

MATCHING MULTISCALE REMOTE SENSING DATA TO INTERDISCIPLINARY CONSERVATION NEEDS: THE CASE OF CHIMPANZEES IN WESTERN TANZANIA

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ABSTRACT

Efforts to preserve biological diversity increasingly require work across spatial scales and disciplinary boundaries. Remote sensing represents an important tool capable not only of characterizing landscapes, but also helping to understand biological and socio-economic factors relevant to addressing conservation problems. The challenge is to develop information products that are meaningful, practical and accessible to scientists, managers and a variety of other stakeholders with often contrasting interests, backgrounds, values and technical capacities. This paper describes the combined use of multitemporal, multiscale remote sensing data to understand and support diverse chimpanzee research and conservation needs in Gombe National Park and northwestern Tanzania. At Gombe, Dr. Jane Goodall has carried out chimpanzee behavior research since 1960. For 30 years field assistants have followed chimpanzees, every 15 minutes recording their location, party membership, and feeding behavior. Remote sensing is the only tool that enables the combination of such a unique long-term animal dataset with historical information on habitat change at the local and regional scales. In this paper we describe how historical aerial photos, Landsat MSS, TM, ETM+, ASTER and IKONOS data can aid chimpanzee behavior research and conservation inside and outside the park. The vegetation map clearly shows drastic decreases in forest and woody canopies from 1972 to 2001 adjacent to the park and along the major roads and settlements close to the Tanzanian-Burundi border. This coincides with the political crisis in adjacent Burundi and Democratic Republic of Congo and suggests a possible role of refugees in aggravating the chimpanzee habitat loss in the region.

REMOTE SENSING, CONSERVATION AND BIODIVERSITY CRISIS

Conservation efforts worldwide are in race against time to cope with unprecedented biodiversity crises including loss of species and habitats and the destruction of the “very fabric of Life on earth” (Meffe 2001). Our closest living relatives, the great apes, for example, will become extinct in the next 30 years if current forest exploitation, deforestation and poaching trends continue. The science of conservation biology claims to be a crisis, mission-oriented discipline, built on the failure of other academic fields to effectively address biodiversity problems (Soulé 1986). In this context, remote sensing has a special place in the toolbox of conservation practitioners.

Conservation applications of remote sensing have some unique characteristics that reflect the nature of conservation biology objectives. This includes an emphasis on real world problem solving that recognizes the need for case specific, interdisciplinary and participatory approaches. Consequently, information needs that could be met by remote sensing are also diverse and case sensitive involving multiple users with various backgrounds, cultures, values and technical capabilities (Vogelmann 1995; Chatelain, Gautier et al. 1996; Keating 1997; Fuller, Groom et al. 1998; Smith, Meredith et al. 1999; Roy and Tomar 2000; Liu, Yang et al. 2001; Zomer, Ustin et al. 2001). In this context remote sensing and conservation objectives face some common challenges: to balance research and technology capabilities with specific information needs and learn to take into consideration decision-making processes, time, economic, political, infrastructure, capacity or other constraints that influence information development and its actual use.

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Moran and Brondizio (1998) noted that different specialists could bring different perspectives to the analysis of remote sensing imagery rather than only naming classes after a standard vegetation classification. A biologist will tend to look for biological meaning while a social scientist will be inclined to search for social-economic forces behind a landscape pattern (Moran and Brondizio 1998). In the case of conservation, such interdisciplinary perspective could be critical to better understand biological and socio-economic aspects of specific biodiversity problems (Kramer, Richter et al. 1997) or to evaluate the effectiveness of conservation actions (Schweik and Thomas 2002). Therefore, the concept of “mining the pixel” (Geoghegan, Pritchard et al. 1998) as applied to conservation biology could mean to use the images and find biological, social or any other information relevant to the understanding, implementation and evaluation of specific conservation projects. The challenge is to identify information needs that could be met by remote sensing methods and work across disciplines to find that information, which like social meanings could often be deeply hidden in the imagery (Moran, Brondizio et al. 1994).

The present paper deals with the combined interpretation of multisensor, multiscale remote sensing data to identify and meet some of the spatial information needs of chimpanzee research and conservation inside and outside Gombe National Park, northwestern Tanzania. First we introduce our case study and outline data collection and analysis methods. Then we provide some examples on the use of existing and new sensors to look at the chimpanzee-habitat interactions and conservation implications at spatial and temporal scales that have never been achieved before. Finally, we examine some of the common challenges that both remote sensing and conservation biology share in assisting biodiversity problems in general and chimpanzee conservation in the Kigoma region in particular.

THE CASE OF GOMBE CHIMPANZEES

Gombe National Park is a narrow strip of mountainous area of only 40 sq km on the east coast of Lake Tanganyika and bounded inland by the steep crest of the eastern Rift Valley escarpment in northwestern Tanzania (Figure 1). The vegetation is a mosaic of riverine evergreen and deciduous forest, thicket, woodland and grassland (Figure 2). The rich variety of plant species in the park is influenced by the interaction of western Guinea Congolese and Afromontane forests and Zambesian miombo woodlands (Clutton-Brock and Gillett 1979). Despite its small size, Gombe is home for a diverse number of primates including redbellied colobus, blue monkeys, bushbabies and world-famous chimpanzees studied by Dr. Jane Goodall (Goodall 1986). Research began in 1960 and is one of the longest ongoing studies of any wild animal population in the world.

