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Spatial trypanosomosis management: from data-layers to decision making

Guy Hendrickx, Stéphane de La Rocque, Robin Reid and Willy Wint

The use of geographical information systems (GIS) in the management of African animal trypanosomosis in sub-Saharan Africa offers potential in assisting decisions on allocation of resources, prioritization of control areas, and planning and management of field operations. Here, Guy Hendrickx and colleagues review approaches being used to develop reliable data-layers and to incorporate these data into GIS models. They argue that techniques should be further refined to produce more-detailed data layers and to include a dynamic element, a problem rarely addressed until now.

Historically, African animal trypanosomosis (AAT) has profoundly affected settlement and economic development in much of the African continent, and remains a major constraint to increased livestock production[1]. Moreover, tsetse infestations, by transmitting AAT, prevent the successful integration of crop and ruminant production[2]. Apart from the impact of the disease itself, it is argued that the mere presence of tsetse alters the distribution of susceptible livestock over vast areas and thus influences the type and number of animals kept, as well as the use of oxen for draught power, manure as crop fertilizer, and crop-residues and by-products as cattle feed[1,3].

Geographical information systems (GIS) are problem-solving tools that allow users to process and analyse spatial data layers in a multidisciplinary context. A GIS should thus be ideal for display, analysis and interpretation of the various factors affecting the epidemiology of AAT and its impact on people and their agriculture including: (1) the spatial patterns in tsetse challenge; (2) trypanosomosis risk; (3) clinical disease; (4) livestock biomass; (5) breed distribution; (6) farming systems; and (7) land use. GIS-related research activities discussed here can be divided into two groups: first, the development of improved methods to build reliable individual data layers; and second, the multilayer spatial analysis needed for improved decision making.

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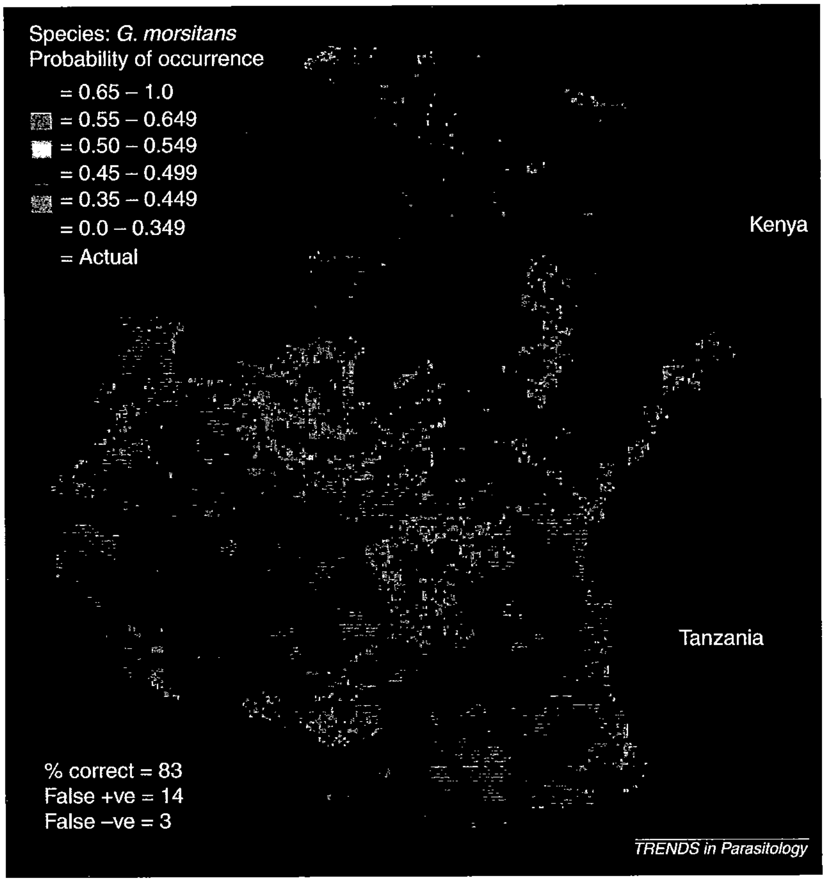

Fig. 1. Predicted probability of occurrence for *Glossina morsitans* in Kenya and Tanzania (83% correct predictions of presence or absence; 14% pixels wrongly predicted as present; 3% pixels wrongly predicted as absent).

