Termite mound identification through aerial photographic interpretation in Lubumbashi, Democratic Republic of the Congo: methodology evaluation

Authors: Isabelle, Vranken, Marielle, Adam, Basile, Mujinya Bazirake, François, Munyemba Kankumbi, Geert, Baert, et al.

Source: Tropical Conservation Science, 7(4) : 733-746

Published By: SAGE Publishing

URL: https://doi.org/10.1177/194008291400700411

The BioOne Digital Library (https://bioone.org/) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (https://bioone.org/subscribe), the BioOne Complete Archive (https://bioone.org/archive), and the BioOne eBooks program offerings ESA eBook Collection (https://bioone.org/esa-ebooks) and CSIRO Publishing BioSelect Collection (https://bioone.org/csiro-ebooks).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commmercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Tropical-Conservation-Science on 23 Mar 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Mongabay.com Open Access Journal - Tropical Conservation Science Vol.7 (4):733-746, 2014

Research Article

Termite mound identification through aerial photographic interpretation in Lubumbashi, Democratic Republic of the Congo: methodology evaluation

Vranken Isabelle[1], Adam Marielle[2], Mujinya Bazirake Basile[3] , Munyemba Kankumbi François[4] , Baert Geert[5] , Van Ranst Eric[6], Visser Marjolein[7] and Bogaert Jan[8]

[1]Université Libre de Bruxelles, Research unit of Landscape Ecology and Plant Production Systems; University of Liège, Gembloux Agro-Bio Tech, Biodiversity and Landscape Unit, ivranken@ulb.ac.be
[2]Royal Belgian Institute of Natural Sciences, adam.marielle@gmail.com
[3]University of Lubumbashi, Laboratory of Soil Science, basile.mujinyabazirake@ugent.be
[4]University of Lubumbashi, Faculte des Sciences Agronomiques, munyembaf@yahoo.fr
[5]Ghent University, Department of Applied Biosciences, geert.baert@ugent.be
[6]Ghent University, Laboratory of Soil Science, eric.vanranst@ugent.be
[7]Université Libre de Bruxelles, Research unit of Landscape Ecology and Plant Production Systems, mavisser@ulb.ac.be
[8]University of Liège, Gembloux Agro-Bio Tech, Biodiversity and Landscape Unit, j.bogaert@ulg.ac.be

Corresponding author : Isabelle Vranken (ivranken@ulb.ac.be)

Abstract:
Tropical termites are of critical importance for ecosystem functioning and ecosystem services in woodland and savannah areas. Termite mounds can also be used as fertilizer and biological indicators of anthropogenic disturbance linked to agriculture or charcoal production. Remote sensing may help to identify and characterize termite mound density and distribution at low cost. To test its effectiveness, termite mounds were identified in the field and compared with the results of image interpretation of free Google Earth aerial photographs. This comparison was carried out for 17 sites in the hinterland of the mining city of Lubumbashi, Katanga, Democratic Republic of the Congo, which faces high population growth, food insecurity, and intense fragmentation and degradation of the original Miombo woodland cover. The influences of mound height and diameter as well as the timing of the image capture (year and dry or wet season) were statistically tested. The actual number of termite mounds observed in the field was generally overestimated on the corresponding image. Height and wet season favoured correct identification, while spatial distribution was not significantly influenced by misidentifications. A corrective model was defined and its relevance statistically verified. Mound identification using Google Earth appears efficient so long as the precise individual mound position is not concerned. This approach represents considerable cost reduction for field surveys of termite mounds.

Keywords: anthropogenic biological indicator, food self-sufficiency, Macrotermes, aerial photographic interpretation, woodland

Résumé
Les termites des régions tropicales sont d'une importance critique pour le fonctionnement et les services écosystémiques dans les régions de forêt claire et de savane. Les termitières peuvent également être utilisées comme engrais et bio-indicateurs de perturbations anthropiques telles que l'agriculture ou la production de charbon. La télédétection peut contribuer à identifier et caractériser la densité et la distribution des termitières à moindres frais. Afin de tester son efficacité, les termitières ont été identifiées sur le terrain et comparées avec les résultats d'interprétation de photographies aériennes Google Earth en libre accès. Cette comparaison a été appliquée sur 17 sites dans l'hinterland de la ville minière de Lubumbashi, Katanga, République Démocratique du Congo, confrontée à une croissance élevée de population, à l'insécurité alimentaire ainsi que d'intenses fragmentation et dégradation de la couverture originelle de forêt claire (Miombo). Les influences de la hauteur et du diamètre des termitières ainsi que de la période d'acquisition de l'image (année et saison) ont été testées statistiquement. Le nombre de termitières observées sur le terrain est généralement surestimé sur l'image. La hauteur et la saison des pluies en favorisent l'identification correcte, tandis que la distribution spatiale n'est pas significativement influencée par les erreurs d'identification. Un modèle correctif a été défini et sa pertinence statistiquement vérifiée. L'identification des termitières via Google Earth s'avère efficace tant que la position précise de chaque termitière n'est pas requise. Cette approche constitue une réduction considérable des coûts de missions de terrain liées aux études sur les termitières.

