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Research Article

Parks, people and pixels: evaluating landscape effects of an East African national park on its surroundings

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Abstract

Landscapes surrounding protected areas, while still containing considerable biodiversity, have rapidly growing human populations and associated agricultural development in most of the developing world that tend to isolate them, potentially reducing their conservation value. Using field studies and multi-temporal Landsat imagery, we examine a forest park, Kibale National Park in western Uganda, its changes over time, and related land cover change in the surrounding landscape. We find Kibale has successfully defended its borders and prevents within-park deforestation and other land incursions, and has maintained tree cover throughout the time period of the study. Outside the park there was a significant increase in tea plantations and continued forest fragmentation and wetland loss. The question of whether the park is a conservation success because of the network of forest fragments and wetlands or in spite of them remains unanswered.

Keywords – remote sensing, fragmentation, islandization, parks, Africa

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Introduction

Protected areas (hereafter parks)[1] are the primary means of biodiversity conservation in most of the world today [1, 2]. Parks are embedded in larger, dynamic landscapes comprising full ecosystems within which energy flows, materials flow and cycle, and organisms, including humans [3], reside. While many parks do seem to be adequately protecting natural systems within their borders, the linkages between the areas within the parks and the larger ecosystems can be altered by those human activities outside the parks [4,5]. Likewise, the human activities outside parks can be influenced by the presence of the park [6-9].

Landscapes surrounding parks, while still harboring considerable biodiversity, often have rapidly growing human populations, some of whom may have been drawn to the area by the park [10], although this finding is still under discussion, and has already been refuted by other research groups [11]. There continues to be an open dialogue regarding the impacts of parks on human and biological populations. While the negative and positive outcomes are hotly debated [10, 11], park landscapes are of increasing interest for research, with a real need for specific, detailed case studies to help highlighthese issues. The domesticated portions of these landscapes are zones of dynamic change in demography, land use, and land cover, and are characterized by biological and socio-political risks not usually found elsewhere. If there is enough moisture available, agriculture is already or is rapidly becoming the main land use in most of these areas [12]. The confrontation between human activities, such as agriculture, and biodiversity conservation, may threaten the conservation objectives of parks, and impact the well-being of people who live around them [13-15]. This conflict is particularly intense in East Africa, where agriculture or pastoralism remains the predominant livelihood activity. In this region, population growth rates are among the highest in the world, and the number and extent of parks continue to increase, driven by economic as well as conservation objectives. In East Africa and elsewhere, the areas surrounding parks – comprising important interactions among parks, agricultural systems, and biodiversity – are both inadequately understood and critical to the future of all three [16].

Clearly, the "success" of a park is a function of many complex factors that include environmental, ecological, economic, political and social issues [17]. The location of a park within a landscape is a key factor for understanding these dynamics and also for the study of likely future changes which may occur e.g., due to land cover change, climate change, etc. A major concern for conservationists has been the "islandization" of parks [15], i.e., the increasing isolation of natural habitat into smaller areas surrounded by human-

[1] We use the term "parks" to refer to protected areas of all sorts, including wildlife reserves – areas where land use is restricted mostly to wildlife and preservation of "natural" existing habitat.

dominated land covers. Isolation can affect natural movement patterns of organisms, altering dynamics and genetics of natural populations. Isolation, increasing human populations, and the expansion of agriculture are viewed as major contributing factors to wildlife decline, especially in East Africa [18,19].

Parks can affect land use and livelihoods both directly through constraints on traditional activities as well as presentation of new opportunities, and indirectly by affecting perceptions of risk and uncertainty for both the short and long term, which then influence land use and livelihood strategies. These risks include crop loss from wildlife, restriction of resource access, and future loss of land or resources due to expansion of parks. Responses to these constraints, risks, and opportunities by local people are evident in the intensity of agricultural land use and in the diversity of agriculture and agro-pastoralism. While direct loss of specific cover types (e.g., forest or wetlands) is often a primary concern, land-cover arrangement and fragmentation are also important for maintaining "natural" variability in the mosaic of patches within a landscape [20, 21]. The most frequently used techniques to study changing patterns of land cover and land cover arrangement are via the use of remotely sensed data. Specifically a time-series of land cover data is usually created based on land cover classifications, and changes in amounts, patterns, and arrangements of these land cover classifications are evaluated [22-24]. Since these classifications are spatially explicit, they not only provide information on absence, presence, and proportional change in different land cover types, but also allow for evaluation of changes in landscape spatial patterns and fragmentation over time, factors with critical effects on biodiversity [25-27].

Parks drive people to conduct certain activities that in turn may be detrimental to the function of the park. Most studies are concerned with the influence of human activities on the park itself. To some degree, we turn this notion on its head and examine the influence of the park on the activities outside the park, specifically land-use/land-cover change (LUCC). Land-use/land-cover change (deforestation, conversion to non-habitat agriculture) around parks is often seen as a threat to biodiversity conservation but necessary for the livelihoods of people living around the park. Extra-park landscape features (corridors, habitat fragments) can play an important part in how extra-park landscapes degrade or enhance within-park conservation. The question of what landscape-level effects the park has had on both the environment within the park and the surrounding landscape cannot be answered until we know the spatial patterns of changes caused by the presence of the park.

Most forest reserves or protected areas are ecosystem remnants of limited size. Few, if any, represent intact ecosystems; and it has become increasingly important to locate each protected area as a functional component of a larger landscape [26-28]. This paper examines spatial and temporal land cover patterns and changes of a forest park landscape and the surrounding agricultural mosaic.

Kibale National Park, a forest park in western Uganda, is considered by many to be an example of "successful" conservation of park features (increasing primate biomass, forest regeneration after plantation) [29], for the time being. Spatial dynamics of the agricultural/natural landscape around Kibale may be related to this success (maintenance of corridors, habitat patches – stepping stones, other connections to outside), but continued change in the future along current trajectories may begin to threaten this success.

While change in land cover (specifically forest area) is of primary concern, land-cover fragmentation also assumes vital significance for maintaining "natural" variability in the size, shape, and distribution of the mosaic of patches that exist within landscapes with little human influence [20]. This variability affects the flow of species and materials within landscapes [30]. In addition to estimating percent change in area over time, quantifying changes in landscape pattern is an important component of understanding landscape dynamics.

