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Multi-Scale, Multi-Temporal Vegetation Mapping and Assessment of Ecosystem Degradation at Gashaka Gumti National Park (Nigeria)

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Abstract: The study aimed at assessing vegetation cover and status of Gashaka Gumti, Nigeria's largest national park. For this, a traditional pixel-based maximum likelihood classification of a Landsat-7 scene, recorded in December 2000, was carried out. Because simultaneous ground truthing had not been possible, and because of the dynamic nature of the given habitats, different reference data were used to allocate training areas, specify ecological conditions and assess classification accuracy. These included initial unsupervised classifications of multi-temporal images, inter-seasonal field observations and visual interpretations of newly acquired Quickbird mini scenes. The latter served as spatial and temporal scaling tools and were found to be particularly valuable to detect anthropogenic interference. The data reveal that, during most of the dry season, green vegetation is absent in up to one fifth of the park or in about half of the environments of settlement enclaves. This is largely due to human activities such as cattle grazing and burning. Environmental degradation is already detectable in the older imagery, and clearly confirmed as a trend in the newer scenes. The results of this study are suitable to stimulate enhanced and targeted protection measures.

Key words: Landsat, maximum likelihood classification, protected area management, Quickbird, vegetation dynamics

INTRODUCTION

Land cover assessment is a major prerequisite for the monitoring of ecosystem degradation, which proceeds at alarming rates in many regions of Africa, including some protected areas. Regardless of the continuous development and testing of new technologies and techniques by the remote sensing community, there are still extensive areas on the continent with insufficiently mapped land and vegetation cover. The main focus in the last decades has been on sub-continental vegetation monitoring with multi-temporal coarse resolution imagery such as Advanced Very High Resolution Radiometer (AVHRR) scenes. Time-series which also often include Normalized Difference Vegetation Index (NDVI) images for biomass estimates have for instance been a key tool in desertification studies of the Sahel region (Anyamba and Tucker, 2005). Another emphasis has been on forest cover and deforestation assessment in tropical rainforests, where AVHRR images were often combined with radar data (Laporte *et al*., 1995, 1998; Mayaux *et al*., 1999, 2000; Bwangoy-Bankanza *et al*., 2010). Vegetation dynamics at forest-savanna boundaries have likewise been investigated at similarly small scales (Achard and Blasco, 1990; Mitchard *et al*., 2009). However, studies on regional level remain comparatively few (Ngamabou, 2006). One of the reasons is that many field researchers lack suitable medium-resolution data, especially where pixel sizes equivalent to 1 ha and more are already considered too coarse to depict the actual land cover patterns. At the same time, hyperspatial material from commercial sources is offering new perspectives for large-scale studies and their results may partly be extrapolated to wider areas (Aplin, 2004; Wulder *et al*., 2004).

Mapping present-day vegetation patterns constitutes a key factor in promoting environmental research, conservation initiatives and general management of Gashaka Gumti National Park (GGNP). Remote sensing and digital image processing have proven to be highly suitable and powerful tools for this purpose (Kerr and Ostrovsky, 2003). Considering that the park comprises hardly accessible terrain and a broad land cover spectrum, semi-automatic mapping techniques such as multi-spectral image classifications can be particularly useful. There have been previous efforts to achieve this, and the latest vegetation map of the area derived from SPOT XS,

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Landsat TM, ERS-1-SAR and JERS-1-SAR material dates back to 1995. It contains four categories of dominantly trees, undisturbed forest, montane forest and montane grassland, but also errors and inaccuracies, especially with respect to the actual altitudinal positions of the montane vegetation. Newer land cover maps have recently been produced within other geopolitical zones of the country (Salami and Balogun, 2006). Moreover, local change detection studies are becoming increasingly popular in Nigeria but, unfortunately, are not always taking seasonal or radiometric influences into account (Ati *et al*., 2008; Idoko and Bisong, 2010).

For the recent mapping of GGNP, a Landsat-7 (LS7) Enhanced Thematic Mapper (ETM+) image from early December 2000 provided the baseline data. Since the Scan Line Corrector (SLC) of LS7 malfunctioned in 2003, and the area of interest is outside of the reach of ground receiving stations for LS5 TM data, no other Landsat product could be obtained for a current date. Most of the systems generating similar data over Africa suffer from the handicap of small image sizes, with the exception of NigeriaSat1, which has been used in some comparative studies (Salami and Balogun, 2006), but the authors failed to get any response to image enquiries from the Nigerian Space Research and Development Agency. As an alternative to large area, medium-resolution coverage, hyperspatial Quickbird (QB) sub-scenes were acquired, which offer the opportunity to assess vegetation formations at great spatial detail. Newer methodological approaches such as object-based classifications and fusion algorithms have been successfully tested in heterogenous landscapes with such high-resolution data. However, they are often not yet implemented in conventional mapping projects (Moat *et al*., 2008), especially since the imagery is uneconomical for large area studies (Sawaya, 2003). Consequently, there is a continuous need to apply standardized methods such as pixel-based unsupervised and supervised classifications, particularly in hitherto inaccurately mapped, biologically diverse areas (Saatchi *et al*., 1999; Salami, 2000). The aim of this research was to extract maximum thematic information from a varety of data sources on the existing vegetation types and their dynamics especially in the last decade. Vegetation change is seen as an important indicator of ecological degradation, and a major concern has been the state of the ecosystems around settlement enclaves in the park, which experience serious environmental stressors. This is because activities such as farming, regular burning, grazing and excessive fuelwood collection are carried out partly legally inside and illegally outside the enclave boundaries. The acquired QB images are predestined to facilitate the comparisons of field data with the LS image contents across the existing spatial and temporal scale gaps (Goward *et al*., 2003; Kerr and Ostrovsky, 2003), thus aiding in the production of a current land cover map of the park, and at the same time shedding light on ongoing anthropogenic disturbance. The approach emphasizes the practical value of qualitative image analysis when possibilities for quantitative change detection are restricted.

