Quantification of anthropogenic effects in the landscape of Lubumbashi

Anthropogenic effects: Lubumbashi

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Abstract

In order to understand the dynamic of the (sub)urbanisation and so, to quantify the anthropogenic effects of the rapid growth of tropical cities, it is crucial to find and apply valuable methods. In this contribution, the transferability of the Rüdisser et al. (2012) «Distance to Nature» hemeroby assessment method to the landscape surrounding the city of Lubumbashi (DRC) is evaluated. That methodology has the advantage of taking structural connectivity into account by computing the distance to natural habitats. As it had never been applied to an African city before, some adjustments (fitting of the local land uses types into the hemeroby levels designed to Austria) and amendments (suppression of the final classification into hemeroby level simplification) are proposed. Moreover, an analysis of the decanal (2002-2013) hemeroby dynamics is presented. Results suggest that the Distance to Nature methodology is transferable but requires good field knowledge to define reference habitats and identify them in the Landsat classified images. There was a dramatic decrease of the «natural» and «near-natural» levels in the study extent during the studied period. In addition, 32% of the land underwent anthropisation increase, mostly around cities and following a ribbon development.

Keywords: anthropic influence – Geographic information system – land cover mapping – landscape – land cover change – tropical Africa

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Quantification de l’intensité d'anthropisation dans le paysage de Lubumbashi

Anthropisation: Lubumbashi

Résumé

Dans un contexte de croissance rapide, souvent non planifiée, des villes tropicales, il est crucial d’appliquer les méthodes les plus adéquates permettant de comprendre la dynamique de (péri)urbanisation et, ainsi, de quantifier l’anthropisation de ces villes. Dans cette étude, la transférabilité de la méthodologie d’estimation de l’hémérobie « Distance to Nature » de Rüdisser et al. (2012) est évaluée via son application au paysage entourant la ville de Lubumbashi (RDC). Cette méthode a l’avantage de prendre la connectivité structurelle en compte via le calcul de la distance aux habitats naturels. La méthodologie n’ayant encore jamais été appliquée au contexte d’une ville africaine, certains ajustements (mise en correspondance des utilisations du sol locales avec les niveaux d’hémérobie mis au point en Autriche) et amendements (suppression de la simplification finale de la classification en niveaux d’hémérobie) sont proposés. De plus, une analyse de la dynamique décennale (2002-2013) d’hémérobie est présentée. Les résultats suggèrent que la méthodologie « Distance to Nature » est transférable mais que la définition des habitats de référence ainsi que leur identification sur les images Landsat classifiées requièrent une excellente connaissance du terrain. Durant cette période et sur l'étendue d'étude, les niveaux « naturel » et « proche de naturel » ont considérablement diminué. De plus, 32% du territoire ont vu leur anthropisation augmenter, principalement autour des villes et suivant un développement en ruban.

Mots clés: influence anthropique – Système d'information géographique – cartographie de l'occupation du sol – paysage – changement de couvert végétal – Afrique tropicale

Introduction

Human affects many Earth's ecosystems by converting/changing the original ecosystem functions to provide essential requirements (Vitousek *et al.*, 1997). Anthropisation is studied as for the impact of human activities on landscape composition, configuration and dynamics but remains difficult to quantify. As the conservation biology and the restoration ecology focus on the ecosystem composition, the landscape ecology brings considerations about the spatial and temporal patterns to infer this impact on ecological processes (Turner, 1989, Young, 2000).

The region of Lubumbashi is representative for landscape anthropisation in Katanga: situated in the Katangese copper belt and well known for its copper and cobalt veins (Chapelier, 1957), this formerly rural zone developed for mining development (Narendrula *et al.*, 2012). Non-ferrous metal exploitation and processing have led to a strong industrialisation and therefore to the building of new towns, quarries and plants under Belgian colonialism since the beginning of the 20th century (Banza *et al.*, 2009, UMHK, 1956). Historically, the city consisted of a densely built-up zone provided infrastructures, today aged, and industrial areas in the suburb (Bruneau *et al.*, 1990). However, the consequences of the economical attractiveness of mining industries, leading to a massive rural flight and a rapid population growth (1,200,000 inhabitants in 2006, near 2,020,000 estimated in 2015), are different anthropogenic effects, mostly reported as unplanned deforestation, urbanization and suburbanisation patterns (Chapelier, 1957, Groupe Huit, 2009, Khonde *et al.*, 2006, Vranken *et al.*, 2013). Industrial infrastructure is now fully included into the urban fabric, and recent industries installed just outside the urban belt (Vranken *et al.*, 2014, Vranken *et al.*, 2013). The inhabitants of the city depend on food imports due to the heavy metal soil contamination and the absence of a tradition of farming (Khonde *et al.*, 2006, Vranken *et al.*, 2014).

In order to understand the dynamic of the (sub)urbanisation and so, to quantify the anthropogenic effects of the rapid growth of tropical cities, particularly for developing countries, it is crucial to select valuable methods. Human activities can be assessed in three ways. First, using simple indexes and proxies of anthropogenic activity like area of a certain land use type, road and population density. Secondly, using a qualitative hemeroby scale, which will assess how much local naturalness has been disturbed or replaced, based on general criteria of disturbing processes and resulting land cover. Thirdly, anthropogenic effects on landscapes can also be represented by composite indicators of any of the aforementioned tools (Vranken *et al.*, submitted). Among the existing methods, the Rüdisser *et al.* (2012) «distance to nature» composite indicator and methodological framework (i.e., D_2N methodology), a recent method that has the advantage of taking structural connectivity into account by computing the distance to natural habitats, appears most suitable for a landscape ecological analysis in our study zone. As most approaches, it has been implemented in a temperate context. In this chapter, it will be applied for the first time to the context of an African city. The objectives of the study are therefore to assess the effect of local activities on landscape spatiotemporal structure in Lubumbashi and its hinterland as well as the transferability of the method to a different context.

