The Effectiveness of Protected Areas in Central Africa:
A Remotely Sensed Measure of Deforestation and Access

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ABSTRACT

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For protected areas that are extensively forested, the rate of deforestation is one indicator of the integrity of the protected area, and the effectiveness of protected area management. The goal of this study was to examine the deforestation rate in protected areas in Central Africa. Using remote sensing techniques, I measured levels of deforestation in 87 protected areas in five countries in Central Africa from 1990-2000. To examine possible causes of deforestation I also measured the level of access in these protected areas. A lack of access to remote areas can limit deforestation, forest degradation, and the resulting loss of biodiversity while decreasing development in rural areas. Access was defined either as natural (rivers) or constructed (e.g. roads or transmission lines).

The annual net deforestation rate for protected areas in Central Africa, among the protected areas studied, was 0.05%. This is lower than the annual rate of forest loss found by other studies for the entire Congo Basin forest. Based on the rates of deforestation in the entire Congo Basin and the assumption that protected areas are trying to avoid deforestation, this suggests that Central African protected areas may be effective safeguards against deforestation. Five of the 87 protected areas exhibited zero deforestation, while one forest reserve, Kaga Bandoro in the Central African Republic, showed a five percent net increase in forest cover since 1990. Cameroon's protected areas had significantly higher levels of deforestation than those in the other countries in

Central Africa. Within protected areas in each country studied there was a similar level of reforestation of 5%. Deforestation in a 10km area around protected areas was not significantly higher than that found within the protected areas. Protected areas that border other protected areas had significantly lower levels of deforestation than protected areas that were isolated from each other.

The increased disturbance caused by increasing access to the forest seems to be of an ephemeral nature, initially resulting in forest loss, but leading to reforestation. There was no difference in deforestation rates when a road or river bordered a protected area, or crossed through a protected area. Only the density of roads or rivers had an effect on the deforestation rates. The secondary impacts of human use on both the forest structure and the wildlife inhabiting the forest are likely to be detrimental, and worthy of further study.

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DEDICATION

To my family,

to those that share my blood and those that share my life

I am eternally grateful for your presence.

Introduction

Protected areas are defined by the IUCN as “an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means” (IUCN et al. 1994). This broad definition leaves a lot of room for interpretation by governments and non-governmental organizations (NGOs) in their pursuit of conservation. Determining the effectiveness of this conservation was the initial goal of this thesis and directed the research that followed.

Today there are over 100,000 protected areas, many of which are the focus of conservation efforts for an entire country or region (UNEP 2003). There are many different categories of protection and management to guide the conservationists toward their goals, from sustainable use areas that allow limited resource extraction to strict protection that enables research of endangered species (IUCN 2002). I chose to look specifically at protected areas because they are discrete areas where much conservation work is done, and a great deal of conservation policy focuses on them (Balmford et al. 2003; Cabeza & Moilanen 2001). Chapter one of my thesis discusses the different ways protected area effectiveness has been examined.

I was interested looking at the different ways the effectiveness of conservation was evaluated. Several possibilities that have been examined include looking at the influence of management (Hockings & Phillips 1999), funding (McKinney 2002), the number of guards and wildlife persistence (Brashares 2003; Brashares et al. 2001). Protected areas in developed countries had the most research done about their effectiveness with individual governments being accountable for their protection

(Cameron 2006; Wiersma & Nudds 2009), but I looked for a region of protected areas that had been less thoroughly studied and in need of some baseline research.

I wanted to look at conservation with Central Africa because it has a large intact forest with many protected areas, and is less studied than the Amazon. In 2002, just before I started graduate school, Gabon had announced they were formally creating 13 brand new protected areas, conserving over 10% of their forest (Quammen 2003). It seemed like a good time to investigate how protected areas could be evaluated, and potentially improved. Another idea that contributed to studying this particular system was DeFries et al.'s (2005) paper on the increasing isolation of protected areas in tropical forests as increased levels of deforestation left the protected areas surrounded by a matrix of human influence (DeFries et al. 2005). This paper only used a few protected areas from Central Africa, and it seemed important to add their hundreds of protected areas to the discussion of isolation, and added deforestation as a way to measure effectiveness of protection.

Deforestation can be used as a surrogate for effectiveness of protection, with less deforestation equating to stronger effective conservation. Satellite images over the Congo Basin Forest are relatively easy to obtain from Google Earth™ and recently declassified Landsat images, specifically Landsat 4/5 and 7, are available on the internet.. However, satellite images do not, and so far cannot, determine an empty forest (Redford 1992). This is the problem of having a forest with an intact floral ecosystem bereft of wildlife left. Satellites currently cannot pick up the animals within a forest, though combining deforestation research with on the ground monitoring of wildlife may give a clearer picture of a forested protected area's health. While an intact forest is difficult to observe from afar, it can be certain that a cleared forest no longer provides habitat for the same wildlife that used to depend upon it.

For Chapter Two, I first looked at the deforestation rates within protected areas in six countries – Cameroon, Central African Republic, Congo Republic, Democratic Republic of Congo (DRC), Equatorial Guinea and Gabon. The Congo Basin is tropical rain forest that begins along the African coast and spreads inland. This proximity to the coast meant cloud cover limited the scope of my research. Nearly half of the protected areas and the entire country of Equatorial Guinea were eliminated from the study due to high levels of cloud cover (above 15% covered). This probably leads to a conservative estimate of deforestation due to the influence of forests on the microclimate that creates clouds (Makarieva et al. 2006). Once the images were classified, they were input to GIS software and broken down by their respective protected areas, from the World Database of Protected Areas. Looking at deforestation in 87 protected areas in five countries, I found a low level of net annual deforestation 0.05% which is a bit lower than deforestation levels found by other studies for the Congo Basin as a whole (Achard et al. 2007; Zhang et al. 2005), though given the varied methods each study used, comparisons are difficult. DRC and Gabon had almost zero net deforestation due to high levels of reforestation.

Protected area units (PAUs) provided better protection against deforestation than isolated protected areas. I've defined isolated as not adjacent to other protected areas. They might be surrounded by forest, but they are not bordering another protected area. PAUs had mixed levels of management and IUCN categories, and were not generally managed as a group. I controlled for the size of the larger PAU, and it still had lower deforestation rates than isolated protected areas. Isolated protected areas had higher rates of deforestation, but it was not clear what caused these differences.

Some of the variables that I examined were found to have no statistically significant differences in deforestation rates – which can sometimes be as telling as major differences. For the IUCN management categories, which encompass a range of human use allowed within different categories, I expected that greater use would correlate with increased levels of deforestation, but the category assigned to a protected area had little effect on its deforestation rate. It seems that the least disturbance (little deforestation and little reforestation) did occur in the most protected areas with the most protection, but low deforestation also occurred in areas with high human access, with the most deforestation occurring in areas with moderate human use. Another issue I examined was how long a protected area had been gazetted (formally designated), which had no effect on its deforestation rate. The next step was to examine a possible cause, and future threat to protected areas, access via roads, rivers, and transmission lines.

There has been extensive research on how wildlife responds to the presence of roads, with many species actively avoiding roads (Blake et al. 2008; Laurance et al. 2006). Work by Laurance et al. (2006) showed that duikers and elephants avoid roads and Blake et al. (2008) found large roadless areas attract elephants; as the distance to a road increases, so does the abundance of wildlife. So in addition to dividing populations of wildlife, the presence of roads can decrease the available habitat for wildlife. But I was also interested in what increased access does to the deforestation rates of protected areas.

In Chapter Three, I found that the roads within and around protected areas lead to more deforestation along them than in the protected area as a whole, but on average protected areas with roads did not have higher levels of deforestation than those without roads. Conversely, along rivers and transmission lines the reforestation rate was significantly higher. Ultimately, it was the density of roads that mattered most, not the total number of miles within the forest. The increased density of roads lead to higher deforestation, but the quality of forest change could not be measured.

The ephemeral nature of rivers in Central Africa means that in cyclical drought and flood years, the forest could regenerate enough to appear on a satellite image the same as an older forest, though its species and habitat suitability might not be comparable. Transmission lines are not a strong cause of deforestation, but seem to be abandoned to regrow once installed. Roads aren't yet a major deforestation problem, but might be once the density reaches a certain threshold, or if they become permanent fixtures by being paved and regrowth along them does not continue.

For the final Chapter, I worked with a colleague to examine bushmeat in a market in Northern Congo as a possible measure of conservation effectiveness. Bushmeat, wild caught meat, is the source of protein for most people in Central Africa (Milner-Gulland & Bennett 2003). Some of it is harvested sustainably for local use and some as part of a livelihood to earn an income, as well as to eat. We examined the 39 different species brought into the Ouesso market over the summer of his research. He tracked the techniques used to catch bushmeat, mostly duikers, and where the meat was coming from.   Ouesso had many routes into and out of the marketplace that brought bushmeat to the Ouesso market and then into Brazzaville, the capital city of the Republic of Congo.

Bushmeat was brought in by hunters on the road and Sangha River, on logging trucks and on foot. The biggest limitation of the study was a measurement of the reach of the hunters to determine sustainability of the surrounding forests.

In summary, deforestation can be used as a surrogate for effectiveness of conservation efforts. The deforestation rate in protected areas in Central African protected areas is low, which is good for conservation in the future, but access does have a small effect that will likely grow as industry and human populations pave roads around protected areas and the presence of tourists requires paved roads to and inside protected areas. However, the effects of access on the wildlife of the protected area cannot be overstated. Bushmeat, obtained both legally and illegally threatens protected areas and increased roads only enables more hunting.

This work is only a small measure of effectiveness. It could help improve the overall usefulness of other studies, if researchers could incorporate these results into measures of funding, guards, monitoring, and management, as other measures of effectiveness. Quantifying carbon stocks for sequestration and avoided deforestation uses will contribute to carbon policy, particularly for the Congo Basin as the Kyoto Protocol is renegotiated. The techniques I used can be repeated, with even great precision in other areas due to greater availability of high-resolution images in some regions like the Amazon. As the technology improves, so will an understanding of deforestation in Central Africa.

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Chapter One

Effectiveness of Protected Areas in Central Africa

Introduction

Protected areas are a central part of the global strategy to protected biodiversity and ensure the sustainability of services that natures provides to people. The 2003 World Parks Congress reaffirmed the global commitment to protected areas and national parks as a means of conserving habitat and wildlife and called for a new approach to conservation that incorporates the needs of local communities and indigenous peoples (IUCN 2005). More recently, the 2010 Conference of the Parties to the Convention on Biological Diversity amplified this global commitment, increasing targets from 10% to 17% of terrestrial areas (COB 2010). While the reasons for protection may vary, all parks have a shared focus – protecting resources for the future.

The declaration of a protected area, however, says little about whether that protected area is managed effectively, or whether it is achieving its goals and objectives. The effective management of protected areas will depend on many factors: political will to fund and manage the protected area; the resources (human, financial) to address the threats to its integrity; and the attitudes and the acceptance of the protected area by local and indigenous communities may all contribute to the success of protected areas in meeting their ecological and social objectives (Alcorn 1993; Hackel 1999; Kremen et al. 1999; Tear et al. 2005). Park managers often face problems meeting their goals (or even clearly defining their objectives). Hence, having clear goals and objectives for protected areas, and measuring the management of these lands against these goals and objectives is critical to evaluating the effectiveness of a protected area, or a system of protected areas.

The literature that examines how one should measure the effectiveness of protected areas is scattered over several areas of study including' spatial priority setting (Reddy & Davalos 2003), reserve design (Wiersma & Nudds 2009), strategic planning (Burgman et al. 2005; Rodrigues et al. 2004), landscape ecology (particularly aspects of spatial persistence of landscape structure) (Baum et al. 2004; Caro et al. 2009; Koh & Sodhi 2004), and species conservation (Koh & Sodhi 2004; Stokes et al.). In addition, understanding the threats to the protected areas is a crucial part to understanding effectiveness. The literature on threats and threat remediation overlaps with, but is often distinct from, the discussion of park effectiveness (Aleksandrova et al. 2005; Struhsaker et al. 2005; Wilson et al. 2005).

One of the reasons that effectiveness literature is so scattered is because the term "protected area" covers a wide range of landuse types (Hockings 2000). The World Conservation Union (IUCN) defines a protected area as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN et al. 1994). However, this broad definition is further differentiated by the IUCN in their definition of seven management categories of protected areas, ranging from Strict Nature Reserves from which all human activity is excluded (in principle) to Managed Resource Areas which provide limited recreation and resource extraction activities to people (IUCN 2002; IUCN et al. 1994). The less strictly protected areas tend toward goals of species and landscape protection but all human use of the area to observe these protected species and landscapes. As such, many protected areas are managed to include sustainable development and interactions with, and use by, local and indigenous peoples. Protected areas which include a management goal of sustainable use of resources encourage activities that often required increased access.

In Central Africa, many protected areas have been formally protected for decades Across the Basin, both inside and outside protected areas, the Congo Basin forest has remained relatively intact (Duveiller et al. 2008; Hansen et al. 2010) when compared to either the Amazon or Southeast Asia, the other two major forested tropical regions. This may be due, in part, to the relatively low population densities and hence reduced demands on the forest, in part to poor infrastructure, and the corresponding difficulty in accessing and exploiting the forests, or in part to strong conservation measures. The goal of this review is to examine the question: what factors influence protected area effectiveness in the Congo Basin?

Background on Central Africa

The Central African forest has high biodiversity and low human population pressure. Suchantke (2001) used plant and animal remains to hypothesize that before the last ice age the Central African rain forest extended from the west coast of Central Africa, along the coasts of Gabon, Cameroon and Nigeria and Angola, east through the Congo River basin to the east coasts of Tanzania, Mozambique and north into Sudan (Suchantke 2001). The last ice age pushed the forest into small pockets of refugia, which have since expanded into the current extent of forest covering less than a third of its previous range (Suchantke 2001). The biogeographical history of this area, as well as its relatively low human population density, has allowed a great diversity of large mammals to survive to the present day. It has been hypothesized that the presence of these larger mammals in

Central Africa has led to a functionally different rain forest ecosystem than its Amazonian counterpart due to different pressures from herbivory and human hunting techniques (Cristoffer & Peres 2003), though the hypothesis fails to address the differences with the Asian tropical forests which still contain large mammals.

The Central African forest is clustered around the equator, stretches from the ocean to the mountains, and has a generally warm climate with short seasonal dry periods where rainfall decreases to only 50-100mm/month. The forest floor is bereft of nutrients and contains only a thin humus layer resulting in germination usually occurring within either a decaying tree or within dung piles (Blake & Fay 1997; Suchantke 2001). There is often a patchy blanket of an herb family, *Marantaceae*, which can be found in both the understory and also in open clearings (White 2001). According to White (2001) these *Marantaceae* forests can support four times greater mammalian biomass than a bare understory as it provides an important food source during times when fruit is scarce. The forest canopy is made up of trees whose seeds are dispersed by fruit, such as *Gilbertiodendron dewevrei*, *Chrysophyllum* sp. and *Scagoglottis gabonesis*, that mast their fruit at different times of the year and are important in both monodominant and mixed forests (Babaasa 2000; Blake & Fay 1997). These complex forests have led to a complex arrangement of niches for many different animal species. Protecting these ecosystems and the species within them is the focus of many conservation efforts.

Effectiveness

Research to measure protected area effectiveness has been undertaken at varying scales and with differing emphases. Some researchers have attempted to evaluate effectiveness by examining the impact of protected areas on the persistence of species that the protected area, or network of protected areas, may harbor. For example, Newmark (1995) and Brashares (2003) examined species persistence in western North America and West Africa respectively. Newmark's analyses focused on a traditional island-biogeographical approach, and found that extinction was related to protected area size as well as the generation time of species studied (Newmark 1995). Brashares found similar results, but also looked at the effect of social organization on species persistence (Brashares 2003). He found that social species isolated in parks were less likely to persist, irrespective of body size or hunting pressure, than species in interconnected areas. While these data are important and informative, they do not examine the integrity of the protected areas itself or analyze the impact of the landscape matrix surrounding a protected area on ecological integrity or species persistence.

Woodroffe (2000) dealt with this issue by combining the concept of species persistence with a landscape level analysis that looked at human population density around protected areas as a surrogate for human impact; she did not examine the issue of landscape-level indicators of persistence. Her work shows that species persistence is related to the density pressure of people living around a protected area; increased density threats the persistence of large carnivores in East Africa. While examining the significant relationship between protected area size, average home range of individual carnivore species, and persistence, Woodroffe and Ginsberg (1998) showed that increasing home range size led to a need for larger reserves if persistence is to be maintained. Because they also showed that the great majority of mortality of species studied occurred outside reserves, their work suggested that protected areas must not be thought of in isolation of the matrix of human dominated landscapes that often surround them.