MATERIALS AND METHODS

Study area: GGNP is, at about 6,670 km^2, the largest protected area within Nigeria. It is located in Adamawa and Taraba states along the Eastern Border Highlands on the Cameroon volcanic line (Udo, 1970) (06º58′-08º05′ N and 11º10′ N-12º13′ E; Fig. 1). GGNP marks the northernmost extension of Africa's Gulf of Guinea forests, and is considered a hotspot of faunal and floral diversity (Oates *et al*., 2004). It is one of West Africa's prime primate habitats especially renowned for harbouring the largest surviving population of the rare Nigerian-Cameroonian chimpanzee (*Pan troglodytes vellerosus* aka *ellioti*) (Oates *et al*., 2008; Morgan *et al*., 2011) as well as other species of diurnal primates such as olive baboon, putty-nosed guenon, mona monkey, black-and-white colobus, tantalus monkey, and patas monkey (Sommer and Ross, 2011a, b). The park has a multitude of crucial ecological functions by encompassing most of the catchment of the Taraba river, largest tributary to the Benue. It is divided into the undulating Gumti sector in the north and the hilly to mountainous Gashaka sector in the south, where elevations rise to 2,419 m asl at Gangirwal (also called Chappal Wade), Nigeria's highest peak. Located in Köppen's Aw (tropical wet and dry) climatic zone, Kwano field station (583 m asl, 7º19′ N, 11º35′ E) has an average total annual precipitation of 1,973 mm (period: 2001-2002/2004-2008), with interannual maxima in 2004 (2,337 mm) and minima in 2001 (1,683 mm). About 95% of the yearly rainfall is recorded between April and October, with highest monthly means in September (332 mm). The influence of Sahara trade winds (Harmattan) accounts for 0 mm of rainfall between December and January (Sommer and Ross, 2011a, b). Significantly higher precipitation falls along the southeastern escarpments and allows lush rainforests to thrive albeit southern Guinea savanna is considered to be the zonal climax (Keay, 1959). The steep terrain is not only responsible for orographically induced rainfall, but also the occurrence of sub-montane and montane vegetation types, contributing to a highly complex forest-savanna mosaic. The diverse habitats shelter carnivores such as civets, golden cat and leopard, ungulates such as buffalo, bushbuck, duiker, waterbuck, hartebeest, red river hog and one of the last remaining populations of giant forest hog. Aquatic and semi-aquatic fauna comprise rare fresh-water fish, otters, crocodiles

Fig. 1: Location of Gashaka Gumti National Park

Fig. 2: Rainy season scenes of forest-woodland mosaic near Kwano (above) and secondary shrub- and grassland in the highland enclave Hendu (below)

and hippopotami. The park has also been designated an "important bird area" with more than 500 avian species. In the Northern plains around Gumti, savanna animals such as roan antelope and giant eland are present, but elephants, hyenas, wild dogs and lions went extinct in the last decade.

Vegetation patterns have been strongly influenced by increasing human impact since historic times. Deforestation and dry season burning are believed to have turned considerable parts of semi-deciduous forests into pyrophytic woodlands and led to the prevalence of extensive grasslands at the expense of montane forests (Louppe *et al*., 1995; Chapman *et al*., 2004; Fig. 2). GGNP is located at the eastern edge of what is referred to as the Nigerian Middle Belt, an ethnocultural transition zone where Hausa-Fulani from the Muslim north mix with smaller tribes with Christian and traditionalist backgrounds. The cattle-rearing Fulani, which are in parts maintaining a semi-nomadic livestyle, constitute the ethnic group with the most severe impact on the park's ecosystems. They started to expand their sphere of activities during the 19th century Jihad, that was coupled with slave raids among the minority peoples which initially led to a decrease in population density in the area. However, Fulani influx has continued until present times, especially to the Tsetse free highlands, but also to other areas, after realizing that the threat of Trypanosomiasis in the Guinea savanna zone had formerly been overrated. Since its creation, GGNP has been harbouring several settlement and grazing enclaves, with an estimated overall human population of 5,000 and about 10,000 cattle. Thus, legal and illegal human activities within the park such as grazing, burning, cutting of trees, and poaching, together with the poisoning of carnivores to protect cattle, have aways remained an issue, sometimes resulting in violent conflicts with national park staff. This does not only create numerous conservation challenges regarding wildlife (Adanu *et al*., 2011), but puts increasing pressure on all natural resources especially in the vicinity of the enclaves (for more detailed information, e.g. on physical setting, animal species, and human-wildlife conflicts, Bawden and Tuley, 1966; Bennett and Ross, 2011; Chapman *et al*., 2004; Dunn, 1998, 1999; Gumnior, 2009; Sommer and Ross, 2011a, b).

Fieldwork: During a previous mapping project, unsupervised classifications of the available LS imagery had been carried out, distinguishing 10 spectral classes representing different physiognomic vegetation types. They had been followed by basic ground checks in and outside the park (January-March 2008), using a preferential sampling scheme because of limited accessibility. In the recent project, ground truthing was extended to three separate campaigns that also looked at seasonal variations, with a stratified random sampling design implemented on smaller areas of special interest covered by the newly obtained QB imagery. A total of 42 plots of 30x30 m was sampled, ensuring that all signatures from former unsupervised classifications were visited at least twice in each focus area. Encompassing all major habitats, particularly within the ecologically most diverse Southern sector, these areas include:

- Gashaka, a village that is the main gateway to the park, hosting both ranger station and research facilities
- Kwano, site of a field station run by the Gashaka Primate Project from which most biodiversity research is carried out (Fig. 2)
- Gumti, a lowland enclave within the park in the transition zone to the more uniform tree and grass savannas of the Northern sector
- Selbe/Hendu, a highland enclave that includes settlements and grazing areas in a sub-montane to montane setting (Fig. 2)
- Gangirwal, highest peak within the park and in West Africa

Data collection focussed on diverse ecological parameters such as relief, geology, hydrology, the presence of woody, herbaceous and grassy plants, dominant species, number and heights of strata, canopy cover, and human impact. In addition to GPS waypoints, 12 photographs per plot per season were taken from all four corners, featuring horizontal views as well as vertical views of canopy and ground. The first campaigns took place in early December 2009 and late January/early February 2010, correlating with the months in which the two previously classified Landsat scenes had been recorded. A third campaign in August 2010 provided evidence of the situation in the rainy season, such as temporary recovery from earlier burning.

It is known that forest-savanna mosaics in Africa are comparable to rainforest in species richness (Purvis, 2005), and the floristic associations of the area of interest have never been mapped conventionally (Bawden and Tuley, 1966). Even if mapping at community level may be possible with Landsat (Xie *et al*., 2008), the information on predominance and composition of taxa obtained during ground truthing has not been sufficient for that purpose. Attributes predominant on the ground may not all be equally distinguishable on the imagery and vice versa, leading to some divergence in the nomenclature of preliminary field and final mapping classes (see section 4). During ground truthing, physiognomic units and field parameters were identified as follows:

