Chapter 1
Tsetse fly habitat and land cover: an analysis at continental level

TSETSE HABITATS

A habitat is the place where a particular species lives and grows. It is essentially the biophysical environment that surrounds, influences and is utilized by a species population. Tsetse flies are found in a number of habitats in sub-Saharan Africa, ranging from the rain forest to savannahs. Their presence is usually related to the characteristics of land cover (i.e. vegetation), which is affected primarily by climate and human activities. The presence of a suitable source of food is also essential for tsetse. Like many other arthropods, tsetse flies are particularly sensitive to temperature and humidity and at the northern edge of their distribution high temperature and dryness limit the spread of the flies. This is also true for the southern limit of the distribution, even though in some areas seasonal low temperatures can be more important.

The three groups of tsetse flies (*morsitans, palpalis* and *fusca*) prefer different types of habitat. With one exception (*G. longipennis*), the species of the *fusca* group (corresponding to the subgenus *Austenina*) are forest flies inhabiting either rain forest or isolated patches of forest, along with riverine forest in the savannah zones. Flies of the *palpalis* group (subgenus *Nemorhina*) are found mainly in gallery forests, swamps and in watersides with closed canopy. The typical habitat of the *morsitans* group (subgenus *Glossina* s.s.) is open woodland and woodland savannah, but they are found also in forest edges, scattered thickets or even open country.

In addition to the typical habitats mentioned above, *Glossina* species can be found in less usual habitats, among which the man-made ones are the most important. Tsetse are found in and around villages, especially in the rain forest belt of West Africa, where the original vegetation has been cut down to create farms and plantations (mango, oil palm, bananas, cola nuts, cocoa, coffee).

Along with the macrohabitat, it is also important to know which are the microhabitats of tsetse flies. Microhabitats are suitable places for a species that can be depicted at a finer resolution. They can significantly differ from the surrounding areas in many ways, including the climate. Suitable microhabitats for tsetse are able to provide cooler or more humid conditions, especially in particularly harsh seasons or times of the day. The fly's behaviour can bring it into these places where it can survive better than if it had to suffer the general climatic conditions of the area.

LAND COVER CLASSIFICATION SYSTEMS: CONCEPTS AND DEFINITIONS

Land cover is the observed (bio)physical cover on the earth's surface. It describes vegetation and man-made features, whereas **land use** is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO, 2005). Land use establishes a direct link between land cover and the actions of people in their environment.

Classification is an abstract representation of the situation in the field using well-defined diagnostic criteria, i.e. the classifiers. Classification can be defined as the ordering or arrangement of objects into groups or sets on the basis of their relationships (Sokal, 1974). A classification describes the systematic framework with the names of the classes and the criteria used to distinguish them, and the relationship between classes. Classification thus requires the definition of class boundaries, which should be clear, precise, possibly quantitative, and based upon objective criteria.

A classification should therefore be:

- source independent, implying that it is independent of the means used to collect information (satellite imagery, aerial photography, field survey or a combination of sources); and
- scale independent, meaning that the classes should be applicable at any scale or level of detail.

A **legend** is the application of a classification in a specific area using a defined mapping scale and specific dataset. Therefore a legend may contain only a proportion, or subset, of all possible classes of the classification. Thus, a legend is:

- data and mapping methodology dependent; and
- scale and cartographic representation dependent.

A critical factor in the production of reliable and comparable land cover and land-use data is the availability of common, harmonized classification systems that provide a reliable basis for interaction among the increasing number of national, regional and global mapping and monitoring activities. While the creation of a standard land-use classification system is still in its infancy[1], the definition of a standard of the International Organization for Standardization (ISO) for land cover classification is close to being achieved.

The Land Cover Classification System has been developed by FAO and UNEP to meet the need for improved access to reliable and standardized information on land cover and land cover changes. The Land Cover Classification System enables comparison of land cover classes regardless of mapping scale, land cover type, data collection method or geographic location. Currently, LCCS is the only universally applicable classification system in operational use. The inherent flexibility of LCCS, its applicability in all climatic zones and environmental conditions, and the built-in compatibility with other classification systems have given it the potential to be accepted as the international standard. For these reasons, LCCS is currently in the approval process by ISO.

The advantages of the classifier, or parametric, approach are manifold. The system created is a highly flexible *a priori* land cover classification in which each land cover class is clearly and systematically defined, thus providing internal consistency. The system is truly hierarchical and applicable at a variety of scales. Rearrangement of the

[1] http://www.glcn.org/news/downs/pub/res/GLCN-Bulletin4-JanFeb06.pdf

BOX 1

Land Cover Classification System design criteria

In LCCS, land cover classes are defined by a combination of a set of independent diagnostic criteria, the 'classifiers', which are hierarchically arranged to assure a high degree of geographical accuracy. The classification has two main phases:

- an initial dichotomous phase, where eight major land cover types are distinguished; and
- a subsequent modular-hierarchical phase, where the set of classifiers and their hierarchical arrangement are tailored to the major land cover type.

Further definition of the land cover class can be achieved by adding attributes. Two types of attributes, which form separate levels in the classification, are distinguished:

- environmental attributes (e.g. climate, landform, altitude, soil, lithology and erosion), which influence land cover but are not inherent features of it, and which should not be mixed with 'pure' land cover classifiers; and
- specific technical attributes, which are associated with specific technical disciplines (e.g. for (semi)natural vegetation, the floristic aspect can be added; for cultivated areas, the crop type; and for bare soil, the soil type).

classes based on regrouping of the classifiers used facilitates extensive use of the outputs by a wide variety of end users. All land covers can be accommodated in this highly flexible system.