This paper is structured around two central questions: (1) What is the spatial and temporal pattern of land-cover and forest fragmentation in and around KNP, and how does the landscape within the park compare to that surrounding it?, and (2) How does proximity to a park affect land cover and hence land use (and as such livelihood strategies) of surrounding households and communities? A comparison of the park and the surrounding landscape, and study of the interactions between them, can give insights into how the border, the park, and the domesticated landscape can be managed.

Methods

Study Area: East Africa, Uganda and Kibale National Park

Despite recent demands for expansion of agriculture and other human activities, parks that exclude or restrict human land use have been important environmental and economic features of East Africa since the early 20th century. The first game control ordinances in East Africa were put in place at the beginning of the 20th century, and the first national parks were designated in the 1940s [31, 32]. The segregation of land for conservation purposes continued throughout the colonial period and accelerated following independence. Uganda currently includes 26 protected national parks and game reserves, representing 20,650 km^2 (about 13%) of its total land area [33].

Over 80% of the human population in Uganda is rural and agricultural, and the population increased more than 240% from 1960 to 2000 [34]. Many rural areas have very high population densities. Rural-to-rural migration is an important process; often from areas of high human density to areas where uncultivated land can still be found [35].

Kibale National Park (KNP, 795 km^2), located in western Uganda near the foothills of the Rwenzori Mountains, is one of few remaining mid-altitude rain forests in East Africa, and is one of the best studied forest sites in Africa (Fig. 1) [29]. The park was designated a Forest Reserve in 1932, and elevated to national park in 1993 [18]. Although primarily forested, the park includes woodlands, grasslands, and wetlands. The range of habitats in the park, as well as intermittent historic human occupation and alteration of land cover have also affected the park's ecological diversity [36]. The park is notable for its 12 species of primates, particularly chimpanzees (*Pan troglodytes*). Some of these primates, as well as elephants (*Loxodonta africana*) and other mammalian species, periodically move out of the park and damage surrounding farmers' fields [37, 38]. A long-term research program with headquarters in the park and participation by many Ugandan and international researchers has led to very effective conservation programs [29].

The human population surrounding KNP has increased seven-fold since 1920, and exceeds 270 people/km^2 at KNP's western edge [38] (versus 92/km^2 for the Kabarole District; [39]). Population growth rates in the surrounding parishes range between 3 and 4% per year [39]. The Batoro are the largest ethnic group in the area (~52% of population), but immigration of Bakiga people and others from the densely populated regions in southwest Uganda and elsewhere have greatly increased population growth and demand for agricultural land and forest products. Farms surrounding the park range from smallholder agricultural plots to large tea estates. Landholdings range in size from small farms averaging <5 ha [6] to large tea estates of 250 ha or more.

Over 30 years of continuous research has been conducted in KNP, resulting in over 500 scientific publications and extensive biotic inventories of a number of taxa. In contrast, there has been relatively little research on the increasingly intensive agricultural systems surrounding the park [38, 40]. The area has been characterized by intensive smallholder agriculture for several decades, and thus exemplifies the future of many protected areas in Africa as isolated ecological islands. The ongoing demographic and agricultural changes provide an opportunity to examine how landscapes surrounding parks continue to change even after becoming highly domesticated and populated, and how remote sensing technologies can be used to monitor and measure such changes.

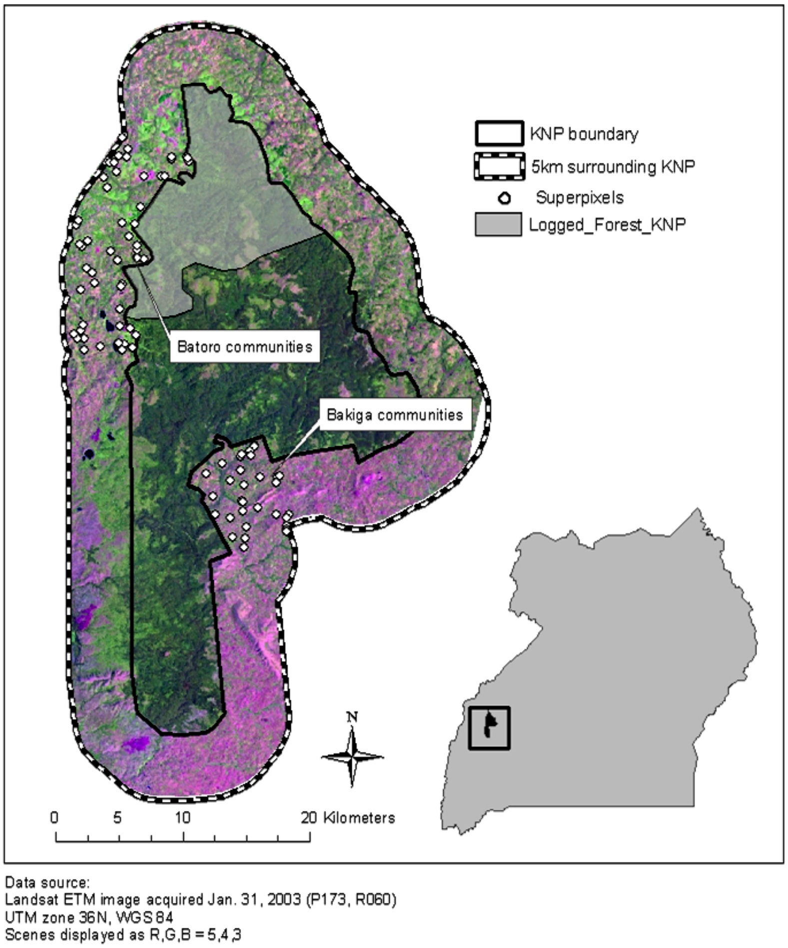

Fig. 1. Landsat ETM+ composite image of Kibale National Park and its surrounding landscape, including the 5-km surrounding landscape within which the landscape analysis was conducted. The inset map was redrawn from Struhsaker's (1997) figure 1.9.

Field Sampling

We used a digitized park boundary[2] and created a 5-km zone outside the park boundary (hereafter called the surrounding landscape) (Fig. 1), for inside-outside the park comparison. We chose 5 km because 20+ years of informal observation by C. and L. Chapman indicate that this is the distance people might travel to get resources, and animal movement outside the park stops before this distance.

We recorded standard training sample information [41] for a 3x3-Landsat TM pixel, or 90 m^2 areas, centered on randomly generated points created for the study region, and described the vegetation and general physical characteristics at each location, following a modified version of the Green et al. (2005) [41] protocol. In addition, 150 3x3-pixel-sized training samples from inside KNP were collected in 2002-3 [42] and used for comparison with the surrounding-landscape measurements.