First, we describe the study zone and its main natural and human components. We go on summarizing the details of satellite image acquisition, treatment and classification we used to obtain a land cover map of the area. Then, we detail the adjustment we brought (calculation of the decadal anthropisation dynamic) to the D_2N method, its application and the meaning of its outputs. The results and discussion section highlights the anthropogenic and natural patterns for each of the two years (2002 and 2013), their decadal dynamics and comments the transferability of the method. Anthropisation (mostly (sub)urbanisation and deforestation) is expected to increase within this period. Some recommendations for future application of the methodology in the same context are then detailed in the perspective and conclusion section.

Material and methods

Study zone

Lubumbashi is the capital city of Katanga, a province in the Southern part of the Democratic Republic of the Congo (DRC). The study zone consists of a plateau that has been eroded into a wide valley by the Lubumbashi River and its tributaries (Chapelier, 1957). The altitudes of the inner-city, on the plateau, vary between 1200 and 1250 m (Sys *et al.*, 1959). The local climate is characterised by a wet season (from November to April) and a dry season for the rest of the year and corresponds to the Cw

Köppen category (Kottek *et al.*, 2006). Currently, the vegetation cover is continuous only during the wet season (Adam, 2010).

Islets of dry evergreen forest called *muhulu*, present in the area (Malaisse, 2010), could indicate that the actual climax was *muhulu* and that *miombo* (called woodland in this paper), the woodland forest strata that has dominated the area at least since the first observations during the colonial period, would be a disclimax resulting from former slash and burn agriculture (Noti *et al.*, 1996, Schmitz, 1962, Sys *et al.*, 1959, White, 1983). Diverse forms of savannah, from wooded savannah to grassland, as well as bare soils are now progressively replacing the woodland (Malaisse, 2010). Bare soils result mostly from mining activities and heavy metal eolian deposits (Mbenza *et al.*, 1989, Narendrula *et al.*, 2012). Near the smelters, debris are piled into tall and wide slag heaps. If forest, more or less degraded, still covers about 50 % of the area, derived savannahs and cultivated areas, generally resulting from forest clearance by the almost annual fire (Malaisse, 2010), represent now the second largest land cover in the area (about 30 %). These diverse savannah therefore result from anthropogenic degradation and do not present the same biophysical characteristics (including floristic composition) as natural savannahs (Parr *et al.*, 2014). In tropical Africa, most fires are of anthropogenic origin (van der Werf *et al.*, 2008). In our study area, where fire practices seem to have significant importance on the land use, that origin is corroborated by Malaisse (2010) and an existing correlation between fire starts and proximity to the city and roads (R^2 = 0.78, data not shown) as well as surrounding villages (R^2 = 0.77, data not shown). Moreover, the absence of correlation between fire starts and proximity to industrial sites (R^2 = 0.09, data not shown) also suggests that those fires are mostly operated by villagers for agriculture and charcoal production, which is a regular practice in the area (Stromgaard, 1985, Vranken *et al.*, 2011). Besides great effect of leaching on soil structure and organic matter content, fire impacts as well edaphon through superficial depressive effect on soil fungi and animal populations (Malaisse *et al.*, 1975). Natural metallophyte herbaceous flora ("copperflora") is also present in natural highly metalliferous soils (mainly copper and cobalt), generally found on hills among the forest ("copper hills") (Leteinturier *et al.*, 1999, Malaisse *et al.*, 1994). Some species were also able to colonize the soils contaminated by metalliferous atmospheric deposits (Faucon *et al.*, 2011). Specific features called *dembos*, natural grasslands temporarily flooded in valleys around water streams, are frequent in the area (Sys *et al.*, 1959, White, 1983). Permanent wetlands are found as well round the riverbanks and depressions on impermeable ground, some of which are cultivated (Sys *et al.*, 1959). Nearly all the lakes are of anthropogenic origin: reservoirs built during the colonial period.

Choice of the analytical framework

Vranken *et al.* (submitted) expose, analyse and criticise in details the different concepts and quantifications related to anthropogenic effects assessment. According to this contribution, we will refer to anthropogenic effects assessment and associated terms using the term anthropisation, that represents human-driven landscape changes (Vranken *et al.*, submitted). Here, the D_2N methodology was chosen for several reasons: first, it is designed to be used at landscape level; then, it combines stretched values, patch and categorical analyses (Gustafson, 1998, Wiens *et al.*, 1993), while the resulting values exist in both continuous and discontinuous variations, combining the advantages of the two output types. Moreover, it takes processes (different types, intensities and frequencies of human pressures on ecosystems) into account and integrates the presence of secondary habitats. Structural connectivity between natural habitats, which is important to ecological processes, is also included through the «distance to natural habitat» (D_n) component of the index. It can be evaluated even when few other data than land cover are available. Finally, it has been conceived to facilitate the interpretation, comparison and communication of the results. We though implemented some adaptations to the methodology according to Vranken *et al.* (submitted) and the specificities of our study zone and data availability.

Adaptation of the D_2N methodology to local landscape classes

Data acquisition

We used Landsat ETM+ and OLI multispectral images, from 2002.07.07 and 2013.07.13, with a spatial resolution of 30m (USGS, 2014). They were pan-sharpened with the corresponding panchromatic images to obtain a resolution of 15m using the ENVI 5.0 software. The study site consists of intersection of the area covered by the Landsat images from 2002 and 2013 (about 23,400 km²).

