Fortresses and fragments: impacts of fragmentation in a forest park landscape

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Abstract
Our research addresses patterns of land cover and forest fragmentation in and around Kibale National Park in equatorial East Africa, and how park presence affects local livelihoods. Combining discrete and continuous data analyses of satellite imagery with a geographically random sample of two agricultural areas neighboring Kibale, we examine multi-scalar landscape change and diminishing resources in the context of population increase, potential climate change, and fortress conservation. While park boundaries have remained relatively intact since 1984, the domesticated landscape has become increasingly fragmented, with forests and wetlands shrinking, becoming more isolated, and suffering decreased productivity. Remnant wetland and forests are of particular interest because they supply ecological goods and services, but also provide habitat for primates and elephants from which to raid crops, not only posing a risk to food security, but may also lead to zoonotic disease emergence through spillover and spillback events.

Keywords: Kibale National Park, forest fragments, protected areas, landscape fragmentation

1. Introduction

Recently, there has been a call for an integrated methodology that crosses temporal and spatial scales to promote understanding of the social, ecological, and climatological dynamics within park landscapes and to identify global trends, focus conservation priorities, and enable innovative and effective policy and resource management at multiple levels (DeFries et al. 2007). This paper details our data acquisition methodology that is designed to anticipate the consequences of a dynamic social and ecological system faced with anthropogenic pressures and climate change at multiple scales to inform appropriate management or legislative interventions for the mechanisms using Kibale National Park as a "natural laboratory".

Establishing parks is the primary mechanism used to protect tropical forest biodiversity, particularly in regions with high human densities. Parks (protected areas of

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all sorts) protect and maintain endemic, threatened or endangered, flora and fauna, geological features, and cultural heritage sites. In addition, they can generate income for the local and national economies, and provide important benefits associated with enhanced tourism sectors. However, many parks are also associated with negative social and ecological impacts. Human populations neighboring parks are often excluded from settlement, access, resource extraction, and most forms of consumptive land use in the park, which in turn affects farmers' land use and livelihood options.

The processes that drive land cover change are complex and cannot be understood without addressing underlying cause and effect relationships. Changes in climate, population, and land use occur and interact simultaneously at different temporal and spatial scales, having major implications for both livelihoods and biodiversity. Forest loss and fragmentation are regarded as the greatest threat to global biological diversity (Turner and Corlett 1996). Fragmentation negatively impacts species composition due to a reduction in forest area and isolation of remaining fragments. Between 1990 and 2005, forest cover in Africa decreased by 21 million ha (Chapman et al. 2006). Since most parks are already ecosystem remnants of a limited size, it is important to consider each as a component of a larger landscape.

The presence and use of forest fragments outside parks illustrate the interconnected nature of the park-domestic landscape.Within the greater continuous landscape, remnant fragments of larger forests can be important to neighboring human communities, providing subsistence-based resources. These forests represent reservoirs of land, resources, and economic opportunity for people, while at the same time are often viewed as buffers for parks by managers, as wildlife corridors and habitat that extends the effective size of the park.

Unfortunately, these forest fragments are also hazards for local farmers, as sources of crop raids by primates, elephants, and birds. There has been extensive conversion of fragments, both to claim more land and to destroy the habitat of would-be crop raiders. Health concerns have also arisen as pest animals move pathogens across landscapes, leading to spillover of disease (potential zoonotic emergence), and spillback (pathogens transferred back into parks).

The decline of remaining fragments in the human-dominated landscape may be an inevitable process, exacerbated by the impacts of current and future changing climate. The impacts that fragmentation has on both wildlife and vegetation within a fragment and perhaps more importantly, the impact of loss of intact habitat and wildlife on the people relying on the remaining fragments, are important to understanding and slowing or preventing future decline. As fragments decrease and become more degraded, encroachment into the park and the number and severity of human-wildlife incidences may increase.