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Data-layer development

Vector distribution and abundance

Since the early 1900s, when the link between tsetse and trypanosomosis was established, considerable efforts have been made to map the distribution of the different tsetse species. This wealth of information, gathered by often anonymous fieldworkers, at subnational or country level has been compiled regularly to produce maps at a subregional or continental scale, the latest of which are still widely used[4,5]. The problem of mapping tsetse abundance, although essential, has been less frequently addressed and was largely limited to monitoring tsetse populations in areas earmarked for vector eradication[6,7]. More recently, detailed tsetse abundance maps have been produced in the Gambia[8] and Togo[9].

Years of field studies have documented the influence of climatic variables on the distribution and abundance of tsetse at local and regional levels using ground measured data[10,11]. The increased availability of satellite imagery should allow us to produce much improved vector distribution maps. The source, technical characteristics and availability of remotely sensed data used in epidemiological studies have been reviewed in great detail elsewhere[12,13]. Variables used in the studies described below are mainly acquired from two different meteorological satellite series: the US Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanographic and Atmospheric Administration (NOAA) satellite series and the European Meteosat satellite series. Despite their rather low spatial resolution (8 × 8 km in the studies referred to here), they have the major advantage of a high temporal resolution. About two images are collected every day by orbiting NOAA satellites and one image every 30 min by the geo-stationary Meteosat. This characteristic, together with the fact that satellites ignore administrative boundaries, has opened new perspectives for the detailed analysis of eco-geographical temporal trends from derived variables such as vegetation cover (e.g. normalized difference vegetation index; NDVI), temperature, and vapour pressure deficit from AVHRR- and Meteosat-derived rainfall estimations (e.g. cold cloud duration, CCD).

Rogers and colleagues first used discriminant analysis with remotely sensed and ground-measured variables to successfully predict the presence of *Glossina morsitans* and *Glossina pallidipes* in Kenya, Tanzania and Zimbabwe[14–16] (Fig. 1), and the presence of eight tsetse species in Ivory Coast and Burkina Faso using historical fly distribution limits. The latter study[17] included some prediction of fly abundance in northern Ivory Coast. The authors addressed the problem of data overload (i.e. one image per variable per ten-day interval over a period of several years, by using data reduction techniques based on Fourier processing). Another study[18,19] compared different monovariate and multivariate analysis techniques used to predict fly distribution in the common fly belt of Malawi, Mozambique, Zambia and Zimbabwe, based on the Ford and Katondo distribution maps. In Togo[20], similar techniques were used to identify tsetse habitat in an attempt to minimize the use of expensive, ground-collected data and to optimize satellite imagery application. Results included satisfactory distribution maps for the six tsetse species present and, more importantly, predicted abundance maps for both riverine species (*Glossina tachinoides* and *Glossina palpalis palpalis*).

These studies revealed important features of local and regional fly distribution patterns[21] and led to the production of continent-wide predicted distribution maps of all tsetse species and subspecies at one tenth of a degree resolution [soon to be released on the Program Against African Trypanosomosis (PAAT) website: http://www.fao.org/paat/html/home.htm]. Nevertheless, problems with regard to the selection and replicability of training sets have yet to be solved before affordable area-wide abundance maps can be produced using similar techniques[20].

Disease mapping

Until the late 1980s, vector eradication and the expected subsequent elimination of AAT, was accepted as the principal strategy to tackle the problem of AAT (Ref. 22). Efforts focused on mapping tsetse; there are few records of the systematic mapping of trypanosome prevalence and most of these remain unpublished.