Chimpanzees are highly social, long-lived species. They live in a fission-fusion society in which members of a single community spend their time in parties of fluctuating size (Nishida 1968); Goodall, 1986). Community members share a common territory within which they forage from dawn until dusk and the adult males defend a territory against neighboring communities (Wrangham 1986). At night, chimpanzees build and sleep in nests alone or in groups. Chimpanzees are characterized by male philopatry where males are kin and stay and breed within their natal community while females usually disperse as they reach adulthood. During forty years of research at Gombe and other long-term study sites it has been shown that chimpanzees share many of the traits that previously have been attributed to only humans such as tool making and use, empathy and war-like violent intergroup aggression.

The relationship between ecological and social factors is a central issue in understanding the evolution of social structure in primates and our hominid ancestors. Therefore, it became clear that the long-term datasets on the social behavior of Gombe chimpanzees have to be integrated with changes in environmental variables in both time and space. Despite the remote sensing potential for mapping primate habitats only few applications have been developed. For example, Hashimoto et al. (1998) used Landsat TM images to investigate the habitat use and ranging of wild bonobos at Wamba, DRC. They concluded that 30 meters resolution had limitations to the mapping of highly patchy bonobo habitat but even such generalized forest types were valuable. It was prohibitively time consuming and expensive to make a more detailed vegetation map for such a large area by actually surveying on the ground. Therefore at Gombe, we decided to use existing and new generation of spaceborne sensors such as ASTER (15 meter) and IKONOS (1-4 meter) capable of imaging areas as small as 1 square meter. It was expected that multiscale remote sensing would significantly increase the likelihood of matching technology capabilities with primate research needs.

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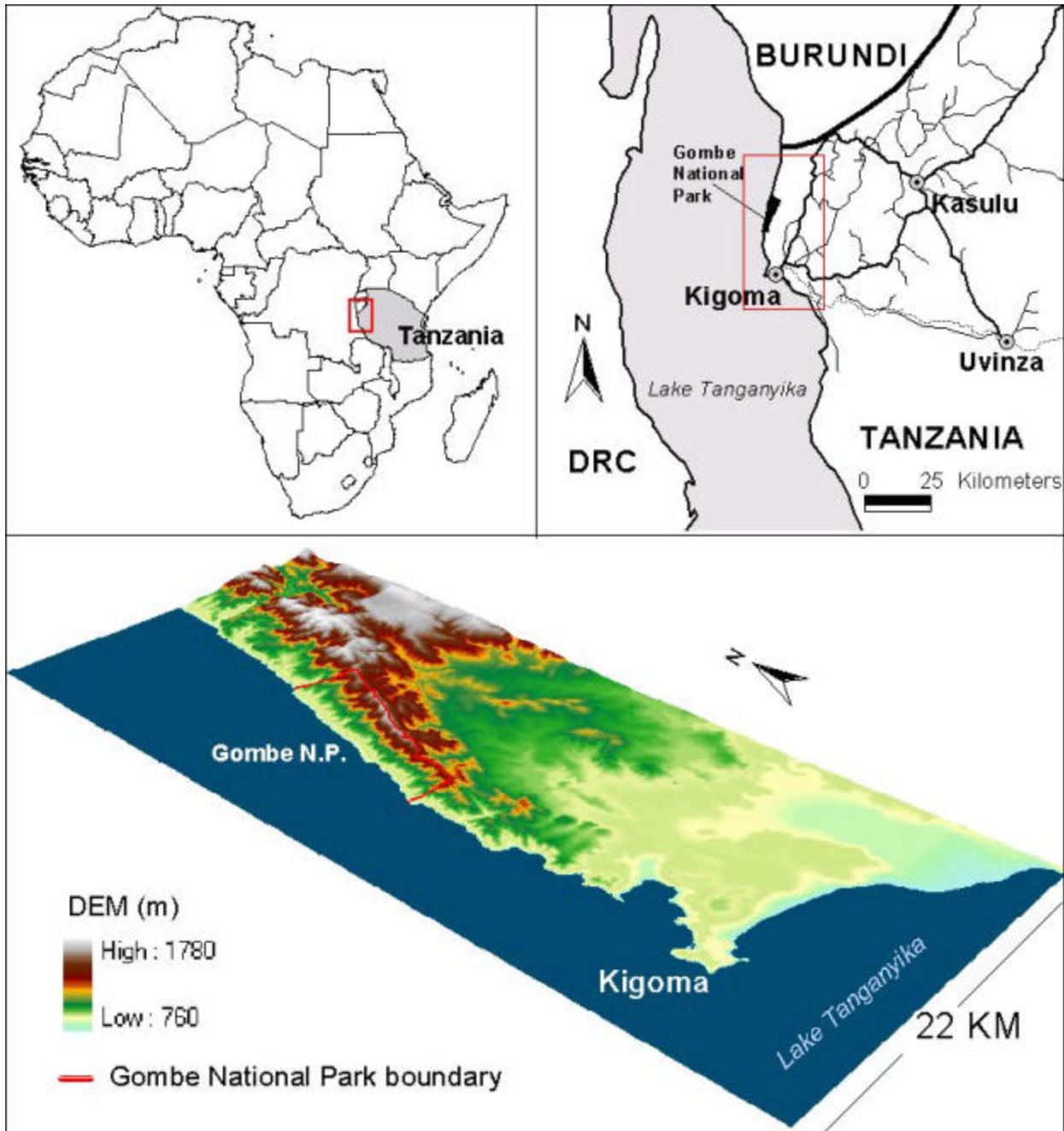