Studies evaluating the integrity of a landscape have been done in parallel with those examining the persistence of species focus but the two have rarely been considered together. Landscape level variables that have previously been studied include the abundance or diversity of wildlife preserved (Gustafsson 2002), the studies have also considered the size of the reserve (Parks & Harcourt 2002), the altitude and physical characteristics of the protected area (Hansen & Rotella 2002), the value of local involvement (Rao et al. 2003) and the economic status of the country itself (McKinney 2002). Each of these studies presents a piece of the overall puzzle that is the evaluation of protected area effectiveness at the landscape level. The matrix in which the park exists has also been shown to have a strong influence on the park and therefore its effectiveness (Hansen & DeFries 2007). Designing management to take into account the surrounding landscape can have a positive influence on the parks’ effectiveness.

Management

Management of the protected area can be crucial to limiting the influence of the human presence in and around a protected area. The number of park rangers (hereafter referred to as ecoguards to differentiate them from military or police guards) can have an effect on the maintenance of the protected area (Bruner et al. 2001). Bruner and colleagues found, through a self-assessment exercise, that the number of ecoguards correlated to “effectiveness” (as defined by Bruner et al. 2001 as lack of forest loss). Bruner et al. did not examine the further impact of the quality of protection by Scholte et al (2005) showed that educating and equipping protected area managers may be the best way to improve their success at their job (Scholte et al. 2005). Songer et al. (2009) found that improved patrolling and conducting wildlife surveys led to better protection of the wildlife in Chatthin Wildlife Sanctuary in Myanmar. They also found that in addition to increased ranger presence and activity, increased education, increased local involvement and infrastructural improvements led to less forest extraction (Songer et al. 2009). Thus, balancing the needs of the local people with those of the protected area improved effectiveness.

The importance of funding to parks effectiveness has a long academic history (see (Leader-Williams & Albon 1988). Funding to monitor the ecological status of the park, conduct research, and maintain infrastructure can also be very important to park persistence. Bruner et al. (2001) concluded that increased funding led to increased integrity and persistence of protected areas. While simplistic, it is also intuitively probable that by providing more funding and a more knowledgeable staff should improve protected area management. But a study done on the funding of parks around the world demonstrated that parks in wealthier nations tend to be smaller and less-well protected than parks in poorer nations (McKinney 2002), though the pressures of each region differed greatly. For example, many of the parks in the United States are very well funded, well patrolled, and well protected, but still degradation occurs. The Everglades National Park, which is a U.S. National Park, a UNESCO World Heritage Site, a Biosphere Reserve and a Ramsar wetland of international importance, suffers from hydrologic changes, species depletion, and invasive exotic species and has been given funds to improve restoration of the area (Brinson & Malvarez 2002). Thus, the management of this park was not necessarily improved by increased funding for management or guards or by raising its profile with global recognition because the threats to the ecosystem were well outside the boundaries of the protected area and other larger-scale change was needed to reverse the protected area degradation.

Protected Areas within a Landscape

In practice, conservation science has developed many ways of dealing with the interactions between the matrix and protected areas, although not by integrating them into the landscape, but rather by trying to prevent the matrix from interacting with the protected area in ways that lead to deforestation. One of these ways has been to create a buffer around a protected area. While this will likely lead to decreased impact on the protected area directly, it only marginally increases the area of protection. These areas within the landscape matrix of informal protection surrounding parks should be recognized as such and not just in their capacity to buffer the protected area, but as additional measures of protection within the greater matrix (Bhagwat et al. 2005).

Recognizing a gradient of habitat around a protected area rather than just defining it as part of the matrix can lead to better overall conservation effectiveness. However, a metapopulation analysis will only focus on one species at a time. It is not generally possible to examine many different species in one analysis unless they use the same habitat. While the patch-matrix models are improving and attempting to address how the matrix affects a variety of different species, they are only minimally helpful to conservation practice. To consider a protected area simply a patch of habitat in a sea of non-habitat makes little sense in areas without hard edges around the park. In parts of the

Amazon and the Congo Basin, protected areas are a proactive approach to conservation and are surrounded by contiguous habitat. To consider everything outside the protected area insufficient for wildlife would be a gross misunderstanding of the ecosystem.

Protected Area Access

In Central Africa, human populations and infrastructure are growing, and with them the potential threat to protected areas is also growing (Blake et al. 2008; Laurance et al. 2006). Roads and rivers can provide people with easier access to protected areas for extractive uses such as farming, logging, and poaching, and also make it easier to bring the products from these uses to market. The increased presence of roads in the Amazon Basin has led to increased levels of human access into previously intact wilderness. However, in developing countries such as those found in Central Africa, roads and electricity lines (known as linear infrastructure) are often built through large contiguous forests as human populations become linked (Laurance et al. 2009). Some development of roads in protected areas is necessary for adequate monitoring and management, but these roads may also indirectly contribute to an increase in the rate of deforestation within the protected area. Roads and trails are also integral to tourism, from which many protected areas derive funding and support for conservation efforts. The need to ameliorate the effects of increased tourism, which necessitate roads or trails, will often be overshadowed by the need to monitor biodiversity, but tracking deforestation could potentially assist with both conservation goals (Davenport et al. 2002).

Roads in Central Africa produce direct effects such as deforestation and habitat loss, habitat fragmentation, impediments to animal movement and road-kills (Forman et al. 2003). Creating a single road removes only a small portion of forest habitat, but cumulatively road creation is not an inconsequential conversion of potential wildlife habitat (Forman et al. 2003). Many roads in Central Africa are created using bulldozers, simply knocking over trees until a path several dozen meters wide has been created (Wilkie et al. 1992). While infrequently paved, any path that is maintained, even by infrequent traffic, will be used to more easily access the forest. The resulting habitat loss and forest fragmentation are among the greatest threats to most endangered species across Africa (Brashares et al. 2001; Ewers & Didham 2006). Habitat degradation, while not a direct loss of forest, does change the available habitat and occurs with greater frequency along roads (Buchanan et al. 2009; Forman et al. 2003).

The indirect effects of roads are often more substantial and less easily elucidated than the direct effects. One of the most significant interactions between land use and roads around protected areas that has the strongest indirect effects occurs when logging companies begin to extract timber. In Gabon, it has been estimated that selective logging removes only 10% of the canopy (White 1994), but this does not take into account the forest loss necessary to construct a road to remove these selectively logged trees which removes more forest, and increases hunting access into the forest. Logging concessions, areas given by the state to a company for extractive purposes, are not usually given within protected areas. In the past, concessions have been granted within protected areas in both Cameroon and Gabon (GFW 2001), but today they more often border protected areas (e.g. Nouabale Ndoki National Park in Congo Republic and the surrounding Mokabi logging concession (Blake et al. 2007)). Logging within the landscape, even if not within a protected area, opens up access to the forest by creating roads to bring equipment in and timber out (Roy et al. 2005; Wilkie & Carpenter 1999) as well as increasing access to the forests on either side of the road (Pfaff et al. 2007). To transport timber out of the forest, roads must be created, felling more trees, and camps and other infrastructure are also created.(Kasenene 2001) Concessionaires (companies given the rights to log a particular area of forest) are often required to set up and maintain a roads system locally (Karsenty et al. 2008). In the Lobeke region of Cameroon, timber company road systems have created a well-armed poaching network (Curran & Tshombe 2001) that leads to further indirect effects, specifically a bushmeat trade. Bushmeat is then sold along this route to trucks heading to market (Bowen-Jones & Pendry 1999; Mendelson et al. 2003).

While it is not practical to stop logging in many places, there are measures that could be put into place to lessen the effects of logging. These include checking logging trucks for illegal bushmeat along their route (Draulans & Van Krunkelsven 2002) or preventing logging roads from being maintained after logging has ceased (Poulsen et al. 2009). Poulsen et al. (2009) studied the bushmeat trade in five logging towns in Northern Congo, and concluded that the permanent urbanization of frontier forests left by logging companies posed the greatest threat to biodiversity in the region (Poulsen et al. 2009) Wildlife populations within protected areas are threatened by increased roads, as they allow increased access for hunting (Clayton et al. 1997; Wilkie et al. 2000), and the lack of roads will only improve the condition of wildlife (Hart 2001; Wilkie & Morelli 1998). Animal populations outside a protected area will be captured alive for the pet trade or killed for the bushmeat market (Milner-Gulland & Bennett 2003). When this is done at unsustainable levels, animals from inside a protected area will often move to available habitat, further exacerbating population declines. Roads that border a protected area can provide access for poachers to hunt animals inside the protected area and export them to markets outside the forest. A road created for the oil industry outside a protected area in Ecuador led to the development of a wild meat market (Suarez et al. 2009).

Bowen-Jones & Pendry (1999) provide recommendations for decoupling the economic benefits of low impact logging with the costs of illegal hunting, such as monitoring trucks at check-points to be sure meat is not being illegally transported, as well as random sweeps through markets by officials checking for illegal meat. Cameroon has a relatively well-developed set of roads which provide access, but the police force in Cameroon also attempts to enforce some of the species protection laws by monitoring markets and policing the transports. Because of the strong protection in Cameroon, the illegal bushmeat trade is pushed into Congo where such levels of protection or legal enforcement is more difficult (Hennessey & Rogers 2008).

In general, strong management has balanced the effects of increased access with strong protection to provide a sanctuary for wildlife, such as Yellowstone or Kruger National Parks. However, the level of disturbance from tourism can become a problem for wildlife (Crist et al. 2005; Sindiya 1984). The local people will often benefit more from a national park than from a wilderness area as there is more opportunity for tourism revenue and employment (Adams & Infield 2003), however, the protection is usually higher around a national park, thus restricting local use of any resources from within the park. This balancing act between benefits and costs has become the focus of much study on the impact national parks have on local people from both a conservation planning and anthropological perspective (Bauer 2003; Brandon 1992; Stolton & Oviedo 2003).

Roads can provide access to introduce alien and potentially invasive species, both within and outside protected areas (Pauchard & Alaback 2004), which can have detrimental effects on the indigenous flora and fauna. The introduction of predators or disease can also have unknown consequences to the protected area's biodiversity. In parts of Gabon, logging roads have helped speed the invasion of exotic and destructive species (Walsh et al. 2004).

In addition to roads, rivers in Central Africa act as a form of transportation and as a means of accessing the forests. The well-known Congo River, as well as smaller navigable rivers, can provide access for moving harvested timber or moving bushmeat to market (Hennessey & Rogers 2008). The Congo River watershed reaches into thirteen countries in Central Africa, and is a source of navigable rivers (Singh et al. 1999). Protected areas should be safe from the indirect effects of increased access such as logging and hunting, which often occur nearby and can have lasting effects on the sustainability of the protected area populations.

Threats

Global extinction drivers, such as overexploitation, habitat destruction, and climate change, do not act in isolation, but often interact with each other causing further species loss and land cover change. The megaherbivores of Central Africa are threatened by each of these drivers, although some more directly than others. In much of the Congo Basin, bushmeat is the primary source of protein (Wilkie & Carpenter 1999). There have been many different studies of bushmeat in specific markets (Apaza et al. 2002; Fa et al. 2002; Hart 2000; Hennessey & Rogers 2008; Mendelson et al. 2003) as well as examinations of the global impact and issues surrounding the bushmeat trade in general

(Milner-Gulland 2002; Milner-Gulland & Bennett 2003; Robinson & Bennett 2002; Rowcliffe 2002; Tomlinson et al. 2002). The bushmeat trade is the biggest threat to large mammals in Central Africa, even though most of the species are protected by law (Wilkie et al. 1992; Wilkie & Carpenter 1999). However, much of the unsustainable practices surrounding the bushmeat trade are actually secondary effects of a different threat – habitat destruction by logging (Wilkie et al. 1992). As discussed above, access to the forest by creating roads to bring equipment in and timber out can lead to species loss and hunting (Wilkie & Carpenter 1999) as well as the loss of habitat through destruction or degradation. Human encroachment into the edges of reserves and fragmenting populations has different effects on different species, and can eliminate habitat as people settle in villages within a protected area.

The other major threat facing this ecosystem, as well as the rest of the world, is climate change. The Intergovernmental Panel on Climate Change (IPCC 2001) predicts that tropical Africa could experience 5-20% increase in precipitation during the 21st Century. However, they also suggest that the frequency and severity of droughts that hit western Africa and the Sahel region north of the Congo Forest Basin could increase. The unpredictability of climate change makes it difficult to prepare management or conservation goals with its effects in mind, though knowledge of past climatic changes is helpful (Asner et al. 2010). The 15th Conference of the Parties to the Framework Convention on Climate Change (FCCC) in Copenhagen produced an Accord that describes the current global commitment to avoiding a global temperature increase, while understanding that developing countries like those in Central Africa, cannot commit to this without first committing to social and economic development and poverty eradication, while considering a low-emission strategy to do so (FCCC 2009).

While things like financial investment and patrolling effort, community-based involvement and management, etc. are all potential surrogates for measuring effectiveness, for many forested protected areas the simple measure of deforestation is both a direct measure of success and potentially an indirect measure for wildlife protection (the exception being the Empty Forest (Redford 1992)).

Deforestation

Deforestation is an important variable to examine for several reasons. Deforestation can often be a surrogate for conservation activities; it is relatively easy to measure from satellite images, and hence a large area can be broadly studied. From a research perspective, comparing deforestation rates can inform policy decisions for a large area. Several studies have looked at the deforestation in and around protected areas, looking at regions around parks and their changes over several decades (DeFries et al. 2005; Struhsaker et al. 2005). DeFries (2005) studied forest loss inside large, highly protected areas (IUCN Category I and II) that were forested when gazetted. This limits the size of their sample significantly, but their work does provide evidence to build on with a more comprehensive study, using control areas as well as protected areas to determine if protected areas have fared better than the surrounding area. DeFries' study only compares parks to themselves over two time periods, rather than comparing the protected areas to the entire matrix, not just the buffer around the park. Broader research on land-cover change provides much of the background information upon which to start discussing different types of land-cover change within and around protected areas (Zhang et al. 2005; Zhang et al. 2006). Understanding how the protected area is influenced by the greater matrix, particularly in terms of deforestation, has long been the subject of protected area network design, but also fails to answer the question of effectiveness.

Most of the work on land cover change at a scale similar to the Congo Basin has been done in the Amazon Basin, although the impact of protected areas on deforestation rates is infrequently taken into account. The work done in the Amazon provides examples of methodologies for using remote sensing (Alves et al. 1999; Arroyo-Mora et al. 2005; Fuller 2006), for road development (Arima et al. 2005; Asner et al. 2006; Locklin & Haack 2003), and other causes of deforestation (Armenteras et al. 2006; Fujisaka et al. 1996; Kaimowitz 1997). While the work in Amazonia is not a direct comparison to the work done in Central Africa, these studies provide methods for studying forest change with a similar level of development and threats. Land cover change has been studied in Central Africa, but generally at smaller scale. In Gabon, Laurance and colleagues (2006) studied the threats to forested areas, including encroachment of loggers and hunters into nature reserves (Laurance et al. 2006). In Cameroon, the laws to protect forested areas exist, but the areas are threatened due to lack of enforcement of existing laws (Mertens et al. 2001; Mertens & Lambin 1997; Mertens et al. 2000). These specific studies in Central Africa speak to the land cover change threats, but involve minimal comparisons between countries or between protected areas and other forested areas.

Humid tropical forests deserve our attention because demographic, economic and social changes continue to exert considerable pressure on forest cover and conditions in the region (Achard et al. 2002). While much of the work has been done in the Amazon, there are several organizations that try to measure land cover change across all the forested areas. Mayaux (1998) did an analysis of these different approaches. The European Community has done an analysis of the tropical forests called TREES (Tropical Ecosystem Environment observations by Satellite) based on 1km resolution data (Mayaux et al. 1998). The FAO has also done a Forest Resource Assessment nearly every decade since 1946 to assess forest change and presence of forest (Mayaux et al. 2006; Zhu & Waller 2003). Integrating their approaches with an understanding of protected areas and conservation goals would be helpful to predict future conservation needs in protected areas.

The Role of Protected Areas in Carbon Sequestration

Carbon is going to be the greatest pollution concern in the 21st Century. Finding ways to mitigate that pollution has been the concern of the Kyoto Protocol and its current round of renegotiations. The various Conferences of the Parties (COP) have discussed ways to develop a carbon market under the Clean Development Mechanism (CDM). Zhang and Justice studied the forested areas in Central Africa as source of reforestation and avoided deforestation (Zhang & Justice 2001). Continuing this work is important because it will show the areas that were deforested in the early 1970s and how that network of forested areas has changed through the present day. One of the things missing for these countries to become involved in the CDM is information documenting their deforested areas and the dates of clearing and regrowth (Baker et al. 2010). In addition, if the current policies regarding avoided deforestation are changed within the Kyoto

Protocol, as suggested by (Niesten et al. 2002), documentation on the current and previous states of protected areas will become crucial to allowing Central Africa to gain from their protected resources. The new UN Framework Convention on Climate change wants the historical baseline for developing countries forest inventory, and DeFries (DeFries et al. 2007) looked at the different ways monitoring can be done and its reliability. They provide different suggestions for improving further capabilities for developing countries. The most recent COP created the Copenhagen Accord which calls for assistance to developing countries at an increased level to support understanding how protecting carbon stocks and increasing reforestation will help combat increasing carbon in the atmosphere (FCCC 2009). Valuing the stocks of carbon sequestered will be the challenge for economists after ecologists and conservations determine how many acres of forest remain (Anonymous 2010).