The Land Cover Classification System is already an important tool in global mapping, being used in initiatives such as the GLC2000 project and the next global assessment, GLOBCOVER, that aims to produce a land cover map of the world for the year 2005. Developed initially through the practical experience of the FAO Africover project, LCCS has been widely adopted at the national level throughout Africa, Asia, Near East and Latin America.

MATCHING TSETSE HABITAT AND LAND COVER: POSSIBLE APPROACHES

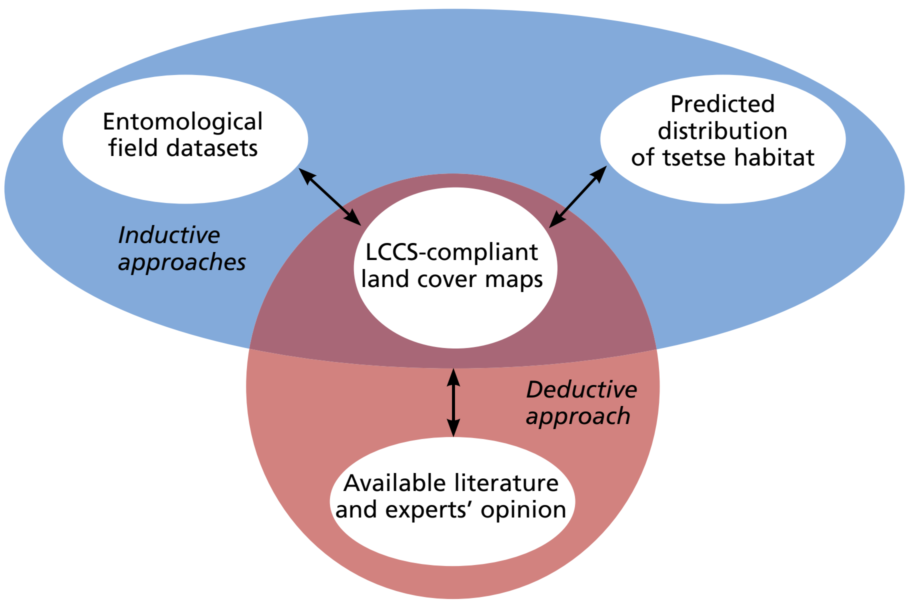
The availability of multipurpose land cover datasets at different resolutions released into the public domain makes the prospect of matching standardized land cover classes and tsetse habitat very promising. It is expected that T&T research and control activities will greatly benefit from the use of existing and future land cover maps produced in compliance with the standard FAO/UNEP LCCS.

It is well known that among the factors influencing the suitability of habitats for tsetse flies, land cover is one of the most relevant. Vegetation is affected by and affects temperature and humidity, the two major abiotic determinants of tsetse distribution; trees in particular provide shade for developing pupae and resting sites for adults. The analysis of the vegetation cover has often played a major role in the estimates of the tsetse distribution and in the description of their habitat (Ford and Katondo, 1975; Ford and Katondo, 1977a,b; FAO, 1982; Katondo, 1984), but recent developments in remote sensing techniques provided global, regional and national datasets that can be used to bridge the gap in our knowledge on the relationship between tsetse habitat and standardized land cover classes in Africa.

Three methods can be used to assess the suitability of land cover classes for tsetse: analysis of land cover maps and entomological field datasets (traps catches), analysis of land cover maps and predictions of tsetse distribution (e.g. based on remote sensing), review of available literature and experts' opinion (Figure 1). The two former methods belong to the category of inductive approaches, where the relationship between the variables is not assumed *a priori*, the latter can be defined instead as a deductive approach, which uses the species' known ecological requirements to extrapolate suitable land cover classes (Corsi *et al.*, 2000).

The first method is thought to be capable of providing the most accurate results, but as a result of the lack of updated and consistent field datasets for the whole continent, its application can only be envisaged over single countries or smaller areas. The second method is the one used in this chapter to estimate the land cover suitability for tsetse in sub-Saharan Africa; its major drawback is the use of predictions of tsetse habitat that have not yet undergone a full field validation. Therefore, this approach can only provide qualitative results. The third method is used in Chapters 2 and 3 to estimate the land cover suitability for tsetse flies, respectively in sub-Saharan Africa and in Uganda. The main problem in the application of this method lies in the fact that the scientific community studying tsetse habitat and ecology has not adopted LCCS yet, therefore the comparison of ad hoc defined classes and standard ones can be troublesome.

FIGURE 1
Possible approaches for estimating the suitability of standardized land cover classes for tsetse



TSETSE HABITAT AND LAND COVER IN SUB-SAHARAN AFRICA: AN INDUCTIVE APPROACH

In this chapter, the land cover of tsetse habitat in sub-Saharan Africa is described by means of the GLC2000 of Africa, and the FAO predicted distribution of tsetse habitat, produced in 1999. Both datasets, in their respective category, represent the best available information to date for the whole continent. The results are in substantial agreement with the literature related to tsetse habitats and they demonstrate that general-purpose land cover maps can be effective in supporting strategic decision-making in the field of T&T intervention.