Figure 1. Location and topography of Gombe National Park in northwestern Tanzania.

At the same time we also recognized the urgent conservation needs of chimpanzees in the region and their complex relations with socio-political factors and people's livelihoods. Chimpanzees are increasingly pushed to survive in isolated remnant forests all around Africa. When Jane Goodall arrived at Gombe in 1960, the chimpanzee population extended throughout all of the eastern shore of Lake Tanganyika and was linked with chimpanzees in Burundi and Rwanda (Goodall 1989). Today, there are only tiny and isolated pockets of habitat left immersed in a matrix of human settlements, cultivation and degraded land. These remnant pockets of habitat are critical elements in maintaining the viability of the chimpanzee population in the region. However, because of several factors, including the lack of spatial information on land use/land cover change, conservation efforts have not yet linked Gombe National Park with the larger landscape context. Community based conservation and reforestation efforts

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have been established, but without a clear idea about the original and current extent and distribution of chimpanzee habitat.



Figure 2. The vegetation mosaic of Gombe National Park

Kigoma region is a remote and previously politically and economically neglected part of the Tanzania. Gombe National Park is placed in the center of a cultural and historical area called Buha, with the main population related to the Ha people (Wagner 1996). However, several waves of refugees from Rwanda, Burundi, and the Democratic Republic of Congo have substantially changed the social and physical landscapes of the region. Refugees have been a factor in deforestation and chimpanzee habitat loss since the initial reserve establishment in 1943. An article in "The Tanganyika Standard" mentions that "This area, practically untouched forest five years ago, is now almost open country due to colonization by the Ba-Rundi natives" (Moreau 1945). However, it was unclear how much forests have been lost then and where.

Since the 1970s several new refugee waves have occurred. During only the last 1993-1998 influx, both Kigoma and Kagera regions experienced 50 percent overall increases in population, and in some areas refugees outnumbered locals five to one (Whitaker 1999). Some refugees registered with the United Nations Higher Commissioner for Refugees (UNHCR) and were placed in one of the dozens of camps spread in western Tanzania. However, many others avoided UNHCR and settled directly at the periphery of villages, adjacent to woodlands and forests, and are now scattered all along the Gombe National Park boundary. The environmental impacts of refugees are complex, but it is likely that refugees increased the pressure on forests through direct consumption of firewood, charcoal production and that the provision of cheap labor has driven conversion of forests and woodlands into farmland (Whitaker 1999). Nevertheless, the lack of the data on the spatial distribution and dynamics of deforestation made it difficult to understand or manage the impacts of refugees on local natural resources.

METHODS

We have built a common "GombeGIS" database to integrate 25 years of chimpanzee observations with remote sensing and GIS layers that include roads, settlements, elevation contours, streams and water bodies. We constructed a basemap using digitized 1:50,000 topographic maps and GPS control points with a spatial error between 7 and 10 meters. We have developed a TIN and DEM in ArcGIS from digitized 1:50,000 elevation contours and have calculated slope and aspect.

Research assistants at Gombe Stream Research Center, Kigoma, Tanzania, have collected chimpanzee data using focal sampling with 15 minutes intervals. Every day, for almost 30 years they have recorded location, party membership, and feeding behavior of the focal chimpanzees. The data have been computerized, quality checked, and

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analyzed at the Jane Goodall Institute's Center for Primate Studies, at the University of Minnesota (Pusey, Williams et al. 1997). Locations on a paper map have been manually digitized, linked with the chimpanzee behavior data and added to the database.

The Environmental Resources Spatial Analysis Center (ERSAC) at the University of Minnesota has facilitated the effective use and access to geospatial technologies. In order to complement the long-term chimpanzee dataset with habitat information at different spatio-temporal scales we located as many remote sensing imageries as possible. Dry season historical aerial photos and Corona, Landsat MSS, TM, ETM+, ASTER and IKONOS satellite images acquired between 1947 and 2001 have been rectified using image-to-map and image-to-image methods. The RMS errors varied by sensor's spatial resolution but were less than half the size of a pixel.