- **High forest (12 plots):** Partly with open canopy, often extending from riverine forest, Canopy Coverage (CC) 70-85%, Tree Height (TH) 20-30 m, average Circumference at Breast Height (CBH) 135 cm, number of strata excluding ground cover (NS) 2-3, average number of trees per test plot (NT) 30, Dominant Species (DS) e.g., *Brachystegia eurycoma*.
- **Forest thicket (2 plots):** Often secondary, CC>85%, TH 8-12 m, CBH 30 and 70 cm respectively, NS 2-3, NT 12 and 50 respectively (in the first case, most tree trunks were below 30 cm CBH and therefore not counted), with lower strata being dominant, DS e.g., *Cola gigantea*.
- **Higher density woodland (4 plots):** CC mainly 25-50% (once 50-70%), TH 12-20 m, CBH 100 cm, NS 1-2, NT 30, DS e.g., *Uapaca togoensis*, with grassy ground cover (species see below).
- **Lower density woodland (9 plots):** CC 25-50%, TH 8-12 m, CBH 78 cm, NS 1-2, NT 23, DS e.g., *Crossopteryx febrifuga* and *Hymenocardia acida*; CC of some plots <25%, with higher numbers of (significantly taller) trees and DS *Uapaca togoensis*, with grassy ground cover (species see below).
- **Tree and shrub savanna/Montane shrub- and grassland (7 plots):** CC<25%, NT 16, TH 4-8 m, species e.g., *Crossopteryx febrifuga* and

Table 1: Data set overview

Sensor type	Image info	Location/image size/pixel size	Spectral bands	Source	Major analyses
Landsat Thematic Mapper (TM)	Path 186 Row 55 Date: 02 Feb1988	covering approx. 9/10 of park 183x183 km (original) 30x30 m	Blue Green Red NIR SWIR TIR	University of Maryland Global Land Cover Facility (http://glcf.umiacs.umd.edu)	Unsupervised and supervised classifications (ISODATA and Maximum Likelihood Algorithms)
Landsat Enhanced Thematic Mapper (ETM+)	Path 186 Row 55 Date: 03 Dec2000	covering approx. 9/10 of park 183x183 km (original) 28x28 m			
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	4 scenes from archives Dates: 11Oct2004 04Dec2006	W/SW of park 60x60 km (original) 15x15 m/ 30x30 m	VNIR SWIR TIR	U. S. Geological. Survey(www.glovis. usgs.gov)	Visual comparisons
	4 scenes from archives Dates: 21Nov2004 09Feb2005	Center/SE of park 60x60 km (original) 15x15 m/ 30x30 m			
SIR-C (space shuttle)	1^{o} lat-long tile Date: 02/2000	110x110 km (Original) 90x90 m	C, X	University of Maryland Global Land Cover Facility (http://glcf. umiacs.umd.edu)	Extraction of altitudinal zones for derivative maps of vegetation associations
Quickbird	acquired on request Date: 09Jan2010	Kwano 10x10 km 0.65x0.65 m	Blue Green Red	Fugro Maps, U.A.E. (Regional Digital Globe Distributor) (www.fugromaps.com)	Visual interpretations and definition of training areas for the supervised classification
	acquired on request Date: 27Jan2010	Gashaka 7x13 km 0.65x0.65 m	Blue Green Red NIR		
	from archive Date: 04Feb2008	Gumti 5x5 km 0.65x0.65 m	Green Red NIR		
	from archive Date: 04Feb2008	Selbe/Hendu 3.5x7 km 0 0.65x0.65 m	Green Red NIR		
	from archive Date: 04Feb2008	Gangirwal 5.5x11.5 km 0.65x0.65 m	Blue Green Red		
Landsat Enhanced Thematic Mapper (ETM+)	Path 186 Row 55 Date: 14Feb2010 *SLC-off*	covering approx. 9/10 of park 183x183 km (original) 28x28 m	Blue Green Red NIR SWIR TIR	U. S. Geological. Survey (www.glovis. usgs.gov)	Visual validation of observed changes

Hymenocardia acida; grasses dominant, e.g., *Andropogon tectorum*, *Imperata cylindrica*, Montane environment: e.g., *Combretum* sp., *Ficus mucoso*, *Parinari excelsa*, with grassy ground cover (species).

- **(Mainly) Montane grassland with scattered trees and shrubs (8 plots including 2 which are lowland varieties in waterlogged places):** largely equivalent to areas with sparse to no vegetation in the dry season. NT$\leq$5, DS grasses, e.g., *Andropogon tectorum*, *Pennisetum purpureum* (lowlands), *Hyparrhenia spp.*, *Imperata cylindrica* (highlands), herbs such as *Sesbania sesban*.

Image analysis: All available satellite scenes are listed in Table 1, together with the most relevant digital processing techniques carried out between 2008 and 2011. Radiometric and geometric corrections had already been implemented by the image distributors, with a geometric accuracy of 14 m in case of the QB imagery. ERDAS Imagine 9.0 was used for all subsequent analyses and Arc View GIS Version 3.1 for final map productions. After the earlier unsupervised classifications of the LS imagery during which the ISODATA clustering algorithm had been applied, eight ASTER scenes from 2004-2006 had been ordered for visual comparisons and productions of NDVI/NDVI difference images. They offered only a