Understanding the role management decisions can have on the protected area and the species is important when changing the management paradigm within a protected area in response to new threats like global warming (Cromsigt et al. 2009). Protected areas in the Congo Basin include tropical forests that can contribute to the sequestration of carbon, but the countries they are within will only benefit if a mechanism can be produced for a post-Kyoto treaty that takes into account the measures of protection (Griscom et al. 2009). The new Reducing Emissions from Deforestation and forest Degradation (REDD) projects are hoping to integrate all the different techniques for forest preservation in developing countries to encourage payment for ecosystem services provided by the forests both inside and outside protected areas (Busch et al. 2009; Phelps et al. 2010).

Tools for conservation

One of the reasons a landscape mosaic model has become easier to develop and use is the increase availability of tools such as remote sensing, the Geographic Information Systems (GIS) toolbox, and improved equipment for field data collection. Because these tools have been improving over the last several decades it is possible to analyze the temporal and spatial changes in the landscape with a certain degree of accuracy. In addition, with different methods to confirm data, the accuracy continues to improve (Bird et al. 2000).

Remotely sensed data, data collected from afar such as aerial photographs or satellite images, in combination with GIS tools have improved data collection for vast areas around the world. Instead of having to set up expensive field stations and hire staff to go out and measure vegetation, using several time series of satellite images, vegetation regrowth can be mapped to determine habitat availability throughout protected areas and the surrounding landscape(de Colstoun et al. 2003; Steininger 1996).

Remotely sensed images can also provide an enforcement mechanism, by determining if a protected area has been converted into agriculture or if human settlements have moved into the area (Laurence & Gascon 1997). As a method of protection remote sensing cannot prevent forest fires, but can determine where forest fires have occurred and monitor how the forest grows back (Dennis et al. 2005; Ravan & Roy 1997). These methods of helping to enforce the protection of the protected area come at minimal effort and a single set of images for an entire country can be analyzed at once by trained staff, creating a historical record of park protection.

Land use planning can be much improved with manipulation of remotely sensed data. The Human Footprint mapping has provided areas that are considered the “last of the wild”, which are the largest remaining pieces of land with minimal human impact (Sanderson et al. 2002). Planning to keep these areas minimally affected by careful land use planning could provide long term protection of these areas. This would not have been possible at a global scale before the human footprint analysis was done. At a smaller scale, large, luxurious homes are being built across the western U.S., and satellite images can assist with land use planning across the landscape to prevent these large open areas from being fragmented for homes and becoming unavailable to wildlife access (Polasky et al. 2005).

While the quality of remotely sensed data has improved, there is still a need to ground-truth much of the data to ensure accuracy, particularly of smaller changes made either through roads or small agriculture conversion (Nagendra et al. 2004; Wilkie 1994). However, used together with field research, remotely sensed data can provide improved estimates for where field research would be most productive and where more information is necessary to improve conservation work. This would assist field researchers in choosing areas to study, or to suggest areas for reintroduction of species based on GIS predictions of habitat availability. Models can become more spatially explicit by including carefully collected data and using GIS to evaluate those data.

In Africa, specifically, remotely sensed data have been used to determine baseline levels of deforestation across much of the Congo Basin Forest (Duveiller et al. 2008; Hansen & DeFries 2004; Zhang et al. 2005; Zhang et al. 2006). DuVeiller et al. (2007) sampled 10 x 10km squares every 0.5 degrees and found that certain areas designed as high priority conservation zones by the Congo Basin Forest Partnership underwent less deforestation between 1990 and 2000. Zhang et al. (2006) also looked at large scale change and the probability of that area remaining forested into the future. A few studies have even examined protected areas in Central Africa, though DeFries' study only used 12 Central African strictly protected areas (DeFries et al. 2005). All of these deforestation studies recommend using the data collected from remote sensing to better understand how the developing world can contribute to and help fight the global warming crisis.

Understanding the role management decisions can have on the protected area and the species is important when changing the management paradigm within a protected area in response to new threats like global warming (Cromsigt et al. 2009). Management effects could become problematic if rigid protection leads to over-crowding of species within an area, leading to the destruction of habitat (e.g. elephants in savannah parks) (Caro et al. 2009). The protected area management could create a paradox of protection, though clear management goals should prevent this.

Conclusion

With the most recent wave of extinction leading to a global loss of biodiversity, and over 102,000 protected areas around the world as part of the global equation to protect the remaining diversity, it is important to know whether or not protected areas actually contribute to protection. In Central Africa, in particular, this is a crucial moment; a time in which forests could be lost to growing human needs and potentially altered by a changing climate.

Protected areas might be the best way to save these resources, both for their local and global value. However, there are few methods that can assess the impact of protected areas at a scale that is meaningful, but using a metric that is sufficiently simple and transparent to enable analysis at a regional or global scale. Several different methods exist to measure effectiveness of individual protected areas. Some of these methods can show whether a particular species has been saved or an ecosystem conserved, or determine whether deforestation has increased. The data examining deforestation and reforestation rates could be harnessed as a surrogate for effectiveness of protected areas. The influence of these studies of conservation success have on the global warming crisis has yet to be fully explored but they hold potential for developing countries to contribute to solving the problem.

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Chapter Two

Deforestation in Protected Areas in Central Africa from 1990-2000 using satellite images and remote sensing

ABSTRACT

For protected areas that are extensively forested, the rate of deforestation is one indicator of the integrity of the protected area, and the effectiveness of protected area management. Using remote sensing techniques, I measured levels of deforestation in 87 protected areas in five countries in Central Africa. The annual net deforestation rate among the protected areas studied in Central Africa was 0.05%. This is lower than the annual rate of forest loss found by other studies for the entire Congo Basin forest. This suggests that Central African protected areas may be effective safeguards against deforestation and may mitigate the loss of biodiversity, although for wildlife direct harvesting may remain a serious threat. Five of the 87 protected areas exhibited zero deforestation, while one forest reserve, Kaga Bandoro in the Central African Republic, showed a five percent net increase in forest cover since 1990. Cameroon's protected areas had significantly higher levels of deforestation than those in the other countries in Central Africa. Within protected areas in each country studied there was a similar level of reforestation of 5%. Deforestation in a 10km area around protected areas was not significantly higher than that found within the protected areas. Protected areas that border other protected areas had significantly lower levels of deforestation than protected areas that were isolated from each other.

KEYWORDS Central Africa, deforestation, protected area, remote sensing, IUCN

INTRODUCTION

The World Conservation Union (IUCN) defines a protected area as “an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means”(IUCN et al. 1994). While the reasons for protection may vary, all parks have a shared focus – conserving resources for the future.

The 2003 World Parks Congress reaffirmed the global commitment to protected areas and national parks as a means of conserving wildlife and wild lands but demanded a new deal for protected areas and local communities and indigenous peoples (IUCN 2005). Similarly, the Aichi Biodiversity Targets of the Convention on Biodiversity (the “2020 targets”) stress an increase in terrestrial and marine protected areas (Target 11) as well as reaffirming the right of, and the need for, engagement by local and indigenous peoples in parks establishment and management (Targets 11, 14) (COB 2010).

Understanding a protected area’s effectiveness over time can help us understand its role in protecting biodiversity. The success of protected area management has been extensively studied as a proxy for protected area effectiveness (Abbot & Mace 1999; Bleher et al. 2006; Buultjens et al. 2005; Mayaka 2002; Mbile et al. 2005), and often includes analyzing the impact of the World Conservation Union’s (IUCN) management categories on the goals and objectives of parks management (Bishop et al. 2004; Hockings 2000, 2003). Some scientists also believe that the level of species protection should be the main goal of protected areas and have measured effectiveness based on species persistence within a protected area (Adams & Infield 2003; Blom et al. 2005).

Protected areas around the world have been criticized as insufficient for biodiversity conservation (Chape et al. 2005; Gaston et al. 2002). This criticism, while perhaps valid, is hard to substantiate because there are few ways to determine the effectiveness of protected areas at protecting faunal or floral diversity, or even for determining the integrity of forest cover. Within a protected area system, there are data that suggest that a comparison of successful and unsuccessful protected areas can help improve the function of the entire network of protection (Gaston et al. 2008). But many protected area systems often do not have specific goals and targets, or adequate indicators to measure these goals and targets where they exist, making it difficult to evaluate the effectiveness of a protected area network. Even a simple goal such as protecting biodiversity can be interpreted in many ways depending on the targets chosen as surrogates (Lawler et al. 2003; Rothley et al. 2004; Sergio et al. 2006). The way in which value is placed on things like total species representation, redundancy, taxonomic uniqueness, or population size and persistence probabilities for a species can be protected area goals. Diversity-focused targets may also not overlap well with conservation aimed at more utilitarian goals, such as the preservation and amplification of ecosystem services or the extraction of a particular resource such as timber (Abbot & Mace 1999; Bhagwat et al. 2005; Wright 2005). Hence, both the lack of goals and targets in some areas, and the multiplicity of targets and goals among those protected area systems that have them, makes comparison between and among protected areas within a region, or globally, a difficult task.

Targets must be linked to the landuse categories that a protected area encompasses. The categories are best described in shorthand by the IUCN classification system. The process of designating a protected area under one of the IUCN categories is the responsibility of the individual national government agency for protected areas. In addition to describing specific examples of assigning categories, guidelines for applying the categories have been published by the IUCN to help clarify what each of these categories should represent (IUCN 2002; IUCN et al. 1994). This has created an international standard for protected area designation, but categories are interpreted by each country and applied to national systems of protected areas (Ravenel & Redford 2005). Because of individual interpretation at the national level, this system still lacks precision in application (Ravenel & Redford 2005). Often, protected areas are created with different zones designated by different categories, with a strictly protected core area (Ia or Ib), surrounded by an area allowing more human access (IV or VI) and less strict protection, but managed as a single area (Bishop et al. 2004; Regan et al. 2000).

The use of a set of objective criteria that measures a universal conservation target allows a comparison of the effectiveness of a protected area, a national protected area system, or systems across a biome. Forest loss or gain has been used as a surrogate measure for looking at the effectiveness of forested protected areas (Bruner et al. 2001; DeFries et al. 2005). With increased attention to the value of tropical forests in carbon sequestration, the measure of forest loss (or gain) has both direct (climate change) and indirect (biodiversity, other measures of sustainability) values as a measure of protected area effectiveness (Blake et al. 2008).

Central Africa is under-represented in the deforestation research, with much of the focus on Central America and the Amazon, both inside and outside protected areas (Achard et al. 2007; Achard et al. 2002). Several studies have looked at global deforestation rates, particularly in tropical countries (Achard et al. 2007; Hansen et al. 2010). Studies that have looked at protected area deforestation focused on only strictly protected areas, IUCN Categories I and II (Bruner et al. 2001; DeFries et al. 2005). Bruner et al (2001) used questionnaires to collect date and DeFries et al (2005) used satellite images to look at the isolation of protected areas in tropical countries. Few data from Central Africa were included in these studies, so this study was planned to add to the deforestation data with specific focus on Central African protected areas.

Zhang et al. (2005) looked at deforestation across the entire Central African region using remote sensing but did not divide the analyses between protected and unprotected landuse categories. They found that an average of 0.12% of the forest in Central Africa was degraded annually between 1980 and 1990 (Zhang et al. 2005). Given this relatively low average level of deforestation (the Latin American mean annual forest loss is 2.2%, and 2.0% in Southeast Asia (Achard et al. 2002)), it is important to understand whether this deforestation is taking place within or outside protected areas.

Deforestation has secondary effects that can have an enormous impact on the effectiveness of protected areas. For example, commercial logging within the landscape, even if not within a protected area, opens up access to the forest by creating roads to bring equipment in and timber out (Forman et al. 2003; Wilkie et al. 2000). When an area becomes more accessible, permanent settlements will be established, increasing the potential threat to protected areas. Planning a road system, like planning land use, could create fewer negative interactions between a protected area and its matrix while still providing for infrastructure development for local communities. Deforestation affects wildlife within the forest, whether along the edges or in a fragmented forest (Pedlowski et al. 1997; Verburg et al. 2006; Waltert et al. 2005). The “empty forest” concept was well described as an overly hunted forest that remains intact while emptied of its wildlife (Redford 1992). While this would be nearly impossible to measure from the satellite images, but using deforestation as a proxy for wildlife presence has potential to aid conservation policy making.

Studying the area around parks is a common part of the study of protected areas and their effectiveness (Kintz et al. 2006; Maikhuri et al. 2000). In these studies, their authors found that the areas around reserves gain some of the protection provided by the core protected area, a kind of halo effect. The goal of creating a buffer zone around a protected area, such as the UNESCO Biosphere Reserves (UNESCO 2008), is to lessen the impact of human use on a core protected area while still providing for sustainable use of the area by local people. Studies have looked at the creation of such buffer zones for use by local people and their impact on core zones (Li et al. 1999; Maikhuri et al. 2000). Designated buffer zones, however, are often added later to increase protection to a core area, and might not be part of the same ecosystem as the protected area because natural boundaries, such as rivers or mountain tops, are often used as park boundaries (Mas 2005). Mas et al. (2005) discussed the likelihood that buffers of a protected area are not always ecologically comparable to the protected area. Many Central African protected areas use natural borders, suggesting that areas outside the protected areas may differ ecologically from the core zones. Hence, buffers may not have a rate of deforestation similar to the protected area if its underlying geological patterns create a different potential for forested areas.

The goal of this study was to examine the protected areas in Central Africa, and calculate rates of possible landcover change within them. Based on the rates of deforestation in the entire Congo Basin and the assumption that protected areas are trying to avoid deforestation, it is likely the rate of deforestation within protected areas will be low. The landcover changes I hypothesized are as follows:

1. The level of deforestation within protected areas will be lower than that found for the entirety of the Congo Forest Basin as measured in previous studies.
2. The 10km area around the protected area will have a rate of deforestation more similar to that found in the protected area than in the forest basin as a whole (halo effect of protection), but will have lower levels of reforestation than in protected areas due to a lower level of protection outside the protected area.
3. Protected area groups (contiguous protected areas) will have lower rates of deforestation than isolate reserves because connectivity and increased size should improve persistence of forest.

METHODS

Protected areas in this study (n=161) were drawn from the World Database on Protected Areas (WDPA) and covered six countries from Central Africa: Cameroon (48), Central African Republic (CAR) (20), Congo Republic (22), Democratic Republic of Congo (DRC) (38), Equatorial Guinea (11), and Gabon (22). Satellite images were used from the NASA Applied Research & Technology Project Office, Mrsid Landsat TM and ETM+ bands, all are in the Universal Transverse Mercator UTM WGS 1984. Further details about the original images (including rectification details) can be found at zulu.ssc.nasa.gov/Mrsid. Satellite images from 2000 were matched with 1990 images via ERDAS software layering techniques. The images were stacked and three bands from each image were layered (2, 4, 7). Due to the size of the images, they were not put into a mosaic but were evaluated individually around each protected area. Changes in landcover between these two time periods were then obtained using ERDAS software that calculates a pixel reflectance value for each image and then classifies the images with the difference in pixel values between 1990 and 2000 and creates a new image. This allows areas with changes in land cover to be made clear as the pixel values will differ from those in areas with consistent landcover over the 10 years. I used an iterative non-supervised classification process with a >95% confidence level.

Two hundred classes were distinguished and an individual examination of each class was done to further classify these 200 classes into eight sub-classes: deforestation, reforestation, forest, non-forest vegetation, cloud cover, water, developed land, and no data. Developed land included areas that were cleared and reflected as bare earth, so large unpaved roads and areas cleared for agriculture were included in the developed category. “No data” was an infrequent category, but if it was not possible to discern a landcover class, or small glitches in the satellite photo were present as streaks, they were classified as no data. Non-forest vegetation was an amorphous category that included riparian zones of scrub vegetation, areas that were neither agriculture nor forest, and anything that reflected as none of the other categories but was clearly vegetated.

Deforestation was classified when an area was forested in 1990 and no longer forested in 2000, while reforestation is the reverse, not forested in 1990 and forested by 2000 Net deforestation was calculated by subtracting reforestation from the deforestation rate. When this value is negative, it meant more reforestation than deforestation. Gross deforestation is simply the deforestation rate alone. When just deforestation is addressed, it signals gross deforestation.