Materials

Global Land Cover 2000

The Global Land Cover database for the year 2000 was produced by an international partnership of about 30 research groups coordinated by the European Commission's Joint Research Centre (JRC). The database contains regional land cover maps with detailed, regionally relevant legends and a global product that combines all regional classes into one consistent legend.

The land cover maps are based on daily data acquired between 1 November 1999 and 31 December 2000, from the VEGETATION sensor on board the fourth Satellite Pour l'Observation de la Terre (SPOT) satellite, SPOT 4. In addition, data from other sensors (the Along Track Scanning Radiometer [ATSR], the Japanese Earth Resources Satellite [JERS], the European Remote Sensing Satellite [ERS] and the Defense Meteorological Satellites Program [DMSP]) were used to solve specific problems, in particular in regions with persistent cloud cover, especially in equatorial regions, and for identification of urban areas. Each partner used the LCCS, which ensured that a standard legend was used over the globe. This hierarchical classification system allowed each partner to choose the most appropriate land cover classes to describe their region, whilst also providing the possibility of translating regional classes to a more generalized global legend. Data and information update may be found on the GLC2000 web pages[2].

In the present study, the regional product over Africa was used (Mayaux *et al.*, 2003; Mayaux *et al.*, 2004). The relevant legend (Global Land Cover 2000 of Africa) is given in Table 1 (p. 6).

Tsetse distribution maps

The predicted absence or presence of the three tsetse fly groups across Africa was derived from the FAO–PAAT predicted distribution of tsetse habitat (1999). All of the distributions were produced by modelling the 'known' presence and absence of the flies (usually the 1977 Ford and Katondo maps modified with more recent information collected from national and international agencies and researchers). The modelling process relied on logistic regression of fly presence against a wide range of predictor variables for a large number of regularly spaced sample points for each area. The predictor variables include remotely sensed (satellite image) surrogates of climate, vegetation, temperature and moisture, which were subjected to Fourier processing to provide an additional set of

[2] http://www-gem.jrc.it/glc2000/

TABLE 1
Legend of the Land Cover of Africa for the year 2000

English name	Nom français
Forests	**Forêts**
Closed evergreen lowland forest	Forêt dense humide
Degraded evergreen lowland forest	Forêt dense dégradée
Submontane forest (900–1500 m)	Forêt submontagnarde (>900 m)
Montane forest (>1500 m)	Forêt de montagne (>1500 m)
Swamp forest	Forêt marécageuse
Mangrove	Mangrove
Mosaic forest / croplands	Mosaïque agriculture / forêt
Mosaic forest / savanna	Mosaïque forêt / savane
Closed deciduous forest (Miombo)	Forêt décidue dense (Miombo)
Woodlands, shrublands and grasslands	**Savanes**
Deciduous woodland	Savane boisée décidue
Deciduous shrubland with sparse trees	Savane arborée à arbustive décidue
Open deciduous shrubland	Savane arbustive décidue
Closed grassland	Savane herbacée dense
Open grassland with sparse shrubs	Savane herbacée ouverte à faible strate arbustive
Open grassland	Savane herbacée ouverte
Sparse grassland	Pseudo-steppe
Swamp bushland and grassland	Savane herbacée et arbustive inondée
Agriculture	**Agriculture**
Croplands (>50%)	Agriculture (>50 %)
Croplands with open woody vegetation	Mosaïque agriculture / végétation sèche
Irrigated croplands	Agriculture irriguée
Tree crops	Vergers
Bare soil	**Autres occupations du sol**
Sandy desert and dunes	Roche nue
Stony desert	Désert rocheux
Bare rock	Désert sableux et dunes
Salt hardpans	Dépôts salins
Other land cover classes	**Autres occupations du sol**
Waterbodies	Eau
Cities	Villes

season- and timing-related measures for each parameter. Demographic, topographic and agro-ecological predictors were also used. These models were then applied to the predictor imagery to determine the probability of fly distributions. Data are at 5 km resolution for the whole sub-Saharan Africa. The 5 km continental maps were produced for the FAO Animal Health and Production Division and the Department for International Development (DFID) Animal Health Programme by the Environmental Research Group Oxford (ERGO) Ltd in collaboration with the Trypanosomosis and Land-use in Africa (TALA) research group at the Department of Zoology, University of Oxford.

Method

The predicted distributions of tsetse habitat define habitat suitability in probabilistic terms; for the present study, the threshold of 50 percent was used to discriminate suitable from unsuitable areas. The mask of suitable areas was overlaid onto the Global

TABLE 2
Thresholds for the tsetse suitability classes

	Suitability of land cover for tsetse *(0–3)*	Criterion: proportion of suitable habitat within the class *(%)*
3	High	> 50
2	Moderate	> 25 and ≤ 50
1	Low	> 5 and ≤ 25
0	Unsuitable	≤ 5

Land Cover of Africa to calculate the proportion of each land cover class within the potential fly distribution. The results of the analysis were used to define for each fly group and land cover class a degree of suitability for tsetse. For each land cover class, the suitability value was assigned as a function of the percentage of tsetse infestation area within the total area covered by the class (fifth column in Table 3, Table 4 and Table 5). The thresholds used are given in Table 2.
The chi-square test was used to measure the relative magnitude of the statistical relationship between land cover and tsetse presence.