Mots-clés: bio-indicateur d'anthropisation, auto-suffisance alimentaire, Macrotermes, photointerprétation aérienne, forêt claire

Received: 14 July 2014; Accepted 23 October 2014; Published: 15 December 2014

Cite this paper as: Vranken, I., Adam M., Mujinya, B. B., Munyemba, F. K., Baert, G., Van Ranst, E., Visser, M. and Bogaert. J. 2014. Termite mound identification through aerial photographic interpretation in Lubumbashi, Democratic Republic of the Congo: methodology evaluation. *Tropical Conservation Science* Vol.7 (4): 733-746. Available online: www.tropicalconservationscience.org

Introduction

Since the start of aerial photography and satellite imagery, remote sensing has made land cover analysis far more effective and complete, as well as less costly [1]. In Africa, where natural resources are abundant, though threatened [2], this tool has important potential applications, especially given the lack of financial resources and the practical problems arising with field work.

In Katanga, province of the Democratic Republic of the Congo (DRC), the city of Lubumbashi was developed for mining development under Belgian colonialism at the beginning of the 20th century. Both heavy metal pollution and the absence of a tradition of farming prevent the town from being food self-sufficient [3, 4]. Furthermore, fast-growing local populations (1,200,000 inhabitants in 2006, 1,500,000 in 2009) [4] and mining companies keep on deforesting the suburban belt to produce charcoal or to develop new mines, hence destroying local ecosystems [5]. These landuse and land cover changes are likely to disturb some tropical termite species in the area, like *Macrotermes falciger* (Gerstäcker). This species builds mounds possibly tall enough for identification by remote sensing [6]. The mounds' structure and composition play an important part in ecosystem functioning [7] and provide ecosystem services such as food for local populations [8]. Termite mounds are a potential soil amendment for agriculture [9-11]. In addition, the influence of human activities like deforestation on termites' behaviour and presence can make them a bio-indicator for anthropogenic land cover change or degradation [9, 12-14].

The ability to identify termite mounds by remote sensing could ease preliminary research on termite activity and conservation. Minimizing costs by using free images is of particular interest, especially in developing countries. The objective of this research is therefore to assess the capacity to identify termite mounds (density, position, distribution) on high resolution aerial and satellite imagery, particularly free Google Earth images. The underlying hypothesis is that these images have enough spatial resolution for systematic termite mounds mapping. This hypothesis supposes that the in-image termite mound density is a satisfactory estimator of on-site termite mound density and that sampling errors are randomly distributed in space and time.

Methods

Study area

The study zone was situated in Katanga and centred on the city of Lubumbashi, within the southern latitudes of 11°30’ and 11°50’, and the eastern longitudes of 27°17’ and 27°40’ (Fig. 1)

The site consists of a plateau that has been eroded into a wide valley by the Lubumbashi River and its tributaries [3, 9]. The altitudes of the inner-city, on the plateau, vary between 1,200 and 1,250 m. Geology consists mainly of two systems: shale-sandstone (Kundelungu) and shale-dolostone [15]. Lubumbashi is located in the Katangese copper belt and is well known for its copper and cobalt veins, contained in the Roan series, Upper Kundelungu [3]. The majority of local soils where termite mounds are found are yellow-red to red latosols and ferrasols [13]. To build their mounds, foraging termites use the clays contained in the deepest soil horizons [10].

The local climate corresponds to the Cw category in the Köppen classification and is characterised by a wet season from November to April, and a dry season for the rest of the year. Vegetation cover is continuous only during the wet season [9]. The main vegetation cover is woodland (*Miombo*), but it is being progressively replaced with savannah and bare soils by deforestation as well as by mining activities and eolian deposits of heavy metals [8]. On both the contaminated and natural highly metalliferous soils, a specific metallophyte herbaceous flora develops [16-18].

