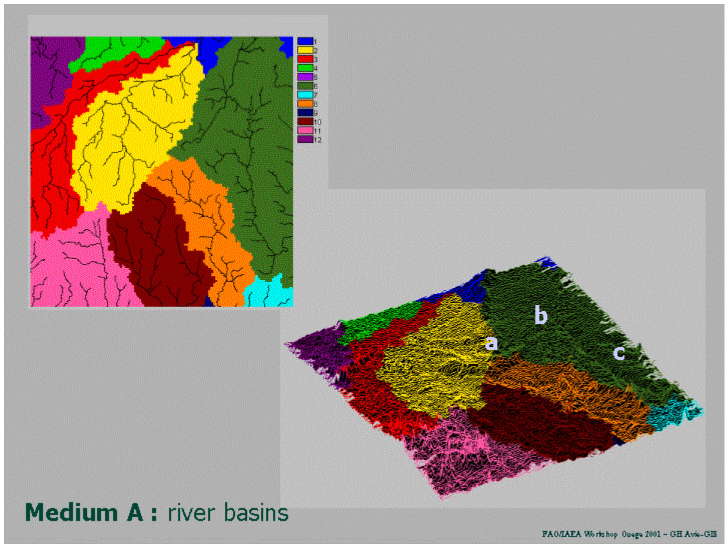

Fig 14 Priority area (a): basins and DEM

In the last part of this study an attempt is made to more precisely identify fly ecology bands in priority area (a), Mali – Burkina Faso (Fig. 14), as described previously in the Mali/Burkina Faso priority area. In summary the following procedure has been followed:

1. Allocate "ecological band value" to respective river basins based on field survey results:
   - Burkina Faso: FAO Project GCP-RAF-347-BEL and CIRDES data.
   - Mali: published results (Djiteye *et al.*) updated by Dr. Djiteye.
2. Create training set to train spatial prediction model (Fig. 15). River basin data were extracted using a 2.5 km buffer along main rivers and tributaries. A distance of 2.5 km on each side of the rivers was chosen since the resolution of the satellite data used in the next step was 5X5 km.
3. Run spatial prediction model, i.e. discriminant analysis model (UNISTAT™), using a set of 5 km resolution NOAA derived meteorological satellite data (satellite data were provided by Prof. D.J. Rogers, TALA research group, Zoology Department, Oxford, UK). The rationale underlying discriminant analysis is to determine whether known gridcells (e.g. 2.5 km buffer training set) belonging to predifined classes (e.g. ecological bands) differ with regard to the mean of a set of variables (e.g. satellite data), and then to use that knowledge to predict class membership of new cases (pixels not covered by training set).
4. Display output.

This approach was first applied using only training data for Burkina Faso and at a second stage using both training data sets from Burkina Faso and Mali.

Figure 14 shows the different river basins together with a three-dimensional 5 km resolution digital elevation model (DEM).

River basins of particular interest for this study include:

- Red, yellow and blue: Niger river basin in Niger
- Green: Mouhoun river basin in Burkina Faso, part of the Volta river system

The 5 km DEM clearly highlights the ridge (a) between Niger and Volta river basins and the Mouhoun “curve” (b) or boucle du Mouhoun and Mouhoun valley flowing southwards (c).

Main rivers and tributaries are derived from the same 1km DEM.

The river buffer training set used to predict fly ecology bands is given in figure 15.

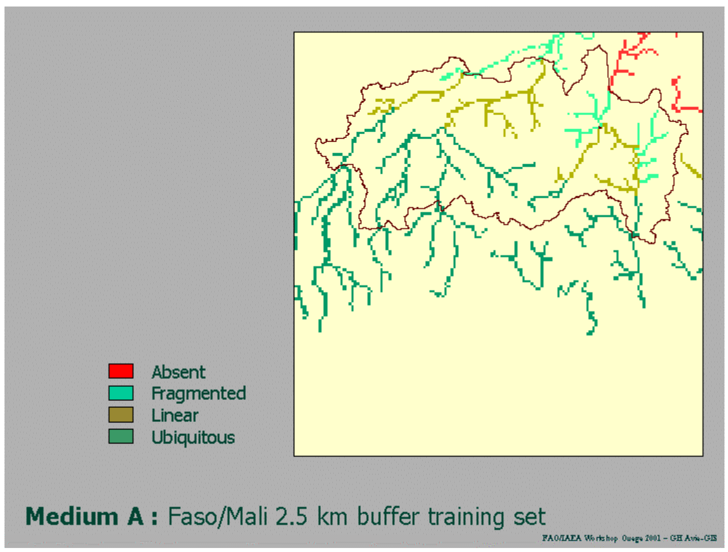

Fig 15 River buffer training set (2.5 km)

Discriminant analysis output 1 (top left map fig.16) :

Based on the Burkina training set the model allocates an “ecological band value” to each pixel.

After comparison with known literature sources for Niger it appeared that the limit between class 2 (fragmented) and 3 (linear) may be more to the North. Therefore Dr. Djiteye (LCV, Bamako) was asked to independently allocate class values to Niger river basins according to his current knowledge of tsetse distribution and ecology in Niger.

In a next step the model was further refined by including these training data for Niger.

Discriminant analysis output 2 (main map fig.16) :

Predicted fly ecology bands using the complete training set are shown in figure 15. The table includes respective surface areas per band for both outputs. These areas are important to study the feasibility of fly eradication and for ex-ante cost-benefit analysis studies.