Results

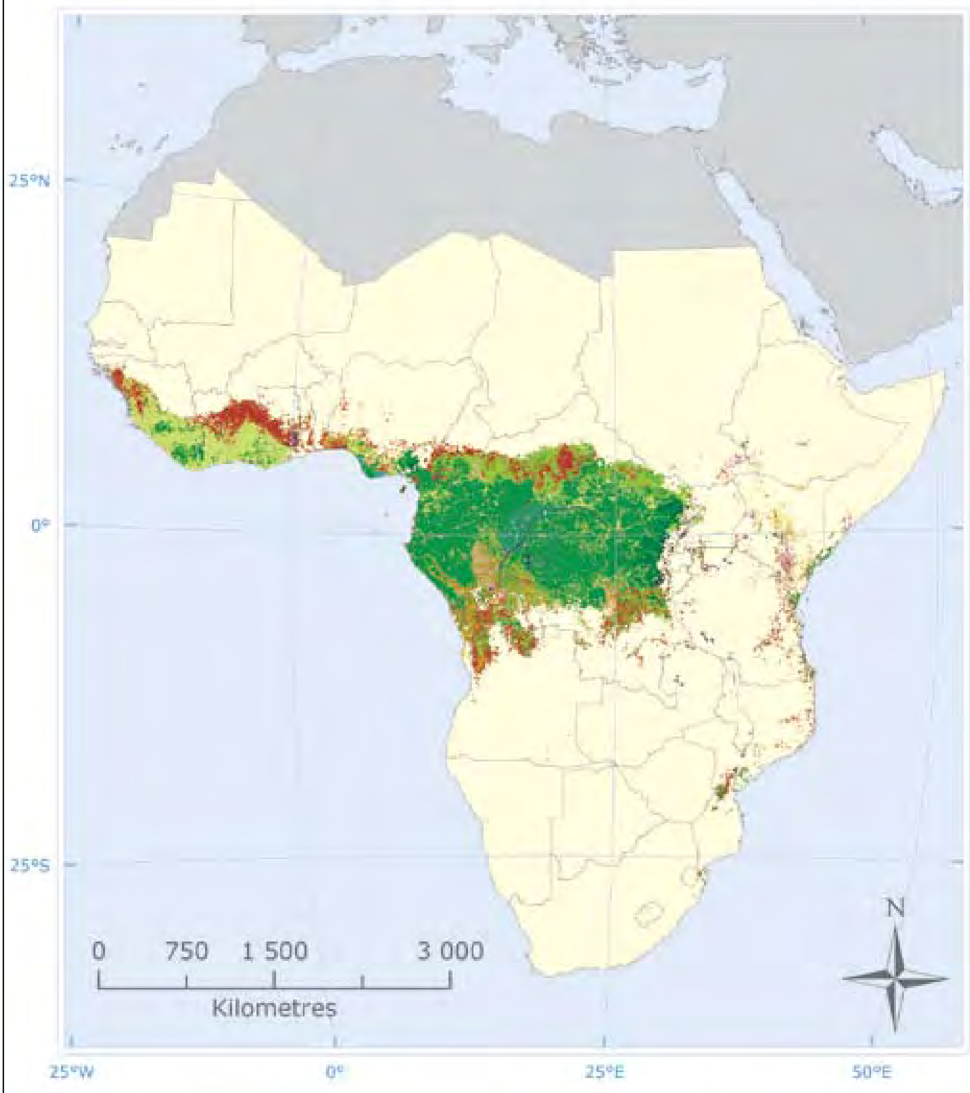
The results of the analysis are summarized in Figures 2, 3 and 4 and in Tables 3, 4 and 5, and charted in Figure 5.

'Closed evergreen lowland forest' is the most important land cover class for the *fusca* group, covering almost 40 percent of its distribution. The principal habitat of these forest flies is clearly confirmed by the analysis; a forest or woodland component is present in the first five classes ranked in Table 3. Similarly, for the *palpalis* group (Figure 3 and Table 4), the single most relevant land cover class is 'Closed evergreen lowland forest', which accounts for more than 25 percent of the distribution. More generally, most of the classes with a forest component appear to be highly suitable for flies of the *palpalis* group, meaning that more than 80 percent of their distribution falls within the tsetse infestation area e.g. 'Mosaic forest/croplands', 'Mosaic forest/savannah (Gallery-forests)', 'Swamp forest', 'Submontane forest (900–1500 m)', 'Degraded evergreen lowland forest'.

For the *morsitans* group (Figure 4 and Table 5), the marked preference for savannah habitats is clearly described. 'Deciduous woodland' and 'Deciduous shrubland with sparse trees' account for more than 50 percent of the distribution and include such habitats as tree savannah, woodland savannah and shrub savannah. 'Closed deciduous forest', more commonly known as Miombo woodland, accounts for an additional 10 percent of the distribution. Also important are landscapes with an agricultural component – 'Croplands (>50 percent)', 'Mosaic forest/croplands', 'Croplands with open woody vegetation' – which add up to around 18 percent of the distribution[3].

[3] The detection of agriculture in Africa from remote sensing data at 1 km spatial resolution is quite problematic because of the characteristics of prevailing farming systems and the spatial pattern of croplands. The fields are small and mixed with savannahs and fallows, which preclude a reliable mapping. On the other hand, the low intensification level of agricultural techniques induces spectral or temporal properties of agriculture close to the surrounding natural vegetation.