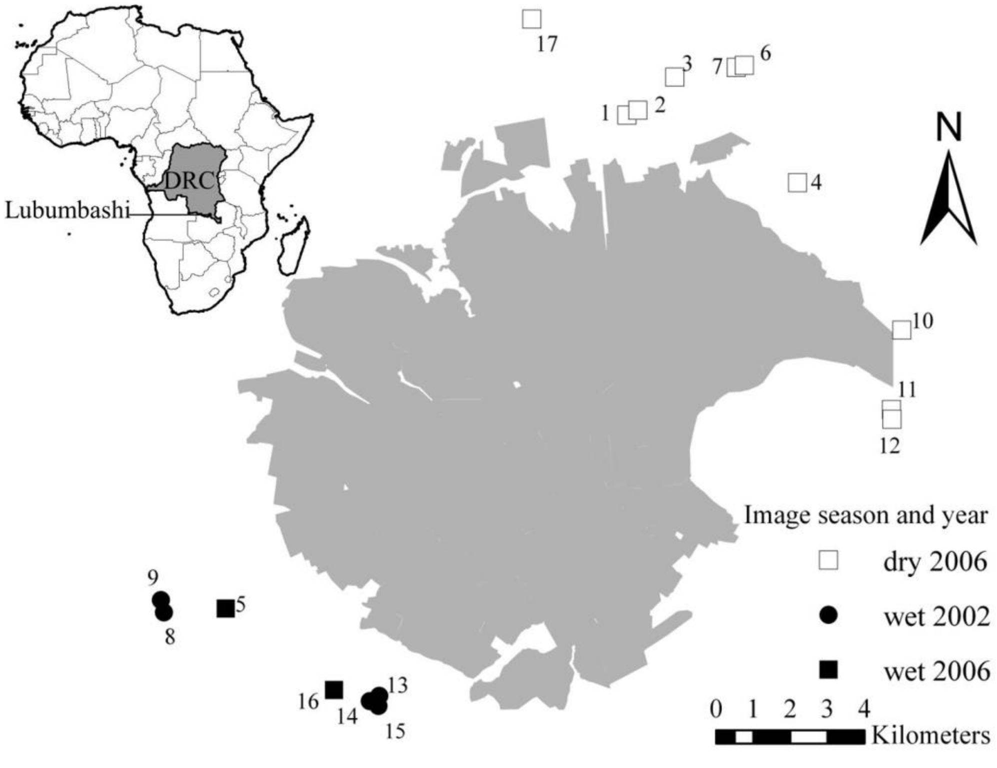

Fig. 1. Location of the different sampling sites around the municipality of Lubumbashi (shown in grey). The season and year of the Google Earth image on which each polygon was analysed during the study (February 2010) are detailed in the legend. DRC: Democratic Republic of the Congo.

Data collection

The termite mounds were identified and located using two different methods: aerial photographic interpretation and field survey. Mound identification in the images was performed using a Google Earth image mosaic (© Google 2009; © 2009 CNES/Spot Image; © 2009 GeoEye; © 2009 DigitalGlobe; © U.S. Dept of State Geographer) because of its free access. The images composing this mosaic were characterised by different seasons and years of capture (see Fig. 1 and Table 1). According to Google Earth, the available images were DigitalGlobe aerial photographs taken from a height of 250 to 350 m. The resolution of this mosaic is not exactly known because the captors vary depending on the location and year of image capture [9], but DigitalGlobe [Digitalglobe.com] states that the lowest resolution is 2.62 m. In any case, this resolution can be considered several times higher than the horizontal projection of a termite mound, i.e. more precise than 10 m [9]. Indeed, termite mounds were visible on the images, even without using the closest zoom distinguishing the individual pixels. The termite mounds were sampled and georeferenced directly in the images by visual identification of pixel clusters lighter or darker than their immediate environment, sometimes associated with shadow, depending on the time the image was captured.

In order to evaluate the precision of in-image termite mound identification, mounds were directly located in different sites in the suburban area of Lubumbashi during field surveys and compared with the number and positions of the termite mounds identified by visual interpretation in the images. On-site prospecting was carried out in February 2010 on 17 different sites from two to 27 ha, chosen according to their accessibility, soil type (only one type per site), and termite mound presence. Consequently, areas with too dense vegetation and private estates were excluded. In each site, each termite mound, its height, its diameter and its position were inventoried using a GPS (Garmin 60CSx) with 5 m average precision. Sampling sites and the mounds they contained were reported as polygons on the Google Earth image mosaic. The map (Fig. 1) was drawn in ArcMap 9.3 based on the KML representing the sampling areas, generated directly in Google earth.

Data management

On-site prospection represents field reality. Data comparison between field reality and aerial photography interpretation was performed by comparing KML points corresponding to the location of each mound identified in the field as well as in the image, generated directly on the Google Earth interface. This comparison could identify individual termite mounds in the image that were not reported on the site (false positive), or termite mounds reported on the site that were not detected in the image (false negative).

Then, it was tested whether the positioning errors in the images cause a significant effect on mounds' spatial distribution. This was performed by calculating the Clark and Evans [19] aggregation index (R) for the termite mounds of each polygon and by comparing the differences between its value in the image and in situ. The comparison was applied using a paired Student t-test on the difference between R_i (aggregation in the image) and R_s (aggregation *in situ*). The Shapiro-Wilk normality test was applied beforehand [20] to this difference to test if the t-test was applicable.