There is growing interest in the academic community and by policy makers as to the extent of climate change impact on ecological communities (Walther et al. 2002). Climate variability and change are affecting wildlife populations, posing serious risk to poverty reduction and threatening rural livelihoods. Local climate variability directly impacts crop yields, resource quality and abundance, vegetation productivity, and wildlife habitat and food sources. Climate change can also adversely affect the availability of resources for human populations outside of parks, who depend on the land for their livelihoods. In addition, changes in food abundance within parks may force wildlife to seek food in agricultural areas near the park boundary, increasing the vulnerability of farms to crop damage and predation.

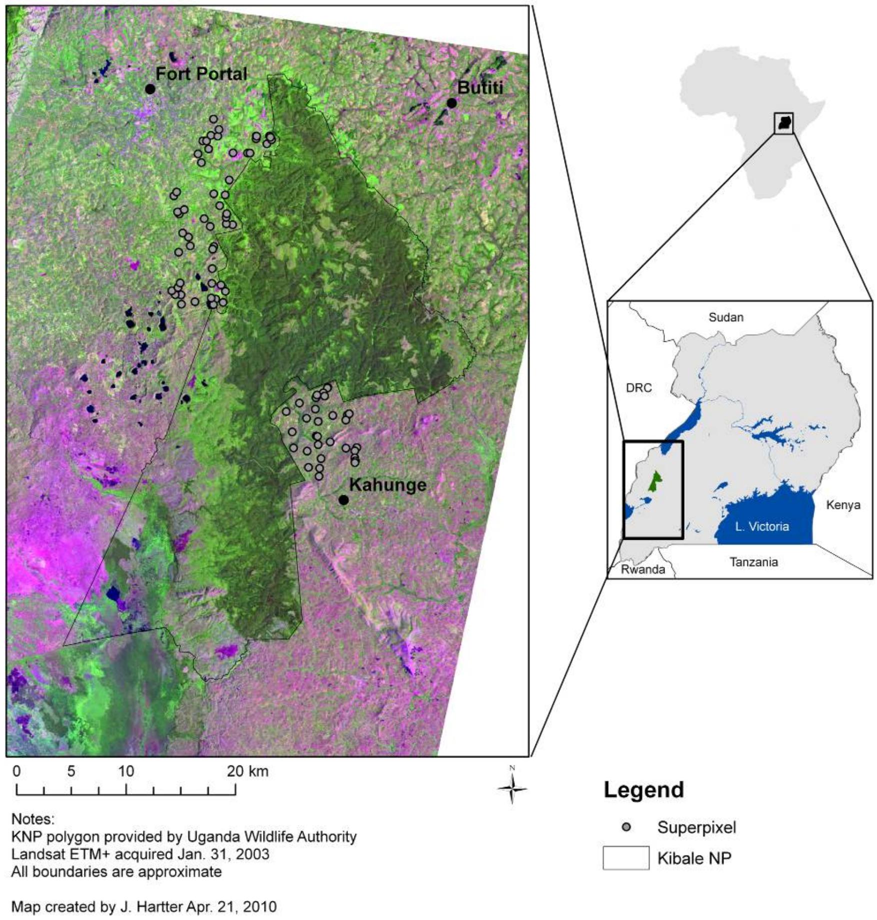

Figure 1. Kibale National Park in western Uganda.

2. Study Site

Kibale National Park (795km^2, Figure 1), medium altitude tropical moist forest in western Uganda represents one of the best-studied forest sites in forested Africa, having been the site for multiple field projects for 40 years. The human population surrounding Kibale has increased seven-fold since 1920 and exceeds 270 people/km^2 at the western edge. Annual population growth rates range between 3 and 4% per year. The landscape is a mosaic of small farms (most <5ha), large tea estates (>200ha), and interspersed forest fragments and wetlands (0.5-200ha or more), effectively isolating the park (Hartter and Southworth 2009). Forest fragments and wetlands extending from Kibale's boundaries and isolated within the agricultural matrix vary in size, shape, and resource types and amount. The Kibale landscape is an extremely valuable setting because the biophysical and social response to social and ecological change may be emblematic of forest park landscapes across the entire Albertine Rift and likely elsewhere. Parks in the Albertine Rift have been identified as areas of extremely high endemic biodiversity and have been classed as a conservation priority (Plumptre et al. 2007).