In order to obtain a minimal surface of burned areas (that were very abundant in our study zone), we applied a filter for the spectral signature of the burned areas on a set of Landsat calibrated images shot at different moments of the same year (05.04, 07.07, 08.08 and 10.11 for 2002, 06.27, 07.13 and 08.30 for 2013). We then recomposed a multidate image for each year from the filtered original images before performing a multiresolution segmentation using all the spectral bands of both images. Afterwards, we performed a supervised object-oriented classification based on spectral values and a shuttle radar topography mission (SRTM) image with a 90m resolution (Trimble Documentation, 2013). The training sets for this classification were defined by 1) direct field surveys regularly conducted between January 2012 and April 2014, 2) the Modis MCD14ML « Active fire » products with a detection confidence of 100% and 3) the freeware licenced version of Google Earth© imagery (from 2002 and 2012) for the remote areas (Giglio, 2013). Both segmentation and classification operations were performed using the eCognition© software. After a first land cover based classification (13 classes), we refined the results to display more information on the land cover and specific patches. As it was not possible to distinguish which wetlands were cultivated according to their spectral signature, a proximity rule was used : wetland segments touching anthropogenic ones (burned areas, continuous and discontinuous built-up areas, crops, pastures, young fallow and slag heap) were assumed to be potentially cultivated at least sporadically and therefore considered as anthropised. These latest were called « anthropised wetlands » while the uncultivated ones were called « wetlands ». As for the reservoirs, first identified as « water », another kind of proximity rule was used in order to isolate them: water segments sharing 70% or more of their edges with other water segments were assigned as «reservoirs», while the others were labeled « streams ». This classification refinement is particularly relevant for the quantification of anthropogenic impact. The aforementioned method allowed to distinguish 15 land use/cover classes (LULCC): « natural grasslands », « wetlands », « streams », « woodland », « wooded savannah and old fallow», « savannah and bushland «, « savannah-crops mosaic », « reservoir », « crops, pastures, grasslands and young fallow », « anthropised wetlands », « recurrent burned areas », « bare soil », « slag heap », « discontinuous built-up » and « continuous built-up ». The Landsat classified images were then exported in raster format with 25m pixels, as in Rüdisser *et al.* (2012) for further treatment in ArcGIS©.

Data analysis

In order to obtain the D_2N index values, we proceeded in three steps.

First we built hemeroby scales and maps, called « degree of naturalness » (N_d) by Rüdisser et al. (2012). We preferred using the term hemeroby here because, following Vranken *et al.* (submitted), hemeroby corresponds to a scale positively correlated with anthropisation, to the contrary to naturalness, and the purpose of Rüdisser *et al.* (2012) was an anthropisation-oriented index.

The land use types provided by Rüdisser *et al.* (2012) were only suitable for Austria and similar landscapes, but their qualitative hemeroby scale provided process information on type, intensity and impacts of human activities for each hemeroby level. Based on this description and specific site knowledge on local ecosystems and activities, we were able to fit the existing land use types of Lubumbashi into the D_2N-related hemeroby scale.

As a first step, we assigned one of the seven hemeroby levels to each land use or cover existing in our study extent. As a second step, we sorted each of the 15 LULCC from our classification into the seven hemeroby levels. The decision tree used by the analyst in the field to discriminate the land cover classes, based on Trochain (1957), Letouzey (1982) and Bellefontaine *et al.* (1997) is shown in Appendix 1. As some ecosystems could not be distinguished and had to be grouped in an heterogeneous land cover class, the latter was allocated to the level of hemeroby corresponding to the dominant ecosystem (Table 1). Dry evergreen forest, copper hills, wetlands and natural grasslands were assigned to the first level, « natural », but the classification identified only the latter two. The amount of anthropised grassland was so negligible that they were discriminated from natural grassland. Woodland and Streams were assigned to level 2, « near-Natural » in both cases. Indeed, water streams are in most cases of natural origin but present eutrophication. Regenerating forest, wooded savannah and old fallow were put in the third level (« semi-natural ») because those vegetation types are most of the time not found in the area before human direct intervention (Parr *et al.*, 2014). The classification did not identified the first. The ecosystems young fallow, savannah, bushland, pasture and grassland were assigned to level 4, « altered », corresponding to the definition given by Rüdisser *et al.* (2012). In the class sorting, young fallow, pasture and grassland had to be assigned to the level 5 (« cultural »), being grouped with crops. Crops, along with anthropised wetlands and reservoirs were as well put in this level. As the savannahs in the area mostly correspond to early stages of ecological succession to fires, the recurrent burned areas that could not be eliminated were assigned level 5 too. We put one of the LULCC (« savannah/crops mosaic ») in between hemeroby levels 4 and 5 because the crops land use was assigned to level 5 while savannah was assigned to level 4. Level 6, « artificial with natural elements », corresponded to discontinuously built areas and bare soils. Finally, the seventh level, « artificial », with soil sealing over 30 %, was assigned to continuous built areas and slag heap. After performing those operations, we normalized the class values along a scale from 0 to 1, following the D_2N methodology and built the N_d map.

Secondly, we built a map of distance to natural habitat (D_n): this corresponds to the Euclidean distance (in meters) from each pixel of the images to the nearest natural or near-natural habitat (levels 1 and 2). Following the D_2N methodology, distances superior to 1000 m were set to 1000 m. In order to increase the effect of the proximity of anthropogenic features, we took the square root of the resulting distances. Then, we normalized the results in order to obtain dimensionless values ranging from 0 to 1.

Thirdly, we multiplied the N_d maps by the D_n maps and normalized the result from 0 to 1 in order to maximize the variation range of the results and re-scale it in the same way than the other normalised indexes. This gave the D_2N index map also called D_2N maps. Rüdisser (2012)'s methodology also reclassifies the results in four levels, but in our case, the choice was made to keep the continuous variation in order to detect the finest nuances of anthropisation variation.

Anthropisation dynamics analysis

In addition to the D_2N methodology, we highlighted the dynamics of anthropogenic influence in Lubumbashi between 2002 and 2013 by subtracting 2002 to 2013 D_2N values, constructing a post-classification change detection map. That step aims at evaluating anthropisation changes during the period. We constructed a transition matrix to show how the natural and near natural LULC changed during the 2002-2013 period.

Results and discussion

Adaptation of the D_2N methodology to local landscape classes

Data acquisition

As for the image classification precision, the obtained Kappa coefficients were rather low (0.349 for 2002 and 0.316 for 2013, see confusion matrices in appendix 2) (Congalton, 1991). This may be due to different factors: firstly, seasonal variation is strong in the area, especially concerning fire dynamics, and may have led to misclassifications (Congedo *et al.*, 2012). Secondly, bare soils have a very similar spectral signature as built-up areas (Congedo *et al.*, 2012). Thirdly, the very fast urban dynamics in the area may have lead to land use change-driven differences between the field surveys and image captures given the time elapsed between both operations. Fourthly, spatial structure in Africa is loose, compared to Northern countries: land cover patches are less clearly delimited (Vranken et al., 2013), probably due to differences in land planning practices. This may lead to confusion between adjacent land covers. Fifthly, due to the medium spatial resolution of the images, pixels may contain different ecosystems (this phenomenon is known as the "mixel" problem) but have to be attributed to a single class, therefore not representative of the entire pixel area (Pham *et al.*, 2011). Finally, ecosystems, as often responding to regressive or progressive processes, are seldom "pure" but often reflect transition states from one ecosystem to another. Analysts and the classification algorithms may settle the threshold between borderline land covers differently, leading to virtual misclassifications.