According to Bütler [21], the R aggregation index is calculated as in equation (1):

$$R = \frac{r_o}{r_e}, \qquad (1)$$

where r_o is the average distance between each couple of nearest neighbours, and $r_e = {}^{1}\!/_{2\sqrt{p}}$ with p, the density of individuals. R = 1 if the distribution is random, R ≈ 0 if the distribution is aggregated, and R ≈ 2.15 if the distribution is uniform. For the purpose of this study, it is not the interpretation of the index value that is considered, but the differences between the pattern *in situ* and in the image.

Four parameters linked to possible errors were tested. False negatives are ticked because either the height or the diameter of the mounds may be too small to allow their identification in the images or else because of termite mounds hidden by the vegetation cover during the wet season. The time elapsed between image capture and field survey (Table 1) may result in false positives as well as false negatives.

The effects of mound height and diameter on false negatives identification were tested as follows. First, frequency distributions of height and diameter classes were computed for each false negative, on one hand, and for the whole *in situ* sample, on the other hand. Then, to compare false negatives with field reality, a homogeneity χ^2 test was applied between false negatives and real frequency distributions of height and diameter classes as observed in situ. The null hypothesis to be tested was that the false negative distribution in height / diameter classes was not different from the height / diameter distribution of all the termite mounds observed *in situ*. If this was the case, mound height or diameter would not influence the identification capacity of aerial photography interpretation. The classes were defined in order to meet the Cochran rule, according to which each class needs to contain at least five observations [9, 22, 23].

To account for the effect of season and year of the different Google images, non-parametric tests were used [9, 22]. Indeed, the number of individuals in the sample is rather small (only 17 sites), so the conditions of homoscedasticity and normality of the distributions were not met. Two different techniques were applied in a complementary way to compare the relative error percentage for each season and year: the Wilcoxon-Mann-Whitney test (unpaired) and bootstrapping. The Wilcoxon-Mann-Whitney or W test is the non-parametric counterpart of the Student t-test and compares two observed medians [23]. Bootstrapping is a technique to obtain a population distribution based on a single sample by creating new samples by permutations of the initial one, allowing repetitions [24]. The null hypothesis states that both medians (of error percentage in dry vs. wet season and in 2002 vs. 2006) come from the same distribution [23].

Afterwards, a corrective model was created to obtain image values closer to field reality. First, a linear regression between the number of observed termite mounds on-site and the ones in the image for each of the 17 sites (Fig. 1) was performed using the least square method [22, 23]. To test the applicability of the corrective model, the Shapiro-Wilk normality test was applied [20] and homoscedasticity was tested with a scatter plot representing residues and predicted values [22]. Model relevance to verify whether the corrected version was significantly different from original data was estimated with a confidence interval.

Results

As shown in Table 1, a total of 427 termite mounds were observed in the 17 sites, 33 of which could not be identified in the image (false negatives) while 64 false positives were spotted. This indicates that the mound number in the image was overestimated. The relative error rate is 7.3% representing the absolute difference between the number of termite mounds in the field and in the image.

Compared spatial distributions

Table 1 also shows the values of the aggregation index for field reality (R_s) and image (R_i). When the Shapiro-Wilk test for normality was applied to the differences between site and image for the 17 polygons, it was found that the data set was normally distributed ($W = 0.98$, $p = 0.98$); thus Student's t-test could be applied. The t-test, applied to R_s and R_i, showed no significant difference ($p = 0.34$) between on-site and in-image termite mound distribution.

Effects of termite mound height and diameter

The frequency distribution of false negatives in height or diameter classes shows that mounds with the lowest diameter tend to escape identification in the image. The χ^2 tests performed between observed and expected values are shown in Table 2. Height has a significant effect on mound detection in the image: the highest (> 4 m) termite mounds tend to yield significantly fewer false negatives. However, no significant effect of diameter was shown.

Effects of season and year of image capture

The one-sided W test to evaluate if the error percentage was significantly higher during the dry season gave $W = 11$ ($p < 0.05$), indicating an effect of the season on the ability to identify mounds in the images: there are significantly more counting errors during the dry season. Bootstrapping tests also indicated that the error percentage was significantly higher during the dry season ($p < 0.05$). As for the effect of the image capture year, the one-sided W-test gave a W value of 11 ($p < 0.05$), with a significantly higher error percentage for 2006. The bootstrapping confirms this effect ($p < 0.05$). Apparently, the images captured in 2002 rendered less counting errors than in 2006.

Table 1. Number of termite mounds actually observed on site (N_s), false positives (F_p), and false negatives (F_n). Aggregation indexes of the termite mounds observed on site (R_s) and in the image (R_i) for each of the 17 investigated polygons. The polygon numbers refer to their position, detailed in Fig. 1.