The Congo Forest Basin, a rainforest ecosystem, has an exceptionally high average cloud cover due to the level of moisture and its proximity to the coast. Other studies of the region which utilized satellite images have chosen to only use data from cloud-free images (Achard et al. 2007). Some studies augmented their satellite images with aerial photography to see underneath the clouds (Munoz-Villers & Lopez-Blanco 2008), but this was not possible for this study. Other studies used images with some cloud cover though with little description for why a certain level was used (Achard et al. 2002; Duveiller et al. 2008; Hansen et al. 2008). I chose to limit my analysis to those areas that had less than a maximum level of 15% cloud cover. I did elimination analyses to determine what happens to deforestation rates with the presence of clouds, and there was a substantial decline above 15% cloud cover. I looked at each protected area rather than entire images because some images were more than 15% covered, but individual protected areas within that image were not covered by clouds at all. This reduced the number of protected areas in the study to 87, and eliminated Equatorial Guinea as a study country. Given the small amount of missing data caused by cloud cover, the deforestation rates are a conservative estimate.

To understand the possible changes in deforestation at the border of the protected area, I analyzed data from an area 5km inside from the boundary and outside 5km from the boundary. When the entire protected area was less than 10km across, a swath 2.5km from the boundary was used for the inside analysis. Bruner et al. (2001) used a 10km distance from the boundary outside the protected area, rather than 5km, so to facilitate comparison with that study, a 10km margin from the boundary outside the protected area was also explored. In this study I use the term buffers to describe the region 10km from the border of the protected area. These buffers are substantially different from the designation of a “buffer zone” as it is an exact distance from the protected area border at all points, and “buffer zones” are often a different shape than the core area. The buffers in this study are exactly 2.5, 5, or 10km from the protected area border all the way around the protected area. Collectively, the core protected area, the 2.5, 5, or 10km “buffer” are referred to as protected zones.

The shape of the protected area was also considered as to whether it correlated with rates of deforestation. A simple measure of shape = perimeter/area was calculated for each protected area and a correlation analysis was done.

To calculate the annual rate of deforestation in each of the protected areas (Puyravaud 2003), I used the formula

$$r = 1/(t_2-t_1) \ln (A_2/A_1)$$

r = annual deforestation rate; t_2 = time 2 (year 2000); t_1 = time 1 (1990); A_2, and A_1 are the forest cover at t_2 and t_1 respectively. To calculate the average annual rate of deforestation for the entire Congo Basin protected areas as well as for protected areas in individual countries, a weighted average was done to account for the varying sizes of protected areas. To see a comparison of annual deforestation rates calculated using formulas for r, P, and Q, see the Appendix. Except where expressed as an annual rate of deforestation, all rates are considered over the ten-year study period.

To validate the results, since I used an unsupervised classification, I chose 1801 random points from each of the static, presumably unchanging categories – forest, clouds, water, non-forest, and development. The points were spread across the entire region and were areas of pixels of each that clustered in a minimum 3x3 size. Then each of these points was compared to its location in Google Earth to verify the result with the same or higher resolution images. For the change categories – deforestation and reforestation, 595 random points were chosen with similar cluster size, but instead of Google Earth, I reexamined those points in the 1990 and 2000 images again to confirm the change in forest cover. The results were put into a confusion matrix (Foody 2002; Inzana et al. 2003). Since clouds were both a permanent fixture and a changing feature, I did a second confusion matrix removing the pixels with clouds. The user’s accuracy and the producer’s accuracy have also been calculated. The user’s accuracy measures the probability that a pixel classified on the map/image actually represents that pixel on the ground, represented by Google Earth. The producer’s accuracy indicates the probability of a reference pixel being correctly classified (Inzana et al. 2003). The accuracy results are found in the Appendix.

There were a number of protected areas that bordered other protected areas, and a significant difference was found between “isolated” protected areas and those connected to other protected areas. Areas were deemed “isolated” if they did not border another protected area – though they could still be surrounded by contiguous forest or even agriculture and still be deemed “isolated”. To examine this result, the groups of protected areas were re-analyzed as a single unit in ArcGIS, designated a Protected Area Unit (PAU). This created 12 new protected area units, made up of 36 protected areas. The most common unit was made up of 2-3 protected areas, with the largest contiguous group of nine protected areas in a single unit. There were a total of 69 protected area units including single protected areas. There were six protected areas that became part of protected area units that were not included in the original study due to high levels of cloud cover. The new protected area units all fell below the 15% cloud cover limit, except one which was excluded from the PAU analysis, for a total of 68 PAU. A buffer area, 10km from the border of the new protected area unit was analyzed. This removed the interior buffers around individual protected areas. PAU that consist of only one protected area are described as isolated protected areas, which only describes their proximity to other protected areas and does not indicate that they are more or less isolated from human settlements or access points.

For the details about each protected area, I used the databases provided by the World Conservation Monitoring Center (WCMC)(WDPA 2005). This included a date the protected area was designated which I grouped into three categories: before, during and after the study dates of 1990-2000. Also included in the WCMC data was the IUCN category assigned to the area and the general designation of the area (e.g. faunal reserve, hunting area, private park, forest reserve, etc.). For this study I examined deforestation in protected areas within Central Africa representing various IUCN categories, including undesignated reserves. The IUCN categories assigned to the protected areas in this study were showed a similar pattern of distribution among categories as the global distribution: Ia (2), Ib (1), II (20), IV (13), VI (14), and unassigned (36). I used multiple sources to establish the status of a protected area; all protected areas that were unassigned to a category were considered unassigned by all sources (Chape et al. 2003; WDPA 2005). The protected areas included in the study covered only four of the six total categories, Ia and b, II, IV, and VI. Category II – National Park, made up the largest category under protection with over 30% of the global area protected (Davey 1998; IUCN 2003; IUCN et al. 1994). Category VI – Managed Resource Protected Area, made up the second largest block of protected areas, with Category IV - Species Management Areas third. These three categories made up over 75% of the designated protected areas, demonstrating a very uneven distribution of categories and, ultimately, biodiversity protection. However, on a scale of human use and management levels, the categories of the protected areas in the study are more evenly distributed, from low management/high biodiversity protection, to high management/low biodiversity protection.

RESULTS

Across Central Africa

There were no significant differences in total deforestation inside and outside the protected areas ($p<0.54$) (Tables 1 and 2). There were also no clear examples of deforestation increasing outside protected areas as might be expected if protected areas provided increased protection against deforestation. There was a significant difference in deforestation rates within protected areas among countries ($p<0.03$) with Cameroon having the highest rate of deforestation and the lowest in Gabon. When examining the annual deforestation rate inside the protected area (rather than the total deforestation), Cameroon also had the highest rate, 0.019, though this result was not significant ($p<0.10$). The annual rate of net deforestation (which includes the rates of reforestation) showed that Cameroon had the highest rate. All the other countries had reforestation rates that outpaced their deforestation rates (See Table 3).

The protected areas in all countries were significantly influenced by the presence of another protected area on their borders ($p<0.02$). The presence correlates with a decrease in deforestation rates. The same pattern of decreased deforestation holds true within the 5km and 10km distances from the protected area border ($p<0.01$ and $p<0.01$, respectively), and the 2.5-5km zone within the protected area ($p<0.04$) for those protected areas that are contiguous with other protected areas (See Table 4).

To better understand the influence of contiguous protected areas, I examined protected area units (PAU), with similar outside buffer areas at 5km and 10km from the new contiguous border and 2.5-5km zone inside the boundary. The differences between deforestation rates between inside and outside a PAU were even less pronounced ($p<0.90$) than when the protected areas within the PAU were all treated individually. The difference in deforestation rates between countries was also insignificant ($p<.17$), although the same pattern occurred with the highest deforestation rates in Cameroon. There was a decrease in the deforestation rate between isolated protected areas and protected area units although not significant ($p<0.11$).

I examined the effect of the date a protected areas was gazetted on deforestation and found no significant difference ($p<0.45$) in deforestation between areas gazetted before ($n<37$), during ($n<24$) or after ($n<7$) the 1990-2000 study, or with an unknown date of gazettement ($n<17$). Also, I found no statistically significant difference in deforestation rates among IUCN category designations ($p<0.28$). Even when combining category Ia and Ib, and removing the undesignated protected areas, there is no significant difference in deforestation among categories.

The shape of protected areas was also considered. Several protected areas (Okapi Faunal Reserve and Ituri Forest Reserve) are “necklace” reserves of smaller patches managed as a group and others are much larger, but long and narrow. Looking at the ratio of perimeter to area as measure of core and edge (perimeter/area) (Schonewaldcox & Bayless 1986) there was no correlation between the shape and the annual deforestation rate ($p<0.55$) nor the annual net deforestation rate ($p<0.67$) across the Congo Basin.

There is another measure of shape that is independent of protected area size put forth by Timmons and Williams, based on a perfect circle as the ideal shape for a protected area (Timmins & Williams 1991). Their formula is $\text{perimeter}/(200 * (\text{area} * 3.14)^{0.5})$. While this shows a slightly stronger correlation with annual deforestation rate ($p<0.15$) and annual net deforestation rate ($p<0.23$) it is still not a significant correlation.

Within Country Analyses

All of the Cameroon protected areas study sites (protected area, 2.5km, 5km, and 10km buffers) showed only net deforestation, In comparison, in the other countries protected areas, and their buffers, showed net reforestation (negative deforestation). Within the Cameroon protected areas, there is a significant difference between rates of reforestation and deforestation ($p<0.002$) with total deforestation nearly four times higher than total reforestation (11.8% vs. 3.3% over 10 years, Table 5).

Gabon has the lowest rate of gross deforestation, but because of persistent cloud cover the sample size ($n=2$) was too small to statistically compare with other countries or to do a within country analysis. The other three countries (CAR, Congo, DRC) have nearly the same average rates of deforestation and reforestation within the protected areas, leading to low net deforestation. The Congo Republic has the largest net reforestation, though the location of the highest reforestation is not found inside the protected area, as expected, but rather in the nearest boundary zone (outside 5km). In Congo, the lowest level of reforestation is present inside the protected area as a whole, and the highest reforestation is in the 5km buffer surrounding protected areas, though the difference is not statistically significant. DRC has the second highest level of deforestation, but given an equal level of reforestation, there is nearly zero net deforestation. Deforestation increases near the border (inside 2.5-5km), there is some deforestation outside the border (outside 5km), but there is higher deforestation the farther from the protected area border (outside 10k).

DRC protected areas show the greatest significant statistical differences in deforestation between adjacent protected areas and isolated protected areas (see Figure 1). In other countries, there was little to no significant difference in deforestation rates for protected areas bordering others, but the pattern of increased deforestation within isolated protected areas is maintained for each country. Two protected areas in DRC are close chains of very small individual protected areas, Okapi Faunal Reserve (Cat. II) and Ituri

Forests Reserve (Cat. VI), and have net reforestation rates in each area: both inside the reserves and within both the surrounding regions.

These small chains of protected areas led to the analysis of shape, by examining the core vs edge effects. Within the individual countries, there is a strong correlation in Cameroon between the shape of the protected area and the annual deforestation rate ($p<0.02$) and annual net deforestation rate ($p<0.02$). Cameroon also has the smallest average protected area size (~1100 square meters, compared to ~5200 for CAR, 2400 for Congo, 5800 for DRC, and 3500 for Gabon) and smaller protected areas will be most influenced by their shape.

Within each of the individual countries the sample sizes were too small for comparisons of IUCN categories or date of gazettement. In addition, because there are only 12 protected area units spread among the different countries, each country had too few for a robust analysis at the country level.

DISCUSSION

There were low levels of total deforestation in all countries, both in protected areas and in their buffers, which agrees with the findings of Zhang et al. (2005) in their study of net deforestation at a national and Congo Basin level. I hypothesized that deforestation within protected areas would be lower than the deforestation rates for the entire Congo Basin forest, and that was proven true. An annual net deforestation rate of 0.05% was found in this study, compared to 0.42% (with a range from 0.003 – 2.72%) by Zhang et al. (2005). Their work looked at deforestation rates from 1980 to 1990, so perhaps my study showed a decline in deforestation from their time period, which would be a positive result for the effectiveness of protected areas. While these rates show a low deforestation rate, they should not diminish the value of protected areas. The future influence of protected areas will be important as human populations grow and the need for forest resources increases.

Due to nearly equal deforestation and reforestation rates, both inside and outside the protected areas, the net deforestation rate was close to zero. Reforestation levels are almost the same among all countries; deforestation was also similar among most countries, with the exception being Cameroon with a forest loss of 11.82 % for the whole study period. Cameroon’s annual rate of net deforestation within protected areas is higher than the average levels found for the entire Congo Basin Forest including protected areas and closer to the levels found in other studies of forests outside protected areas (Duveiller et al. 2008; Zhang et al. 2005) or from forest monitoring by international organizations (TREES and FAO)(Achard et al. 2002).

Bruner et al. (2001) measured the difference in response to threats within 10km of the protected area border and inside the protected area border and found that all protected areas overcame threats better than the surrounding areas for deforestation. However, the data from my study fail to show the same significant effects for surrounding areas. Congo Republic, CAR, DRC, and Gabon have lower levels of deforestation within the protected areas than outside, but Cameroon has significantly higher levels inside the protected areas than outside, possibly due to an influx of human population to the rural parts of Cameroon just before the start of this study due to a national economic crisis (Mertens et al. 2000; Sunderlin et al. 2005; Sunderlin et al. 2000).

Protected areas had lower deforestation rates when bordering other protected areas than isolated protected areas, confirming my third hypothesis. This suggests that close chains of protected areas will provide better protection against deforestation than areas in isolation. Furthermore, the literature has extensively documented the difficulty faunal species, particularly large, wide-ranging species, have persisting within small reserves (Carroll et al. 2004; Turner et al. 2006; Wiersma & Nudds 2009) suggesting that the result may have impacts beyond preventing the loss of just forests. There may be an increase in faunal persistence in connected protected areas.

Similar country-level results occurred when looking at the contiguous protected areas as a single unit, though the differences were not as significant. This pattern suggests better protection is provided when many protected areas are near each other. A protected area system of contiguous or closely linked protected areas might provide the best level of protection against deforestation (Rouget et al. 2006; Turner et al. 2006). Of course, my study does not provide any information about how contiguous protected areas might benefit the wildlife within those protected areas, but many studies have proven that, particularly for large faunal species, creating areas large enough to contain a viable population is difficult without large protected areas (Bauer & Iongh 2005; Blake et al. 2008; Klaus-Hugi et al. 2000; Rabinowitz & Zeller 2010).

When looking at the designation of IUCN Management Categories, there were no significant results – in Central Africa the low rates of deforestation across the basin appear to lead to only marginal differences between and among categories of protected areas. As such, the sometimes contentious debate about the relative value of strict protection and/or sustainable use of resources is not relevant as it relates to the loss of forests in this region. That Category VI (Sustainable Use Areas) had the lowest average rate of deforestation might suggest that lower rates can be achieved by creating a cooperative arrangement with local people for sustainable use of the protected area. However, these are only measures deforestation rates. Increased access to a protected area through sustainable use activities might not extend to the sustainable use of faunal species. Increased hunting is not the goal of sustainable use areas, but careful management and study could allow for some level of hunting abundant species (Hennessey & Rogers 2009; Wilkie et al. 1998).

There was no difference in deforestation rates in protected areas gazetted before, during or after the study dates. Areas have continued to be added to protected area networks throughout the last century and I expect they will continue to be established; however, the data fail to prove the areas protected earlier are better at preventing deforestation than more recently protected areas. Also, while there were a large number of protected areas without a designated IUCN category (36), they were almost all given a designation such as community reserve, faunal reserve, forest reserve, hunting zone, national park, private park, strict nature reserve, though six were unknown. There were no significant differences in deforestation rates between designations either. The reason areas designated after the study were included in the same analyses was to understand whether an area's designation influenced its deforestation rates, and the length of time of official protection. Many protected areas in Central Africa, including some not part of the study due to cloud cover, were research sites long before they were officially designated by the government and maintained a level of protection (e.g. Lopé Reserve in Gabon (White 1994; Williamson et al. 1990).

Since nearly half of the protected areas listed for the Congo Basin were not included in this study due to high levels of cloud cover, it is possible more details would be revealed if the sample size for each country was higher and all cloud cover was able to be eliminated from images. Future advances in radar detection of landcover will hopefully make it possible to study areas with near constant cloud cover using high resolution images (Achard et al. 2007). Until that is possible, the general findings for only half the protected areas will have to represent them all. Perhaps there are biophysical reasons for the cloudless areas that affect their deforestation rates, but improved technology will be required to find out.

Forest degradation is among the most important drivers of landuse change (Asner et al. 2009; Bellassen & Gitz 2008) but could not be examined in this study because the resolution required (1-10m) was not available for this region. Extractive activities such as specific high value logging is common in the area, and may contribute to forest degradation (Makana & Thomas 2006). Furthermore, the degradation of the forest along the edges of clearings or the regrowth of forest into sub-prime forest habitat also changes habitat availability for wildlife (Lamberson 1994) and forest use potential for humans (Van Gemerden et al. 2003). As better imagery becomes available, further study of the impact of forest degradation should be pursued.