Both outputs show major differences for Niger. This can be due to two factors:

1. Even when two areas are adjacent a similar set of eco-climatical conditions may affect tsetse ecology in a different way. In this case this may be highlighted by the DEM model given above where it is clearly seen

that basins in Niger and Burkina belong to different watersheds. Field data confirm this: vegetation patterns along the Niger river are different from patterns observed along the Mouhoun river.

2. Class division into a set of “ecological bands” is subjective, and limits between classes will vary from author to author. This can be illustrated with the Bamako example : close to Bamako large parts of the Niger river vegetation are infested with tsetse. Further north a gap of approximately 50 km exists before the next fly concentration is found. Should this be classified as “linear distribution” (argument: vegetation absent in gap, therefore no flies) or “fly pockets”?

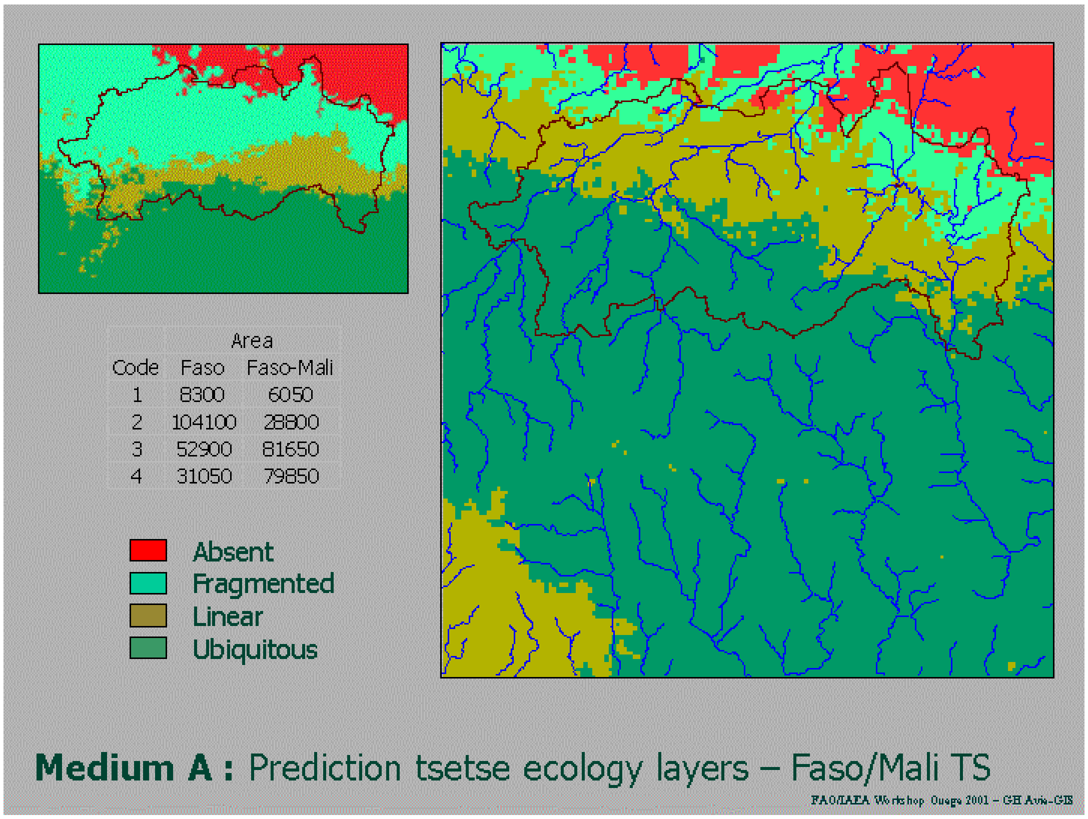

Fig 16 Priority area (a): predicted fly ecology bands

Conclusion

Produced results are a significant step towards data driven selection of priority areas for large-scale vector management. Whilst previously such approaches aimed at selecting areas for trypanosomosis control, the focus here is on concerted vector eradication. Taking the selected Mali - Burkina Faso priority area as an example, a series of subsequent fly ecology bands, of particular interest with regard to vector eradication feasibility, were identified.

Follow up studies should now focus on:

- Further refining obtained results by the use of higher resolution satellite data to identify and predict more accurately different vegetation patterns and river basin settings.
- Ground truthing obtained results.

References

Buxton, P.A. (1957) 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, N°10,* London, H. K. Lewis & Co., pp. 739.

Hendrickx, G. *et al.* (2001) Spatial trypanosomosis management. From Data-layers to Decision-making. *Trends in Parasitology (*formerly *Parasitology Today),* **17**, 35-42.

Nash, T.A.M (1937) Climate, the vital factor in the ecology of *Glossina*. *Bulletin of Entomological Research.* **28**, 75-127.

Putt, S.N.H. *et al.* (1980) The social and economic implications of trypanosomiasis control. A study of its Impact on Livestock Production and Rural Development in Northern Nigeria. Study N°25, 1980. Veterinary Epidemiology And Economics Research Group, University of Reading, pp. 549.

Reid, R.S. *et al.* (2000) Human population growth and extinction of the tsetse fly. *Agricultural Ecosysytems and Environment*. **77**, 227-236.