Polygon number	Season	Year	area (ha)	N_s	F_p	F_n	R_s	R_i
1	Dry	2006	3.56	12	4	2	1.76	1.50
2	Dry	2006	4.51	13	4	0	1.72	1.61
3	Dry	2006	23.31	60	8	8	1.43	1.54
4	Dry	2006	27.73	48	8	6	1.49	1.54
5	Wet	2006	7.23	20	3	0	1.50	1.53
6	Dry	2006	5.87	22	6	4	1.69	1.67
7	Dry	2006	6.77	25	10	6	1.23	1.41
8	Wet	2002	5.92	14	1	1	1.79	1.61
9	Wet	2002	5.08	15	1	0	1.80	1.79
10	Dry	2006	14.47	29	2	2	1.58	1.61
11	Dry	2006	3.40	14	3	2	1.47	1.54
12	Dry	2006	6.26	16	1	0	1.72	1.77
13	Wet	2002	2.22	12	0	0	1.76	1.76
14	Wet	2002	3.31	11	1	0	1.86	1.74
15	Wet	2002	5.90	19	3	0	1.60	1.54
16	Wet	2006	24.27	61	6	1	1.78	1.72
17	Dry	2006	12.61	36	3	1	1.62	1.58
Total			162.41	427	64	33		

Table 2. Height and diameter classes for the termite mounds observed *in situ*, false negatives and χ^2 test results. The false negatives percentage (% False neg.) is calculated by height or diameter class. The expected values correspond to the null hypothesis, i.e. if the error percentage were constant in each height or diameter classes. $\chi^2_{(\alpha = 0.05;\ dof = 2)} = 5.99$. N.B: dof = degrees of freedom.

		Height classes				Diameter classes			
		0-2 m	2-4 m	> 4 m	Total	0-10 m	10-20 m	> 20 m	Total
Observed	Field reality	25	179	223	427	65	258	104	427
	False neg.	5	22	6	33	8	22	3	33
	% False neg.	20.00	12.29	2.69	7.73	12.31	8.53	2.88	7.73
	Total	30	201	229	460	073	280	107	460
Expected	Field reality	27.85	186.58	212.57	427	67.76	259.91	99.32	427
	False neg.	2.15	14.42	16.43	33	5.24	20.09	7.68	33
	% False neg.	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73
	Total	30	201	229	460	073	280	107	460
χ^2	Field reality	0.29	0.31	0.51	1.11	0.11	0.014	0.22	4.49
	False neg.	3.77	3.99	6.62	14.37	1.46	0.18	2.85	0.35
	Total	4.059	4.29	7.13	15.48	1.57	0.20	3.07	4.84
	p-value	0.044	0.038	0.0076	0.00043	0.21	0.66	0.080	0.089

Corrective model

The regression model between the number of termite mounds on site and in-image was tested using the Shapiro-Wilk test, that returned p = 0.96 (α = 0.05), so the distribution of the number of termite mounds according to image and field reality was not significantly different from normal. The scatter plot representing residues and predicted values (not shown) showed high homoscedasticity. Therefore, the conditions of a regressive corrective model were fulfilled. The scatter plot and regression line used for the corrective model are shown in Fig. 2. The R^2 determination coefficient shows that the model explains over 99% of the on-site termite mounds identification variability. The regression is very highly significant ($p = 2.2^{-16}$). The Student t-test confirmed that the regression line slope was very highly significantly different from zero ($p < 2^{-16}$).

The 95 % confidence interval for the slope was between 0.962 and 0.983, hence not including 1.00, which means that, the slope being significantly lower than 1 (equality), the difference between the numbers of termite mounds observed on site and identified in the image is significant.