It should however be noted that the accuracy of the classifications is inversely proportional to the thematic resolution (number of land cover classes): if a lower number of classes had been put forward (for example 7), the Kappa would have risen (to 0.49 in this example). Note that Congedo *et al.* (2012) obtained a Kappa value of 0.57 on a similar area using Landsat images, but their classification contained only 5 classes, against 13 in the current study. Here, we chose to privilege thematic resolution in order to obtain relevant classification for the elaboration of our hemeroby scale. The aforementioned considerations do however not question the validity of the D_2N methodology, which was applied as a post-treatment on the classified images.

The consequences of the misclassifications depend on: (1) the confusion between LULCC of distinct hemeroby levels, (2) the definition of the reference states (natural and near-natural levels) and other hemeroby levels, (3) the correct classification (user precision) of these reference states. Errors in the two latter points have multiplicative effects on the results, given that the D_2N methodology is based on both hemeroby levels and distance to natural and near-natural levels, and given that the dynamics map depends on the two D_2N maps. In the case of this research, the most problematic misclassification is the erroneous classification of wooded savannah (level 3) as woodland (level 2) (see Appendix 2 and 3), which naturalises the landscape.

Data analysis

The application results of the D_2N methodology to Lubumbashi in 2002 (Figure 1a) and 2013 (Figure 1b) show the anthropisation levels in the area. The extent of this first study area includes more than one urban zone (4% of total area in 2002, 11% in 2013), dispersed in a natural or near-natural matrix (about 60 % of the total extent, against 75% in 2002). Connectivity between natural habitats seems not only hampered by urban and cultivated areas, but also decreases the D_2N values of those areas themselves, making them benefit from the proximity of natural and near-natural areas. Therefore, the inclusion of the notion of connectivity in the analysis naturalises the representation of the landscape.

Dark spots, representing the highest levels, correspond to the main urbanised zones in the area, the largest of which is Lubumbashi (center-right), followed by Likasi, along the Tshangalele Reservoir, Northwest of Lubumbashi, Kipushi, the closest dark zone Southwest to the city.

To build their N_d map, Rüdisser et al. (2012) used a large amount of data (forest hemeroby, CORINE classification, roads, etc.), some of which were available as stretched values (gradients, under continuous variation, see Gustafson (1998) and Vranken et al. (submitted)), but were integrated as a discontinuous and qualitative hemeroby scale, displayed as a categorical map. In our first approach, we followed the same guidelines, except that less reliable data were available for our study zone.

Patches of the same land cover may follow different anthropogenic dynamics. For example, one savannah area may result from a regressive series that can be linked with fire disturbance, while the other may result from a progressive series, i.e. ecological succession, linked with the end of previous disturbances. In the present study, such distinction between progressive and regressive series could not be achieved yet. This is partly due to coarse data spatial resolution and lack of classification precision (map categories include here different land covers, sometimes displaying different hemeroby levels).

The choice of the ecosystems corresponding to the reference states and their identification on the classified image is of particular importance. In the case of Katanga, woodland is said to correspond to a pyroclimax on deep soils (dry evergreen forest being the natural vegetation in this case) but to a natural vegetation on shallow soils (Lawton, 1978, Schmitz, 1962, White, 1983), which was the choice made (see Table 1). However, this is to some extent controversial among scientists (Mahy, personal communication). In Table 1, level 1 is considered as virtual naturalness, considering pre-colonial human interventions on landscape structure as anthropogenic, distinct from nature (Lecomte *et al.*, 2005, Peterken, 1996, Vranken *et al.*, submitted).

The choice not to apply the four-level D_2N scale displayed in Rüdisser *et al.* (2012) is justified by two facts. First, continuous variations of the D_2N values appear more precise: simplifying them in only four levels, while there were seven levels in the original scale, represents information loss. Secondly, African spatially continuous spatiotemporal structure (Vranken *et al.*, 2013) appears best represented using continuous transitions between anthropisation levels. Attention should be given to the fact that the results, showing dominant natural or near-natural classes, are due to the very large extent of the study zone (23,400 km²). It may give the wrong impression that Lubumbashi causes little anthropisation in the area.

Anthropisation dynamics between 2002 and 2013

The overall darker colour of the 2013 image (Figure 1) as well as preliminary observations on Figure 2 (a) suggest that during the period, the studied area underwent an anthropisation increase principally concentrated around the cities and spreading as a ribbon development (Dumont *et al.*, 2006, Ewing, 1994). Thus, the suburban zones of Lubumbashi and Kipushi almost merged, while they were still separated in 2002. Furthermore, though natural and near-natural areas still dominate the area, they are now strongly fragmented.

The relative changes in anthropisation levels, quantified in Figure 2 (b), show that about 46% of the land underwent an anthropisation level change in 11 years. The moderate increases dominate the anthropisation dynamics (24.5 % of total extent increased by 0.001 to 0.3 in D_2N value). The zones encountering anthropisation increase cover 32 % of the total area, while the total anthropisation decrease only represents 15 %, which confirms an overall anthropisation increase.

The area change for each anthropisation level between 2002 and 2013 (Figure 2 (c)) shows that dominant dynamics are dramatic decrease (about 11 % of total extent) in the natural and near-natural level and substantial increase in intermediate levels of anthropisation, probably following the aforementioned anthropisation dynamics. The transition matrix shows that the natural and near-natural areas lost between 2002 and 2013 corresponds mostly to « woodland » and « natural grasslands » converted mainly to « anthropised wetlands » (for woodland) as well as to « recurrent burned areas », « crops, pastures, grasslands and young fallow » and « wooded savannah and old fallow» (for both).