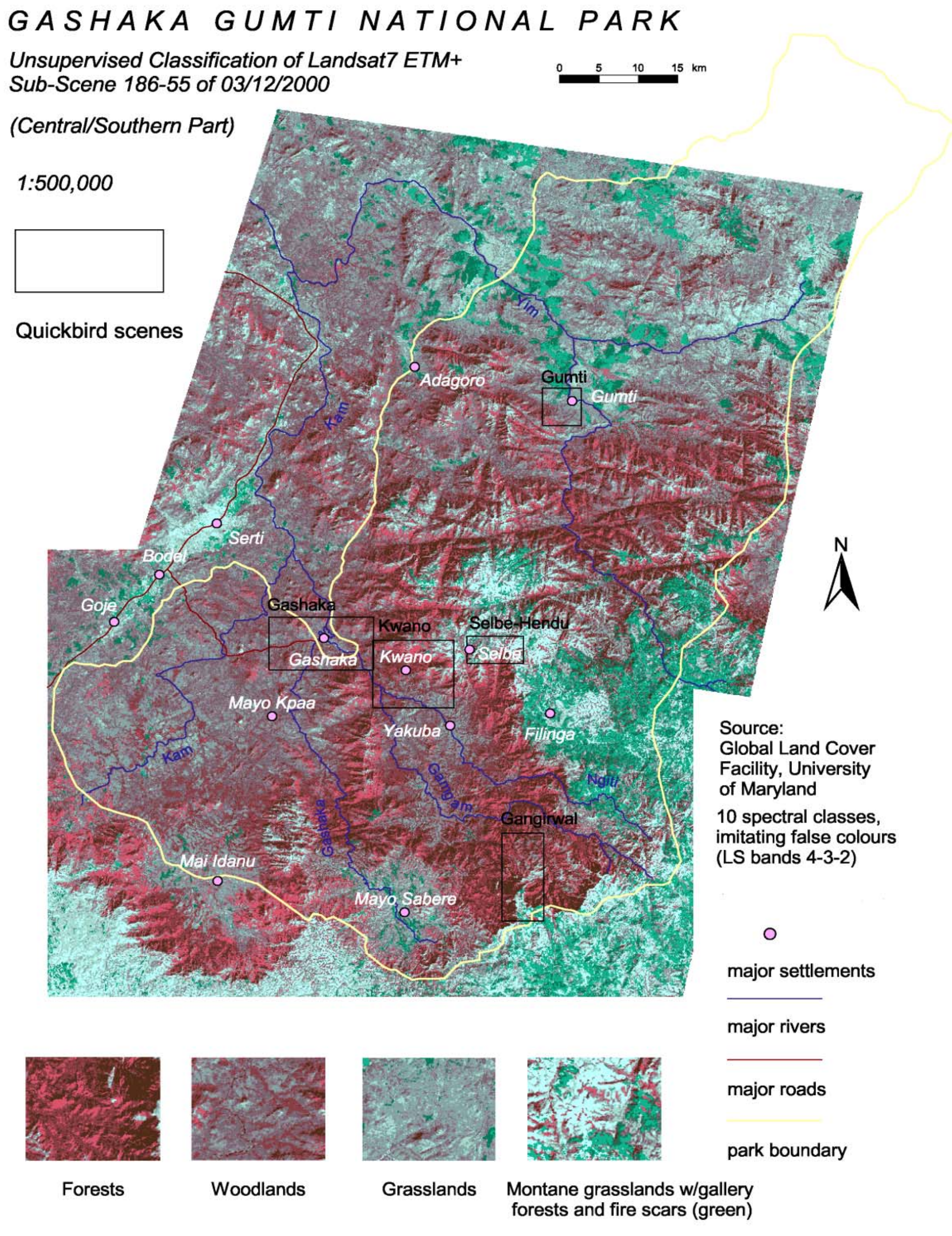


Fig. 3: Unsupervised classification of LS7 ETM+ scene 186-55 of Dec 2000 featuring principal land cover categories and Quickbird coverage of areas of special interest

few useful insights because of the wide spectrum of recording dates and atmospheric conditions. The five QB mini scenes for the recent mapping project were obtained via data acquisition requests and from the archives, with the main purpose of linking the spectral and spatial information of the LS7 scene of 2000 with the situation on the ground in 2010 (and 2008). Figure 3 details their location in relation to the unsupervised classification of the LS7 scene (the legend highlights only the major land cover categories, for further class specifications, Fig. 6). After comparing the field data with the inherent spectral and structural information in the hyperspatial imagery, training areas for the supervised classification were located on the QB scenes and cross-checked with the

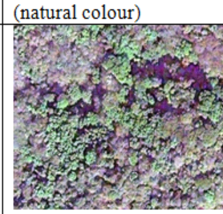
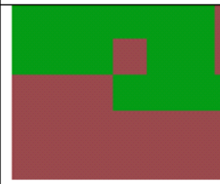
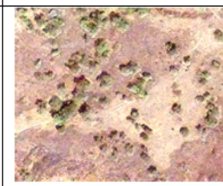
Class statistics (total area/percentages referring to LS-covered part of national park only)	LS7 ETM+ (classified)	Quickbird (natural colour)
1) Rainforest, *7 training areas (583 pixel counts, shown in dark green in the classified image);* total area 1340.5 km² (22.3 %), *together with* 2) Rainforest, drier sub-type *6 training areas (211 pixel counts, green);* total area 696.4 km² (11.6 %)		
3) Savanna Woodland, denser sub-type, *7 training areas (229 pixel counts, maroon);* total area 968.9 km² (16.1 %), *together with rainforest, drier sub-type (class 2, darker colour)*		
4) Savanna Woodland, moister sub-type, *6 training areas (459 pixel counts, brown);* total area 591.3 km² (9.9 %), *together with* 5) Savanna Woodland, drier sub-type, *7 training areas (271 pixel counts, yellow);* total area 438.8 km² (6.3 %)		
6) Shrub- and Grassland, *5 training areas (262 pixel counts, pink);* total area 775.6 km² (12.9 %), *together with* 7) (Montane) Grassland (sparse to no vegetation incl. fire scars), *4 training areas (566 pixel counts, light beige);* total area 1192.2 km² (19.8 %)		

Fig. 4: Land cover types identified in the supervised classification of LS7 ETM+ scene 186-55 of Dec 2000 including class statistics and appearance on imagery (approx. 1 : 6,750)

original LS7 scene, to exclude, for example, fire scars or former forests cleared in the interim. It was already noticed in the process that changes within the three major vegetation categories, e.g. from one woodland class to the other, have been common within the overall period covered by the data, making it difficult to find a larger number of areas for signature extraction. Fire scars, characterized by peaks in LS bands 6 and 7, would later be adopted from the unsupervised classification (Fig. 6) as no correlation with other material could be used.

Semi-automatic classifications of the QB scenes were not attempted, mainly because single pixels are only partially characteristic for classes on high-resolution images and intra-class spectral variability is high (Yu *et al*., 2006; Perea *et al*., 2009). The material was also considered to be too fragmented for a comparative object-based classification or image fusion approaches. Instead, a traditional per-pixel classification was carried out for the LS7 image with ERDAS' well-established maximum likelihood algorithm. With a priori knowledge such as the interpretations of the unsupervised classifications of both LS scenes, terrain information in form of a Digital Elevation Matrix of the whole park and Triangulated Irregular Networks for the study areas, NDVI images and others, training areas could all be taken from the QB images, leaving the test plot data for final accuracy assessment. The number of reference points had been increased to 158 during fieldwork, by recording GPS coordinates in the surroundings of the sample plots. Post-classification measures also included 3x3 low-pass spatial filtering to reduce salt-and-pepper noise, and a final verification of the observed changes evident in the multi-temporal imagery, and the related differences in the unsupervised and supervised classifications. This was done by visual comparison of the results with a current LS7 scene recorded in early March 2010 in SLC-off mode.