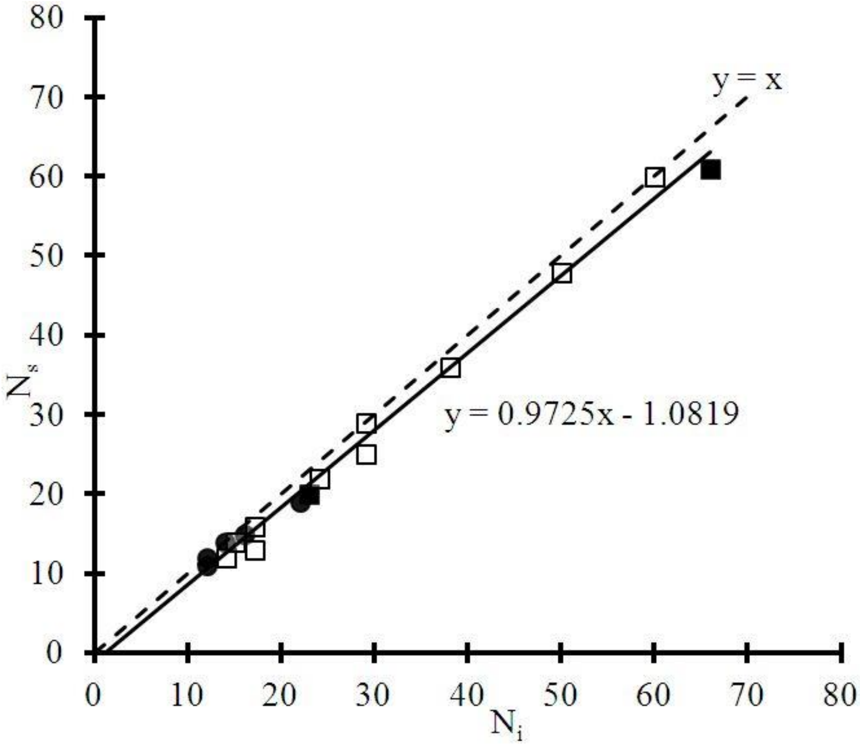

Fig.2. Relationship between the numbers of termite mounds identified on the images (N_i) and *in situ* (N_s) on each polygon. Symbols refer to the seasons mapped on Figure 1: empty squares: dry 2006; black squares: wet 2006; black dots: wet 2002. Dashed line shows the theoretical relationship of perfect equality (slope = 1). Continuous line shows the corrective model ($R^2 = 0.992$, $p = 2.2^{-16}$, slope = 0.97).

Discussion

Termite mounds identification capacity of Google Earth images

Does the in-image termite mounds density represent a satisfactory estimator of the on-site termite mound density and are sampling errors randomly distributed in space and time? The comparison between on-site prospecting and in-image identification suggested a slight overestimation in the image, as there were twice more false positives than false negatives. However, despite these positioning errors, overall mound spatial distribution in the image is not significantly different from field reality. Indeed, nearest neighbour distance was not significantly influenced by false positives or false negatives.

False positives may be due to the presence of isolated trees or shrubs that can be wrongly identified as termite mounds, which is more likely to happen in dry seasons. In wet seasons, a characteristic flora often develops on termite mounds due to their particular composition and structure. Indeed, termite mounds are composed of clay aggregates containing micronutrients coming from deep horizons (10-12 m) and organic debris, more fertile than the surrounding topsoils [10, 13, 25, 26], the latter being more frequently subject to erosion [6]. This specific vegetation makes them more easily identifiable on a continuous vegetation cover. False positives can also depend on image quality, defining the minimal image pattern size that can be correctly identified as a termite mound. They may as well be linked to the time elapsed between image capture and field survey, mounds being possibly flattened for agriculture or brick manufacture [11, 27]. However, the results showed that the error rate was higher for 2006 than 2002. This can be explained by the fact that all images from 2002 were captured during the wet season, while dry season has a negative effect on in-image termite mound identification.

False negatives may be due to termite mound height and diameter. The first parameter has indeed a higher influence on visibility, probably due to the shadows of the mounds in the image. On the other hand, the widest termite mounds are often older, sometimes abandoned by their inhabitants, so more likely to collapse, reducing their height and consequently their shadow [8, 9, 13]. In addition, as the slope of the termite mounds flattens over time, easier deposits accumulation hampers the distinction between the mound itself and the debris accumulated on it [8, 26], so the diameter measures may not be representative of ground reality and lead to incoherent results. Mound growth should also not be excluded, making them visible during the field campaign but too small at the image capture date. The morphological and compositional evolution related to the age of the termite colony should be further analysed as for the probability of correct identification and fertilization potential [13].

Methodological aspects

Google Earth images prove to provide a good density and general distribution estimation and do not require the systematic on-site localisation of each individual termite mound. Indeed, in-image counting of mounds resulted in few relative errors (7.3% on average). Moreover, no significant difference in general mound distribution between image and field reality was detected through the nearest neighbour distance analysis, which shows no influence of false-positives and false-negatives. However, significant differences between field reality and image analysis for some peculiar sites within the sample should not be excluded.

The overestimation of the number of termite mounds and corrective model efficiency described above highlight the need for partial on-site verification, especially for Google Earth images and the related resolution or seasonal problems. This enhances the precision of the in-image observation while reducing the cost of *in situ* investigation. Considering the low error rate obtained with Google Earth images, except for precise geographic location analyses, the use of high resolution satellite imagery or spatial photography to enhance the identification precision is questionable since it would induce significantly higher costs.

The Student t-test on the aggregation indexes on the ground and in images shows a good approximation of the effect of positioning errors on mounds' spatial distribution. The dispersion and Morisita indexes could complete the distribution characterisation [9, 28] if larger samples were available. To compensate for the insufficiencies linked to vegetation cover and seasonality or even termite mound height, it is still possible to search other capture dates in Google Earth historical imagery. Rainy season and morning or evening image captures to maximize projected shadows are preferred [9]. It would also be beneficial to upgrade such an on-site prospecting by choosing homogeneous sample zones (polygons) according to the independent and dependent variables: soil type, but also image season and year, in order to isolate the effect of each of them (maximal inner-sample homogeneity, maximal between-samples heterogeneity). This would help to avoid problems such as interactions between season and year effect, as happened in our sample. Attention should therefore be paid to the fact that the present results and conclusion apply specifically to woodland areas and savannahs.