FIGURE 2
Land cover of tsetse habitat, *fusca* group, in sub-Saharan Africa



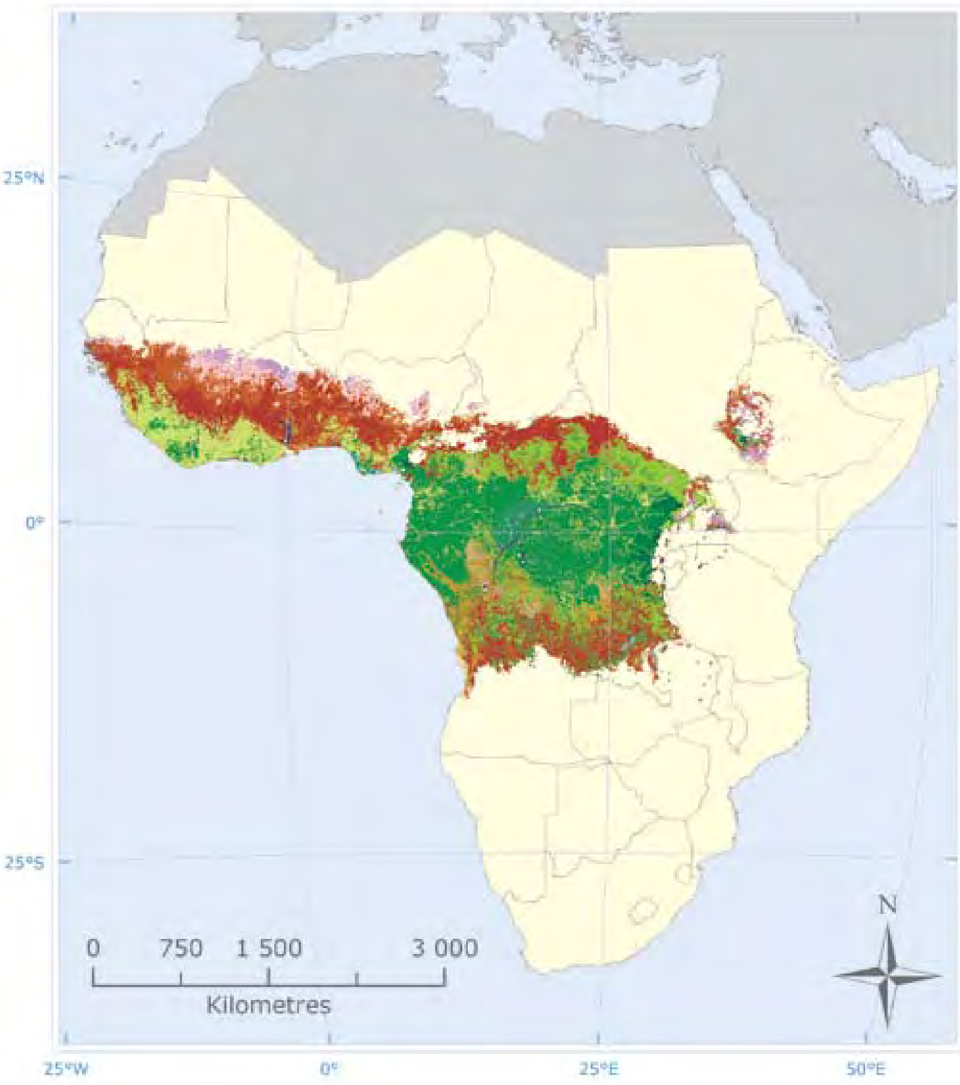
The last class worth noting is the ‘Mosaic forest/savannah’ that contains vegetation formations including forest elements and savannah elements; in this class of the GLC2000 fall the gallery-forests, tree formations developed along the riverbanks in the middle of shrub or grass vegetation. Gallery-forest is a typical habitat of riverine flies (*palpalis* group) but used by *morsitans* group too, in particular during the drier periods of the year.

TABLE 3

Land cover and tsetse habitat, *fusca* group, in sub-Saharan Africa. For the definition of the suitability index the thresholds in Table 2 (p. 7) were used

Land cover class name	Tsetse habitat (km²)	Tsetse habitat (%)	Proportion of the land cover class in sub-Saharan Africa (%)	Suitable habitat within the class (%)	Suitability index for tsetse (0–3)
Closed evergreen lowland forest	1 638 800	39.7	7.3	95.5	3
Mosaic forest / Croplands	628 100	15.2	3.2	82.9	3
Deciduous woodland	458 200	11.1	12.3	15.9	1
Mosaic forest / Savanna (Gallery-forests)	422 100	10.2	2.9	61.5	3
Closed deciduous forest (Miombo)	175 300	4.2	5.1	14.8	1
Open deciduous shrubland	167 900	4.1	4.4	16.4	1
Swamp forest	133 600	3.2	0.6	100.0	3
Submontane forest (900–1500 m)	107 400	2.6	0.6	80.4	3
Deciduous shrubland with sparse trees	107 200	2.6	7.2	6.4	1
Closed grassland	95 200	2.3	3.7	11.1	1
Croplands (>50 percent)	51 400	1.2	9.4	2.3	0
Open grassland with sparse shrubs	38 600	0.9	6.8	2.4	0
Degraded evergreen lowland forest	32 800	0.8	0.2	94.9	3
Open grassland	19 100	0.5	4.8	1.7	0
Montane forest (>1500 m)	14 700	0.4	0.3	21.8	1
Mangrove	13 200	0.3	0.1	46.4	2
Sparse grassland	10 200	0.3	6.2	0.7	0
Swamp bushland and grassland	7 900	0.2	0.5	7.5	1
Croplands with open woody vegetation	5 000	0.1	4.1	0.5	0
Cities	2 800	0.1	0.1	16.4	1
Irrigated croplands	1 400	0.0	0.1	4.1	0
Bare rock	1 100	0.0	3.8	0.1	0
Stony desert	400	0.0	8.4	0.0	0
Sandy desert and dunes	200	0.0	7.9	0.0	0
Salt hardpans	200	0.0	0.1	1.2	0
TOTAL	4 132 800	100.0	100.0		