RESULTS

For the supervised classification, seven vegetation classes have been distinguished. Statistics and distributions are shown in Fig. 4, Table 2 and Fig. 5 and the average spectral profiles across all bands in Fig. 6. The classes comprise moist and dry semi-evergreen rainforests (34% of the park area covered by the LS image), denser, moister and drier sub-types of savanna woodland (32%), shrub- and grasslands (13%), and

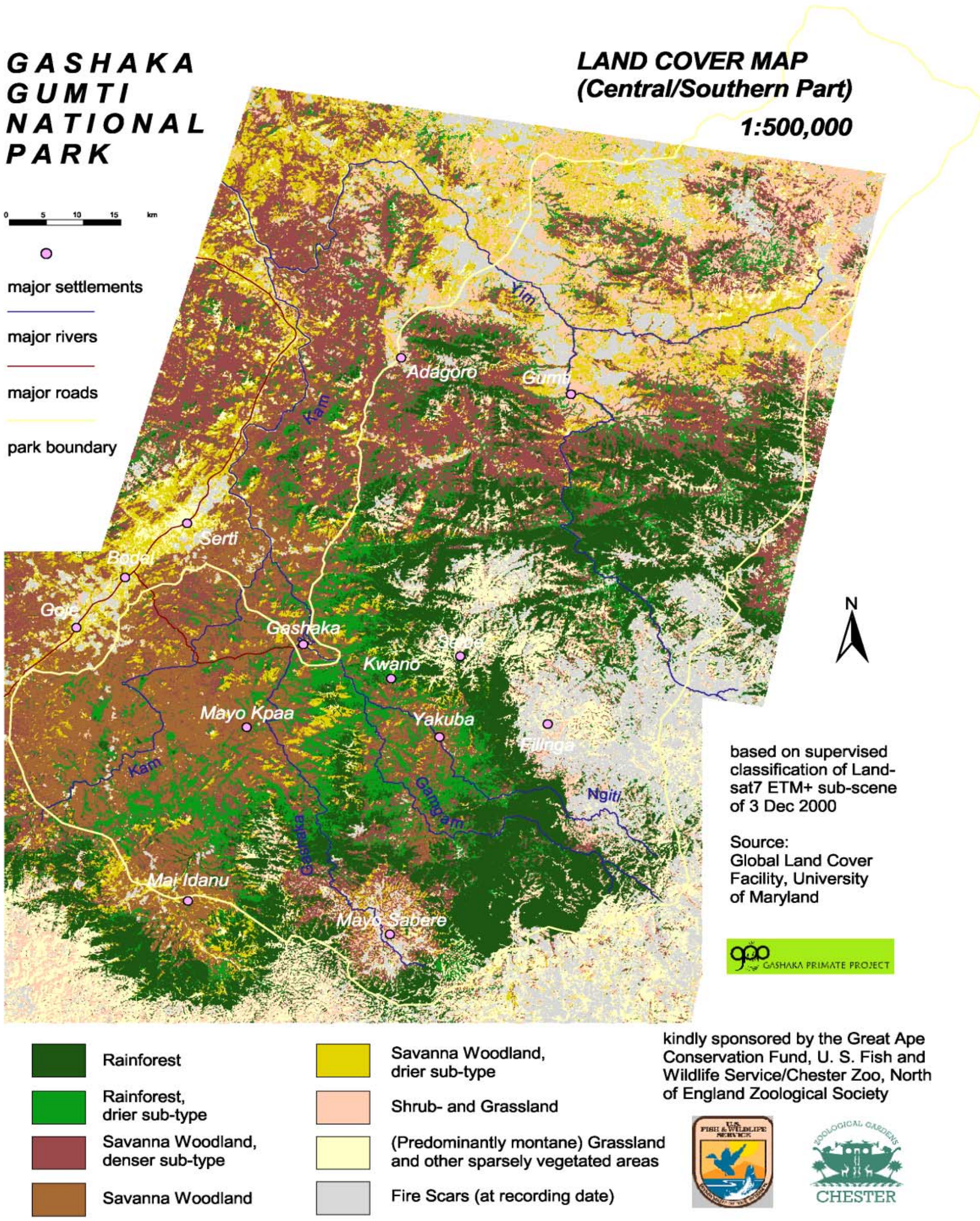


Fig. 5: New/refined land cover map of GGNP, based on supervised classification of LS7 ETM+ scene 186-55 of Dec 2000

predominantly montane grasslands with sparse to no vegetation (20%). After calculating the confusion matrix for 158 sample points, a visual comparison of their locations on LS and QB imagery was carried out. In 17% of the independent test data, it was obvious that vegetation changes had occurred between 2000 and 2010, hence the provision of a second confusion matrix for the unaffected points only (Table 2). The most prominent changes were from forest to woodland (10% of all sample points). Furthermore, twice as many denser woodland varieties had developed into more open ones (4%) than vice versa (2%). The remainder was shrub- and grassland that had been burnt at the recording time of the LS scene (1%). The overall accuracy of the map lies at 74% (Kappa index = 0.69), but would be significantly increased (89%; Kappa 0.87) without the change-related confusion (Table 2). Producer and consumer errors are highest where spectral and morphological characteristics of vegetation classes are particularly variable subject to seasonal and/or climatic influences, and a dynamic

Table 2: Confusion maxtrix and accuracies of the supervised classification of LS7 ETM+ scene 186-55 of Dec 2000 (italics: error and change, bold: error only)

Reference Classified	Rain forest	Rain forest, dry type	Woodland, dense type	Woodland	Woodland, dry type	Shrub- and grassland	Sparsely vegetated	Total	User's accuracy (%)
Rain forest	29	0	4	0	0	0	0	33	87.8
	29	**0**	**0**	**0**	**0**	**0**	**0**	**29**	**100**
Rain forest,	3	16	8	4	0	0	0	31	51.6
dry type	**0**	**16**	**0**	**0**	**0**	**0**	**0**	**16**	**100**
Woodland,	0	4	8	4	1	0	0	17	47.1
dense type	**0**	**4**	**8**	**0**	**0**	**0**	**0**	**12**	**66.7**
Woodland	0	0	0	27	0	0	0	27	100
	0	**0**	**0**	**27**	**0**	**0**	**0**	**27**	**100**
Woodland,	0	0	0	0	2	5	0	7	28.6
dry type	**0**	**0**	**0**	**0**	**2**	**3**	**0**	**5**	**40**
Shrub- and	0	0	0	0	4	20	0	24	83.3
grassland	**0**	**0**	**0**	**0**	**4**	**20**	**0**	**24**	**83.3**
Sparsely	0	0	0	0	0	3	15	18	79
vegetated	**0**	**0**	**0**	**0**	**0**	**0**	**15**	**15**	**83.3**
Total	32	20	20	35	7	29	15	158	Overall accuracy (%)
	29	**20**	**8**	**27**	**6**	**23**	**15**	**131**	74.1 **89.3**
Producer's	90.6	80	40	77.1	28.6	69	100		Kappa coefficient:
accuracy (%)	**100**	**80**	**100**	**100**	**33.3**	**76.9**	**100**		0.69 **0.87**