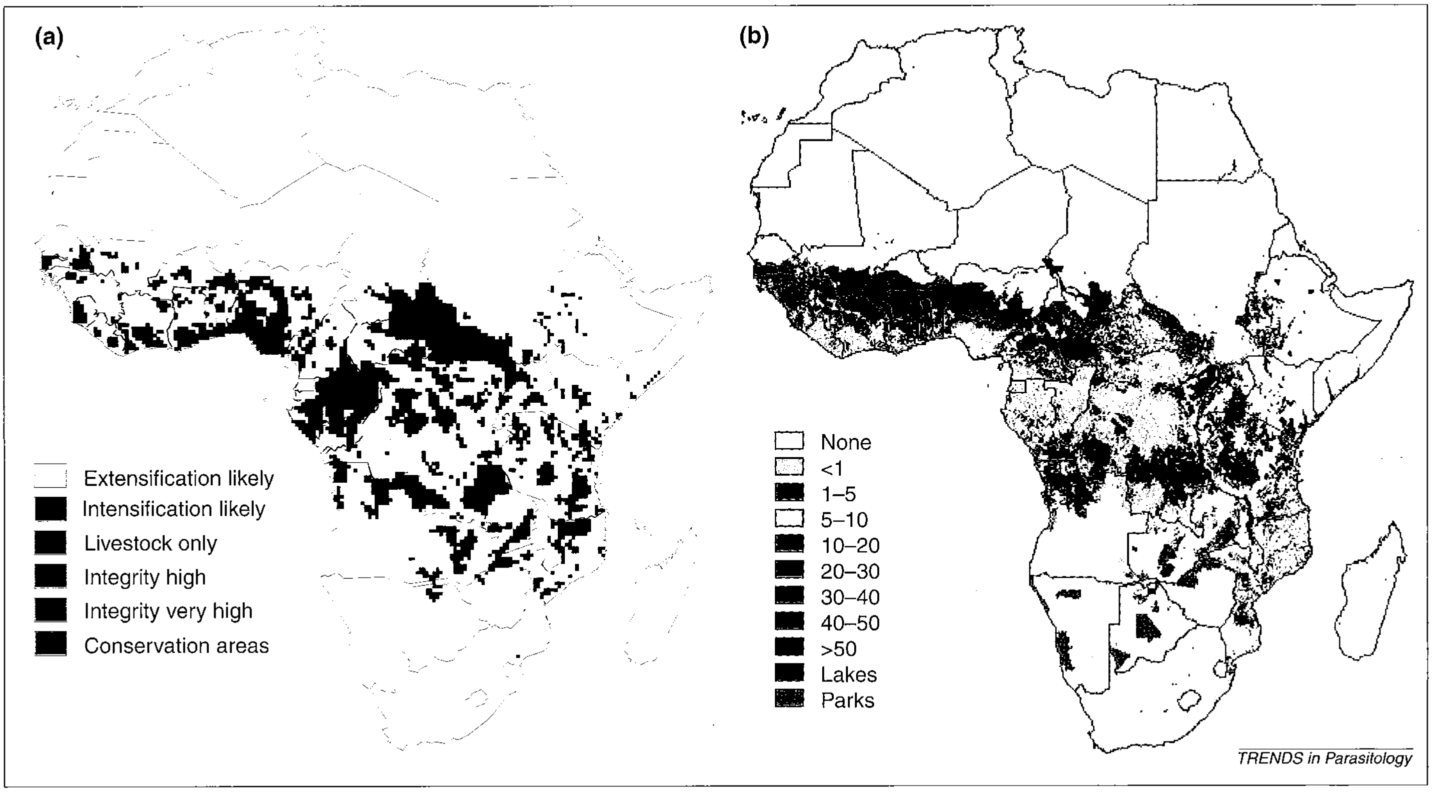

Fig. 2. (a) Possible environmental implications of successful trypanosomosis control in Africa. Colour code: red, areas where agricultural intensification is likely, little expansion of agriculture is expected, AAT control is encouraged; Green, control is discouraged because human populations are low and ecosystem integrity is high; Yellow, expansion or extensification of agriculture is likely, control activities will have to be planned carefully to avoid significant loss of bio-diversity. Figure modified, with permission, from Ref. 28. (b) Predicted increase in cattle density per km^2, assuming the removal of all tsetse species. Modified figure reproduced, with permission, from the PAAT-Information System (1999), http://www.fao.org/paat/html/home.htm.

In the northern Ivory Coast[23], the presence of trypanosomosis was mapped in individual herds classified as either with or without the disease. These results were linked to contemporary animal production data and to the distribution of cattle breeds in order to assess the economic impact of the disease[24]. In Zambia, a standardized tsetse and trypanosomosis sampling method[25] was developed during the Insect Pest Management Initiative Project (IPMI), associated with the Regional Tsetse and Trypanosomosis Program (RTTCP). At a later stage, national AAT surveys were carried out in selected sites covering all countries participating in the RTTCP (P. Van den Bossche, pers. commun.).

The only known example of systematic countrywide disease mapping combined with a subsequent prediction exercise was in Togo[26,27]. Exhaustive surveys at a resolution of 0.125 degrees yielded detailed maps of trypanosomosis prevalence, average herd packed cell volume (PCV; a measure of anaemia, the major symptom of AAT), the level of zebu introgression of trypanotolerant cattle breeds and the distribution of major animal husbandry systems. Discriminant analysis techniques similar to those mentioned above were used to produce satellite-based predictions of the occurrence of AAT. Tsetse predictions yielded the highest accuracy followed by parasitaemia and PCV. Satisfactory results for PCV were obtained only when anthropogenic variables linked to herd management, cattle breeds and land use were used in addition to ground measured and remotely sensed eco-climatic predictor variables.

Data-driven decision support