We engaged in a multi-stakeholder dialogue (Bernabo 1995) to improve our awareness of the land cover information needs in Kigoma region. Meetings were conducted with the villagers, and representatives of Government, village and ward authorities, NGO's, and foreign aid organizations. Traditionally, subtropical areas of savanna or woodland, especially when mixed with scattered agricultural practices, have been difficult to map with spaceborne remote sensing (Haack and Bechdol 2000). In Gombe vegetation canopies are formed by continuous or scattered evergreen and deciduous trees and shrubs that range from 3 to more than 30 meters in diameter (Figure 2). With increase in resolution, statistical separability between forest types decreases due to the highly textured nature of reflectance patterns in which variance within forest classes can be greater than that between forest classes (Hill 1999). Miombo woodlands are also more difficult to interpret due to the complex background reflectance from soil and vegetation (Yang and Prince 2000). We used image enhancement techniques such as resolution merge, texture analysis (Franklin, Wulder et al. 2001) and low-pass spatial filtering (Hill 1999) in ERDAS Imagine to improve the detection of habitat characteristics by supervised and unsupervised classification or prepare the images for visual interpretation using on-screen digitizing.

In regard to measuring habitat change in time, the quality and scale (1:30,000-40,000) of black and white historical aerial photos acquired in 1947, 1958 and 1974, made it difficult to differentiate the transition between evergreen forest, deciduous forest and woodland habitat classes. The use of Corona data has been also restricted by the cloud cover above the northern and central parts of Gombe National Park. In the past, normalized difference vegetation index (NDVI) has been successfully used in Tanzania to examine changes in vegetative cover across the country (Pelkey, Stoner et al. 2000). In similar landscapes, woodland structure was estimated in Zambia from MSS data using a linear relationship between woody canopy cover and red reflectance (Yang and Prince 2000). We used changes in NDVI estimated from Landsat MSS, TM and ETM+ sensors with the common pixel size of 57 meter as the main technique to map vegetation change inside and outside Gombe National Park between 1972-2001. The use of NDVI also helped to minimize topographic effects and improve the comparison between images acquired by various sensors at different time intervals. During analysis we continuously compared vegetation distribution and deforestation patterns derived from Landsat sensors with historical aerial photos, GPS field observations, oblique aerial photos and high-resolution 1-meter sharpened IKONOS image.

MAPPING DEFORESTATION FRONTS

Changes detection of NDVI helped identify extensive areas of deforestation outside Gombe National Park at the regional scales. The Figure 3 clearly shows drastic decreases in forest and woody canopies from 1972 to 2001 adjacent to the park and along the major roads and settlements close to the Tanzanian-Burundi border. The deforestation patterns, our fieldwork and interviews in the region suggest that charcoal production transported to Kigoma and Kasulu towns, conversions of woodlands to farmland and conversion of evergreen forests to oil palm plantations could be the main forces driving deforestation in the region. This coincides with the political crisis in adjacent Burundi and Democratic Republic of Congo and suggests a possible role of refugees in aggravating the chimpanzee habitat loss in the region. However, additional socio-economic modeling of observed deforestation spatial patterns is needed to disaggregate deforestation processes (Mertens and Lambin 1997) and evaluate the exact role of refugees in degradation of natural resources in Kigoma region.

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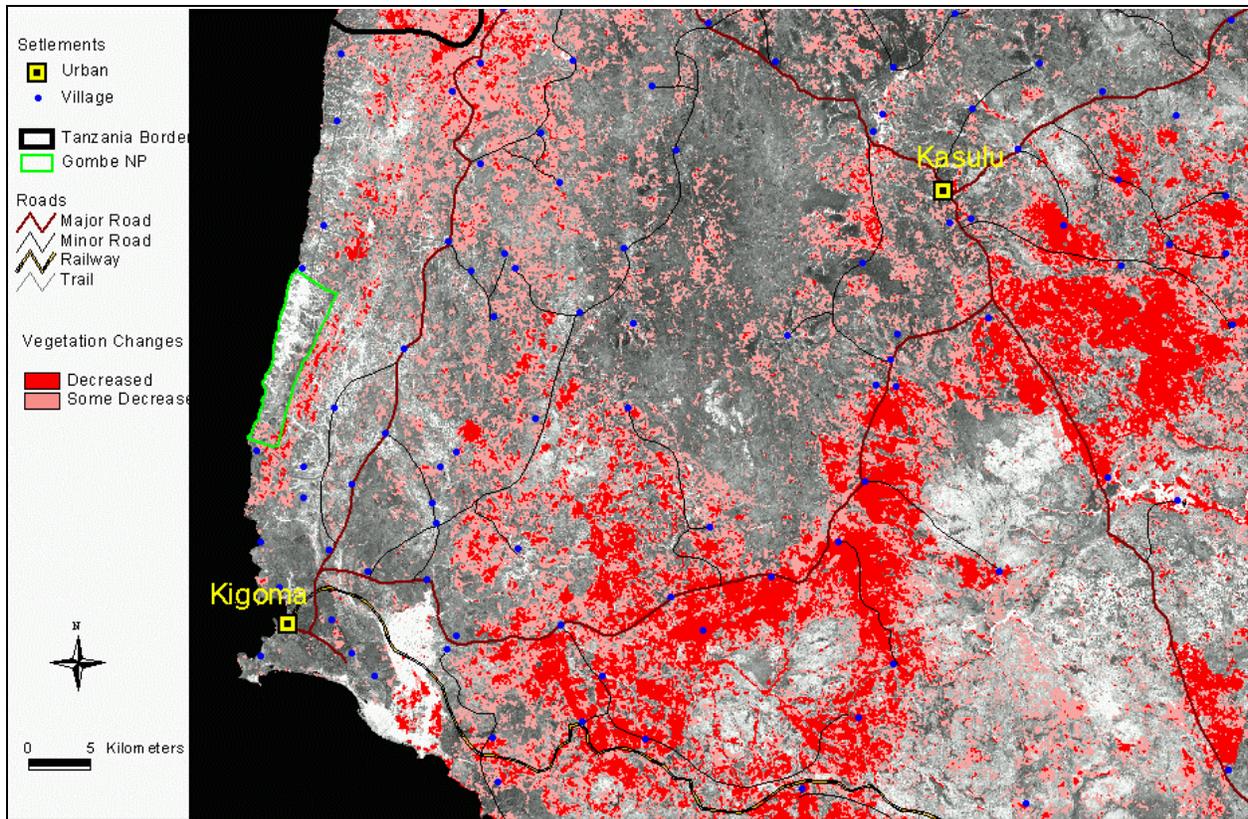