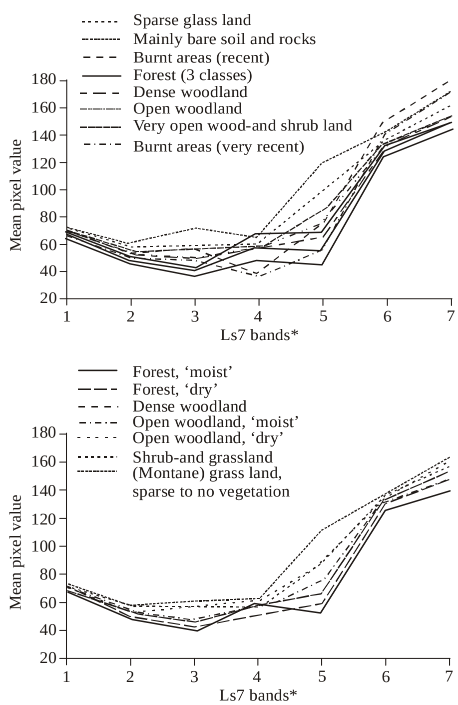


Fig. 6: Spectral profiles of land cover classes in the unsupervised and supervised classifications of LS7 ETM+ scene 186-55 of Dec 2000
*Ls7 band 1 = 0.45-0.52 μm (Blue), 2 = 0.52-0.60 μm (Green), 3 = 0.63-0.69 μm (Red), 4 = 0.76-0.90 μm (NIR), 5 = 1.55-1.75 μm (SWIR), 6 = 10.42-12.50 μm (TIR), 7 = 2.08-2.35 μm (SWIR)

equilibrium with neighbouring formations can be presupposed, e.g., in the case of the dense sub-type of savanna woodland. A lower moisture status of woodlands, partly also of forests, as perceived in the QB imagery, was not necessarily evident on the ground, resulting in very low producer's and user's accuracies of 33-40%. With only 4% of all reference data classified as such, however, the effect on overall accuracy was minor. Even if the systematic field evaluation of the results is essential, details of the standardized accuracy assessment should not be overrated, as the 10-year time gap was willingly taken into account.

DISCUSSION

After ground truthing and comparisons of all imagery, the general adequacy of the unsupervised classification of the LS7 scene has been evaluated and confirmed, as far as a snapshot of the vegetation in late 2000 is intended (Fig. 3 and 6). Two main thematic weaknesses were detected, the first of which are errors of commission in the forest class, as compared to the LS4 image of February 1988. But such errors might have as likely occurred in the dense woodland class of the latter, which is often associated with forest fringes. This is owing to seasonal effects such as the loss of leaves (Bwangoy-Bankanza *et al*., 2010), gradual drying up of forest edges, and partly also increasing accumulation of dust. The second major error is the categorization of some mixed pixels as 'very open woodland' that proved to be an inadequate class name. This is because the spectral characteristics of open woodland plots are completely dominated by the condition of the ground cover and cannot be characterized in terms of tree or canopy density. Consequently, this class no longer exists in the supervised approach (Fig. 5). Here, the definition of training areas and land cover types was mainly affected by the following characteristics of the principal three vegetation units that became apparent during data comparisons:

Fig. 7: Signs of burning, grazing and fuelwood extraction around Gumti and Hendu enclaves (Feb 2010)

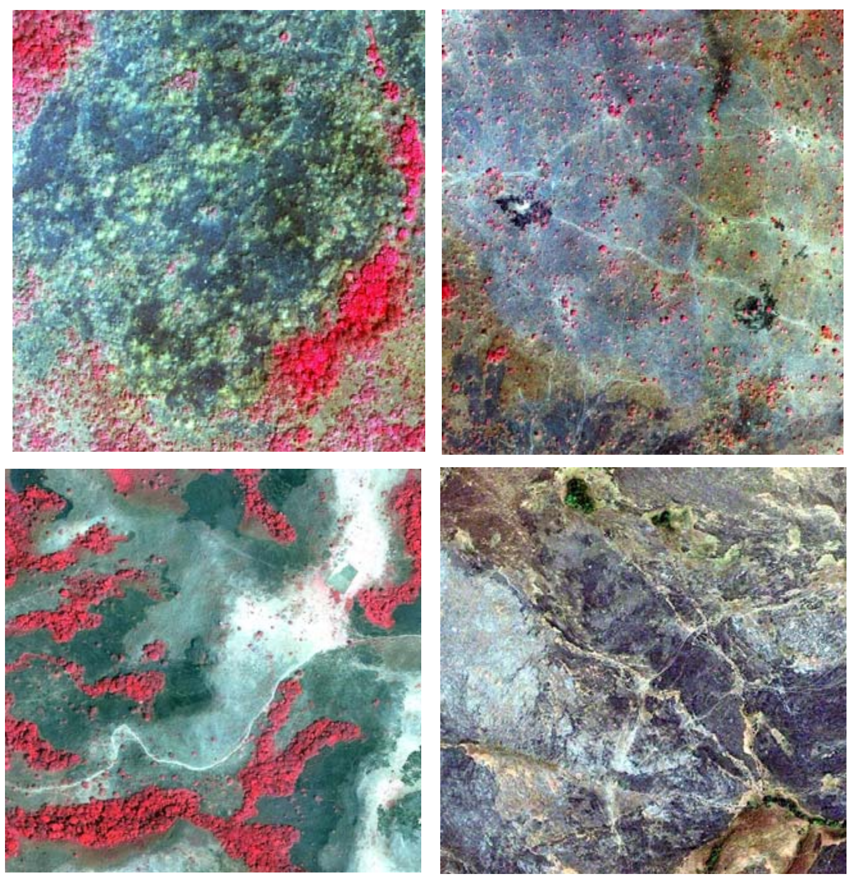


Fig. 8: Signs of vegetation and soil degradation as a result of zoo-anthropogenic activities around Gumti, Selbe and Gangirwal (QB imagery, three false and one natural colour composites, approx. 1 : 5,000)

Forests: Local spectral variation is caused by crown textures, gaps and associated shadows, as frequent windthrow and subsequent rejuvenation occur. This is reflected by the existence of three forest classes in the ISODATA clustering (Fig. 6). As for the distinction into primary or high forest and secondary forest thickets in the field, the QB scene on top of Fig. 4 gives a good account of the heterogenous morphology of the rainforest canopy. Forest thickets devoid of large crown trees can be detected due to shadow effects, even though this was not really the case at the test sites, perhaps due to saturation in greenness (Skole and Qi, 2001), but more likely because of the small number of forest thicket plots. QB images reveal that areas of the size of the sample plots are often dominated by no more than four tree crowns. Wherever larger specimen occur, there tends to be a higher overall reflectance in near infrared (NIR) as well. Vegetation vigour is obviously also increased in riverine forests and generally in areas with a higher stream density such as Kwano. Both QB and LS imagery allow to distinguish a moister from a drier forest type, regardless of the fact that all identified tree species temporarily lose their leaves. The greenness of forests is reduced in the drier varieties and especially towards the end of the dry season (Justice *et al*., 1997; Franklin and Wulder, 2002), leading to occasional mixed pixels. Those can hence be detected by using seasonality criteria, being largely identical with those forests (mis-) classified as dense woodlands in the unsupervised classification of the LS4 image of February 1988. During ground checks, the dry sub-type was only identified in one particular focus area, Gashaka, where it has a partly open canopy and the tendency to contain only two strata. Accuracy improvement would thus require visiting other occurrences of the respective mapping unit.