Implications for conservation

Soil foraging termite mounds like those of *Macrotermes falciger* play an important part in ecosystem functioning, even in their whole landscape structuring : they influence community-wide interactions via changes in the abiotic landscape and induce biological diversity as well as landscape heterogeneity [7, 10, 29, 30]. Their action in the soil, as presented in the discussion, influences resources distribution, which favours the development of microbial activity as well as symbiotic ectomycorhizes on plants growing on the mounds. This favours their development and increases nitrogen content in the soil through atmospheric nitrogen fixation by the mycorhizes [29, 30]. Due to this richer soil composition on termite mounds, specific vegetation develops, inducing new ecosystems locally and heterogeneous patterns in the landscape [10, 30].

The loss of termite activity has important detrimental effects on ecological functioning. Conversely, termite activity could also be used for soil rehabilitation [7, 31]. Termite populations can also be studied as disturbance bioindicators by examining their presence, behaviour, relative abundance, biomass, and species presence or diversity [12, 14, 32]. Those factors are linked to land use and disturbance intensity.

Moreover, termites provide important ecosystem services to local populations : mound use for construction, traditional agriculture around the mounds to benefit from their influence [27, 31], gathering of mushrooms, wood or medicinal plants that grow on the mounds, and use of ancient mound soils as fertilisers [8, 10, 11, 25, 26].

Termites play therefore an important part in ecosystem functioning, landscape formation, rural and peri-urban development, and land reclamation. Their preservation is therefore important in their distribution range. Another reason to support the conservation of termite areas is that little research exists on the use of termite activity for fertility management or for the rehabilitation of degraded soils [7, 31].

In the context of fast-growing populations and food insufficiency in developing countries, the lack of financial and human resources to conduct studies requires alternative tools. The main interest of this paper for conservation or management is that it significantly eases preliminary work of field studies on termites.

Termite mound identification using Google earth imagery could prove useful to spot areas of interest to be further investigated in the field. With regard to using termite mounds themselves as anthropogenic bio-indicators, isolating the year effect, as described in the methodological aspects of the discussion, could identify anthropogenic effects on termite presence over time. Defining polygons according to a distance gradient from human activities could also be useful to evaluate the anthropogenic bio-indicator potential of termite mounds.

In conclusion, although the results of this paper should be checked in other areas, they can greatly further the study of termite activity and mounds in the context of widespread tropical ecosystem degradation processes, and policies to reverse such degradation.

Acknowledgements

Isabelle Vranken is a research fellow at the F.R.S.-FNRS, Belgium. Thanks to Prof. Y. Roisin (ULB) for information on termite ecology.

References

[1] Mumby, P.J., Green, E.P., Edwards, A.J. and Clark, C.D. 1999. The cost-effectiveness of remote sensing for tropical coastal resources assessment and management. *Journal of Environmental Management* 55:157-166.

[2] Groombridge, B., Jenkins, M., WCMC and UNEP 2002. *World Atlas of Biodiversity: Earth's Living Resources in the 21st Century*. University of California Press, Berkeley.

[3] Chapelier, A. 1957. *Élisabethville: essai de géographie urbaine*. Academie royale des sciences coloniales, Bruxelles.

[4] Khonde, C.N. and Rémon, M. 2006. *Stratégies de survie à Lubumbashi (RD Congo): enquête sur 14000 ménages urbains*. L'Harmattan, Paris.

[5] Vranken, I., Djibu Kabulu, J.P., Munyemba, F.K., Mama, A., Iyongo Waya Mongo, L., Bamba, B., Laghmouch, M. and Bogaert, J. 2011. Ecological impact of habitat loss on African landscapes and diversity. In: *Advances in environmental research*. J. Daniels, (Ed.), pp.365-388. Nova Science Publishers, Hauppauge.

[6] Hesse, P. 1955. A chemical and physical study of the soils of termite mounds in East Africa. *The Journal of Ecology* 43:449-461.

[7] Jouquet, P., Traoré, S., Choosai, C., Hartmann, C. and Bignell, D. 2011. Influence of termites on ecosystem functioning. Ecosystem services provided by termites. *European Journal of Soil Biology* 47:215-222.

[8] Malaisse, F. 1997. *Se nourrir en foret claire africaine: approche écologique et nutritionnelle*. Presses agronomiques de Gembloux, Gembloux.

[9] Adam, M. 2010. *Etude de la distribution spatiale des termitières géantes dans la région de Lubumbashi (RDC) sur base d'images de télédétection, et en fonction de différents facteurs écologiques*. Master thesis, Ecole Interfacultaire de Bioingénieurs. Université Libre de Bruxelles, Bruxelles.

[10] Bachelier, G. 1977. Mise au point sur l'action des termites dans les sols. *Science du Sol–Bulletin de l'AFES* 1:3-12.