GIS systems are being developed at continental, national and local level largely to discriminate areas where the control of trypanosomosis is most likely to enhance livestock production and the integration of livestock and cropping that is economically beneficial, environmentally sound and technically feasible.

Continental level

The GIS unit of the International Livestock Research Institute (ILRI) developed a GIS simulation[28] using data on tsetse distributions, human populations, cattle densities and conservation areas, with the aim of identifying the possible environmental implications of successful trypanosomosis control (Fig. 2a). Another model[29] was designed to anticipate the effect of expanding human populations and associated agriculture on the present distribution of different groups of tsetse fly. Results suggested that by 2040, many tsetse species will begin to disappear and the area of land infested and number of people in contact with flies will decline.

The Food and Agriculture Organization of the United Nations (FAO), assisted by the Environmental Research Group Oxford (ERGO), conducted a series of more-refined studies of eastern, western and southern Africa[30] to prioritize areas for tsetse control at a resolution of 5 km. Tentative farming systems were defined, based on combinations of farmer densities, the amount of land under cultivation, cattle numbers and elevation. These were matched with the tsetse distributions to assess the likely outcome of any tsetse control, expressed in terms of expected changes in the levels of cropping and livestock. Multivariate analysis models incorporating satellite data were used to estimate agricultural levels within administrative units. These results have been further expanded to the whole of sub-Saharan Africa, and are available to decision makers through the PAAT-Information System[31] (PAAT-IS; see PAAT website). Major outputs to date comprise a first approximation of tsetse removal on agricultural intensity and cattle densities (Fig. 2b).

The first type of studies are relatively crude, although useful to test 'what if' scenarios at a continental scale. The second type are much more sophisticated and effectively assist decision making at a subcontinental and indeed trans-boundary level. A further development of PAAT-IS towards increased interactivity and accessibility could be a major drive towards a broader use of this type of GIS by national decision makers.