Figure 3. Forest and woodland loss between 1972-1999 as recorded by changes in NDVI of Landsat MSS and ETM+ images. Deforestation pattern is overlaid over the 1999 Landsat ETM+ NDVI with the location of major roads and settlements. Note that most of the linear high “greenness” patterns adjacent to the park are oil palm cultivations converted from evergreen forests.

The effectiveness of any landscape conservation efforts such as protected areas, corridor or buffer zone design depends on proper understanding of human-environment interaction and land use practices. The human landscapes in Sub-Saharan Africa are very difficult to map with remote sensing because the settlements, farmlands and natural



Figure 4. a) Ground photograph of: a) a household scattered along the eastern Gombe National Park boundary and b) typical agricultural landscape on high slopes adjacent to the park.

vegetation are highly spatially intermixed (Haack and Bechdol 1999; Smith, Meredith et al. 1999). In Gombe area, the 15-meter ASTER image was useful to identify major roads and villages located inland and on flat terrain due to

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the contrasts with tree crops and farmland vegetation. However, fishing villages along the coast of lake Tanganyika, numerous settlements scattered in complex terrain (Figure 4a) and farmlands (Figure 4b) could be identified only using IKONOS 14 meter images. An examination of Figure 5 illustrates the usefulness of 1-meter sharpened multispectral IKONOS image for visual separation of households, trees crops and shamba (in Kiswahili, a small farm).

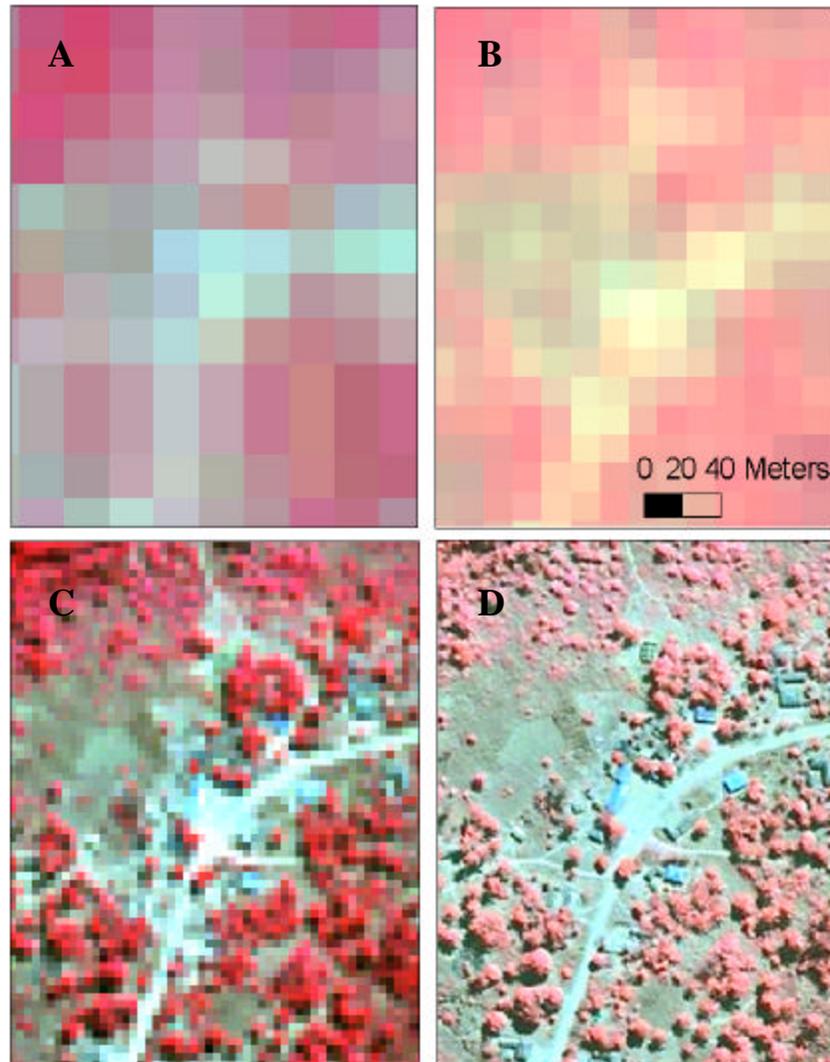


Figure 5. A comparison between color infrared composites of a typical village landscape with a major road, as recorded by: A) Landsat ETM+ (30 m) 10/01/01; B) ASTER (15 m) 10/01/01; C) IKONOS multispectral (4 m) 07/31/00; and D) IKONOS multispectral sharpened (1 m) 07/31/00 images.