3. Methodology

Integrating landscape level change detection with household level processes and ecological sampling requires a sampling scheme that links household surveys and ecological sampling to remotely sensed data. Social and ecological surveys provide valuable fine-scale, ground-data. Household-level decision making is critical to understanding the changes in land-use and land-cover and their effects on livelihoods. Ecological sampling provides means of understanding the consequences of household decisions to biodiversity and allows the generation of future scenarios for change. Linking classifications of land cover to socio-economic and ecological surveys can provide a more comprehensive understanding of land use and land cover change over time. Instead of asserting that deforestation happened, we can now describe the effects of this change (i.e., loss of biodiversity), and pinpoint key social drivers for this change.

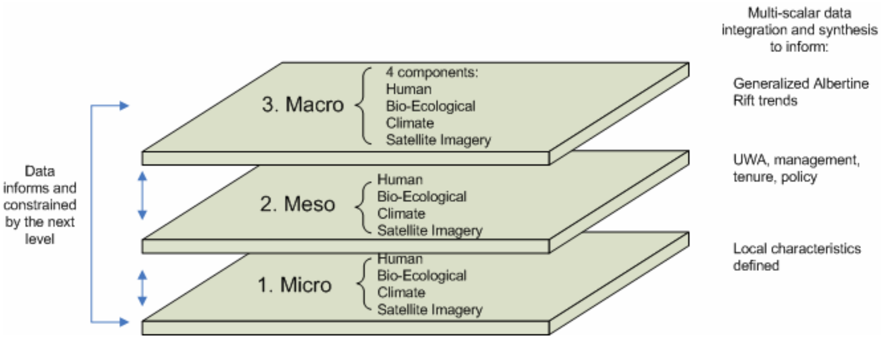

Figure 2. Hierarchical framework that is embedded with multiple datasets at multiple spatial resolutions to examine four elements of the park landscape and their temporal and spatial changes. Within this hierarchical framework, the higher level provides a context and imposes top-down constraints on the lower level, and the lower level provides mechanisms and imposes bottom-up constraints.

3.1 Data Acquisition

To provide the link between landscape and household/ecological data, appropriate areas had to be defined that permitted the integration of research tool and intellectual questions. These areas had to be large enough to include the scales of satellite-evaluated land cover change, and small enough to permit assessment of biodiversity and human activities.

Household Interviews – To link micro-scale land use decisions with meso-scale land cover change area, we used the superpixel methodology (Hartter and Southworth 2009) to define a 5-km perimeter around park boundaries as the meso-scale research area. Interview respondents were selected from among landholders in each of the 95 9-ha circular superpixels for which there were landholders. The number of respondents selected per superpixel was proportional to the number of landholders controlling land within the study area, and at least one interview was conducted in each superpixel. Therefore, superpixels with more landholders (and correspondingly smaller individual landholdings) had a higher sampling intensity than those with fewer landholders. GPS points were also taken at access points for the nearest forest fragment and wetland for each house and were used to calculate the straight-line distance from the house to the nearest wetland and/or forest fragment and park boundary. Thus social and ecological units of interest can be mapped together.

Time Series Analysis of Land Cover, Productivity, & Landscape Fragmentation – To quantify landscape change outside Kibale, Landsat TM and ETM+ imagery was chosen because it offers the best combination of spatial, spectral, temporal and radiometric resolutions. Six dry season images were acquired: (August 4, 1986, August 20, 1989, January 17, 1995, January 9, 2001, January 31, 2003, and September 1, 2008) (path 162, row 60). An additional image (May 26, 1984) 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 phonological difference. Images were geometrically registered to 1:50,000 scale survey topographic maps of the region within an RMS of <0.5 (below 15m accuracy), followed by radiometric calibration and atmospheric correction.