[2] While officially KNP now includes the 'game corridor' (234 km^2), this corridor was acting as agricultural land until it was formally gazetted as part of KNP in late 1993. Therefore, we did not classify it as park in this analysis. By doing so, our analysis is conservative since the addition of the corridor would tend to lessen the difference between park and non-park.

Image Analysis

Image pre-processing

Landsat TM and ETM+ scenes from 26 May 1984, 17 January 1995, and 31 January 2003 were used in this analysis. The latter two scenes were acquired at the end of the dry season when fallow agricultural lands can be easily distinguished from forests. The 1984 scene was acquired near the end of the rainy season and was the only available, cloud-free image within this time period. Our analysis accounts for the phenological difference by undertaking independent image classifications to account for seasonally different spectral signatures. Images were geometrically registered with an RMS error of less than 0.5 of a pixel (or 15 m) and then radiometric calibration and atmospheric correction [40] was undertaken.

Image classification and change detection

Field data were used to determine the land-cover classes and then land-cover maps were derived for each date by independent supervised classification of the Landsat scenes using a Gaussian maximum likelihood classifier. The classification for this study identified five land-covers of forest, crops/bare land (including short grass, crops, and kitchen gardens), wetlands (dominated by papyrus – *Cyperus papyrus* L.) combined with elephant grass (*Pennisetum purpureum* S.), tea, and open water. Crops and bare land were combined because all bare land encountered during three years of field work was recently cleared cultivated agricultural fields, except for tea plantations that were bare during tree replacement or early growth. Bare and early-growth tea plantations were discriminated by their location (within or adjacent to existing tea plantations), size (always much larger than small-holder fields), and shape (mostly quadrilateral shapes surrounded by similar areas). Separability analysis, examination of reflectance profiles, and preliminary accuracy assessment indicated that papyrus swamps and patches of elephant grass had nearly identical spectral signatures. Consequently they were indistinguishable with spectral data alone, thus we combined the two classes into one for this analysis. The final accuracy assessment, using field samples collected in June and July of 2005, indicated an overall classification accuracy of 89.1%, with a Kappa of 0.867 (Appendix 1). In addition, validation was also undertaken of some areas of the 1984 classification, where there was overlap with available aerial photography (1:31,000 scale aerial photography acquired December 1988). While a full accuracy assessment was not undertaken (overlap areas were limited and dates did not coincide perfectly so agriculture was difficult to compare) the land cover classes derived and overall classification accuracy appeared high.

Land-cover classifications were used to create change trajectories, i.e.,sequences of successive changes in land cover types [43]. This technique is used to determine the change between two or more time periods of a particular region or for a particular land cover, and provides quantitative information on spatial and temporal distribution of categories of land-cover change and landscape fragmentation [24, 43-47]. The greater the number of land cover types or classes, and dates, the greater the number of change trajectories. Thus,

$$m_t = m_c^{\,t}$$

where m_t is the number of trajectories, m_c is the number of land cover classes and t is the number of images in the temporal series [43]. In this study, with three dates and five classes in each date, there could be 125 possible change-trajectory classes. Interpretation of this many classes would be confusing but most are rare, nonexistent, or are physically impossible. We restricted our analysis to those change-trajectory classes that individually covered more than 1% of the total landscape, comprising 26 trajectory classes in the surrounding landscape and nine within the park (Appendix 2).

Landscape fragmentation

Landscape pattern metrics, such as the proportion of landscape in various land covers, mean patch size and shape, edge density, interspersion-juxtaposition, contagion, etc. were calculated from land-cover classifications derived from satellite remote sensing data acquired at three different dates (1984, 1995, 2003). Landscape metrics were calculated using Fragstats 3.3 [48] for individual-date images and the trajectory-class image, both within the park and the surrounding landscape. Fragstats provides a comprehensive set of spatial statistics and descriptive metrics of pattern at the patch, class, and landscape levels [49] that provide useful quantification for analysis of landscape heterogeneity and change over time [50]. A patch is defined as a spatial unit differing from its surroundings in nature or appearance (e.g., a tract of forest surrounded by agricultural lands) [51]. Class is then defined as the collection of patches of a given type [52]. The landscape is an aggregation of patches and classes of all types.

We compared descriptive metrics of land-cover pattern at the class level, between forest and the other classes, across categories of land cover change, for both the individual land-cover images and for the change trajectories. Many of the indices that can be calculated are redundant. We considered only the following indices because they quantify different aspects of landscape structure [49]:

a) Proportion of the landscape covered by each land cover (PLAND).
b) Largest patch index (LPI): the area of the largest patch in each class, in hectares.
c) Number of patches (NP): the total number of patches of a given class.
d) Mean patch size (MPS): average patch size or area for a class, in hectares.
e) Edge density (ED): sum of length of all edge segments, divided by total area for each class.
f) Mean shape index (MSI): average complexity of patch shape for a land-cover class compared to a square patch of identical area. For a single patch, the shape index is 1 when square, and increases without limit as the patch becomes more irregular.
g) Interspersion-juxtaposition index (IJI – range 0-100): measures the degree of interspersion of patches of a class, with all other classes. This index decreases as the distribution of patch adjacencies among classes becomes increasingly uneven.
h) Clumpiness (CLUMPY – range -1 to +1): Measures the extent to which patches of a class are aggregated. A value of –1 indicates even dispersal in the landscape. Zero indicates randomly dispersed, and +1 indicates completely aggregated.
i) Connectivity (CONNECT - range 0-100): Measures the number of actual connections (within a threshold distance) between all patches of a class divided by the total number of possible connections, expressed as a percentage. A score of zero indicates that no patches are connected, while 100% indicates that every patch of a class is connected with every other patch. We set the threshold at 60 m, which is quite small.

Complete descriptions of these metrics, and equations for their calculation, are provided in McGarigal and Marks (1995) [48]. The indices of LPI, NP, and MPS correspond to area metrics. Together with ED, these provide indications of the degree of fragmentation for different land cover types and land cover change trajectories. MSI and IJI provide metrics of shape and contagion/interspersion. CLUMPY and CONNECT are indices of patch relationships within the landscape. Together we can use these indices to describe the pattern of land cover distribution across the landscape and its change over time.