One of the other factors that will influence future deforestation rates is whether the deforestation is spread across the entire matrix, in discrete patches, or a frontier of deforestation is created. In the Amazon, an ‘arc of deforestation’ has been designated (Fearnside et al. 2009; Nogueira et al. 2007; Righi et al. 2009), where the highest rates of deforestation are occurring and biomass has decreased. It seems to be a continuous stretch of deforestation close to roads and extending from areas of human development. If this happens in Central Africa, we can expect the effects of roads to increase the deforestation rates (Adeney et al. 2009), as was examined in Rogers (in prep).

CONCLUSION

This work should only support the contribution of protected areas around the world. While the results are ambiguous about the value of protected areas, I believe this is only due to the current low threat of deforestation and not because protected areas have been ineffective. As deforestation increases with growing human populations and an increased need for resources, protected areas may become oases of conservation in a matrix of altered landscapes. Protected areas that border one another leading to improved rates of deforestation will be important in long-term protected area planning. Creating connected protected areas could be useful to maintaining the highest level of protection without increased investment. The Congo Basin Forest still has large areas of intact forest, which could become the sites of future protected areas, so understanding where the best conservation effectiveness can be achieved will be vital to improve conservation. Investigating the causes of these deforestation rates will be the focus of further study.

TABLES AND FIGURES

Table 1 Gross and net total deforestation rates for all the Central African Protected Areas for 10 years, 1990-2000.

	Protected area	Inside Margin	5km Outside Margin	10km Outside Margin
% Gross Deforestation	7.1% ± 0.4	6.2 ± 0.4	6.5 ± 0.3	6.4 ± 0.3
% Net Deforestation	1.9% ± 0.6	0.8 ± 0.5	1.3 ± 0.4	1.1 ± 0.5

Table 2 P-values of deforestation, reforestation and net deforestation rates among countries. There were no differences among countries for the 2.5-5km inside margin. Values marked with * are statistically significant.

	All of protected area	Inside buffer (2.5-5km)	Outside Buffer (5km)	Outside Buffer (10 km, includes 5)
Net Deforest	p = 0.01*	p = 0.38	p = 0.03 *	p = 0.05 *
Deforest	p = 0.01 *	p = 0.22	p = 0.02 *	p = 0.01 *
Reforest	p = 0.22	p = 0.59	p = 0.21	p = 0.35

Table 3 – Annual rates of gross deforestation and net deforestation for the entire Congo Basin and within each country (a positive value = reforestation and a negative value = deforestation).

	Annual Gross Deforestation Rate	Annual Net Deforestation Rate
All Countries	-0.0082	-0.0005
CAR	-0.0045	0.0020
Cameroon	-0.0190	-0.0119
Congo	-0.0048	-0.0022
DRC	-0.0094	-0.0000
Gabon	-0.0004	0.0000

Table 4 – Significance of deforestation rates when another protected areas border one another. * - <0.05 significance, ** - <0.10 significance

	All of protected area	Inside buffer (2.5-5km)	Outside Buffer (5km)	Outside Buffer (10 km, includes 5)
All Countries	p = 0.01*	p = 0.05*	p = 0.01*	p = 0.01*
DRC	p=0.04*	p = 0.04*	p = 0.03*	p = 0.08**
Congo	p=0.61	p = 0.66	p = 0.92	p = 0.99
Cameroon	p=0.36	p = 0.55	p = 0.36	p = 0.40
CAR	p=0.20	p = 0.26	p = 0.09**	p = 0.17

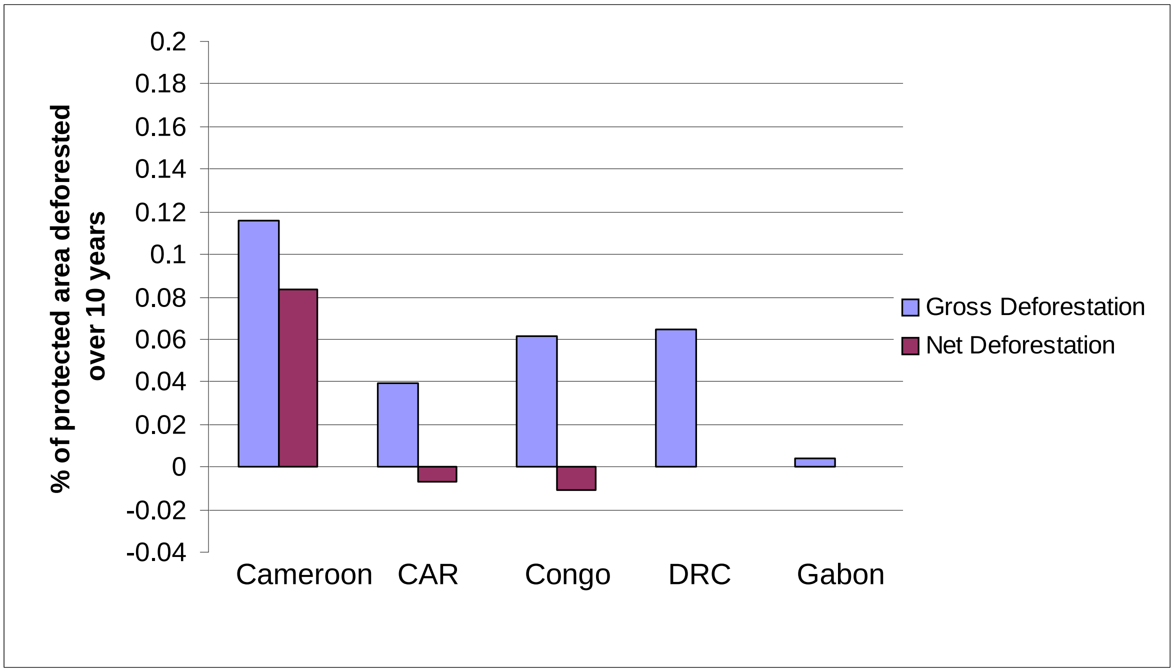
Table 5 % Gross Deforestation inside protected areas with 95% confidence intervals by country over the 10-year study (number of protected areas)

	Cameroon (22)	CAR (19)	Congo (10)	DRC (33)	Gabon (2)
Total Deforestation	11.82 ± 1.34	4.30 ± 0.49	6.09 ± 1.26	6.48 ± 0.50	0.40 ± 0.20
Total Reforestation	3.30 ± 0.40	4.58 ± 0.57	7.19 ± 2.09	6.47 ± 0.58	0.42 ± 0.21

Table 6 % Net Total Deforestation in the protected area and buffers over the 10 year study (sample size in parentheses). Negative values represent deforestation.

	All of protected area	Inside Zone (2.5-5km from border)	Outside Zone (5km from border)	Outside Zone (10 km from border)
Cameroon	-8.51 (23)	-5.18 (15)	-5.81 (23)	-5.20 (23)
CAR	0.54 (19)	0.40 (19)	-0.47 (19)	0.28 (18)
Congo	1.10 (10)	1.47 (10)	2.85 (10)	2.42 (10)
DRC	0.01 (33)	-0.42 (31)	-0.14 (33)	-0.36 (33)
All countries (including Gabon)	-1.93(87)	-0.82 (77)	-1.32 (87)	-1.14 (86)

Figure 1 – Gross and Net deforestation rates inside protected areas for protected areas in each country (Net Deforestation for DRC and Gabon are less than 0.001)



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Chapter Three

The effects of access on protected areas in Central Africa

ABSTRACT

A lack of access to remote areas can limit deforestation, forest degradation, and the resulting loss of biodiversity. Access can be either natural (usually in the form of navigable rivers) or constructed (e.g. roads or transmission lines). In the first stages of development, increased use of natural access and modification of rivers to allow access can lead to expanded extraction of natural resources. Later in a development cycle, roads, rail lines, and power grids are often built through large contiguous forests to facilitate trade and to link population centers. This study examines the short term effects of increased access on the deforestation rate in 87 protected areas in five countries in Central Africa, an area of low overall deforestation. I measured a very small decrease in forest cover for the period 1990-2000, despite an expansion of access. The increased disturbance caused by increasing access to the forest seems to be of an ephemeral nature, initially resulting in forest loss, but leading to reforestation. There was no difference in deforestation rates when a road or river bordered a protected area, or crossed through a protected area. Only the density of roads or rivers had an effect on the deforestation rates. Maintaining low densities of roads throughout large contiguous forests will keep the level of deforestation low. While forest cover may be stable or increase, the secondary impacts of human use on both the forest structure and the wildlife inhabiting the forest are likely to be detrimental, and worthy of further study.

KEYWORDS Central Africa, deforestation, roads, infrastructure, protected area

INTRODUCTION

In Central Africa, both human population density and infrastructure are growing; these changes pose an increased threat to protected areas due to the need for increased forest resources (Bulte & Horan 2002; Burgess et al. 2007). Habitat loss and forest fragmentation are among the greatest threats to most endangered species across Africa (Brashares et al. 2001; Ewers & Didham 2006). Because access makes it easier to bring products from these areas to markets, (Bennett et al. 2007; Milner-Gulland & Bennett 2003; Suarez et al. 2009) the expansion of road networks, power grids and the improvement of access on rivers can provide people with the ability to extract natural resources from remote areas, and to convert land for agricultural and commercial use through activities such as farming, commercial forestry, hunting and poaching. The increased presence of roads in the Amazon Basin has lead to increased levels of human access into previously intact wilderness (Arima et al. 2005; Armenteras et al. 2006; Locklin & Haack 2003; Vina et al. 2004). As in the Amazon, in Central Africa roads and power grids are often built through large, contiguous forests to move goods and services from remote areas to urban centers to facilitate trade and to link human population centers.

At a local scale, roads in Central Africa have been shown to produce negative direct effects such as deforestation and habitat loss, habitat fragmentation, impediments to animal movement and road-kills (Forman et al. 2003; Yackulic et al. in press). The physical creation of a single road removes only a small portion of forest habitat, but cumulatively road creation is not inconsequential and can lead to significant conversion of wildlife habitat (Forman et al. 2003). Many roads in Central Africa are created using bulldozers, simply knocking over trees until a path several dozen meters wide has been created, and are often maintained by being repeatedly mechanically graded (Wilkie et al. 1992). While infrequently paved, any path that is maintained, even by minimal traffic, can be used to facilitate access to the forest, leading to road-side development and access to wildlife resources along the length of the artery (Laurance et al. 2009). Forest degradation, a change in the quality of the forest, while not a direct loss of forest, does change the available habitat and occurs with greater frequency along roads (Buchanan et al. 2009; Forman et al. 2003). Following the degradation caused by infrastructure development, forests can either recover to their original state, or they can slowly recede as access leads to greater disturbance (e.g. increased road use leading to wider roads) and increasing the degradation (Gascon et al. 2000).

Roads also directly and indirectly affect the overall health of the landscape and its wildlife. For animals that do attempt to cross roads, mortality is high in areas when a road is newly introduced and highly trafficked. For example, nearly 50% of wild dog mortality inside Hwange National Park in Zimbabwe has been attributed to road kills (Woodroffe & Ginsberg 1997). Roads also cause considerable mortality for nightjars in Afrotropical forests (Jackson 2002). The direct effects of roads are relatively easy to measure and quantify compared to the far-reaching indirect effects of the creation of roads. Some animals will avoid or not cross roads, dividing populations or limiting mating between separate groups of species with small ranges. Laurence et al. (2008) found that nocturnal mammals had reduced populations within 30m of a road in Gabon, but they observed little difference in population numbers at 300 or 600m from the road (Laurance et al. 2008). An increased presence of other animals was also found further from the road, up to a distance of 1.2km, suggesting some species actively avoid roads (Laurance et al. 2006b) while even larger species avoid them at more significant distances (Blake et al. 2007; Blom et al. 2005). Because an extinction debt can occur, the demographic impacts of road construction may be masked for years, particularly with long lived species like elephants and gorillas (Tilman et al. 1994). Hence, it may take several generations before the effects of increased road density are measurable.

The indirect effects of roads are often more substantial and less easily assessed than the direct effects. One of the most significant set of indirect impacts generated by the interaction between land use and roads around protected areas are those created by logging companies as they begin to extract timber. In Gabon, it has been estimated that selective logging directly removes only 10% of the canopy (White 1994), but this does not take into account the additional forest loss necessary to construct a road to remove these selectively logged trees, which has been estimated to be between 15-30% of the canopy (Wilkie et al. 1992). For wildlife, the collateral damage of road construction can far outweigh the direct loss of habitat or the fragmentation of populations. Logging opens up access to the forest by creating roads to bring equipment in and timber out (Roy et al. 2005; Wilkie & Carpenter 1999). Logging camps and other infrastructure are also created (Kasenene 2001). Companies given the rights to log a particular area of forest are often required to set up and maintain a roads system locally (Karsenty et al. 2008). In the Lobeke region of Cameroon, timber company road systems have allowed for the creation of a well-armed poaching network (Curran & Tshombe 2001) that leads to further indirect effects, specifically a bushmeat trade. Bushmeat is then sold along this route to trucks heading to market (Bowen-Jones & Pendry 1999; Mendelson et al. 2003).

Measures can be put into place to lessen the effects of logging. These include checking logging trucks for illegal bushmeat along their route (Draulans & Van Krunkelsven 2002) or preventing logging roads from being maintained after logging has ceased (Poulsen et al. 2009). Poulsen et al. (2009) studied the bushmeat trade in five logging towns in Northern Congo, and concluded that the permanent urbanization of frontier forests left by logging companies posed the greatest threat to biodiversity in the region. Wildlife populations within protected areas are also threatened by increased roads, as they allow increased access for hunting (Wilkie et al. 2000) and other human activities inside the forest (Yackulic et al. in press), and the lack of roads will only improve the condition of wildlife (Hart 2001; Wilkie & Morelli 1998). Animal populations outside a protected area may be captured alive for the pet trade or killed for the bushmeat market (Milner-Gulland & Bennett 2003). When this is done at unsustainable levels, animals from inside a protected area will often move to available habitat, further exacerbating population declines as they shift from source to sink areas within the landscape.

Roads that border a protected area can provide access for poachers to hunt animals inside the protected area and export them to markets outside the forest. A road created for the oil industry outside a protected area in Ecuador led to the development of a wild meat market (Suarez et al. 2009). Similarly, the bushmeat trade in northern Congo was enhanced when the roads in and out of Ouesso were maintained (Hennessey & Rogers 2008), although in Ouesso much of the bushmeat also arrives by river access.

Roads can provide access to introduce alien species, both within and outside protected areas from seeds on the wheels of trucks to actual planting of alien species near new development (Pauchard & Alaback 2004), which can have detrimental effects on the indigenous flora and fauna. The introduction of predators or disease can also have unknown consequences to the protected area's biodiversity.

In addition to roads, rivers in Central Africa act as a form of transportation and as a means of accessing the forests. The Congo River, as well as smaller navigable rivers, can provide access for moving harvested timber or moving bushmeat to market (Hennessey & Rogers 2008). The Congo River watershed reaches into each of the countries in Central Africa and is the largest of the navigable rivers in the region (Singh et al. 1999).

The limited development of roads in protected areas is necessary to ensure management, monitoring, and enforcement. However, if poorly maintained or patrolled, these roads may also indirectly contribute to an increase in the rate of deforestation (Laurance et al. 2006a). Roads and trails can be integral to tourism, from which many protected areas derive funding and support for conservation efforts. The need to ameliorate the effects of increased tourism, which necessitate roads or trails, will often be overshadowed by the need to monitor biodiversity, but tracking deforestation could potentially assist with both conservation goals (Davenport et al. 2002).

The purpose of this study was to examine the effectiveness of protected areas using low rates of deforestation as a proxy for success (Rogers, in prep.). This part of the study was designed to determine whether increased access led to an increased level of deforestation within the protected area. This study was undertaken to determine the overall effectiveness of protected areas, specifically in the Central African countries of Cameroon, Central African Republic (CAR), Congo Republic, Democratic Republic of Congo (DRC), and Gabon. The levels of deforestation were established in Rogers (in prep.), and this paper aims to discuss how access influences deforestation.

METHODS

To gather the deforestation data within protected areas, digital satellite images were analyzed from the NASA Applied Research & Technology Project Office, Mrsid Landsat TM and ETM+ bands, all are in the Universal Transverse Mercator UTM WGS 1984. Further details about the original images (including rectification details) can be found at zulu.ssc.nasa.gov/Mrsid. Satellite images from 2000 were matched with 1990 images via ERDAS software layering techniques. The images were stacked and three bands from each image were layered (2, 4, 7). Due to the size of the images, they were not put into a mosaic but were evaluated individually around each protected area. Changes in landcover between these two time periods were then obtained using ERDAS software that calculates a pixel reflectance value for each image and then classifies the images with the difference in pixel values between 1990 and 2000 and creates a new image. This allows areas with changes in land cover to be made clear as the pixel values will differ from those in areas with consistent landcover over the 10 years. I used an iterative non-supervised classification process with a >95% confidence level.