According to Wagner (1996), historically, land use decisions in Gombe National Park region have been strongly influenced by the spiritual relationships between Ha communities and physical characteristics of the landscape such as a hill, tree or a stream. In this context, high-resolution sensors could be the only source of land cover information relevant in land use planning discussions with the villagers and local governments. Unfortunately, conservation projects in general are struggling with financial resources and often cannot afford mapping village lands at the current prices of high-resolution data. However, considering that this is the scale where many biodiversity relevant activities and decisions are made in African landscapes, the adequate scale of conservation planning is crucial.

LINKING CHIMPANZEE AND REMOTE SENSING DATA

Gombe Park Scale

It is not clear yet to what extent changes at regional scale as detected from Landsat sensors are useful to understand chimpanzee habitat use. However, the maps were helpful so far to better understand and evaluate conservation implications of habitat change adjacent to Gombe national park. For example, Figure 6 shows that since 1972 majority of woodland and forest patches close to Gombe National Park have been lost to farmland (shown in red) or converted to oil palm crops (shown in green). There are three chimpanzee communities in Gombe. The northern, Mitumba chimpanzees used to be seen visiting the forest reserve, woodlands and the riverine forests outside the park. The southern area adjacent to the park is still occasionally used by Kalande chimpanzees but has also experienced major loss in evergreen forest and woodland cover. Both communities experienced drastic reductions in number of individuals, Mitumba by at least one third, and Kalande maybe by as much as one half. In contrast the central Kasakela group has not changed in number and its annual total range has actually recently increased. It has been suggested that a fourth chimpanzee community lived in the area east of the rift escarpment and went extinct, since the majority of habitats on the eastern rift side has been lost (Figure 6).

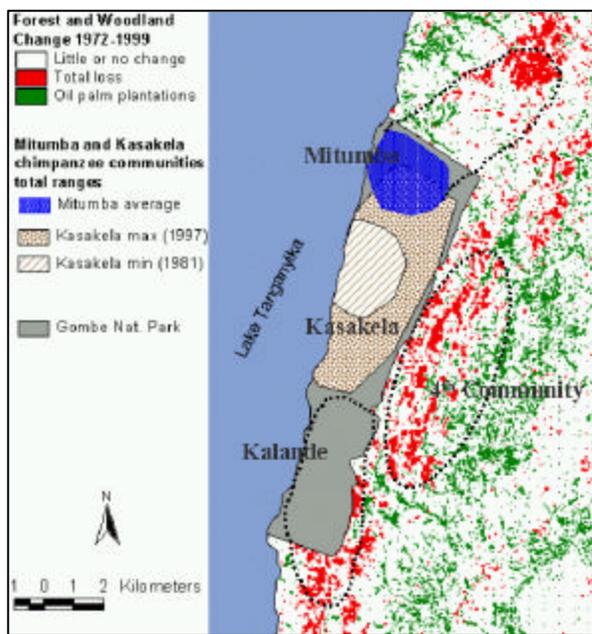


Figure 6. Overlay of deforestation patterns between 1972-1999 as detected by Landsat MSS and ETM+ changes in NDVI and chimpanzee communities inside and outside Gombe National Park. Kasakela and Mitumba territories have been calculated using 99% MCP method from long-term chimpanzee ranging data. The dashed lines indicate approximate locations of the other chimpanzee territories.

It is known that chimpanzees exhibit aggressive territorial behavior in the periphery of their range and could engage in “war” like behaviour when they outnumber their neighbors. Since both northern and southern communities have decreased in number this could potentially increase their risk of extinction by the larger middle Kasakela community. Therefore it is possible to conclude that chimpanzee habitat change outside Gombe National Park as detected from Landsat sensors has had an unequal effect on the two peripheral chimpanzee communities and could potentially increase their risk of extinction. Such

changes complicate the challenge of conserving chimpanzee populations in Gombe and in fragmented habitats elsewhere, since conservationists have to take into account the effect of chimpanzee territorial behavior.

Chimpanzee Community Scale

The success of linking chimpanzee focal point observations with remotely sensed habitat classes depends upon the proper definition and partitioning of habitats at the spatial scales and within habitat classes that are recognized by the chimpanzees (Knight and Morris 1996). Under the term habitat we mean a set of specific environmental features that, in the case of chimpanzees, could be related to a plant community, vegetative association or cover type (Garshelis 2000). Chimpanzees use diverse habitats that vary from evergreen forests, woodlands to open grasslands and savannas but always include at least a small percentage of forest (Wrangham 1977; Wrangham 1996) which provide important food supplies in critical times of the year. The diet consists mostly of ripe tree fruits that they reach by traveling mainly on the ground. However, chimpanzees also hunt small mammals and fish for termites, both important sources of protein. Therefore, it appears that chimpanzee habitat use might involve a macrohabitat selection of habitat types such as evergreen forests and a microhabitat selection at the level of individual trees or tree patches distributed within the larger habitat types.