Three images (1984, 1995, 2003) were used to construct a landscape classification. The 1984 image provided baseline data prior to park establishment at the time the area was a forest reserve, the second captures conditions at park establishment, and the third represents 10 years after park establishment. In 2004 and 2005, 180 training samples were collected and used to construct a supervised classification using the eight-band layer stack and the normalized difference vegetation index (NDVI) layer. Five classes were used in the classification: 1) forest, 2) wetland (mainly of papyrus (*Cyperus papyrus* L.) and grassland (elephant grass (*Pennisetum purpureum*), 3) bare soil, crops, short grasses, 4) tea, and 5) water; and overall accuracy was 89% (Hartter & Southworth 2009).

Vegetation indices are important to help us address changes within land cover classes across dates. Derived composites of NDVI from satellite images provide an indication of photosynthetic activity and a proxy of net primary productivity. NDVI composites from each date will be used to measure the change in forest productivity (e.g., higher NDVI values indicate more photosynthetic activity).

Landscape pattern recognition software (e.g., FRAGSTATS); and spatial ModelMaker in Imagine) was used to conduct spatial analyses with classified and continuous data. The classified data descriptive metrics of land cover pattern (patch area, shape, core area, diversity, effective mesh size) were compared across dates and locations. These techniques reveal patterns of spatial regimes of land cover that may be related to land-use patterns. Examining autocorrelation statistics using continuous variables (e.g., NDVI) provide detail on variations *within* patterns of spatial dependence.

Climate Analyses **–** Precipitation in and around Kibale exhibits a high degree of spatial and temporal variability. Therefore we investigated the temporal and spatial variation in intra-annual precipitation patterns (Stampone et al. *submitted*) and will quantify its contribution to land-cover change. Total seasonal and annual rainfall data were analyzed using the Global Historic Climate Network (GHCN) 5º gridded dataset and from long-term research at Kibale from T. Struhsaker and C. and L. Chapman (1970-). Trends in total seasonal and annual rainfall over the period of record were identified at each station and tested for statistical significance at the 95% confidence level. Significant trends were identified using Mann-Kendall test, a non-parametric test for data interdependence over time. The direction and magnitude of significant trends were then calculated using Sen's slope estimator. Temporal autocorrelation functions associated with each station time series will indicate whether or not there are long-term trends or periodicities in temperature and the amount and variability of precipitation over the period of record. Periodicities in autocorrelation functions are indicative of a cyclical response in seasonal and annual climate variables and may be attributed to fluctuations in large-scale atmospheric circulation patterns (e.g., ENSO). Spatial autocorrelation will be used to assess the spatial variability in temperature and precipitation at sub-regional scales. High spatial autocorrelations between stations may be indicative of strong regional influences on local climate, whereas strong local influences, such as land use, may result in lower spatial autocorrelations between stations.

Integration of data – A series of logistic models will be incorporated into a model selection algorithm, assessed using an information theoretic framework, such as AIC (Akaike's Information Criterion) based estimators. These models will be constructed by overlaying the information gathered and constructing process based models predicting fragment loss as a result of covariates such as ownership, fragment type, isolation and distance metrics, ecological factors, climate in preceding years, neighborly crop types and perceptions of use. We will derive suites of models at different spatial scales, wherein processes will likely differ.

4. Conclusion

While it is well established that models of the park-landscape interface are necessary to the conservation discourse and to the persistence and sustainability of parks and the human populations that surround them, the necessary data to understand the multifarious processes at play are hard to acquire. We have addressed issues of socio-ecological boundaries, climate and both spatial and temporal scale within our data acquisition. We will thus not only document a park-landscape dynamic process, but identify drivers which are relevant to management and policy.

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