Two hundred classes were distinguished and an individual examination of each class was done to classify these 200 classes into eight sub-classes: deforestation, reforestation, forest, non-forest vegetation, cloud cover, water, developed land, and no data. Developed land included areas that were cleared and reflected as bare earth, so large unpaved roads were included in the developed category. “No data” was an infrequent category, but if it was not possible to discern a landcover class, or small glitches in the satellite photo were present as streaks, they were classified as no data. Non-forest vegetation was a amorphous category that included riparian zones of some scrub, areas that were neither agriculture nor forest, and anything that reflected as none of the other categories but was clearly vegetated. Net deforestation was calculated by subtracting reforestation from the deforestation rate. When this was negative, it meant more reforestation than deforestation. Gross deforestation is simply the deforestation rate alone. When just deforestation is mentioned, it is gross deforestation rather than net deforestation.

Because the Congo Forest Basin is a rainforest and has a long a coastal region, the rate of cloud cover is high. Some other studies have used only cloud-free images (Achard et al. 2007) or aerial photography to see underneath the clouds (Munoz-Villers & Lopez-Blanco 2008). Other studies used images with some cloud cover (e.g. (Duveiller et al. 2008; Hansen et al. 2008). Initial analysis showed that a stringent, no-cloud filter eliminated 86% of the protected areas in the study. To avoid throwing out all of this data, I accepted a maximum level of 15% cloud cover over a protected area to be included in the further analysis. Even with this filter, this reduced the number of protected areas in the study from 166 to 86. All data was validated by examining points in Google Earth® and creating a confusion matrix, see Rogers (in prep) for details of the validation.

To understand the possible changes in deforestation at the border of the protected area, I analyzed data from an area 10km outside from the boundary. In this study I use the term buffers to describe the region 10km from the border of the protected area. These buffers are substantially different from the designation of a “buffer zone” as it is an exact distance from the protected area border at all points, and “buffer zones” are often a different shape than the core area. The buffers in this study are exactly 10km from the protected area border all the way around the protected area.

The GIS datasets for roads and transmission lines were collected from the World Bank and French Development Agency program, *Africa Infrastructure Country Diagnostic* (Foster & Briceno-Garmendia 2010). Rivers were extracted from the VMAP0 datasets from the National Imagery and Mapping Agency (NIMA 1997) as used in the Human Footprint work by the Wildlife Conservation Society (Sanderson et al. 2002). The roads, transmission lines and rivers within each protected area and within the 10km buffer around each park were extracted from their respective datasets. The cumulative length of roads, rivers and transmission lines within each protected area and its buffer were calculated using ArcGIS software. A road or river was considered to be bordering a protected area if it followed the exact contours of the protected area border for at least a quarter of the perimeter.

Not every protected area that was included in this study contained roads. While I acknowledge the possibility that the datasets were incomplete, they were the best available at the time of this analysis and were consistent among countries. It is unlikely that any protected area is completely devoid of trails or roads, but the datasets did not represent any for some protected areas in this study.

Transmission lines are usually a single straight line, and sometimes two lines branching within the protected area or buffer. Nearly every protected area within the study had rounded, winding borders that often follow natural boundaries, particularly rivers. Occasionally, national boundaries form the border and create straight lines as protected area borders, but transmission lines did not follow national borders in the study countries. Therefore, the transmission lines did not act as a border to protected areas in the study and were not analyzed as such.

Rivers are natural corridors that grow and recede during wet and dry seasons in the rainforests of Central Africa (Chapman 2001). Every protected area contained rivers, so there was no comparison between protected areas with and without water access. When looking at the rivers and inland water in the VMAP datasets, I only used those rivers or waterways designated as permanent. Navigable rivers change with the seasonal floods as well, and no dataset was available for solely navigable rivers. I used those designated as permanent rivers, which does not necessarily mean they are actually navigable. This means that access by water might not be same for every river; it does indicate that the possibility of easier walking along the river is available. Because the density of rivers was so high, measuring the deforestation within 1km was not useful as it covered the entire protected area, so determining the deforestation rate along rivers was not possible. All analyses involving rivers were made with the entire protected area or buffer, rather than along rivers.

Analyses were done for the entire Congo Basin Forest across the five different countries, as well as individual country analyses, except for Gabon due to a sample size of 2. To control for varying lengths of roads within different protected areas, I calculated the square kilometers deforested along the road per kilometer of road as well as the entire protected area's deforestation rate per kilometer of road present within the area. To control for differing size of protected areas and their buffers, I calculated the density of roads within each. All of these calculations were repeated for transmission lines. With the exception of deforestation along rivers, all calculations were repeated for rivers as well. Statistical analyses were done using the JMP software package for ANOVAs and t-tests.

RESULTS

Roads, Road Density and Protected Area Categories

The cumulative length of roads within protected areas was much higher in CAR than the other study countries ($p<0.0001$); though controlling for the size of the protected area, Cameroon had the highest density of roads within protected areas (5.8m roads/km² of protected area), and DRC had the lowest density (2.8m roads/km² protected), though the difference was not significant ($p<0.18$) (see Table 1). There was a small but significant difference in the density of roads within buffers around the protected areas among the different countries; the density in the DRC buffers was lower ($p=0.003$) than the other countries which all had nearly the same road density in the buffers.

The density of roads was lowest within protected areas designated by the World Conservation Union (IUCN) as Category VI (Sustainable Use Areas) and highest in Category II (National Park), though the sample sizes for each category (n=1, 2, 9, 10, 12) makes conclusive analysis difficult (PA $p<0.44$; Buffer $p<0.10$). The density of roads was not significantly different based on the date of gazettement: before 1990, from 1990-2000, or post 2000 ($p<0.64$).

There was no overall increase in the total deforestation rates or in annual deforestation rates in protected areas that contained roads compared to protected areas without roads ($p<0.84$ and $p<0.67$). Nonetheless, in protected areas where roads are present the deforestation rate within 1km of roads appears higher than the deforestation rate for the rest of the protected area (see Figure 1), but the difference is not statistically significant. There was no increase in deforestation when roads formed the border of the protected area compared to the protected areas where the roads were not found along the border ($p<0.50$).

There is a strong positive correlation with the density of roads and the reforestation rate within the entire protected area. The increased density of roads correlates with increased rates of reforestation ($p<0.03$) but not with deforestation ($p<0.18$). The density of roads within the buffer around the protected area was similarly correlated with the reforestation ($p<0.03$) and not with the deforestation rates and ($p<0.17$).

When I looked at the area within 1km on either side of the road, as opposed to the overall reserve, there was an increase in development within a protected area along a road. This is to be expected because the areas categorized as development, defined as cleared land and not forested, usually contain roads, but the increase along roads is notable ($p<0.06$). The deforestation along a road in the 10km buffer zone also increased if that protected area bordered another country ($p<0.18$), but in general there were few differences in the deforestation along a road compared to within the protected area as a whole.

Within the countries in the study, there is no difference in the rates of deforestation within protected areas that contain roads (Cameroon, $p<0.56$; CAR, $p<0.84$; Congo, $p<0.25$; DRC, $p<0.46$). When a road bordered a protected area there was no difference in deforestation rates from protected areas that were not bordered by a road (CAR, $p<0.90$; Congo, $p<0.99$; Cameroon, $p<0.28$; DRC, $p<0.81$). In CAR there is no correlation between road density and deforestation rate within the protected area or its buffer (CAR PA $p<0.22$, buffer $p<0.25$). In Cameroon, there is a strong positive correlation between road density and deforestation rate only within the buffer, and not within the protected area (PA $p<0.51$, buffer $p<0.01$). However, in Congo the pattern is different with road density in the protected area not correlated to deforestation ($p<0.69$) and positively correlated with reforestation ($p<0.001$). In the buffers around Congo protected areas there is no correlation with road density and deforestation ($p<0.88$), and a moderate correlation with reforestation ($p<0.09$). In DRC, deforestation is negatively correlated with road density within the protected areas, though not within the buffer (PA $p<0.07$, buffer $p<0.33$) but reforestation is not correlated with road density either positively or negatively (PA $p<0.59$; buffer $p<0.84$)

Transmission lines

The density of transmission lines was highest in Congo, but the differences between countries are not significant ($p<0.20$). However, while the deforestation rates along transmission lines appear lower than both along roads and in the protected area as a whole (Figure 2), there was no difference between them ($p<0.40$). The deforestation rate along the transmission lines was not different than the deforestation rate within the protected area as a whole or the buffer region ($p=0.92$) or with the deforestation rate along roads ($p< 0.54$). Reforestation within a protected area is positively correlated with an increased density of transmission lines ($p<0.0001$), though it is not correlated in the buffer zone ($p< 0.14$). The sample size of protected areas containing transmission lines for each country individually was too small ($n<6$) to do analysis at the country level.

Rivers

There is no difference in the density of rivers within each country's protected areas ($p<0.91$). The highest rate of deforestation per kilometer of water was found in protected areas and their buffers in Cameroon (PA $p<0.04$; buffer $p<0.009$). However, when a river acted as a border to the protected area, there was no difference in either the deforestation and reforestation rates than when the rivers were only found throughout the protected area (net deforestation PA $p<0.78$, buffer $p<0.91$). Inside the protected area, the rate of deforestation was no different than with increased river density ($p<0.32$) but reforestation was correlated ($p<0.04$) with increasing density of rivers, and in the buffer around protected areas there was lower net deforestation ($p<0.001$), and higher reforestation ($p<0.001$) with increased density of rivers. In CAR, river density had a moderate correlation with reforestation ($p<0.09$); and in Congo there was a strong correlation with river density ($p<0.02$). Also, in the buffer regions of protected areas in some countries, there was a negative correlation between net deforestation rates and river density (CAR buffer $p<0.19$; Cameroon buffer $p<0.09$; Congo buffer $p<0.04$; DRC buffer $p<0.009$).

DISCUSSSION

In the Congo basin, roads do not lead to net deforestation, but instead lead to an increase in reforestation rates; deforestation rate along roads was higher than within a protected area as a whole but differences were not significant. The result, while somewhat unexpected, may be explained because so many of the roads in these protected areas were built before 1990 and forests have begun to encroach along them. Roads increase disturbance, but following such disturbance, and assuming no great increase in penetration of protected areas for illegal activities, we would expect forests around these roads to regrow (Laurance et al. 2004; Munroe et al. 2004). Hence, over time, we would see a progressive change in areas of forest recovery spreading out from the road. This suggests that the net deforestation rate is not correlated with the density of roads, but rather the presence of roads increases disturbance and regeneration, though the quality of the forest regenerating is unknown. In addition, the increased density of roads correlated with increased deforestation, rather than the total number of miles of roads, suggesting it is the design of road system that will matter most in conservation. However, the density of roads should avoid fragmenting the forest into smaller pieces because many faunal species require large undisturbed forests (Barnes et al. 1997; Blake et al. 2008).

Development increased along roads as well, which has been noted in the Amazon as well (Armenteras et al. 2006). The deforestation in the Amazon tends to be more of a frontier of deforestation, often described as the ‘arc of deforestation’ (Fearnside et al. 2009; Nogueira et al. 2008), and spreads from roads and areas of development. In Central Africa, it seems that deforestation is still spread out across the landscape matrix, and the reforestation rate will likely keep the forest intact. However, if logging companies continue to penetrate deep into the forest and construct towns and markets, this may change to a frontier of deforestation (Poulsen et al. 2009).

The results suggest that in each country the impact of increased access has different outcomes. Cameroon had the highest level of deforestation per kilometer of road, transmission line or river. No single means of access in Cameroon's protected areas stood out as the major factor contributing to Cameroon's high deforestation rates. Congo Republic has nearly the same road density inside protected areas as Cameroon, but has a negative deforestation rate (higher reforestation) within reserves. Similarly, in the buffers around protected areas, Cameroon and Congo have the same road density, but Congo has a much lower level of net deforestation. This suggests that either something other than access might be affecting Cameroon's high deforestation rates, or that in Cameroon the provision of access allows other economic forces to drive deforestation, while in Congo access alone is insufficient.

If access alone does not lead to deforestation in Congo, then the observation of high levels of reforestation in Congo could ironically be caused by the high road density; roads initially lead to deforestation, but if no further development occurs, one observes increased levels of regeneration as the forests removed in road construction regrow after the disturbance. Given that reforestation is not as strongly correlated to road density in other countries, there is something unique in Congo Republic that leads to high levels of reforestation with high road densities. Potentially, Congo may have a higher rate of unpaved roads, hindering development and leading to reforestation, as the deforestation and development are greater when a road is paved and maintained (Laurance et al. 2002; Pohlman et al. 2007; Soares et al. 2004). However, the roads datasets used in this study are not detailed enough to determine the paved status of the roads, so further study is necessary to confirm this hypothesis.

While deforestation rates along transmission lines were lower than along roads and lower than within protected areas as a whole, the difference was not significant. Again, with an increased presence of transmission lines, reforestation increases within the protected area, a result similar to what has been observed with the construction of roads within protected areas. This suggests transmission lines are not used as access points to remove forest, but rather once installed, the forest is allowed to regenerate indicating that the longer term impact of such development on forest persistence may not be as severe as an initial, post-construction survey might suggest (Khanna & Rao 2009; Sebitosi & Okou 2010). Hence, in looking at the balance of infrastructure development and protected area integrity, initial deforestation might not be a reason, itself, to block improvements in a country's electrical grid.

Rivers within protected areas can be havens for freshwater species, as well as provide drinking water for local populations (Deil 2005; Melletti et al. 2007). The level of deforestation along rivers is far outpaced by the rates of reforestation. This could be due to the seasonal rains within the Congo Basin, and its rivers having wide riparian zones that are forested cyclically(Tazalika & Jury 2008). The need to cross a river to access timber or extract timber seems to be a deterrent, creating more consistent forest within the protected area. The regrowth of forests along rivers has a positive influence on the protected area reforestation rate. It seems that rivers share this pattern of regrowth after deforestation that can occur along transmission lines.

This study data was collected between 1990 and 2000, and changes in forested protected areas during that time period could be influenced by a time lag between the actual deforestation and the corresponding wildlife changes. Currently, the ephemeral nature of roads, extraction along rivers, and transmission lines in Central Africa leads to regrowth of forests, increasing areas of forest succession and available habitat variety, while decreasing the original habitat.

One of the limitations of this study is the unknown impact roads and electrical grids have on the wildlife along their routes. Individual studies have looked at the impact of roads on a single species or groups of species in Central Africa (Laurance et al. 2006b; Yackulic et al. in press), while others have examined the "empty forest" concept of an intact forest devoid of wildlife (Redford 1992). While this study examines how the roads affect the conservation of a protected area's forests, it cannot clearly examine the effects on its wildlife. However, understanding how much habitat is lost to road construction and increased access can assist with determining how much habitat is available and predicting possible wildlife needs for the future. As economic growth occurs in this region, the more permanent nature of access, such as paved roads could lead to permanent deforestation

CONCLUSION

These analyses suggest that across much of Central Africa, the direct impact of road development in and around protected areas can be mitigated if extensive extraction does not occur following the construction of roads or power lines. Creatively planning a road system, like planning other forms of land use such as farming or logging, may minimize negative interactions between a protected area and the surrounding human population. This would still provide for infrastructure development for local communities and potential tourism to the protected area, but with an understanding of potential problems. Clark (2009) suggests closing all inactive roads, and restricting active roads in and around logging concessions to monitored logging vehicles only (Clark et al. 2009). Creating a road system with the understanding of how it will affect animal migration needs could prevent future problems generated by the new roads, such as avoiding multi-lane highways that cut off populations migration paths. Access, either by road or river, connects landscapes together. Mitigating the byproducts of increased road creation has met with varying success around the world. In Central Africa, the different forms of increased access to protected areas are not the major cause of deforestation, but further study to determine those causes is necessary.

Looking toward the future, creating a baseline understanding of roads and rivers and their contribution to deforestation or reforestation can help determine some of the carbon emissions cycles in Central Africa. Carbon is going to be the greatest global pollution concern in the 21st Century. If the current policies regarding avoided deforestation are changed within the Kyoto Protocol, as suggested by Niesten et al. (2002), documentation on the current and prior states of protected area forests will become crucial to allow Central Africa to gain from their protected resources (Niesten et al. 2002). My hope is that this study will contribute to the ongoing discussion of preserving forests as a method of mitigating climate change.

TABLES AND FIGURES

Table 1 –Density of roads in protected areas (PA) by country. Density is positively correlated with deforestation and reforestation in both protected areas and their buffers.