FIGURE 3
Land cover of tsetse habitat, *palpalis* group, in sub-Saharan Africa



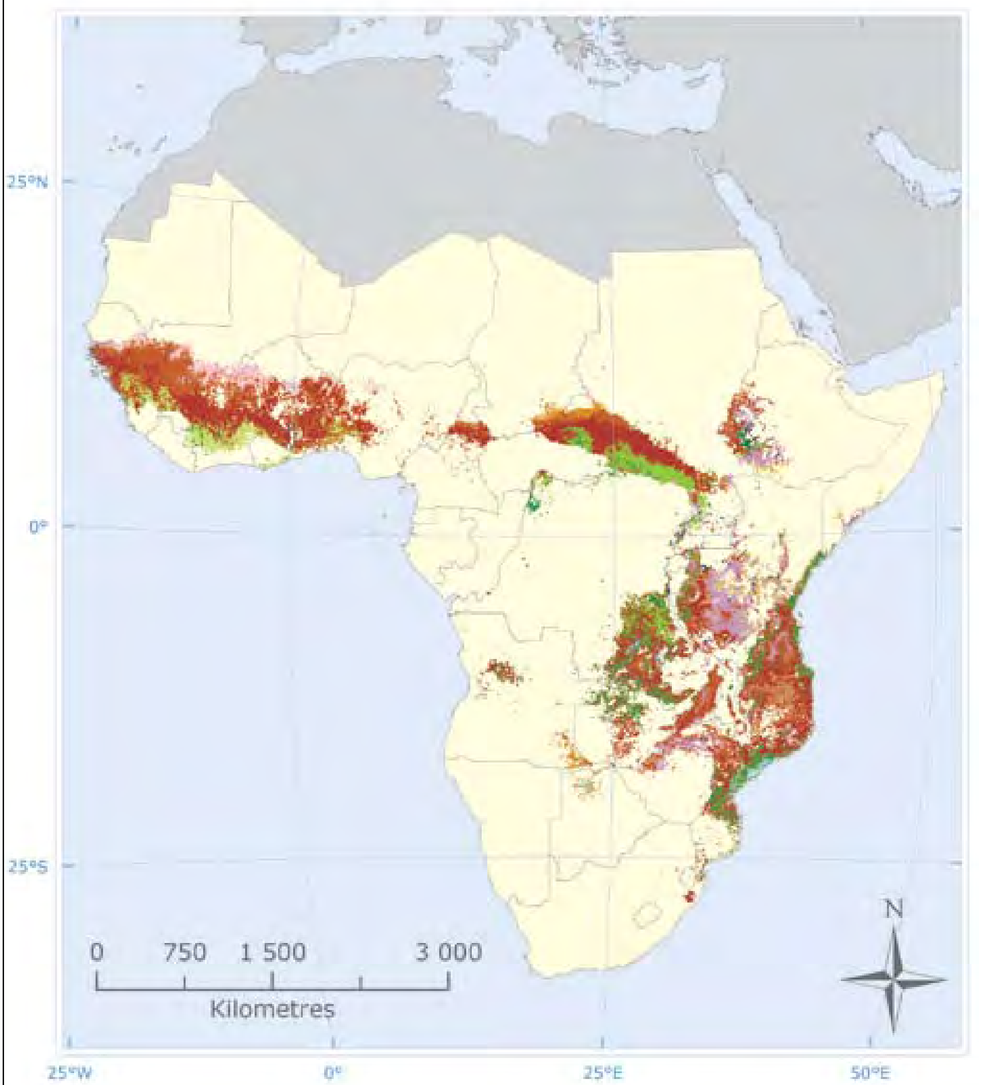
The difference in resolution between the two input layers (1 km for the GLC2000 and 5 km for the tsetse habitat maps) and more importantly the inherent inaccuracies of the two datasets, in particular the tsetse flies predictions, must be taken into account when interpreting the results. Particular care must be taken when reading the figures related to the least represented classes (e.g. 'Cities', accounting for only 0.06 percent in the GLC2000 of sub-Saharan Africa) because of the limited statistical representativeness of the sample.