We know that chimpanzees have very sophisticated mental maps and that they have a good knowledge of the distribution of food patches such as specific fruit trees or termite mounds. However, it is hard to say if chimpanzee habitat selection is hierarchical with chimpanzees first selecting for macrohabitats and then searching for individual

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food patches, or if selection occurs at the microhabitat level that happen to be distributed within a certain macrohabitat type, or both. Therefore one of the major values of multisensor remote sensing is the possibility to view landscapes at various scales. At 30-meter resolution it is possible to differentiate general macrohabitat types such as evergreen forests, grassland and woodland classes. With increase in resolution to 15 meters the shape and distribution of vegetation types could be better differentiated but with little increase in the number of vegetation classes. Finally, 4meter multispectral IKONOS image and, 1-meter sharpened data in particular, offer stunning opportunities to differentiate among individual food patches such as trees.

In general, we found it helpful to use digital image enhancement techniques such as resolution merge, spatial filtering and vegetation indices to prepare the IKONOS data for further visual interpretation of chimpanzee habitats. Figure 7 shows that NDVI from 1-meter sharpened multispectral IKONOS data helped remove topographic effects and it is promising to visualize small and patchy chimpanzee microhabitats.

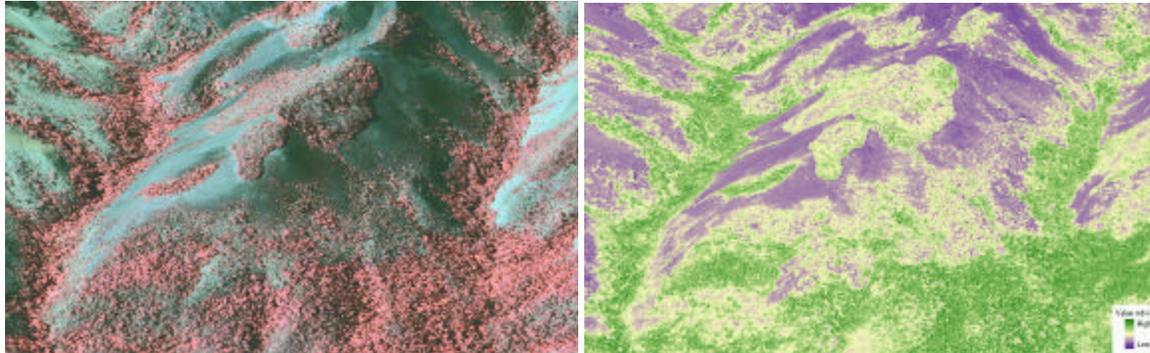


Figure 7. 1-meter sharpened color infrared composite and NDVI of IKONOS image draped over the DEM. The NDVI values are increasing from blue to green.

Finally, when combined with chimpanzee observations and additional GIS layers, such as DEM, high-resolution imagery offers the unique opportunity to visualize chimpanzee-habitat interactions at a scale never reached before (Figure 8).

INTEGRATING SATELLITE DATA AND CHIMPANZEE CONSERVATION

As Turner et al (2001) noted, conservation and remote sensing share some common challenges, and dealing with them together could serve well both remote sensing and conservation biology objectives (Turner, Sterling et al. 2001). Moving between scales of chimpanzee-habitat relations at the local, community and population levels and understanding how they relate to the scales of remotely sensed habitat data is clearly one common challenge that we try to address in this ongoing study. Another common challenge is the integration of the chimpanzee-habitat knowledge from research and land cover information from remote sensing into the conservation planning and management of chimpanzee habitats inside and outside Gombe National Park.

A published paper, better technique or more sophisticated analysis is not always the final product if conservation is to be achieved (Whitten, Holmes et al. 2001). The final product is the actual use of the tool or information to help change policies, institutions, behaviors and business practices that drive species loss. Like conservation biology, many remote sensing methods evolved within academic walls, and a common challenge is to take scientific knowledge out of the ivory towers into day-by-day decision-making. However, scientists frequently develop information that reflect more their own curiosity or understanding of the problem than the information needs of the decision-makers. As a result, impressive maps end up as wallpaper because the information, even if it is a result of a quality work, is not relevant, timely or in a format useful to that particular stakeholder.

Another common challenge is that often people who actually make conservation decisions are not conservation biologists or remote sensing specialists and have limited access to geospatial, or any infrastructure to make use of the complex tools. It has been suggested that collaborations and partnerships could be one way to connect institutions and individuals that have access to techniques, including universities and scientists with different potential users such as government officials, NGOs or villagers (Getz, Fortmann et al. 1999). Another way to integrate findings into the decision-making process is to design information products. An information product could

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be defined as information with a specific user and management context in mind. This is based on an assumption that information has a higher possibility of being used if it is: relevant, designed for a specific audience and for a specific purpose; available when the 'window of opportunity' for decision-making arises (i.e. timely); and it is easily and quickly understood (World Conservation Monitoring Centre 1998).