Woodlands: The savanna woodlands constitute the dominant habitat in the lowlands. They have canopy coverages between 25 and 50% and consist of often pyrophytic, deciduous species with xeromorphic properties such as matte leaf surfaces. These factors all diminish greenness and reflection in the NIR versus red, respectively. On the other hand, particularly after burning, woodlands may undergo vegetation flushes and the subsequent spectral response may be similar to that of forests. They can still be distinguished structurally because crown diameters are usually smaller than those of forest trees. As tree and shrub densities vary significantly within small spatial and temporal intervals, boundaries between the different woodland varieties are more or less random. Some communities may be subject to unimpeded succession when grazing and burning are reduced for a number of years, or natural rejuvenation and a subsequently higher density may follow the death of older plant specimen. In other places, constant extraction of fuelwood is taking place without a possibility of regrowth. With its highly mosaicked and dynamic character, the whole vegetation unit is often regarded as a classic disequilibrium system.

In the lower-density woodlands and especially the tree and shrub savannas lacking contiguous canopies, a mixture of tree crowns, shadows, and background vegetation produces a non-distinctive signal in the LS images. This can lead to inter-class spectral confusion, especially if recording times are distributed over different seasons with varying phenological conditions (Gong *et al*., 1992; Justice *et al*., 1997; Vagen, 2006; Chastain, 2008). As the dry season advances, ground cover reflectance becomes dominant, leading to a prevalence of either green, dry or burnt grasses mixed with similarly variable percentages of green, dry or burnt foliage. Although mixed pixels no longer complicate the interpretation at sub-meter resolution, the temporary nature of the recorded parameters would have required real-time ground checks for precise correlations with the QB image contents, especially of recently burnt areas. The varying impact of fire and prevalence of diverse successive stages in the woodland-savanna ecotones caused a number of contradictions between the unsupervised and supervised classification in terms of different woodland varieties. Correlations between sub-classes on LS and QB imagery led to a clear distinction into moister and drier woodland varieties. The first has slightly greener ground cover and/or darker soils with higher water holding capacities and residual moisture until the late dry season. The second one has a higher percentage of dry bare surfaces, with one of its occurrences on South-facing hills of the Gashaka area, where soils tend to be rich in ironstone concretions with an unfavourable pedoclimate. While the tree composition of the two might be identical, the moisture contents of the grasses can differ drastically, or grass may be absent because of overgrazing or burning. As the same distinction could not always be made for the ground data, especially the dry woodland sub-type has a large overlap with neighbouring classes, and is thus not accurately identifiable with the given data and methods. In the unsupervised approaches, it had also partly been misclassified as 'very open woodland'.

Grasslands: More open savanna varieties dominated by shrubs and grasses occur naturally in waterlogged areas. In all other cases they result overwhelmingly or exclusively from zoo-anthropogenic activities. Historical human impact may be underlined by the presence of indicator species (e.g., *Vernonia* sp.), but current

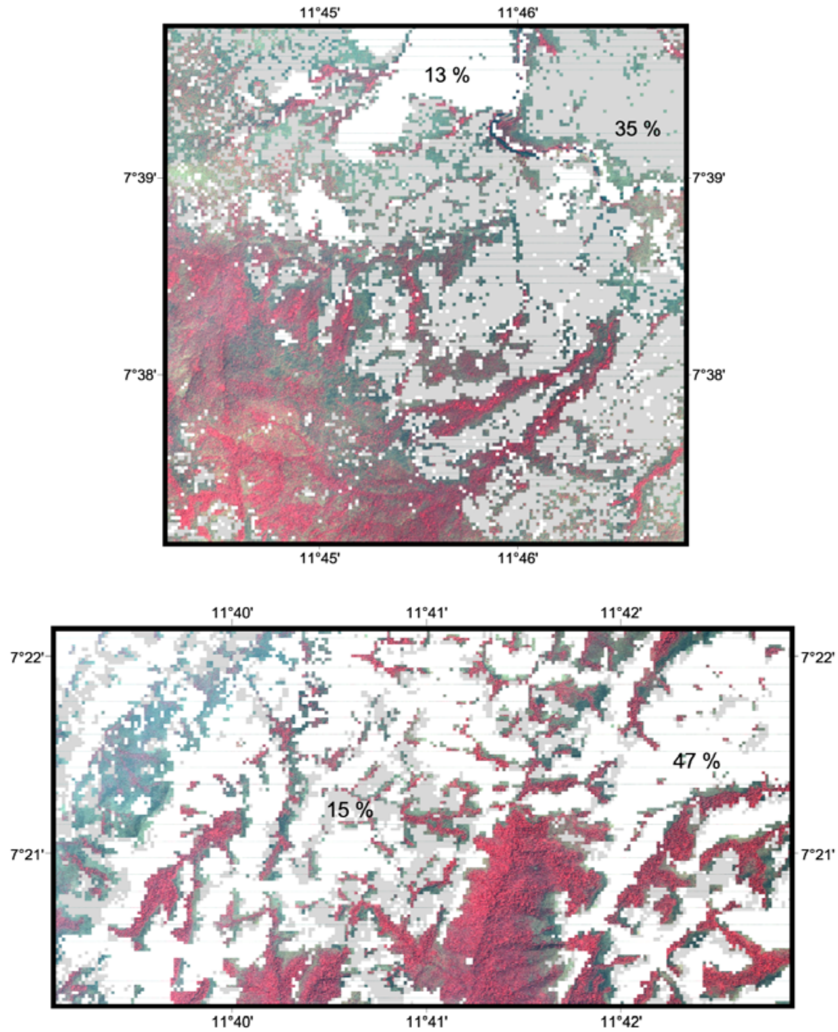


Fig. 9: QB images of Gumti (above) and Selbe/Hendu (below), overlain by those land cover classes pointing at the most serious land degradation (light grey: shrub- and grassland, white: sparsely vegetated areas, with respective percentages, unfiltered, approx. 1 : 50,000)