Results

Land-cover classification descriptions

Land-cover classifications from the three time periods (Fig. 2, Appendix 3: PLAND column) show extreme contrast between the park and the surrounding area. The park is comprised of very large areas of forest (nearly 90% of the area within the park), interspersed with smaller areas of both papyrus/elephant grass and crops/bare land. The surrounding landscape is a fine-grained mosaic of all the land-cover classes, with crops/bare and forested land covering nearly equal areas, papyrus/elephant grass and tea plantations around the northern boundaries of the park, and a network of riparian or bottomland forests and papyrus and other wetlands interspersed throughout. The water class is confined to several crater lakes.

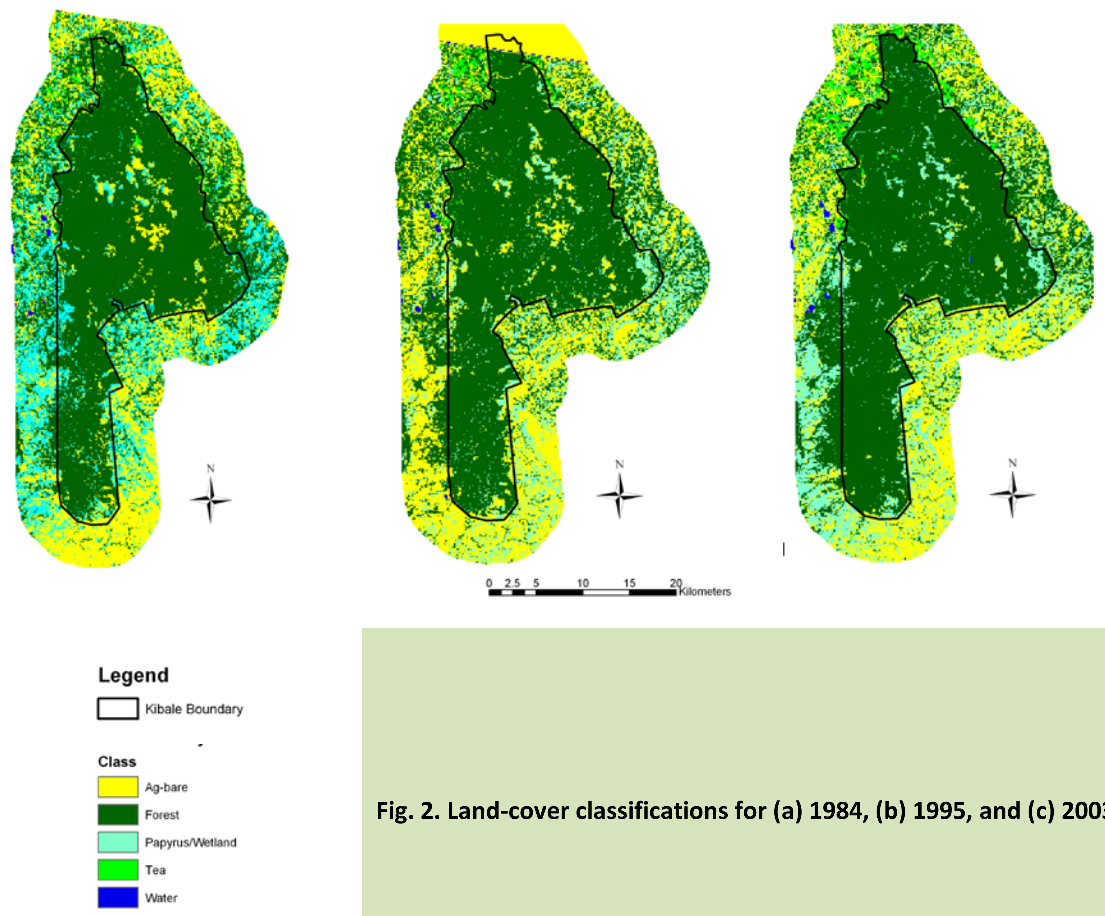

Fig. 2. Land-cover classifications for (a) 1984, (b) 1995, and (c) 2003

Land-cover change

Land-cover change is analyzed both as the percentages and patterns of each land cover at each image date, and as the trajectory of each pixel in terms of the five classes (Fig. 2, 3).

Land-cover class properties at each image date

The proportion of forest changed little within and outside the park, while tea more than doubled between 1995 and 2003. The area identified as “tea” within the park was simply misclassified, usually in areas of harvested pine plantations now regenerating with endemic trees (Southworth, personal observations). Crops/bare in the surrounding landscape increased from 1984 to 1995, then decreased from 1995 to 2003, while papyrus/elephant grass showed the reverse, suggesting that 1995 agriculture may have reverted to fallow by 2003. The number of patches of each land-cover class and the size of the patches followed patterns expected of predominantly forested landscape vs. fragmented forests in an agricultural matrix, with many small forest patches in the surrounding landscape and few large patches in the park. The standard deviation of patch area is noticeably high in the park, since there are a few extremely small patches and a few extremely large patches, while the standard deviation is low in the surrounding landscape as there are many small patches and no large patches.

The landscape indices support the visual impressions of patch size, shape, and patterns (Table 3). Consistently across time there are a few large (and a few small) patches of forest with low perimeter-to-area ratios in the park, and many small forest patches with higher perimeter-to-area ratios in the surrounding landscape. The patches classified as crops/bare area are few and small in the park (where they are actually natural grasslands), and numerous, but still small (3-5 ha) in the surrounding landscape. The papyrus/elephant grass indices are difficult to interpret because they include both papyrus swamps, many of which are linear and dendritic in valley bottoms, and elephant grass patches, many of which are more regular-shaped fallow fields on slopes or hilltops. Interestingly, the IJI values for forest, crops/bare, and papyrus/elephant grass show little difference between the park and the surrounding landscape. Tea has a larger IJI difference, also suggesting that the “tea” in the park is something else, as previously discussed.

Land-cover trajectories

There is little temporal land cover change inside KNP, as would be expected of effectively functioning park boundaries (Appendix 2, Fig. 3). Only nine trajectories each covered more than 1% of the land area within the park, and altogether these trajectories covered 91% of KNP: of these the “stable” (i.e., unchanging between 1984 and 2003 image dates) forest covered over three-quarters of the area. In some small areas, the forest seems to have encroached on both papyrus/elephant grass (P-P-F or P-F-F) and crops/bare (A-F-F or A-A-F). This encroachment likely represents forest that is protected from fire and expanding into areas that were dominated by elephant grass [53].