TABLE 4

Land cover and tsetse habitat, *palpalis* group, in sub-Saharan Africa. For the definition of the suitability index the thresholds in Table 2 (p. 7) were used

	Land cover class name	Tsetse habitat (km^2)	Tsetse habitat (%)	Proportion of the land cover class in sub-Saharan Africa (%)	Suitable habitat within the class (%)	Suitability index for tsetse (0–3)
	Closed evergreen lowland forest	1 674 700	26.1	7.3	97.5	3
	Deciduous woodland	1 282 900	20.0	12.3	44.6	2
	Mosaic forest / Croplands	708 300	11.0	3.2	93.4	3
	Deciduous shrubland with sparse trees	702 400	11.0	7.2	41.9	2
	Mosaic forest / Savanna (Gallery-forests)	643 800	10.0	2.9	93.8	3
	Closed deciduous forest	319 800	5.0	5.1	26.9	2
	Croplands with open woody vegetation	265 900	4.2	4.1	28.0	2
	Open deciduous shrubland	218 900	3.4	4.4	21.3	1
	Croplands (>50 percent)	158 300	2.5	9.4	7.2	1
	Swamp forest	133 600	2.1	0.6	100.0	3
	Submontane forest (900–1500 m)	113 000	1.8	0.6	84.6	3
	Closed grassland	95 500	1.5	3.7	11.2	1
	Degraded evergreen lowland forest	33 800	0.5	0.2	97.9	3
	Mangrove	12 900	0.2	0.1	45.1	2
	Montane forest (>1500 m)	12 100	0.2	0.3	18.0	1
	Swamp bushland and grassland	12 000	0.2	0.5	11.4	1
	Open grassland with sparse shrubs	10 300	0.2	6.8	0.7	0
	Open grassland	5 200	0.1	4.8	0.5	0
	Irrigated croplands	4 200	0.1	0.1	12.5	1
	Cities	3 600	0.1	0.1	21.2	1
	Bare rock	1 300	0.0	3.8	0.2	0
	Sparse grassland	1 000	0.0	6.2	0.1	0
	Sandy desert and dunes	700	0.0	7.9	0.0	0
	Stony desert	700	0.0	8.4	0.0	0
	Salt hardpans	100	0.0	0.1	0.7	0
	TOTAL	6 415 000	100.0	100.0		

FIGURE 4
Land cover of tsetse habitat, *morsitans* group, in sub-Saharan Africa



More accurate results could be obtained in the future through the GLOBCOVER 2005 project that will provide a land cover map of the world at 300 m resolution. Nonetheless, the main limitation in this type of analysis is represented by the resolution and the accuracy of the tsetse distribution maps, whose update and upgrade at continental level would call for long-term studies and investments.

Further studies might concentrate on smaller geographical areas, for example at country level, and take advantage of datasets at a higher spatial resolution. Africover maps, for

TABLE 5

Land cover and tsetse habitat, *morsitans* group, in sub-Saharan Africa. For the definition of the suitability index the thresholds in Table 2 (p. 7) were used

Land cover class name	Tsetse habitat (km^2)	Tsetse habitat (%)	Proportion of the land cover class in sub-Saharan Africa (%)	Suitable habitat within the class (%)	Suitability index for tsetse (0–3)
Deciduous woodland	1 297 100	32.0	12.3	45.1	2
Deciduous shrubland with sparse trees	922 900	22.8	7.2	55.1	3
Closed deciduous forest (Miombo)	407 200	10.1	5.1	34.3	2
Croplands (>50 percent)	371 200	9.2	9.4	16.8	1
Mosaic forest / Savanna (Gallery-forests)	204 700	5.1	2.9	29.8	2
Mosaic forest / Croplands	202 700	5.0	3.2	26.7	2
Croplands with open woody vegetation	191 600	4.7	4.1	20.1	1
Open deciduous shrubland	124 100	3.1	4.4	12.1	1
Closed grassland	102 100	2.5	3.7	11.9	1
Closed evergreen lowland forest	65 100	1.6	7.3	3.8	0
Open grassland with sparse shrubs	64 300	1.6	6.8	4.0	0
Swamp bushland and grassland	34 000	0.8	0.5	32.3	2
Submontane forest (900–1500 m)	19 000	0.5	0.6	14.2	1
Montane forest (>1500 m)	10 000	0.3	0.3	14.8	1
Open grassland	9 100	0.2	4.8	0.8	0
Mangrove	8 400	0.2	0.1	29.4	2
Irrigated croplands	5 900	0.2	0.1	17.8	1
Swamp forest	4 000	0.1	0.6	3.0	0
Degraded evergreen lowland forest	2 900	0.1	0.2	8.3	1
Sparse grassland	2 700	0.1	6.2	0.2	0
Cities	1 000	0.0	0.1	5.8	1
Bare rock	1 000	0.0	3.8	0.1	0
Stony desert	800	0.0	8.4	0.0	0
Salt hardpans	500	0.0	0.1	3.5	0
Sandy desert and dunes	500	0.0	7.9	0.0	0
TOTAL	4 052 800	100.0	100.0		