anthropogenic disturbances are usually immediately evident in the field as all plots showed signs of either regular burning, firewood extraction, heavy grazing and/or trampling. Much of the land is bare in the dry season and bears similar spectral properties to closely built-up rural settlements like Serti (Fig. 3) such as maximum reflectance in LS bands 3 and 5 (Fig. 6). The heavily grazed Poaceae apparently recover during the rainy season (Fig. 2), but tend to reveal damages from overstocking relatively early in the dry season, leaving the soil largely unprotected for several months. This punctual and linear exposure of the topsoil can lead to negative changes in soil parameters relevant for plant growth, before more obvious forms of erosion start to occur. In the montane environment, however, changes in the meso-relief, e.g. in form of terracettes, are already omnipresent, indicating serious problems of soil compaction and loss (Fig. 7 and 8). In the unsupervised classification, montane grasslands had been subdivided into the classes of 'mainly bare soil and rocks' and 'sparse grassland', the second of which correlated strongly with fallow and farmland outside the park (Fig. 6). In the supervised classification, however, which is largely congruent with the QB image contents, one single class with a significant percentage of bare soil or rock predominates, showing a nearly complete agreement with ground observations (Table 2), together with burn scars. When left unfiltered, the land cover map shows slightly more spectral variation, due to local occurrences of fallow and weed plants avoided by cattle. Those forbs, bracken and scrubs represent an initial stage of bush encroachment. Still looking comparatively fresh at the end of the dry season, they were largely confused with woodlands in the unsupervised classification.

Both early and late burning occur in almost all the present ecosystems. Rangers are urged by the park authorities to practice preventive or prescribed burning. Nevertheless, satellite images and field evidence reveal an omnipresence of illegal fires, mostly set to stimulate grass growth for livestock. When the LS7 scene was recorded at the beginning of the dry season in 2000, around 10% of the entire park area had been recently burnt, with strong emphasis on grasslands. The LS4 scene, recorded in the late dry season of 1988, shows evidence of late burning. Practiced in grassland and woodland alike, this affects smaller and more diffusely distributed patches of land, which, however, combine to a similarly large total area. Direct observations confirm that the local people burn vegetation for apparently no reason, as rainforest is also set on fire when passing through. Burning is the major factor that maintains woodlands within the forest-savanna mosaic, preventing recolonization at forest edges (Louppe *et al*., 1995; Bucini and Lambin, 2002). Hot blazes are an additional threat wherever grazing pressure is low and thick, high grasses catch fire. Burning may also have introduced some minor errors in all image classifications wherever it has promoted fresh green growth. For further analysis of burning habits and their effects on land cover, satellite imagery should be analysed over several burning cycles (Roy, 2003). The favourable repetition rates of around 3 days would make NigeriaSat1 a suitable sensor for that purpose.

While the woodland communities are largely subject to quasi natural, subclimactic dynamics, the general results also point at progressive trends between 2000 and 2010. Compared to the current QB imagery, there is more spectral variation in the original LS7 scene, which can only partially be explained with the wider range of wavelengths available. Habitat diversity also appears to be higher in ISODATA clustering, while in the maximum likelihood approach, there is a tendency towards the establishment of a more uniform ecotype, especially in the highlands. There, seemingly intact grass cover identified in the rainy season gives way to multiple signs of temporary and lasting damage, including soil loss, under the increased grazing pressure of the dry season (Fig. 7 and 8). In steep locations inaccessible to cattle, dense (sub-) montane rainforest prevails as the assumed climatic and altitudinal climax. Nevertheless, woody vegetation in general has been reduced, particularly in the vicinity of enclaves, while regeneration of forest thickets is restricted to a few spots. Even in the surroundings of Kwano, dense rainforests alternate with sparsely forested watersheds, where vegetation is prone to wind-driven fires. Although park authorities evicted settlers years or even decades ago, the vegetation cover remains in a state of arrested development. Without pedological or geomorphological surveys, one can merely speculate about the reversibility of the damages to the vegetation cover that also includes the loss of native montane species (Chapman *et al*., 2004). Figure 9 merges the multi-scale, multi-temporal data to visualize and quantify the described phenomena. It reveals that nowadays 48% of the Gumti environment and 63% of the Hendu uplands are covered by sparsely vegetated shrub- and grasslands and predominantly bare throughout the dry season. The general development has been confirmed in a visual comparison with the 2010 LS7 scene in SLC-off mode.

Apart from local human impact, there are of course other possible drivers for vegetation changes such as interannual climatic variations or shifts in the carbon budget. Mitchard *et al*. (2009) are describing forest encroachment as a function of increasing CO_2 concentrations in the atmosphere. A certain variability of rainfall is common in the area and may have influenced greenness in the various images via differences in the duration of each rainy season. But the available figures are not hinting at weather anomalies in any of the years of recording. And as the observed vegetation changes are especially drastic in the surroundings of enclaves, the majority of them is not likely to be climatically induced. For an exact picture of the specific nature and spatial diversity of the potential trend, it is highly advisable to carry out a semi-automatic change detection and/or multi-temporal image classification as soon as new LS material will be available.

CONCLUSION

Landsat has once again been confirmed as an invaluable tool for environmental studies on a variety of scales (Cohen and Goward, 2004). Its potency and versatility is especially related to the positioning of its spectral bands that offer more room for differentiation than the common Green-Red-Infrared combination of SPOT, NigeriaSat1 and others. On a practical level, depicted phenomena can be easily demonstrated to individuals inexperienced in image analysis, such as national park staff, which is an advantage it has over radar. Thus, Landsat is rightly seen as well-suited even for vegetation diversity assessment and particularly in comparison with high-resolution devices such as IKONOS or Quickbird. These can assist either as a means of cover type validation like in the given case, or through additional data fusion or object-based classifications (Goward *et al*., 2003; Sawaya, 2003; Corcoran and Winstanley, 2008; Xie *et al*., 2008; Gibbes *et al*., 2010; Nagendra *et al*., 2010). Comparatively high costs of hyperspatial imagery can be moderated by focussing large-scale monitoring of habitat degradation on limited spaces such as the enclave environments. There, but also in the other areas of special interest covered so far, sensors like QB can provide excellent baseline data for botanical and pedological field studies, *inter al*. Signs of land degradation, such as those visible in Fig. 7 and 8, can be detected even by casual image interpretation and afterwards be specifically targeted by field research.

The severe levels of human impact in GGNP have been known before and after its inception as a protected area, but opportunities to georeference and quantify the threats and damages have been lacking. The recent research had also been designed to familiarize the park's rangers and management staff to various techniques of environmental monitoring, from the use of GPS via visual interpretations of satellite images to encoding of waypoints and digitizing of features, production of maps and management of geodatabases. Immediate steps for improved protection would include the collection of more GPS and field data in relation to the park's enclaves and their integration into the park-GIS. Other endangered habitats with high densities of illegal cattle are found in the Northernmost tip of the park covered by two additional LS scenes and still remain to be analyzed. It is thus hoped that further studies on the status quo of the park's ecosystems can be carried out and that monitoring of areas with critical human impact will continue, eventually triggering more consolidated research and informed protection measures.

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