Country	Cameroon	CAR	Congo	DRC
Density of Roads in PA (m/sq.km)	5.8	2.9	5.6	2.8
Density of roads in Buffer (m/sq.km)	4.4	4.0	4.5	1.9

Figure 1 – Deforestation and net deforestation (deforestation minus reforestation) in the entire protected area and along roads. There is no significant difference between deforestation along roads and deforestation within the entire protected area (p=0.18).

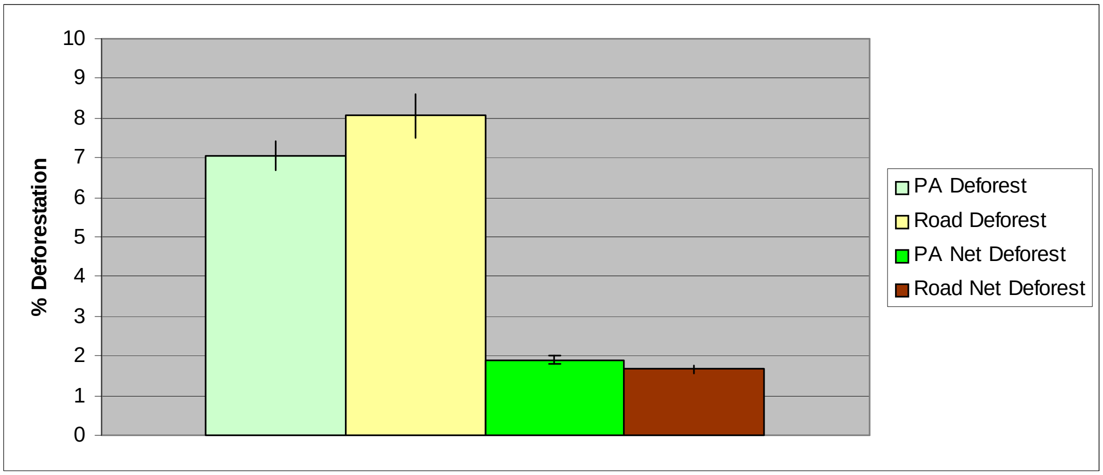


Figure 2 – Deforestation in the protected area (PA), along roads, and along transmission lines (Txl). High reforestation along Txl lowers the net deforestation rate below that for the entire protected area.

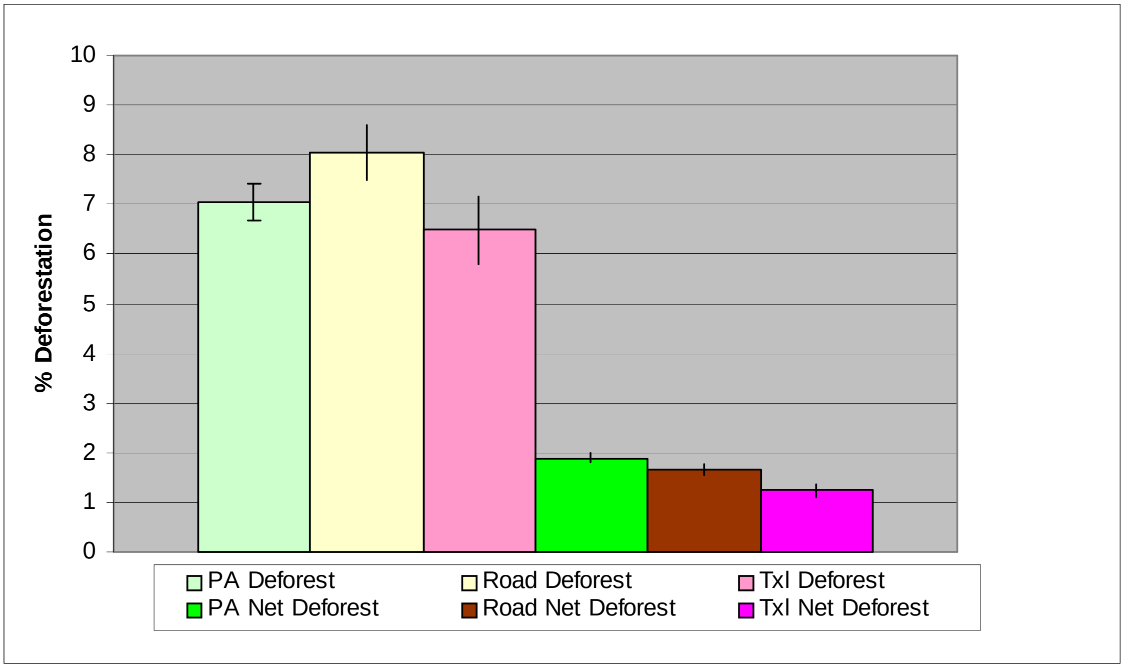
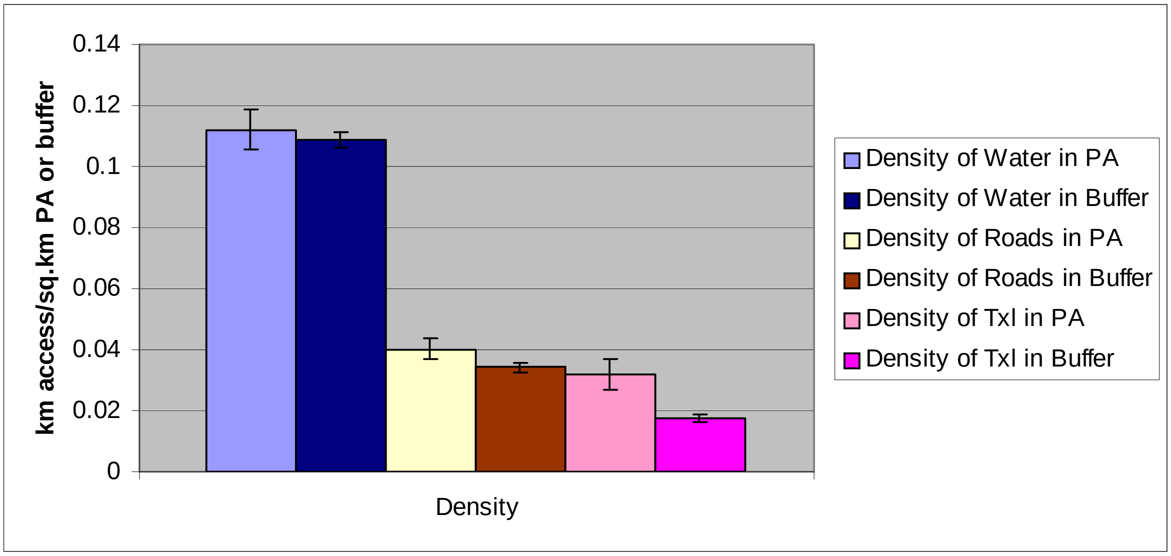


Figure 3 – Density of different types of access. Every protected area contains water access. The density of water in protected areas (PA) is much higher than for either roads or transmission lines (Txl) (PA $p<0.0001$, buffer $p<0.0001$)



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Chapter Four

A Study of the Bushmeat Trade in Ouesso, Republic of Congo

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Abstract

The largest town in northern Congo (Ouesso) has a meat trade that consumed 5700 kg of bushmeat a week in 1994. The purpose of this study was to quantify the bushmeat trade in the town of Ouesso. The study ran from the middle of June to the middle of October 1995. The questions we wanted to answer included: from where does meat arrive in the market, what species are being sold, and how are the species being hunted. We recorded information on the description of the species hunted and the type and location of hunting. We recorded any information of interest since this was the first documentation of the meat trade in Ouesso. We recorded 39 species of animals for consumption, including seven species of monkeys, eight species of antelope, as well as gorillas, chimpanzees, and elephants. Duikers were most abundant, with 390 individuals sold per week. We found three main hunting systems used in the area: snare, night hunting and day hunting. We found that 66% of the meat for the market came from an 80km road traveling southwest to a village called Liouesso. Thirteen percent came from a logging truck trading in Cameroon. Finally, we present our discussion on the law enforcement and management problems for the area.

Keywords: Bushmeat, Central Africa, Congo, wildlife trade

Introduction

Wilkie and Carpenter (1999) suggest that there are three very difficult questions to answer to evaluate the impact of bushmeat hunting on wildlife populations. The first of these is determining the harvest rates of bushmeat species, which can be accomplished by quantifying a known market that services a given area. There is still enormous value in adding the information from our small study to the literature on the bushmeat trade. In 2005, Fa et al. published a study of 36 sites across 7 countries to compare different markets and the species hunted. However, the sites in their study have fewer than 2500 inhabitants around the market (Fa et al., 2005). Ouesso is an important market because it accumulates meat from many smaller unquantified markets and supplied a human population of over 11,000 at the time of the study. Edderai and Dame (2006) studied the large, urban, Yaounde bushmeat market in Cameroon. However, in contrast to Ouesso, bushmeat was only eaten by a small proportion of Yaounde's inhabitants (Edderai & Dame, 2006). The market of Ouesso is unique in the literature, but hardly unique as a market in Central Africa.

In much of the Congo Basin, including within the study area, bushmeat (meat caught in the wild for human consumption), is the primary source of protein (Wilkie & Carpenter, 1999). There have been many different studies of bushmeat in specific markets to track both the sustainability of hunting and the specific species being hunted (Hart, 2000; Apaza et al., 2002; Fa et al., 2002; Mendelson et al., 2003) as well as examinations of the global impact and issues surrounding the bushmeat trade in general (Milner-Gulland, 2002; Robinson & Bennett, 2002; Rowcliffe, 2002; Tomlinson et al., 2002; Milner-Gulland & Bennett, 2003).

Methods

The entire study region in northern Congo is tropical forest habitat. Areas have been cleared around villages and towns but they are always bordered by forest. In addition, in 1995, according to hunters in the area, nearly 20 km² of forest surrounding Ouesso has been almost completely hunted out of large mammals. As a consequence, Ouesso depends on external sources of meat. From our travels with trucks and hunters we observed that meat was often supplied by small hunting camps and villages averaging in size from 50-100 occupants and usually spaced along the roads and rivers every 5km. The meat diet of Northern Congolese was and continues to be almost completely restricted to fish and bushmeat, the only other source being domestic chicken. We observed no cattle in the region at the time of the study and imported beef was usually twice the price of bushmeat in the greater region.

The study was conducted from 15 June to 15 October 1994. Data was gathered with the help of a Congolese assistant, Alain Kabo. There were several routes of meat entering and leaving Ouesso, including trucks 3 days a week to Liouesso, a small town southwest along the main road, dug out canoes on two rivers, the Sangha and the Ngoko, and intermittent trucks from the villages of Sangha Palm and Ngombe. We recorded all the meat that arrived in the market on the trucks. To record the quantity and type of meat transported by these trucks and boats, several days each week we traveled with them recording the meat picked up by the truck. When we arrived in a village or met new people, interviews were done with the hunters regarding their hunting locations and methods, and how they got the meat to market. We also recorded the meat brought into the port in the mornings and evenings, as well as the meat actually in the market. We then recorded the species and its characteristics (sex, smoked or fresh, weight, and length). Species were identified using the Haltenorth and Diller Field Guide (1988).

Results

Species hunted

An average of 5700 kg of meat, total weight, was sold in the Ouesso market each week, an average of 0.5kg per person in Ouesso per week. From talking with villagers and hunters, we found that the Ouesso population diet is about 30% fish, by weight, which was not recorded by species. Of the meat we found in the market, the most common animal sold was Peter's Duiker (*Cephalophus callipygus*), see Figure 1. The majority of duikers (*Cephalophus sp.)*, 64%, were caught with snares. The blue duiker was caught less often with snares, probably because the snares were meant for the bigger duikers. Duikers often arrived in the market smoked and could not be identified by species, but were weighed, measured, and grouped into the "unknown duiker" category.

Primates make up the next largest part of the diversity of the Ouesso meat trade (22% of market). An average of 132 primates of eight different species were brought into Ouesso each week. All gorilla meat (*Gorilla gorilla gorilla)* came in to Ouesso from the road to Liouesso, with an average of 1.6 carcasses per week. From interviews with hunters, we were able to determine that there was one hunter in Liouesso supplying the market in Ouesso. Gorilla meat was sold alongside and at the same price as other meat. Only four chimpanzees (*Pan* troglodytes) and four leopards (*Panthera pardus*) were seen in the market, although for different reasons.

Chimpanzees were listed as vulnerable by IUCN in 1995 (they have since been elevated to endangered (Oates et al., 2007), but offer little value to hunters as they contain little meat and are more difficult to hunt than snaring duikers. The reason for few leopard sightings seemed to be an issue of timing; leopards have been nearly hunted out of the region, with hunters reporting seeing very few in recent years, and only accidentally caught in snares.

Elephants (*Loxodonta africana*), gorillas (*Gorilla gorilla gorilla),* chimpanzees (*Pan troglodytes*), leopards (*Panthera pardus)*, and sitatungas (*Tragelaphus spekii*) make up less than 2% of the meat in the Ouesso meat trade, but represent the species of highest conservation concern. Elephant meat or tusks were encountered an average of 3.8 times per week. It is difficult to translate this into a number of elephants, but based on the number of tusks and the amount of meat, we estimate this to be 32 elephants in the four-month study. Hunters and buyers have said that in the dry season (Dec-April) the community can kill up to three elephants per week. Elephant meat lasts the longest; smoked in chunks 15cm^3, it can last up to four weeks. The most important result was that elephant meat or tusks were continually coming through the Ouesso market, while there were also several sightings of meat or tusks leaving on the plane to Brazzaville. The majority of ivory came from the Pokola area and the majority of meat from the Liouesso area.

Bongo (*Tragelaphus eurycerus*) is the only species in northern Congo that carry a taboo about eating the meat. Bongo meat was never identified in the market, but we were told a desperate hunter will disguise bongo meat by smoking it. We have no way of knowing if this occurred without genetic testing, which was beyond the scope of this study, but we feel fairly certain it did happen as most hunters will eat or sell whatever they can catch.

Hunting methods

Snares are the most popular method of hunting in northern Congo. Snare hunting is prohibited by Congolese law No. 83 (Wilkie et al., 1992). The average snaring system is a line of snares, placed one to three meters apart, along a well-used animal trail. The average snare design is a hole dug about 15cm deep and wide with a loop of cable placed over the hole. The low cost of snare hunting is the main reason it is the most popular hunting method, 40.2% of the carcasses we were able to measure were caught by snares. There is only the initial investment in wire cable, which is rarely prohibitively expensive, and the wire can be reused constantly. It also has the advantage of trapping live animals, which carry a higher price because they can be sold to Muslims for proper killing. However, snares are a very indiscriminate method of hunting. There is no way to stop non-target species from becoming victims.

Night hunting, also known as jacklighting, is supposed to be one of the easiest methods of acquiring game in the forest, as the animals usually freeze when they see the light, the light bounces off their eyes and the hunter fires his gun. Twenty-one percent of carcasses were caught at night, mainly fruit bats and civets. The hunter is not required to have any tracking skills as he just walks down a path, and can usually approach the animal until it is in range. The simplicity of this method has made it illegal in many countries, including Congo (Congolese law No. 48 (Wilkie et al., 1992)). It is considered by many hunters to be too simple and without sport, and only a small number brave night hunting for its other inherent dangers.

Day hunting, the only legal form of hunting, was used to catch 36% of carcasses. However, we only encountered two hunters who enjoyed this type of hunting, most hunters preferring the easier methods of snaring or night hunting. A very small group of carcasses (less than 2%) were caught using traditional methods.

Meat Routes

By the time the meat is sold at the market in Ouesso it has usually gone through many hands. The meat in Ouesso is brought in through several routes (see Map), with 70% coming from the road to Liouesso (4% from the road to Ngombe). The other routes all blend into the port entrance to Ouesso, either on the Sangha (14%) and Ngoko (16%) rivers. Most of the meat on the Sangha River comes from the road into Cameroon and is put on the river in Sucambo. The villages along the road to Liouesso are all similar, and few are located directly on the road. Because the roads south of Liouesso are poor, all the villages there bring their meat to market in Liouesso. From there, two trucks make the trip between Ouesso and Liouesso three days a week. However, 37% of the time only one of the trucks was working, and there was one day that no trucks ran. The truck stops along the route and picks up meat, along with other items being sold in the market, most notably M*egaphrynium* spp.(makassa), a large leafy plant that is used in the market to wrap meat. An average returning truck can carry about 50 passengers, 100 hanging animals, 50 bundles of makassa and personal baggage. We never witnessed a passenger or an animal refused. Many of the villagers said that the forest south of the Ngoko River was becoming over hunted; they were catching less than they had a year earlier. No similar reports came from the Sangha River.