FIGURE 5
Synthetic view of the land cover of tsetse habitat by group

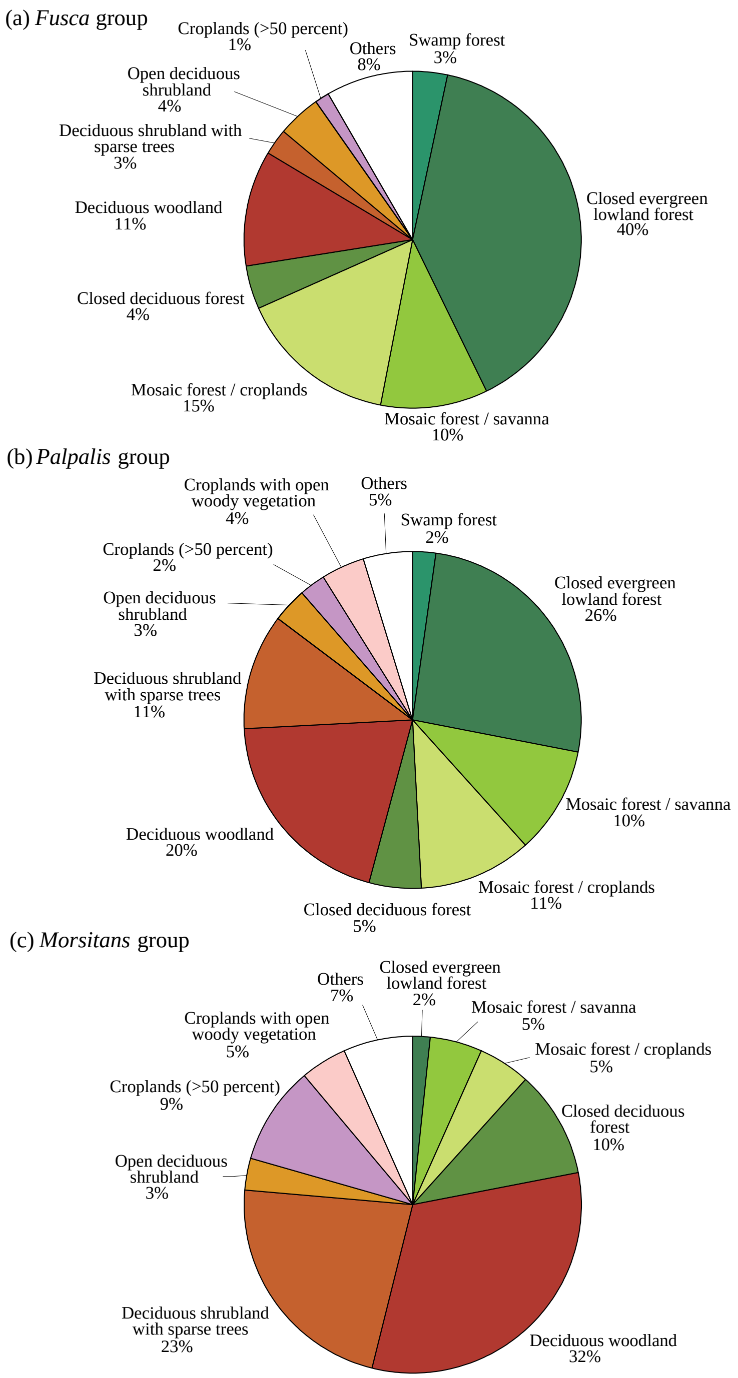


TABLE 6

Shared variance between tsetse habitat and land cover classes (χ^2 test)

Tsetse group	r^2 (shared variance)
Fusca	0.56
Palpalis	0.47
Morsitans	0.19

instance, are produced by means of 15 m resolution Landsat images, which are able to describe potential tsetse habitats with much greater detail. Such high-resolution vector maps could be matched with point entomological datasets on tsetse presence and abundance with a view to studying in more depth the effects of landscape features and patterns on fly populations. It is also possible to interpret the work presented in Chapters 2 and 3 in this framework.

For this exercise we used the threshold of 50 percent to discriminate suitable from unsuitable habitat, using the predicted areas of suitability by PAAT-IS as input dataset. In order to examine the impact of this assumption, for each land cover class we compared two indexes: the 'suitable habitat within the class (percent)' (based on the threshold of 50 percent and reported in Tables 3, 4 and 5) and an 'average suitability'. The latter was calculated averaging the percentage values of the predicted areas of suitability for tsetse. For the purpose of our study, the two indexes can be considered equivalent, to the extent that using the latter to estimate the class of suitability in the last column in Tables 3, 4 and 5 would not alter the outcome for any land cover class (in the linear regression between the two indexes the coefficient of determination [R^2] is equal to 1, 0.9999 and 0.9962, respectively for the *fusca*, *palpalis* and *morsitans* groups).

Chi-square test

Chi-square (χ^2) is a simple non-parametric test of statistical significance for bivariate tabular analysis. Used in this context, i.e. to check the hypothesis that the different land cover classes help us to predict the presence or absence of tsetse flies, the test gave an easily predictable positive result for all three fly groups. More interestingly, symmetric measures based on the chi-square statistic are capable of measuring the strength of the relationship between the dependent and independent variable. In particular, the measure called shared variance[4] is the portion of the total distribution of the variables measured in the sample data that is accounted for by the relationship detected with the chi-square test. The values of the shared variance (land cover–tsetse presence/absence) for the three tsetse groups are shown in Table 6.

It is apparent that for the *fusca* and *palpalis* groups the land cover suitability plays a bigger role in the definition of the environmental suitability than it does for the *morsitans* group. The figure 0.56 for *fusca* means that 56 percent of the tsetse habitat can be predicted by land cover. The p*alpalis* group displays a slightly weaker relationship with the predictor (47 percent), while the *morsitans* group absence/presence can be explained by land cover only to a limited extent (19 percent).

[4] $r^2 = \chi^2 / N(k - 1)$, where χ^2 is chi-square, N is the total number of observations and k is the smaller of the number of rows or columns in the cross tabulation. In this exercise the tables contain 26 rows (land cover classes), and 2 columns (tsetse absence/presence).