[11] Iroko, A.F. 1996. *L'homme et les termitières en Afrique*. Karthala, Paris.

[12] Abensperg-Traun, M., Smith, G.T., Arnold, G. and Steven, D. 1996. The effects of habitat fragmentation and livestock-grazing on animal communities in remnants of gimlet Eucalyptus salubris woodland in the Western Australian wheatbelt. I. Arthropods. *Journal of Applied Ecology* 33:1281-1301.

[13] Mujinya, B., Adam, M., Mees, F., Bogaert, J., Vranken, I., Erens, H., Baert, G., Ngongo, M. and Van Ranst, E. 2014. Spatial patterns and morphology of termite (*Macrotermes falciger*) mounds in the Upper Katanga, DR Congo. *Catena* 114:97-106.

[14] Pribadi, T., Raffiudin, R. and Harahap, I.S. 2011. Termite Community as Environmental Bioindicator in Highlands: A Case Study in Eastern Slopes of Mount Slamet, Central Java. *Biodiversitas* 12:235-240.

[15] Sys, C. and Schmitz, A. 1959. *Notice explicative. 9. Région d'Elisabethville*. Carte des sols et de la vegetation du Congo Belge et du Ruanda-Urundi. INEAC, Bruxelles.

[16] Leteinturier, B., Baker, A.J. and Malaisse, F. 1999. Early stages of natural revegetation of metalliferous mine workings in South Central Africa: a preliminary survey. *Biotechnologie Agronomie Societe Et Environment* 3:28-41.

[17] Malaisse, F., Brooks, R. and Baker, A. 1994. Diversity of vegetation communities in relation to soil heavy metal content at the Shinkolobwe copper/cobalt/uranium mineralization, Upper Shaba, Zaïre. *Belgian journal of botany* 127:3-16.

[18] Vranken, I., Munyemba, F.K. and Amisi, M.Y. 2013. The spatial footprint of the non-ferrous mining industry of Lubumbashi. *Tropicultura* 31:20-27.

[19] Clark, P.J. and Evans, F.C. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology* 35:445-453.

[20] Rakotomalala, R. 2008. *Tests de normalité*. Université Lumière Lyon, Lyon.

[21] Bütler, R. 2000. *Analyse de la distribution spatiale d'objets dans un paysage*. Fiche d'enseignement. Laboratoire de Gestion des Ecosystèmes (GECOS), Lausanne.

[22] Crawley, M.J. 2012. *The R book*. John Wiley & Sons, Chichester.

[23] Dagnelie, P. 2006. *Inférence statistique à une et à deux dimensions*. Statistique théorique et appliquée. Vol. 2. De Boeck Université, Bruxelles.

[24] Hesterberg, T., Moore, D.S., Monaghan, S., Clipson, A. and Epstein, R. Eds. 2005. *Bootstrap methods and permutation tests*. Introduction to the Practice of Statistics. Vol. 5. New York: Freeman.

[25] Sys, C. 1957. L'aménagement des sols de la région d'Elisabethville d'après leurs caractéristiques morphologiques et analytiques. *Bull. Agric. Congo Belge* 48:1425-1432.

[26] Watson, J. 1977. The use of mounds of the termite Macrotermes falciger (Gerstäcker) as a soil amendment. *Journal of Soil Science* 28:664-672.

[27] Mielke, H.W. and Mielke Jr, P.W. 1982. Termite mounds and chitemene agriculture: a statistical analysis of their association in southwestern Tanzania. *Journal of Biogeography* 9:499-504.

[28] Ludwig, J.A. 1988. *Statistical ecology: a primer in methods and computing*. Vol. 1. John Wiley & Sons, Somerset.

[29] Duponnois, R., Assikbetse, K., Ramanankierana, H., Kisa, M., Thioulouse, J. and Lepage, M. 2006. Litter-forager termite mounds enhance the ectomycorrhizal symbiosis between Acacia holosericea A. Cunn. Ex G. Don and Scleroderma dictyosporum isolates. *FEMS microbiology ecology* 56:292-303.

[30] Fox-Dobbs, K., Doak, D.F., Brody, A.K. and Palmer, T.M. 2010. Termites create spatial structure and govern ecosystem function by affecting N2 fixation in an East African savanna. *Ecology* 91:1296-1307.

[31] Roose, E., Bellefontaine, R. and Visser, M. 2011. Six rules for the rapid restoration of degraded lands: Synthesis of 17 case studies in tropical and Mediterranean climates. *Science et changements planétaires/Sécheresse* 22:86-96.

[32] Dosso, K., Konaté, S., Aidara, D. and Linsenmair, K. 2010. Termite diversity and abundance across fire-induced habitat variability in a tropical moist savanna (Lamto, central Côte d'Ivoire). *Journal of Tropical Ecology* 26:323-334.