It should also be noted (Figure 2 (a)) that the highest gains in naturalness are mostly dispersed near the suburban belts. This phenomenon may be linked to young fallow developing into forest, misclassifications or set-aside (Groupe Huit, 2009). The observed ribbon development is similar to the urbanisation patterns in U.S. and European cities (Brück, 2002, Ewing, 1994, Grosjean, 2010).

Perspectives and conclusion

This first attempt to apply an hemeroby based anthropogenic effect quantification to a region in tropical Africa appears promising. It should be applied on other southern cities in order to compare and assess the relevance of the results. It could also be confronted to other methodologies applied on the same area but the lack of informations currently available at this scale is a limiting factor for such implementation. Even this case study still lacks relevant information specific to local data, dynamics and practices.

The functional part of connectivity must be taken into account when evaluating the configurational aspects of landscape anthropisation (Tischendorf *et al.*, 2000). For example, a large compact patch tends to shelter more interior and rare species, while having a less positive impact on structural connectivity than various corridor-shaped patches (Turner, 1989). The methodology could be amended in order to take that functional factor into account and could even be species-oriented.

Concerning the distinction between progressive and regressive series, this should be more feasible using more data, with better spatial and temporal resolution or producing smaller objects by means of segmentation. This would also allow building the same post-classification change detection maps as in this contribution as well as N_d transition matrixes to study specific patch dynamics. Reliable thematic maps such as up-to-date road net, activities and infrastructure could also be added, as in Rüdisser et al (2012). In this case, specific attention should be given to weighing respective influences of each human activity or disturbance data, in order to avoid redundancy and biases.

Considering the methodology application, the mutual influences of anthropised and natural landscape, highlighted by the introduction of a distance gradient, open interesting perspectives for land planning, conservative management and restoration. Indeed, the consequence of adding or removing natural patches in the landscape depending on the distance to existing natural habitats and on the surrounding land use types could be simulated using D_2N maps. This could help prioritize areas to protect and/or degraded ecosystems to restore. It should however be noted that this methodology does not distinguish the natural habitat richness or conservation interest linked to their specific composition, which is necessary to every conservative management and should be complementarily examined (Séleck *et al.*, 2013).

List of Abbreviations

D_2N : Distance to nature (index, map, methodology)

D_n: Distance to natural habitat

DRC: Democratic Republic of the Congo

LULCC: land use/cover classes

N_d: Degree of naturalness

SRTM: shuttle radar topography mission

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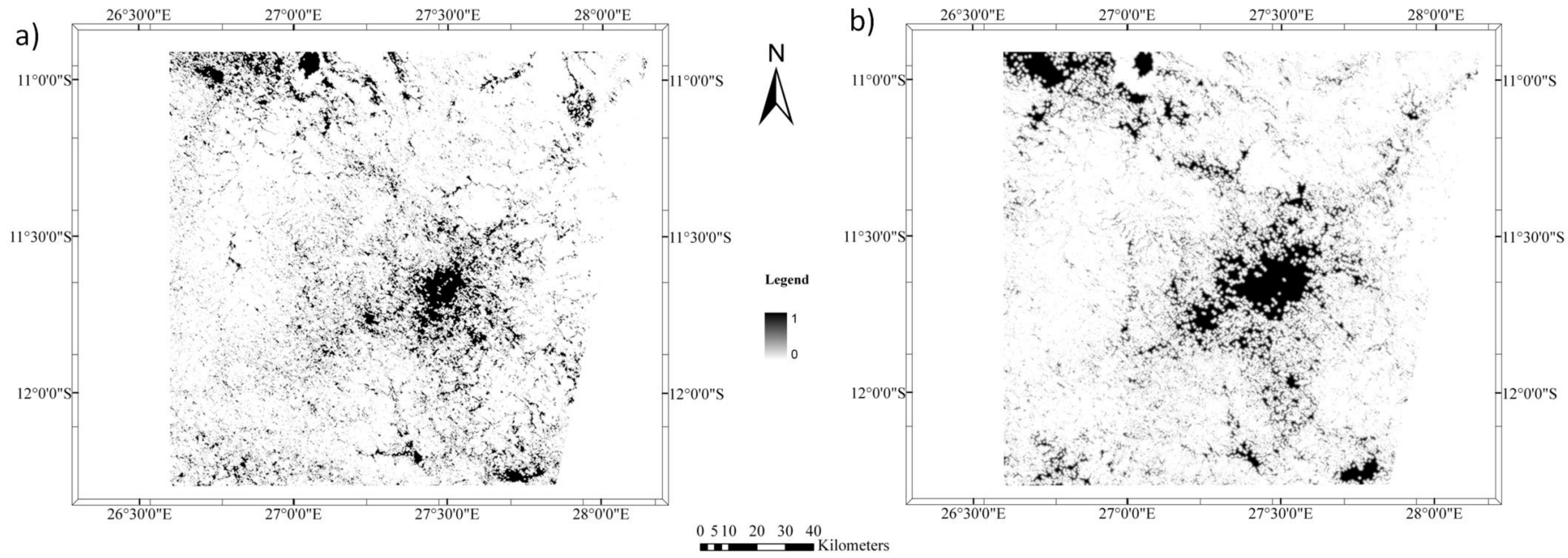
Table 1