Outside KNP, there are 26 different trajectories that each covered more than 1% of the total area (Table 2b, Appendix 2, Fig. 3). Of these, stable crops/bare (A-A-A) and stable forest (F-F-F) were the largest areas, but covered only 16.0 and 13.2%, respectively. Most stable forest is in the valley bottoms and serves as a source of firewood and other resources for nearby households as well as habitat and corridors for wildlife.

The most prominent changes outside the park are the linked increase of crops/bare from papyrus/elephant grass from 1984 to 1995, a crops/bare decrease to 2003, and the more-than doubling of tea plantation area from 1984 to 2003. The transition from papyrus/elephant grass to crops/bare and transition back is probably the result of conversion of fallow land (bushland or tall grasses) to cultivated agriculture, followed by abandonment of cultivation. There are a few areas, notably in the far north and northeastern part of the surrounding landscape, where obvious valley network papyrus wetlands were converted to agriculture between 1984 and 1995 and appear to revert to papyrus/elephant grass from 1995 to 2003. Although substantial conversion of papyrus/elephant grass to crops/bare occurred, we cannot differentiate between papyrus wetlands and elephant grass, so we cannot be sure that this was wetland conversion. We hope to address this with more advanced remote sensing techniques and more detailed fieldwork to attempt a separation of these two important classes. However, reports from the area as well as our observations in the field indicate that conversion of papyrus wetlands is a common agricultural activity even though wetlands are protected by Ugandan law [54]. Large areas of this trajectory on the southwest side of the surrounding landscape may be areas that were converted to cultivated agriculture, and then abandoned perhaps as a result of the ongoing conversion to the conservation corridor. Many land uses are currently being excluded from the corridor (C. Chapman, unpublished data) and some areas are starting to be planted with indigenous tree species [55], and these results indicate that forest restoration will start to occur as these trees mature.

Landscape Pattern

Park vs. surrounding landscape

Appendix 3 shows how the class-specific pattern metrics varied among land-cover classes in the park and in the surrounding landscape, and over time. Forests dominated the area within the park (PLAND) and had larger mean patch size (LPI and MPS), but fewer patches (NP). Park forests had much less edge (ED) and were more regularly shaped (MSI). Forest patches in both the park and surrounding landscape were adjacent to about the same diversity of other land-cover types except for the most recent year when land conversion led to more land-cover classes adjacent to surrounding landscape forests (IJI). Likewise, in-park forest patches were clumpier (CLUMPY) and much more connected to other forest patches (CONNECT) at a local scale of a 60 m threshold while the level of connectivity is low.

Conversely, patches of crops/bare land in the surrounding landscape were larger, more numerous, and had much more edge and more diversity of adjacent land covers. However, these areas had about the same clumpiness and connectedness as those in the park. Since no agriculture is permitted within KNP, and probably does not exist illegally because the Uganda Wildlife Authority has been diligent in its efforts to eliminate it, within-park occurrences of crops/bare are probably lands that are natural short grasslands or bare due to recent burns.

Tea plantations also do not exist in the park, so comparing park and surrounding landscape statistics on tea is meaningless. Land-covers in the park interpreted as tea plantations are minor in amount. Interestingly, papyrus/elephant grass covered more area and had more and larger patches in the surrounding landscape than in the park, but also had more edge, less regular shapes, boundaries with more diversity of other land covers, but roughly the same clumpiness and connectedness.

In contrast with the surrounding landscape, the park landscape can therefore be characterized as having fewer, larger, more regularly shaped patches with lower diversity of adjacent land-cover classes, and the patches are more connected than in the surrounding landscape, which has smaller, more diverse, i.e., more fragmented land-cover distributions. These indices support the visual interpretation of the land-cover classification maps (Fig. 3).