National level

In Zambia, a weighted linear combination model was developed to address the problem of prioritizing areas for tsetse control[32]. The variables used were historical tsetse distribution limits, cattle density, human population density, crop use intensity, relative arable potential, land designation and proximity to control operations. The different thresholds per criterion and the suitability of an area for tsetse control were set by a group of experienced veterinarians and biologists working in the region. At a local level, recommendations were made to modify the boundaries of a proposed community-based target control area in the eastern province of Zambia to maximize the potential benefits. More broadly, the author stressed the need for improved data layers should this GIS approach be adopted for wider use. At a later stage it became apparent to the RTTCP that, in the identification of priority areas of control, the process of strategy formulation should take full account of the socio-economic, institutional, technical and environmental aspects (P. Van den Bossche, PhD Thesis, University of Pretoria, 2000). In a concept note published on the PAAT e-mail list (PAAT-L; see PAAT website), it was further stressed that this is essentially a dynamic process, needing permanent monitoring and feed back, and that overgeneralization should be avoided.

In Togo, a stepwise GIS model was developed[33], largely based on field-collected data and the detailed knowledge of the spatial epidemiology of AAT and its impact on the integration of cattle and crops[26]. Two dominant animal husbandry systems were investigated. In market-oriented systems (where stakeholders are mainly concerned with the direct impact of AAT), data on disease prevalence, PCV and trypanotolerance were integrated to produce a map reflecting the extent of 'veterinary needs' of individual herds – a practical tool towards disease control prioritization. In rural traditional systems (where stakeholders benefit most from an improved integration of cattle and crops), areas where integrated rural development could yield the highest benefits were identified using data on agricultural intensity, human population and cattle density. By cross-tabulating this new 'potential benefit' layer with the previously calculated direct cost of the disease, a final, 'cost:benefit' layer was obtained. Selected priority areas are summarized in Fig. 3 and have been incorporated into a national trypanosomosis control plan. A series of alternative, cost-effective ways to produce a prioritization were tested, including predicted data layers on tsetse abundance and AAT prevalence, as described above. As with the RTTCP example cited above, the major weakness of this type of model appeared to be the absence of a time factor. The positive impact of a successful national extension campaign on AAT was underestimated and not taken into consideration rapidly enough when planning vector control in selected areas, leading to unnecessary costs and poor participation in some areas (A. Napala, pers. commun.).

Local level

Although continental and country level approaches are mainly designed to define priority areas at a relatively broad scale (region, country, subcountry), it is often necessary to conduct more-detailed studies in specific areas. On the Adamawa plateau in Cameroon, GIS was used to map vegetation and land-use classes based on high resolution (20 m) satellite pour l'observation de la terre (SPOT) imagery, as part of a tsetse-control program[34]. In a more detailed study conducted in Lambwe Valley[35], western Kenya, factors associated with local variations of fly density were identified using statistical methods of spatial autocorrelation and filtering. Field tsetse data were combined with fine spatial resolution (30 × 30 m) Landsat thematic mapper (TM) satellite imagery and reference ground environmental data. Although a large part of the association between fly density and spectral data was attributed to unknown determinants, the results clearly demonstrated the value of using fine resolution, remote sensing data to predict vector habitats in inaccessible sites, and to determine the number and location of fly suppression traps in a local control programme.