Hemeroby level	Description		Examples of land use types found in Austria	Ecosystems (land use / land cover) in the area of Lubumbashi	Matching image classes	
	Type of anthropogenic influence	Ecosystem patterns and processes			Matching hemeroby class	Class composition
1. Natural	No or only minimal anthropogenic influence (e.g. global pollution)		Bare rock, sparsely vegetated areas, glaciers and perpetual snow, inland marshes, peatbogs, natural forests	Shallow soil woodland, Dry evergreen forest, Wetlands, Natural grassland, Copper hills	1	Wetland, Natural grassland
2. Near-natural	Anthropogenic influences	Structure and type of ecosystem is basically the same as naturally expected at the side but some characteristics (e.g. plant species composition) are altered	Natural grasslands (above timberline), moors and heathland, water bodies, sustainably managed forests	Deep soil woodland, Water	2	Woodland, Streams
3. Semi-natural	Anthropogenic activities	The naturally occuring ecosystem is no longer present but has been transformed into a new ecosystem type because of anthropic activity	Alpine meadows substituting forest pastures, fallow land	Regenerating forest, Wooded savannah, Old fallow	3	Wooded savannah and old fallow
4. Altered	Regularly disturbing anthropogenic activities (e.g. drainage, regular passing over, intense fertilisation)	Changed ecosystem type, edaphon regularly disturbed	Vineyard, intensively used grasslands, plantation of energy forests	Young fallow, Savannah, Bushland, Grassland, Pastures	4	Savannah and bushland
					4.5	Savannah / crops mosaic
5. Cultural	Intense and regular impacts	Destruction of the natural occuring edaphon. Natural occuring floristic elements are reduced to a minimum (< 25% coverage)	Arable land, green urban areas, sport and leisure facilities	Anthropised wetlands, Crops, Reservoirs, Anthropised grasslands	5	Anthropised wetlands; Crops, pastures, grassland and young fallow; Recurrent burned areas; Reservoirs
6. Artificial with natural elements	Intensive and irreversible changes of terrain and landscape structure; soil sealing up to 30%	Natural elements only in the form of secondary biotopes	Rural settlements, mineral extraction sites, dump sites, airports	Discontinuous built, Bare soil	6	Discontinuous built, Bare soil
7. Artificial	soil sealing over 30%	Artificial systems or structures	Continuous urban fabric, industrial or commercial units, road and rail networks	Continuous built, Slag heap	7	Continuous built, Slag heap

Figure 1



a)
b)
26°30'0"E
27°0'0"E
27°30'0"E
28°0'0"E
11°0'0"S
11°30'0"S
12°0'0"S
N
Legend
1
0
0 5 10 20 30 40
Kilometers

Figure 2

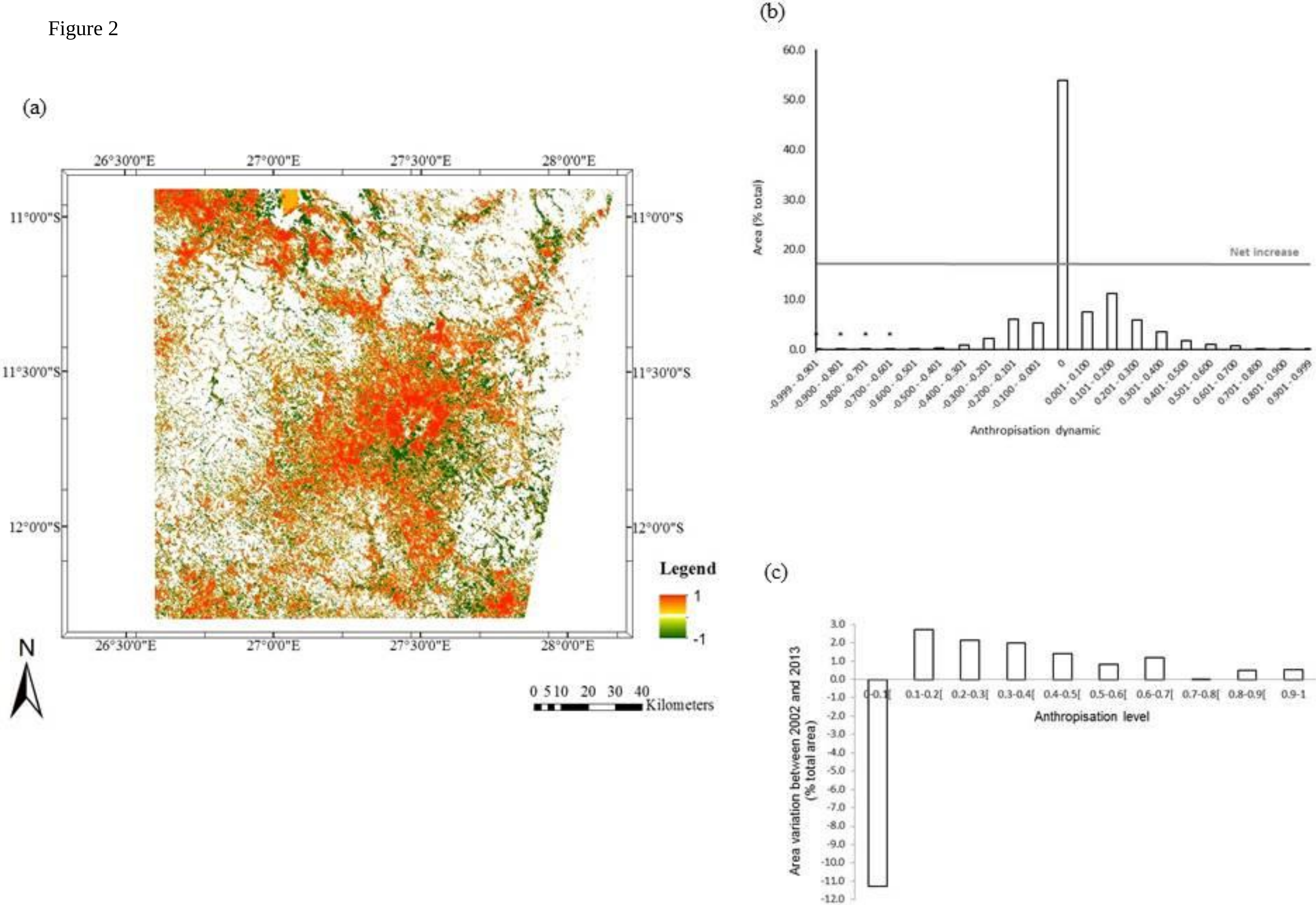

(a)
26°30'0"E
27°0'0"E
27°30'0"E
28°0'0"E
11°0'0"S
11°30'0"S
12°0'0"S
Legend
1
-1
N
0 5 10 20 30 40
Kilometers
(b)
Area (% total)
Net increase
Anthropisation dynamic
-0.999 - -0.901
-0.900 - -0.801
-0.800 - -0.701
-0.700 - -0.601
-0.600 - -0.501
-0.500 - -0.401
-0.400 - -0.301
-0.300 - -0.201
-0.200 - -0.101
-0.100 - -0.001
0
0.001 - 0.100
0.101 - 0.200
0.201 - 0.300
0.301 - 0.400
0.401 - 0.500
0.501 - 0.600
0.601 - 0.700
0.701 - 0.800
0.801 - 0.900
0.901 - 0.999
(c)
Area variation between 2002 and 2013 (% total area)
Anthropisation level
0-0.1[
0.1-0.2[
0.2-0.3[
0.3-0.4[
0.4-0.5[
0.5-0.6[
0.6-0.7[
0.7-0.8[
0.8-0.9[
0.9-1