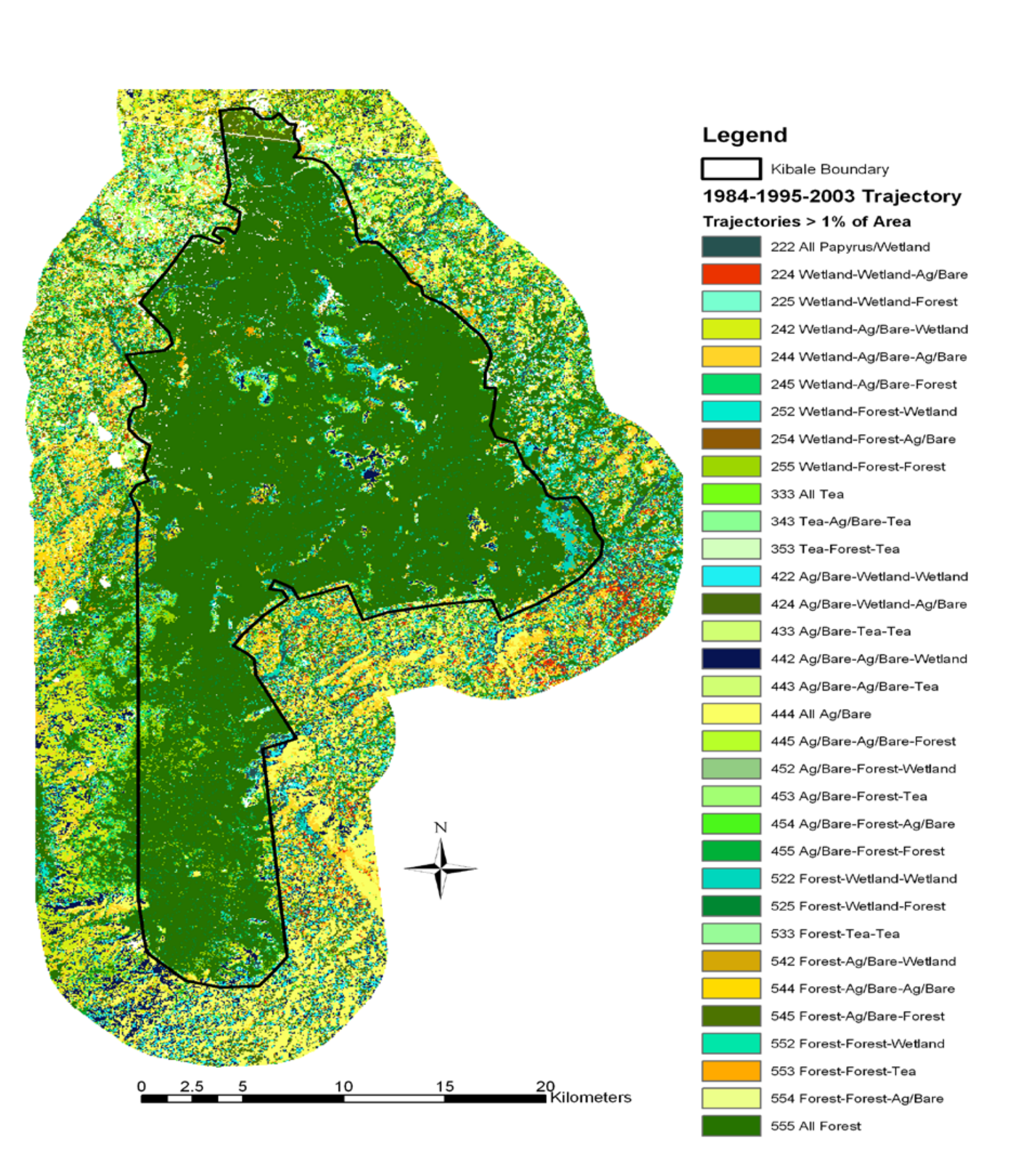

Fig. 3. Land-cover trajectories of Kibale National Park, Uganda, and its 5-km surrounding landscape. Showing all those trajectories making up at least 1% of the landscape

Change over time

Forest area grew somewhat in the park but was reduced in the surrounding landscape over the time period of the study (1984-1995-2003) with most of the change in both areas occurring between 1995 and 2003. The largest forest patches increased in size in both the park and surrounding landscape, but the mean patch size nearly doubled in the park while decreasing by about 25% in the surrounding landscape. Edge density decreased in both areas, while shape regularity remained about the same. There was an increase in diversity of adjacent land covers in the surrounding landscape from 1995-2003 while the forest did not change much. Neither clumpiness nor connectivity changed much in the forested land covers in either landscape from 1984-1995, but then connectivity dropped to nearly 0 in 1995. Recall that the threshold for calling a patch connected to another patch was 60 m, so this change suggests that the intervening land covers have become more extensive.

Landscape indices within each trajectory class.

Remaining permanent forest land was the largest trajectory in both the park and surrounding landscape, although permanent crops/bare was a close runner-up in the surrounding landscape (Appendix 2). No other trajectory class covered more than 2.4% of park area despite having many more individual patches than forest. There was a much greater diversity of change trajectories outside the park, with the largest being recent change from papyrus swamp/elephant grass to crops/bare (P-P-A), followed closely by P-A-P and P-A-F. Both permanent papyrus swamp/elephant grass (probably all wetlands; P-P-P), and A-P-P covered slightly greater than 3% of the landscape. Although they are spectrally confused with elephant grass, most of the areas with trajectories that were papyrus in 2003 are found in dendritic, valley-bottom areas (Figure 3). Edge density (ED), degree of clumpiness, and connectivity of the different trajectories all indicate a much more fragmented landscape outside the park than inside over the entire study period (Appendix 2).

Discussion

Through various measures of analysis, from simple visual examination of composite satellite images to the comparison of various landscape indices, KNP is clearly a forested island, surrounded by intensively-used agricultural land characterized by highly fragmented and rapidly changing land covers (and consequently land uses) (Fig.4.). Although effectively protected from human exploitation, the park itself has also changed, with variation from one land-cover class to another (succession in the grassland areas, some variation from papyrus/elephant grass to bare or burned areas).

Even though much of the land outside the park had been converted to agriculture prior to 1984, the landscape became increasingly fragmented (i.e., there were more forest fragments and many became smaller, more isolated over time). Moreover, the number of patches of all non-forest land covers increased, but the mean patch size decreased. Edge density of all land covers was much higher outside the park while connectivity was much lower at each image date. Measures of aggregation and connectivity also decreased in the surrounding landscape over time.

Another prominent land-cover change outside the park was the increase in tea plantations from under 2% to nearly 5% of the landscape. The major increase in tea occurred between 1995 and 2003, with a 130% (from 2.1% to 4.9% of the landscape) increase in plantation area. A portion of this land-cover increase may be linked directly or indirectly to park establishment since much of it is in areas immediately adjacent to the park boundary. Although most of this land has high agricultural potential, the threat of crop raiding by animals from inside the park in some cases has decreased the value of adjacent agricultural land [56, 57], so these parcels may have been purchased by the tea estate companies at relatively low prices. In such a way, the park becomes even more isolated from the natural environment, as tea continues to develop around its boundaries, although it also develops here due to the presence of the park – proximity to wildlife and crop raiding make this land cheaper to buy. Tea plantations seem to be immune to damage from animal raiding since few wildlife species seem to travel directly through the tea [58]. The tea is unpalatable by would-be crop raiders originating from the park. However, elephants continue to use tea company roads and paths for passage to raid neighboring cultivated fields. So over time, the park becomes more islandized and the tea plantations have increased in size and act as a buffer from wildlife to other forms of land use.

Fig. 4. KNP and its surrounding landscape, where (a) illustrates the stark contrast between the forested park and the intensive agriculture outside the boundary, (b) shows tea fields located right outside the park, (c) shows intensive mixed agricultural land use outside the park, and (d) shows the eucalyptus trees bordering the park, with a guard hut for protecting fields from wildlife raiding right along the park boundary. All photos taken by J. Hartter.

Proximity to the park appears to offer both risks and some opportunity. As crops cultivated in fields closest to KNP tend to be raided heavily [38, 56, 59], landholders face a challenge in making this land productive. By replacing crops with trees or tea, families are able to provide fuel to their families and in both cases produce a marketable commodity from land that has been deemed undesirable. In addition, some farmers want to live closer to KNP because they feel they receive rain and fertile soil to cultivate crops at any time in the season and perceive other benefits [60]. Proximity to parks can also be an important indicator for associated direct benefits, such as tourism, employment, and active engagement with park officials in resource management.

The direct effects of the changes we have documented on the biological integrity of the park are largely unknown. Furthermore, we have a poor understanding of how these changes will impact resource use by communities, which will inevitably have indirect effects on the biology of the park. The analysis clearly illustrates an increasing isolation of the park. While large mammal populations, such as elephants, previously freely mixed throughout the region, populations in KNP are now isolated, with dispersal limited to the game corridor connecting Queen Elizabeth National Park directly south of KNP and occasionally to the forest patches and wetlands outside KNP. The long-term consequences of isolation will depend on their initial population sizes, for which there are poor estimates at best for most mammals, and their present genetic structure. The continuous loss of forest in the landscape surrounding the park has reduced or eliminated many small populations. For example, between 1995 and 2003, 25% of the fragments that supported red (*Piliocolobus tephrosceles*) and black and white (*Colobus guereza*) colobus monkeys were cleared of forest and the population of black-and-white colobus in this landscape decreased by 55% [61].