Similar GIS techniques have been applied to assess the environmental impact of tsetse control at Lake Kariba[36], Zimbabwe, and in Ghibe Valley[37,38], Ethiopia, using Landsat imagery. In the Lake Kariba area, changes in land cover over a 20-year period

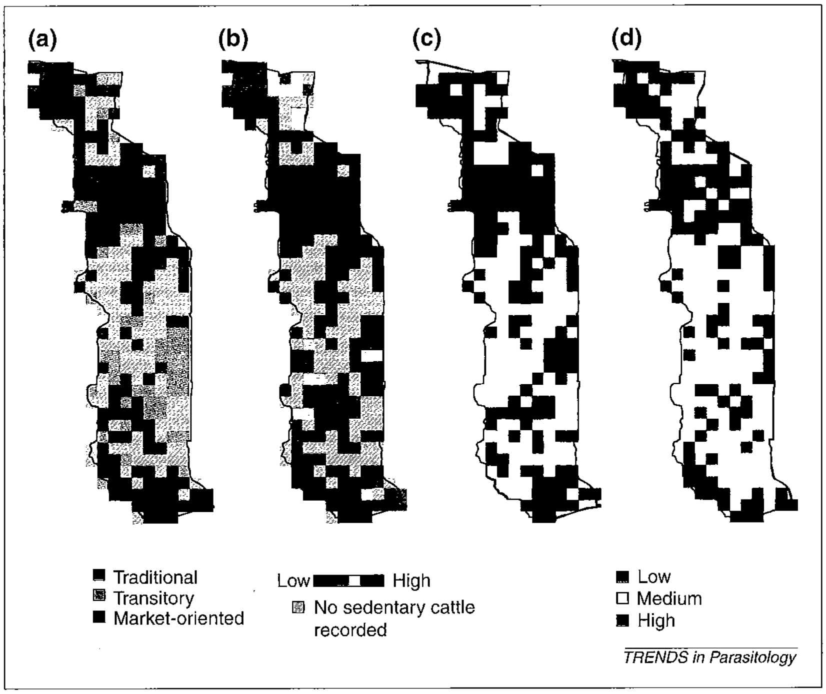

Fig. 3. Priority areas for trypanosomosis control in Togo. (a) Animal husbandry systems. (b) Level of Zebu introgression. (c) Priority areas for disease control in market-oriented animal husbandry systems. (d) Priority areas for integrated disease management in rural-traditional animal husbandry systems. Figures (a) and (b) are modified from Ref. 26. Figures (c) and (d) are adapted from Ref. 33.

revealed little evidence of a direct relationship between patterns of human-dominated land-use change and tsetse-control operations, indicating that there is a complex series of factors, including tsetse control, influencing agricultural development in the area. The Ghibe study shows that outbreaks of trypanosomosis can drive farmers out of infested areas rapidly, which leads to substantial decline in the area of land cultivated, livestock populations and the extent of settlements. Once farmers retreat, wildlife returns and woodlands regenerate, highlighting the importance of rare but biologically rich riparian areas, where the potential impact of tsetse control is highest.

In a more detailed study in Sidéradougou, Burkina Faso, a multidisciplinary team studied all major factors affecting the host–vector interface at a fine spatial resolution, with special emphasis on human impacts[39]. They used high spatial resolution (20 × 20 m) SPOT imagery and detailed field data on entomology, parasitology, ecology and landscape patterns, soil structure, land-use and herd management. Results showed that although riverine tsetse are present throughout the drainage system, distinct spatial patterns appear in the distribution of the trypanosome species present in flies that depend on the presence of cattle[40]. Spatial modelling tools were used to highlight preferential tsetse habitat and to describe the use of natural resources (including daily cattle routes) by cattle-owners[41]. Further analyses revealed particular epidemiological hot-spots representing about 10% of the area.

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As described here, high resolution GIS has been tested for a wide range of purposes including habitat identification, vector control planning, epidemiology and impact assessment. This has provided new insights into the problem at the village or herd level. Although developed techniques seem applicable in other areas, it appears that the extrapolation of results to remote or even adjacent areas has to be addressed properly before prediction exercises can contribute to reduce costs and render this type of GIS more widely applicable.