Figure 3

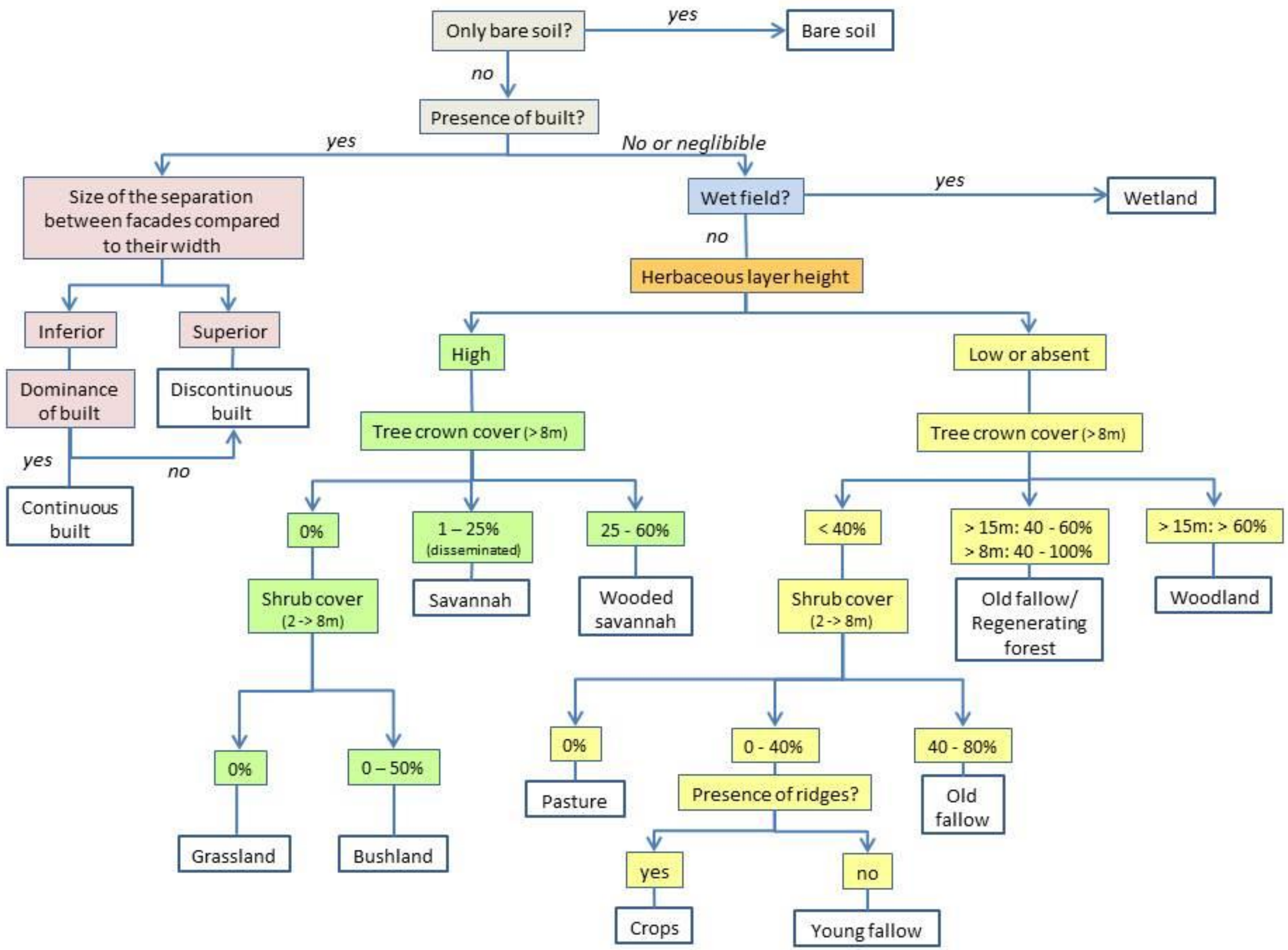

Only bare soil?
yes
Bare soil
no
Presence of built?
yes
No or neglibible
Size of the separation between facades compared to their width
Wet field?
yes
Wetland
no
Herbaceous layer height
Inferior
Superior
Dominance of built
Discontinuous built
yes
no
Continuous built
High
Low or absent
Tree crown cover (> 8m)
Tree crown cover (> 8m)
0%
1 – 25% (disseminated)
25 - 60%
< 40%
> 15m: 40 - 60%
> 8m: 40 - 100%
> 15m: > 60%
Shrub cover (2 -> 8m)
Savannah
Wooded savannah
Shrub cover (2 -> 8m)
Old fallow/ Regenerating forest
Woodland
0%
0 – 50%
0%
0 - 40%
40 - 80%
Grassland
Bushland
Pasture
Presence of ridges?
Old fallow
yes
no
Crops
Young fallow

Table 1

Rüdisser's hemeroby scale (2012) (« Degree of naturalness ») and its adaptation to the region of Lubumbashi (RDC). The four first columns are extracted from Rüdisser et al. (2012). The fifth column shows ecosystem correspondence to the seven hemeroby levels, while the two last columns (dashed lines) show the level of each land use and land cover classes of the classified Landsat images.

Figure 1

Application of the Rüdisser et al. (2012) « Distance to nature » methodology to the landscape of Lubumbashi (DRC) in 2002 (a) and 2013 (b). An index value of 0 means the lowest distance to nature; a value of 1 means the highest distance to nature.