Furthermore, these forest patches supported all the firewood needs of an average of 32 people who lived immediately adjacent to the forests, and partially supported families up to 3 farms away (~400 m), representing 576 people, and it is unclear how local communities will obtain their firewood once the forests are converted [61, 62]. Furthermore, the loss of the firewood sources from the forest patches may lead to indirect impacts on the park since people will have few alternatives to obtain firewood and other resources. Overall, in terms of land cover change and fragmentation, KNP is maintaining its borders and remaining a forested park. However, given the trends in the surrounding landscape of forest loss and increased fragmentation, the future trajectory for this park is in question. It is only through putting such parks within a landscape setting that such issues can be evaluated, since if the park was studied in isolation it would appear to be successful, and this is really only a part of the story.

One multiple-case study that addresses the issue of park effects on surrounding landscapes [4] concludes that tropical parks seem surprisingly effective at stopping land clearing within park boundaries. However, the park examined in this study varied significantly in size, management strategy, and severity of threat. There is a clear need for such broad research to be supplemented by detailed case studies. For example, from the research presented here we see an example of a park which has experienced limited land cover change when compared to the surrounding landscape, and the forest itself has remained largely intact, in part due to agriculture and most extractive activities within the park being banned [18]. Despite many negative associations with this model of conservation, park policies have been successful at least in maintaining forest cover and biodiversity for KNP. Instead, population increase and most extractive pressures and land cover change have been concentrated in the area surrounding KNP, reinforcing the park's island character and perhaps highlighting future problems and issues for park survival as such an "island." Isolation of parks, such as is shown here in KNP, may be an inevitable long-term outcome of protection, with both negative and positive implications. Overall the context and detail from such individual case studies provides an excellent supplement to the more broad scale and often contradictory research studies [10, 11] found in the literature. Such context specificity is greatly needed to highlight the more localized but important trends across these increasingly islandized park landscapes.

Implications for conservation

The results for KNP are optimistic in terms of conservation as the park has maintained its forest cover over time, and appears to be a success. However, it is also clear that KNP exists as an island in the landscape and as such its future may be uncertain, especially given potential future changes such as increased climate variability, climate change, and increasing human population. The presence of this park within the larger landscape is a key context for the study, as looking only within park borders misses much of the story – e.g. pressure on the park for clearing for firewood, agriculture, etc. An additional concern for conservation is the biodiversity issue; with increasing loss of natural land covers (forest and wetlands) outside the park having significant impacts on different animal populations, which links to future biodiversity both across the larger landscape and within the park itself in the future. Overall then, while KNP seems to be a conservation success, implications for future changes are significant based on increasing pressure on park resources, loss of biodiversity, and problems of increasing islandization of KNP

Conclusion

The main conclusions to be drawn from this land cover classification and fragmentation change analysis of Kibale National Park and its surrounding landscape are: Kibale National Park is now a forest island within an agricultural landscape; forest fragmentation continues outside the park, despite major clearance prior to the beginning of study in 1984; the park may have stimulated some of the expansion of neighboring tea and the landscape within the park changed over time. These changes are heterogeneous in space and time and land-cover distribution. We have little idea yet of how the continued fragmentation outside the park, and the isolation of the park, especially with impervious land covers on the boundary, affect biodiversity either inside or outside the park. Future work suggested by this study includes examining the relationship between fragmented forests and biodiversity, effects of impermeable land covers on the boundary of the park, and how people and wildlife respond to the isolation of the park. Overall, however, this research highlights the continued need for detailed case studies, in addition to the larger scale broader research compilations and overviews.

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Appendix 1. Accuracy Assessment of the 2003 land cover classification of Landsat ETM image for five land-cover types

	Ground Reference Classes						
Classification	**Water**	**Papyrus/El. grass**	**Tea**	**Crops/bare soil**	**Forest**	**Row Totals**	**User's Accuracy (%)**
Water	20	0	0	0	0	20	100.0
Papyrus/El. grass	0	27	0	1	3	31	87.1
Tea	0	0	16	3	0	19	84.2
Crops/bare soil	0	2	0	19	2	23	82.6
Forest	0	3	0	1	40	44	90.9
Column Total	20	32	16	24	45	137	
Producer's Accuracy (%)	100.0	84.4	100.0	79.2	88.9		89.1
Kappa statistic =	0.867						

Appendix 2. Land Cover Trajectories landscape analyses, (a) Within Kibale National Park, for all trajectories which represent over 1% of the total land cover, and (b) Landscape around Kibale National Park, for all trajectories which represent over 1 % of the total land cover.

(a)

TYPE	PLAND	NP	LPI	ED	CLUMPY	IJI	CONNECT	COH
F-F-F	78.4	715	35.74	20.42	0.91	69.68	0.26	99.98
P-F-F	1.1	4120	0.05	6.86	0.40	39.03	0.03	76.10
A-F-F	1.7	3537	0.02	6.53	0.42	48.67	0.03	70.93
F-P-F	2.0	6441	0.01	8.96	0.22	27.90	0.02	43.92
F-A-F	1.0	2212	0.28	3.11	0.55	58.21	0.04	88.26
A-A-P	2.4	1020	0.04	0.80	0.57	62.85	0.10	81.66
P-P-P	1.0	869	0.03	0.97	0.57	66.93	0.12	83.10
A-F-A	2.3	1587	0.01	2.35	0.41	77.42	0.06	67.64
F-P-P	1.1	1105	0.10	1.49	0.56	68.69	0.09	88.65

(b)