Concluding remarks

Since its introduction into the field of AAT some ten years ago, has GIS lived up to its expectations or are we still at the stage of wishful thinking and 'promising results'? As described above, important breakthroughs have been achieved in the development of techniques for mapping vector distribution. Remote sensing data are now more widely available[12,13] and prediction techniques can be adopted using commercially available statistical software. These techniques should be further applied to examine vector abundance and which predictor variables are relevant. With regard to AAT mapping, it is clear from the Togo[27,33] and RTTCP experience that anthropogenically determined factors locally influence AAT, breaking the direct link between satellites and animal disease[21]. More adapted determinants have thus to be identified. From a veterinary point of view, efforts should focus on PCV rather than parasitaemia, because the former describes disease whereas the latter might indicate a carrier status only (e.g. trypanotolerant cattle). In addition, PCV data can be gathered more quickly and cheaply over large areas and for a larger number of cattle.

With regard to data-driven decision support, objectives will determine the working scale, where scale refers to both the extent of the area covered and the spatial detail (pixel resolution) at which data are collected. More complex analyses are possible at finer resolutions[42]. In practice, a sequential GIS approach will lead to data and results from the lower scale contributing to the design of the next level. This type of approach is a crucial part of the rational use of GIS, whereby the types of advantages and constraints at different scales are systematically considered to obtain the best cost:benefit ratio (see Box 1). The data layers used are dictated by both what is needed and what is available, or can be derived, at any given scale. Choices require a healthy dose of pragmatism, considerable balancing of the advantages of accuracy against coverage, and speed and repeatability against precision.

Thus the strength of this approach is also its major weakness: expert advice within a multidisciplinary environment and permanent feedback from the field and stakeholders are essential to ensure proper use. Although this might be stating the obvious,

Box 1. The scale factor: from continent to village[a]

	Advantages and scopes	Constraints
Continental and regional level	• Satellite data are easily accessible, cheap, and can provide seasonal series • Robust spatial prediction models have been developed for tsetse presence. This allows gaps in observed data to be filled, which is cheaper than field surveys • 'Ready to use' simulation models (e.g. 'what if' scenarios) • Comparatively quick to implement at a large scale • Trans-boundary decision making and identification of large-scale priority areas for control is possible • Relatively independent of dynamic factors	• Origin, quality, accuracy and homogeneity of field data does not always respond to standards • Local inaccuracies owing to unaccounted factors • Data unavailable for large-scale predictions of tsetse abundance and African animal trypanosomosis prevalence • Can be extrapolated too far • The biological interpretation of statistical results is not always straightforward • Analysis results are costly to validate
National and subnational level	• Allows inclusion of more detailed spatial epidemiological analysis and risk assessment • Versatile, maximal use of existing data layers • Easy to link with existing national programs and to implement • Intermediate in cost	• Quality of existing data layers is often weak • Some epidemiological variables describing the host–vector interface are not practically measurable at this scale over large areas (e.g. fly infection rates) • Complex sample designs and data transformation • Expert input: decision trees and thresholds are very much case dependent
Local level	• Allows in depth study of ecological and epidemiological systems • Allows inclusion of all factors affecting the host–vector interface • Geo-referenced point measurements easy to adapt to different scales • Can be used at field-operational level	• Cumbersome data acquisition • Expensive satellite data • Need for even higher resolution satellite data • Most sensitive to dynamic change and therefore needs regular updates • Results complex to extrapolate to other areas

[a] A summary of advantages and constraints of using GIS tools at different scales. As described in the text, ideally, a sequential GIS approach will lead to data and results from the lower level contributing to the design of the next level, taking maximum benefit of advantages while avoiding disadvantages

experience teaches us that such aspects are too often neglected, and that researchers need to work in closer relationship with developers.

Although the issue of obtaining and integrating reliable and detailed data sets is being addressed effectively, it addresses only one part of the problem. If we want GIS tools to be fully operational, the major challenge yet to be addressed is the anticipation of changes over time of all variables involved (i.e. moving from spatial to temporal predictions). It is to be hoped that this will prove more feasible than predicting next weekend's weather.

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