Figure 2

Dynamics of anthropisation levels between 2002 and 2013 in Lubumbashi (DRC). The numbers from -1 to 1 represent the number of levels respectively lost or gained during this period; 0 represents no anthropisation level change. The map (a) shows the localisation of the dynamics, while the graph (b) shows the percentage of the total area concerned by each change type (* represents values superior to 0 but below 0.1%). The bar diagram (c) shows the percentage of the total area increase of each anthropisation level between 2002 and 2013, ranging from 0 (less anthropised level) to 1 (most anthropised level).

Figure 3

Decision tree used by the analyst on the field to deduce the land cover of the samples points.

Appendix

Appendix 1: Decision tree for the discrimination of land covers

The Figure 3 shows the decision tree used by the analyst in the field to deduce the land cover of the samples points. The analyst placed herself in homogeneous imaginary circles of 10 m radius. Inside those circles, the land cover was evaluated. The iterative evaluation begins with the consideration of the presence of bare soil: if it covered the entire circle, then the sample point was identified as "bare soil". Otherwise, if built surfaces were present and if the size of the separation between constructions was superior to their width or if there was no dominance of built surfaces, the sample point was assigned to "discontinuous built". Alternatively, it was attributed to "continuous built". If the amount of built surfaces was null or negligible, then the analyst evaluated the moisture of the field. In case of wet field, the sample point was assigned to "wetland". Otherwise, the height of the herbaceous layer was evaluated (plants with a height inferior to 2m are considered as "herbaceous"). If it was considered as high, the tree crown cover was evaluated (a "tree" is considered as a wooded plant with a height superior to 8m). If it was null, then the shrub cover was considered ("shrub" are considered as plants with a height between 2 and 8m). If the shrub cover was null, then the sample point was attributed to "Grassland". Otherwise (shrub cover of 0-50%), it was attributed to "bushland". If the tree cover ranged between 1 and 25%, the sample point was assigned to "savannah". If it ranged between 25 and 60%, it was attributed to "wooded savannah". When the height of the herbaceous layer was low or when this cover was absent, as previously mentioned, the tree crown cover was evaluated. When inferior to 40%, as aforementioned, shrub cover was evaluated. When null, the sample point was assigned to "pasture". When superior to 0 but inferior to 40%, when the presence of ridges on the ground was recognized, the sample point was attributed to "crops". Otherwise, it was assigned to "young fallow". When the shrub cover ranged between 40 and 80%, the point was assigned to "old fallow". When the tree crown cover was superior to 40%, then the height of trees was also considered for the segregation. Indeed, when the trees with a height superior to 15m had a crown cover superior to 60%, then the sample was attributed to "woodland". Otherwise, it was assigned to "old Fallow/regenerating forest". The criteria used in the decision tree were documented in Bellefontaine *et al.* (1997), Letouzey (1982), Ruelle *et al.* (n.d.), Trochain (1957). No sample points could be collected in the field for the following classes: natural grassland, streams, savannah/crop mosaic, recurrent burned areas, reservoirs and slag heap. These land cover classes were identified by means of Google Earth.

Annex 2: Confusion matrices for the classification of the Landsat images of Lubumbashi (DRC)

Table 2

Classified data	Reference data									User's accuracy (%)
	Continuous Built	Crops, pastures, grassland and young fallow	Natural grassland	Discontinuous built, bare soil	Woodland	Savannah, bushland	Savannah/ crops mosaic	Water	Wetland	Wooded savannah	
Continuous Built	7	1	0	12	0	0	7	0	1	0	25.0
Crops, pastures, grassland and young fallow	2	10	1	7	0	3	5	1	4	0	30.3
Natural grassland	0	2	7	0	0	1	0	3	1	4	38.9
Discontinuous built, bare soil	5	1	0	10	0	0	1	0	1	0	55.6
Woodland	0	0	6	0	15	3	1	0	0	8	45.5
Savannah, bushland	0	0	0	0	0	0	0	0	0	0	0.0
Savannah/crops mosaic	0	0	0	0	0	0	0	0	0	0	0.0
Water	0	0	0	0	0	0	0	11	0	0	100.0
Wetland	1	0	0	0	0	0	0	0	8	0	88.9
Wooded savannah	0	0	1	0	0	8	0	0	0	0	0.0
Burned area	0	1	0	1	0	0	1	0	0	3	
Producer's accuracy (%)	46.7	66.7	46.7	33.3	100.0	0.0	0.0	73.3	53.3	0.0	
Overall accuracy: 41.2%; Kappa statistic: 0.349											

Table 3

Classified data	Reference data										User's accuracy (%)
	Continuous Built	Crops, pastures, grassland and young fallow	Natural grassland	Discontinuous built, bare soil	Woodland	Savannah, bushland	Savannah/ crops mosaic	Water	Wetland	Wooded savannah	
Continuous Built	15	2	0	9	0	0	0	2	1	0	51.7
Crops, pastures, grassland and young fallow	0	6	0	2	1	4	9	3	3	0	21.4
Natural grassland	0	0	5	0	0	0	0	2	2	2	45.5
Discontinuous built, bare soil	0	1	0	15	0	0	0	1	2	0	78.9
Woodland	0	2	4	0	8	6	0	1	0	5	30.8
Savannah, bushland	0	1	0	1	0	0	1	0	0	0	0.0
Savannah/crops mosaic	0	0	0	0	0	0	1	0	0	0	100.0
Water	0	0	0	3	0	0	0	5	0	0	62.5
Wetland	0	0	0	0	2	0	0	1	5	0	62.5
Wooded savannah	0	2	5	0	4	3	4	0	1	3	13.6
Burned area	0	1	1	0	0	2	0	0	1	5	
Producer's accuracy (%)	100.0	40.0	33.3	50.0	53.3	0.0	6.7	33.3	33.3	20.0	
Overall accuracy: 38.2%; Kappa statistic: 0.316											

Table 2

Confusion matrix for the classification of the 2002 image

Table 3

Confusion matrix for the classification of the 2013 image