TYPE	PLAND	NP	LPI	ED	CLUMPY	IJI	CONNECT	COH
A-A-A	15.7	7953	0.302	20.36	0.68	73.11	0.020	94.13
F-F-F	19.0	6196	0.387	16.78	0.67	80.56	0.023	95.68
P-A-P	5.5	7459	0.175	11.66	0.55	76.52	0.015	90.05
A-A-P	2.6	9964	0.062	14.03	0.45	68.25	0.013	78.71
P-A-A	1.5	8885	0.026	13.46	0.47	72.45	0.016	77.54
P-P-P	3.3	6830	0.017	10.79	0.47	81.78	0.019	77.25
A-P-P	3.4	6783	0.015	9.20	0.44	75.06	0.018	72.22
P-F-F	2.7	8091	0.029	9.13	0.34	75.53	0.014	69.26
F-A-A	1.6	6894	0.008	7.08	0.37	76.36	0.014	61.76
F-F-A	1.6	6307	0.006	6.54	0.38	79.57	0.017	62.77
A-P-A	2.1	6449	0.012	7.36	0.36	64.48	0.018	66.14
A-F-F	2.5	6804	0.004	6.34	0.31	76.76	0.014	55.38
F-A-F	2.0	5940	0.012	5.82	0.36	78.27	0.014	63.36
F-F-P	2.8	6914	0.003	6.73	0.29	77.56	0.014	51.07
A-A-F	1.4	6136	0.010	5.76	0.32	75.77	0.014	56.66
P-P-A	6.9	5275	0.011	5.40	0.32	77.55	0.021	59.88
P-A-F	4.6	5404	0.008	5.44	0.31	80.13	0.017	61.52
F-P-P	3.2	4998	0.017	4.99	0.33	79.75	0.019	62.50
A-F-A	1.5	5867	0.002	5.09	0.27	79.09	0.014	46.78
P-F-P	2.2	6293	0.005	5.70	0.24	85.17	0.014	47.28
P-F-A	3.8	5499	0.003	4.79	0.25	84.43	0.016	45.37
F-A-P	2.0	4937	0.006	4.32	0.26	82.45	0.015	48.29
F-P-F	1.8	5273	0.002	4.34	0.23	70.17	0.016	41.92
P-P-F	6.9	4519	0.003	3.99	0.25	79.35	0.017	48.15
F-F-T	6.9	2681	0.008	2.04	0.41	51.97	0.033	65.65
A-F-P	2.2	5052	0.003	4.06	0.21	84.86	0.014	39.62

Where PLAND is % land in this cover type, NP is number of patches, LPI is the Largest Patch Index, ED is edge density, CLUMPY is the clumpiness index, IJI is the Interspersion Juxtaposition Index, CONNECT is a measure of connectivity (in this case with a 60-m threshold), and COH is a measure of the covers cohesiveness. Where F = forest, A = Agriculture, P= papyrus and elephant grass, and T = tea.

Appendix 3. Landscape Fragmentation statistics for (a) the Park and (b) the Surrounding Landscape for the five land cover classes across the three dates of study

(a)

	YEAR	PLAND (%)	LPI	NP	MPS (ha)	ED	MSI	IJI	CLUMPY	CONNECT	COHESION
Forest	*1984*	86.3	39.54	672	73.3	18.70	1.18	65.2	0.94	0.152	100.0
	1995	85.5	25.64	668	73.1	12.85	1.16	62.8	0.95	0.122	100.0
	2003	90.1	41.49	412	124.9	13.39	1.17	65.9	0.96	0.000	100.0
Crops/Bare	*1984*	7.2	0.31	3424	1.2	12.47	1.21	53.4	0.71	0.011	90.1
	1995	7.5	0.11	2162	1.7	6.78	1.27	54.2	0.73	0.016	91.3
	2003	2.1	0.04	1322	0.9	4.64	1.24	62.6	0.62	0.000	82.6
Tea	*1984*	0.6	0.03	750	0.4	1.72	1.15	39.1	0.49	0.032	75.8
	1995	0.6	0.01	745	0.4	1.10	1.14	25.5	0.51	0.026	71.8
	2003	1.1	0.04	878	0.7	2.38	1.14	39.9	0.64	0.000	82.6
Papyrus/	*1984*	6.0	0.36	4267	0.8	13.16	1.18	44.8	0.63	0.010	92.2
Elephant Grass	*1995*	6.3	0.23	6995	0.5	10.48	1.13	41.0	0.58	0.005	87.9
	2003	6.6	0.38	3262	1.2	11.12	1.18	39.7	0.71	0.000	92.6
Water	*1984*	0.0	0.00	2	0.1	0.00	1.17	50.0	-1.00	0.000	21.7
	1995	0.1	0.00	33	0.2	0.03	1.09	80.7	0.27	0.000	43.2
	2003	0.1	0.00	159	0.2	0.26	1.11	74.0	0.22	0.000	40.4

(b)

	YEAR	PLAND (%)	LPI	NP	MPS (ha)	ED	MSI	IJI	CLUMPY	CONNECT	COHESION
Forest	*1984*	31.6	2.33	6975	3.3	33.74	1.32	65.1	0.74	0.010	98.5
	1995	32.4	1.82	6096	3.9	36.64	1.31	66.4	0.74	0.011	98.7
	2003	29.1	2.69	7441	2.8	30.03	1.30	72.0	0.75	0.000	98.3
Crops/ Bare	*1984*	38.4	4.31	8543	3.3	35.39	1.29	60.2	0.77	0.008	98.7
	1995	45.7	5.21	5996	4.9	37.02	1.31	58.6	0.79	0.012	99.2
	2003	37.0	2.77	7102	3.8	34.89	1.29	63.3	0.76	0.000	98.8
Tea	*1984*	1.8	0.01	3263	0.4	4.44	1.15	54.4	0.48	0.009	72.5
	1995	2.1	0.08	1954	0.8	3.77	1.17	44.7	0.65	0.014	86.3
	2003	4.9	0.10	4249	0.8	7.32	1.15	68.0	0.67	0.000	88.6
Papyrus/	*1984*	27.8	0.98	10485	2.0	39.93	1.31	51.0	0.66	0.007	97.5
Elephant Grass	*1995*	19.3	0.61	10211	1.4	34.08	1.30	50.5	0.63	0.006	94.3
	2003	28.6	0.72	9842	2.1	37.48	1.34	55.7	0.68	0.000	96.4
Water	*1984*	0.3	0.02	59	3.4	0.15	1.14	27.0	0.89	0.468	91.5
	1995	0.5	0.02	76	3.3	0.21	1.18	65.2	0.88	0.140	91.1
	2003	0.4	0.02	311	1.0	0.41	1.10	95.8	0.80	0.000	84.6

Where PLAND is % land in this cover type, NP is number of patches, LPI is the Largest Patch Index, MPS is Mean Patch Size (ha), ED is edge density, MSI is Mean Shape Index with higher values indicating increased complexity, IJI is the Interspersion Juxtaposition Index, CLUMPY is the clumpiness index, CONNECT is a measure of connectivity (in this case with a 60-m threshold), and COHESION is a measure of the covers cohesiveness