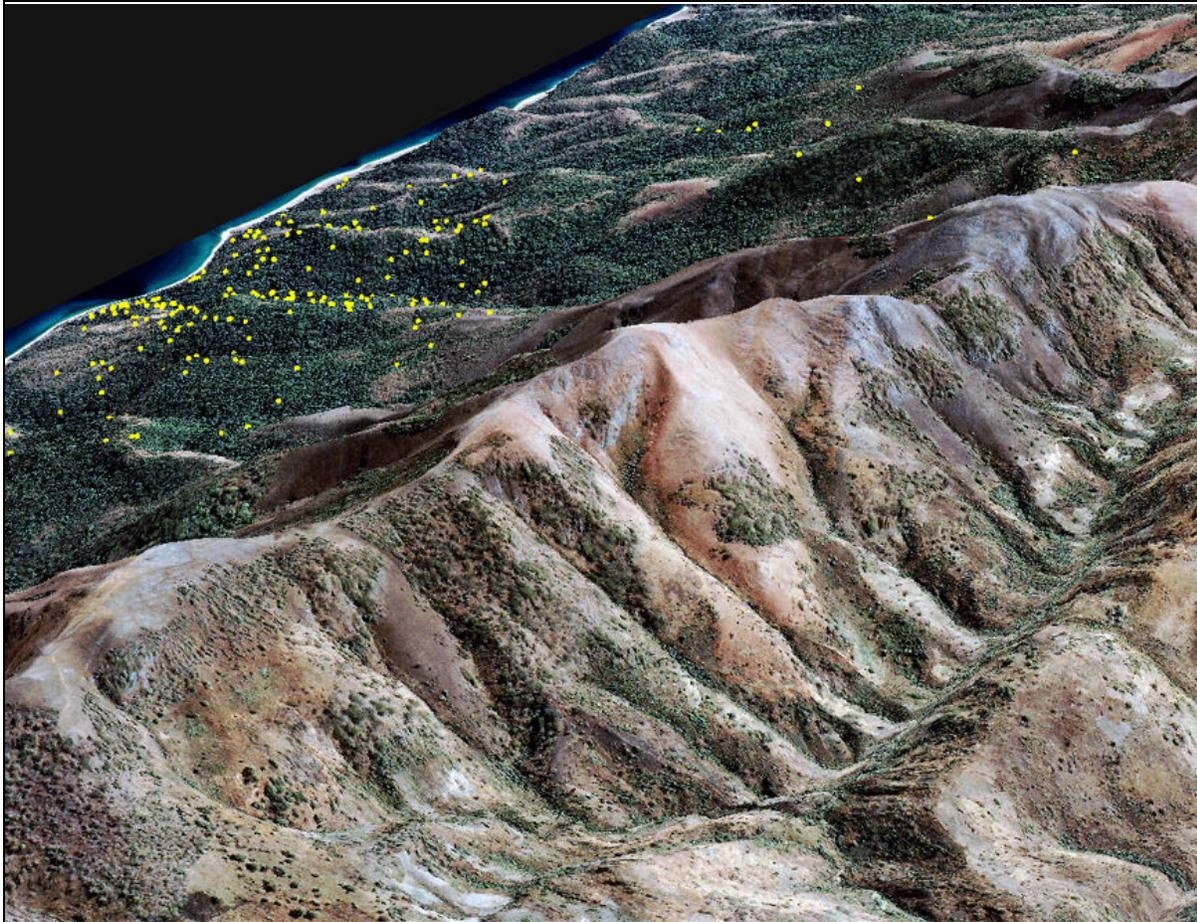


Figure 8. A 3D visualization of the rift escarpment and park boundary towards the Lake Tanganyika. Distribution of female chimpanzee Fifi feeding boots in 1998 (in yellow) are overlaid over IKONOS 1-m natural-color synthesized and sharpened image, draped over a digital elevation model.

There is very limited geospatial data infrastructure available for Kigoma. While some areas of Tanzania are more or less regularly mapped from airborne sensors, the most recent aerial photos available for Kigoma are from 1974 at 1:40,000 scale. Therefore our information products showing the extent of deforestation were met with great concern and served as a call to action for conservationists to restore and reconnect Gombe National Park with the remnant habitats in the region. For example, deforestation maps showed a drastic loss in forest cover in a forest reserve 5 km north of the park boundary (Figure 6). It has been thought that the reserve was home to a community of 30 chimpanzees. However, because of the complex terrain, difficult access and lack of resources, the Forest Department in Kigoma and conservation NGO's have been not aware of the reserve condition. Air reconnaissance and field surveys conducted by a local NGO confirmed that unfortunately the reserve is mostly gone and there are no signs of chimpanzees. We believe that such simple example of the usefulness of satellite data to provide relevant information played a role in making remote sensing part of all chimpanzee conservation projects planned in the near future in Kigoma region.

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