Meat Prices

The price of meat can increase considerably by the time it is ready for public purchase. Little attention is paid to the species, though the price can vary 200-500 CFA by quality and size. The prices are an indication of quantity rather than quality. It was apparent that the market demand was beyond the supply as the meat sold out every single day of the study, and the limiting factor, according to hunter interviews, was affordable technology to increase hunting and access to the markets. The change in these prices in the future has potential as an indicator of the abundance of certain species, which may be easier data to gather than counting wildlife.

Discussion

One of the elements of the Ouesso bushmeat trade that this study revealed was the lack of effective protection or management of wildlife. Most Congolese do not know that snaring is illegal, as hunters felt no need to hide the fact that they were snaring. Conservation is desperately needed in the Ouesso area, especially with the Nouabale Ndoki National Park less than 100km away. The list of protected species in Congo at the time of the study indicated a level of ignorance towards the African forest environment. Most hunters were capable of creating a more accurate list of threatened species than the law acknowledged. Integrating this local knowledge and perception with scientifically based conservation planning could maintain this system of bushmeat trade sustainably.

Since the study was conducted, elephants, gorillas, and chimpanzees have been elevated on the IUCN Red list of Endangered Species from vulnerable to endangered (IUCN, 2007), indicating that the international community has recognized what local hunters already knew; the threats to these species has increased.

As this area of northern Congo becomes more accessible by permanent roads built by logging companies, hunting can only increase, particularly for monkeys and elephants (Wilkie et al., 1992). However, it has been argued, although not yet proven, that sustainable hunting can be accomplished with government support, enforcement of protection laws, and cooperation with timber companies (Bowen-Jones & Pendry, 1999). The benefit of the simplicity of this study is that it can easily be repeated to begin to understand how sustainable this market has become. It is difficult for a single study to understand the sustainability of a market, but with repeated data collection, this will be possible.

Conclusion

The biology of most hunted species in northern Congo has been studied, and can be incorporated to the study of sustainable hunting and species conservation in this area. However, using only biology, the future of the system cannot be predicted as the economics of the trade play a large part in its future (Ling et al., 2002), as does the substitution of an alternative protein source for the local people (Bowen-Jones & Pendry, 1999; Brashares et al., 2004). With better roads and dependable flights and electricity, the meat trade could easily increase and quickly surpass sustainable levels for all species. The goal of this system should be sustainability, and management and protection are essential to achieve this goal. This study provides a quantification and description of the bushmeat trade in Ouesso, from which management decisions can be made and future studies can be compared.

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Figure 1 – Species found in the market

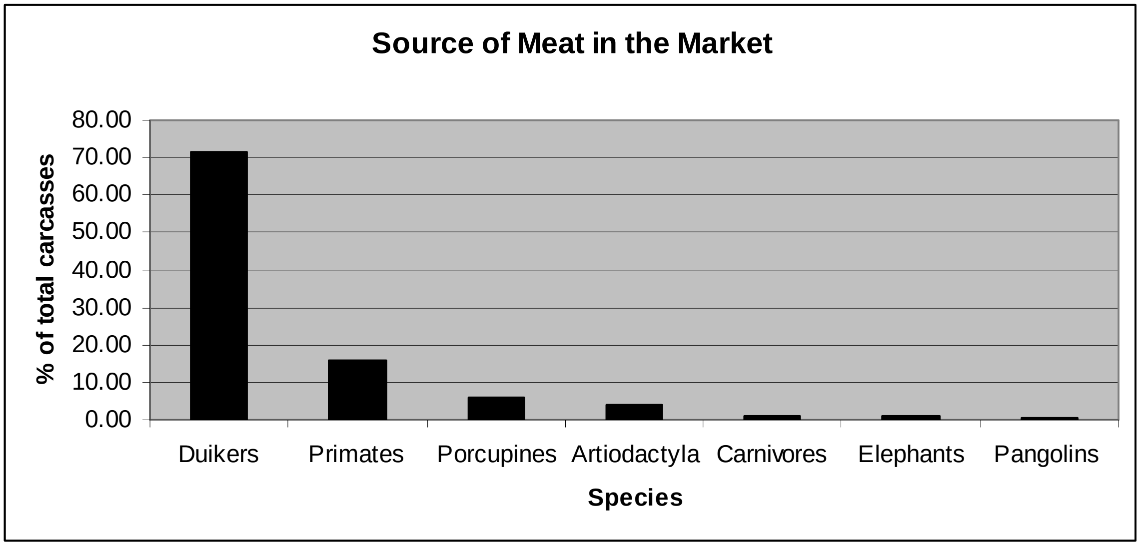
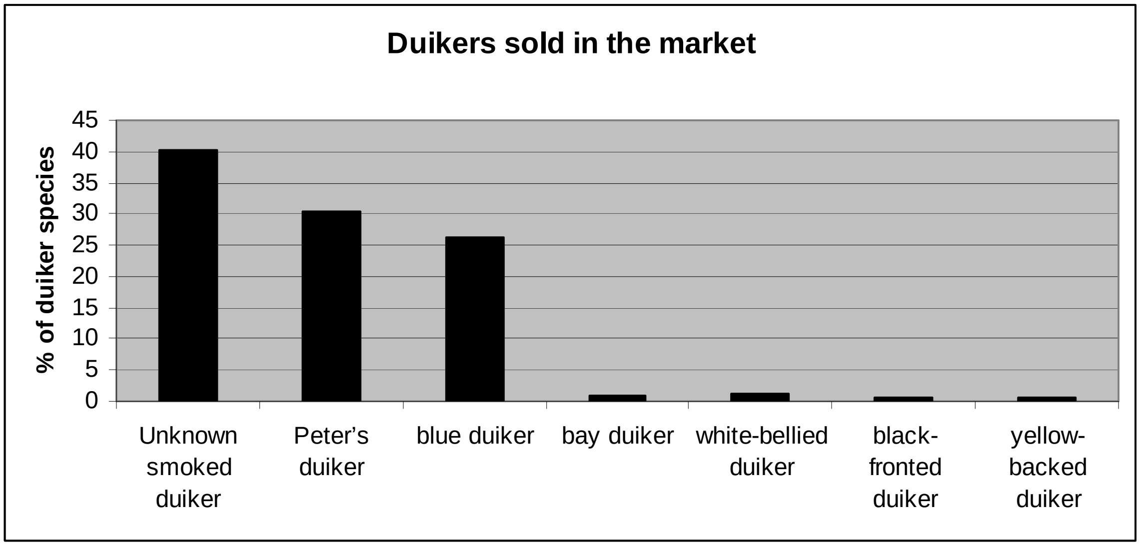


Figure 2 – Duiker species in the market



CONCLUSION

With the most recent wave of extinction leading to a global loss of biodiversity, it is important to know whether or not protected areas contribute to conservation. In Central Africa, in particular, this is a crucial moment; a time in which forests could be lost to growing human needs and potentially altered by a changing climate. If steps are taken to plan for the future of conservation, the protected area networks will provide some of the greatest troves of resources for the world, as well as providing for their countries as sources of sequestered carbon.

Protected areas might be the best way to save these resources, both for their local and global value. However, there are few methods that can assess the impact of protected areas at a scale that is large, while using a metric that is sufficiently simple and transparent to enable scaling up of analysis at a regional or global scale. As discussed in Chapter One, several different methods exist to measure the effectiveness of individual protected areas. Some of these methods can show whether a particular species has been protected or an ecosystem conserved, or can determine whether deforestation has increased. The data examining deforestation and reforestation rates could be harnessed as a surrogate for evaluating the effectiveness of protected areas. The influence of these effectiveness studies on the global warming crisis has yet to be fully explored but they hold potential for developing countries to contribute to solving the problem.

For Chapter Two, I collected and evaluated data which showed very low rates of deforestation within protected areas in Central Africa, as well as little difference between the protected area and the matrix surrounding it. However, there were significant differences in deforestation rates between countries. The possible causes, whether economic, political or social, of these differences should be investigated further. This work should not in any way diminish the value or contribution of protected areas around the world toward the conservation of our forests. While the results are ambiguous about the immediate value of protected areas in a largely intact, contiguous forest, I believe this is only due to the currently low threat of deforestation and not because protected areas have been ineffective. As deforestation increases with growing human populations and an increased need for forest resources, protected areas may become oases of conservation in a matrix of altered landscapes.

Protected areas that border one another, leading to improved rates of deforestation, will be important in long-term protected area planning. These results showed a lower rate of deforestation when protected areas created a unit of protection rather than being isolated from one another. Creating connected protected areas could be useful to maintaining the highest level of protection without increased investment. The Congo Basin Forest still has large areas of intact forest, which could become the sites of future protected areas, so understanding where the best conservation effectiveness can be achieved will be vital to improving conservation planning. Investigating the causes of these deforestation rates, particularly while they are still low and their course undecided, should be the focus of further study.

Chapter Three examined the connection between deforestation and access. These analyses suggested that across much of Central Africa, the direct impact of road development in and around protected areas can be mitigated if extensive extraction does not occur following the construction of roads or power lines. Creatively planning a road system, like planning other forms of land use such as farming or logging, may minimize negative interactions between a protected area and the surrounding human population. This would still provide for infrastructure development for local communities and potential tourism to the protected area, but would help planners anticipate potential problems. Clark (2009) suggests closing all inactive roads, and restricting active roads in and around logging concessions to monitored logging vehicles only (Clark et al. 2009), which could greatly mitigate a concession's indirect effects.

Creating a road system with the understanding of how it will affect animal migration needs could prevent future problems generated by the new roads, such as avoiding multi-lane highways that cut off wildlife migration paths. Access, either by road or river, connects landscapes together. Mitigating the byproducts of increased road creation has met with varying success around the world. In Central Africa, further study to determine the effects of permanent road structures will be necessary as paved roads move further into the countryside around cities, replacing dirt roads.

The study of bushmeat with Bennett Hennessey, as discussed in Chapter Four, provides another look at how effectiveness can be measured by looking at the amount of bushmeat brought to market. The biology of most hunted species in northern Congo has been studied and can be incorporated into the study of sustainable hunting and species conservation in this area. However, using only biology, the future of the system cannot be predicted as the economics of the trade play a large part in its future (Ling et al. 2002), as does the substitution of an alternative protein source for the local people (Bowen-Jones & Pendry 1999; Brashares et al. 2004). With better roads, and dependable transportation and electricity, the meat trade could easily increase and quickly surpass sustainable levels for all species. The goal of this system should be sustainability, and management and protection are essential to achieve this goal.

This study provides a quantification and description of the bushmeat trade in Ouesso in the 1990s, on which management decisions can be made and future studies can be compared. A measure of the effectiveness of surrounding protected areas can be inferred. Repeating the study of the bushmeat trade in Ouesso, particularly coupled with a measure of the total area from which hunters draw animals, will provide a measure of the sustainability of the market and the hunting systems in place. In particular, it will be important to track the variety of species in the market to be sure there is sufficient enforcement of endangered species laws that prevent hunting of chimpanzees, gorillas and elephants.

Looking toward the future, the creation of a baseline understanding of roads and rivers and their contribution to deforestation or reforestation can help determine the Congo forest's influence on the carbon emissions cycles in Central Africa. Carbon is going to be the greatest global pollution concern in the 21st Century. If the current policies regarding avoided deforestation are changed within the Kyoto Protocol, as suggested by Niesten et al. (2002), documentation on the current and prior states of protected area forests will become crucial to allow Central Africa to gain financially from their protected resources (Niesten et al. 2002) and the world to gain a source for sequestration. My hope is that this study will contribute to the ongoing discussion of preserving forests as a method of mitigating climate change.

The most recent 15th Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) created the Copenhagen Accord which calls for assistance to developing countries at an increased level to support understanding how protecting carbon stocks and increasing reforestation will help combat increasing carbon in the atmosphere (FCCC 2009). Valuing the stocks of carbon sequestered in tropical forests will be the challenge for economists after ecologists and conservations determine how many acres of forest remain (Anonymous 2010b). The REDD (Reducing Emissions from Deforestation and Degradation) program, which was heavily supported at the Copenhagen COP, aims to halve global deforestation by 2020, with small projects started in developing countries already (Anonymous 2010a). The REDD program uses several different methods to lower carbon and hopes to address the management of forests, land tenure and wants to use different criteria to choose countries for selection. Rather than a country’s current forest cover level, REDD hopes to use forest cover potential to encourage countries with vastly deforested landscapes to attempt to recover (Phelps et al. 2010) by valuing their reforestation and restoration attempts.

Protected areas in the Congo Basin include tropical forests that can contribute to the sequestration of carbon, but the countries they are within will only benefit if a mechanism can be produced for a post-Kyoto treaty that takes into account the measures of protection (Griscom et al. 2009). The REDD projects are hoping to integrate all the different techniques for forest preservation in developing countries to encourage payment for ecosystem services provided by the forests both inside and outside protected areas (Busch et al. 2009; Phelps et al. 2010). My research can help with the baseline measurements of deforestation within protected areas in five developing countries. Knowing the standing levels of forest as well as the rates of deforestation from 1990-

2000 will provide the individual countries with leverage to gain economic benefit from conserving the forests.

One of the other areas influenced by this deforestation research is the impact of forest loss on the hydrological cycles. According to Shiel and Murdiyarso (2009), and the hypothesis they reference (Makarieva & Gorshkov 2007; Makarieva et al. 2006), even localized deforestation can causes changes in the cycle of rain and drought in an area due to the different availability of moisture (Sheil & Murdiyarso 2009). This idea is supported by Bonan's (2008) work looking at the feedbacks and climate benefits of tropical forests in particular, though they acknowledge the unknown influence of small scale deforestation on clouds and precipitation (Bonan 2008). So knowing where deforestation has occurred and its effects on nearby deserts, could influence where reforestation efforts should take place.

As the Central African human population becomes more urban (see Table 1), distant protected areas may become safer, while peri-urban areas take on even greater importance as sources of conservation activities. Large cities, like New York City and São Paulo, Brazil, tend to rely on peri-urban protected areas as sources for clean water (Torres et al. 2007), which could become threatened as the cities creep into the forest. Protected peri-urban forested areas will help maintain clean sources of drinking water even as populations increase. The techniques used in this thesis can be repeated fairly easily to monitor the deforestation, both natural and human-caused, as cities grow around them.

However, this development will increase the need for forest resources, and the indirect effects of logging cannot be ignored. One of the greatest indirect effects of logging is the urbanization of frontier forests (Poulsen et al. 2009). When logging camps are created, often the "town" will become permanent, creating a market for bushmeat and stripping the forest of its wildlife. While this may remain an ephemeral thing, balanced by people returning to large cities and the subsequent regrowth of forests, governments should consider this side-effect of allowing large companies logging concessions in their forests. Putting in place deterrents from creating permanent settlements in the forest might maintain the contiguous nature of the forest frontier after logging activities have been completed.

This thesis is one piece of a greater puzzle to help understand mankind's impact on the world. In conjunction with wildlife studies, climate research, and conservation policies, this research on deforestation can assist our goals to better manage the needs of a growing planet. By creating a baseline of deforestation, it improves our understanding of a valuable area to the future needs of carbon sequestration and human development. Repeating this study in 10, 20 or 50 years will show mankind's influence on protected areas and will hopefully help managers improve their activities to protect the forests.

Table 1 Central African Human Populations, 1970 and 2005 Source (U.N. 2006)

Country	1970 % Urban	2005 % Urban	% Change
Cameroon	20.3	52.9	+32.6
Central African Republic	30.1	43.8	+13.7
Congo Republic	32.8	54.4	+21.6
DRC	30.3	32.7	+2.4
Equatorial Guinea	26.7	50.0	+23.3
Gabon	31.1	85.2	+54.1

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APPENDICES

Table 1 - Confusion Matrix for all landscape categories Average accuracy = 0.69, all calculations based on methods in Inzana (2003)

	This study									
		Forest	No Data	Cloud	Water	Deforest	Reforest	Non-forest	Development	Total
Google Earth	Forest	165	0	55	8	8	6	9	30	281
	No Data	2	0	0	0	0	0	0	0	2
	Cloud	31	0	228	1	3	3	8	23	297
	Water	4		46	269	3	0	0	4	326
	Deforest	10	1	21	0	247	3	0	19	301
	Reforest	8	1	18	0	6	257	0	4	294
	Non-forest	5	0	7	5	3	2	11	2	35
	Development	34	0	32	3	16	6	12	162	265
	Total	259	2	407	286	286	277	40	244	1801

Table 2 - Confusion Matrix excluding clouds. Average Accuracy = 0.77

WITHOUT CLOUDS	Forest	No Data	Water	Deforest	Reforest	Non-forest	Devel	Total
Forest	165	0	8	8	6	9	30	226
No Data	2	0	0	0	0	0	0	2
Water	4		269	3	0	0	4	280
Deforest	10	1	0	247	3	0	19	280
Reforest	8	1	0	6	257	0	4	276
Non-forest	5	0	5	3	2	11	2	28
Development	34	0	3	16	6	12	162	233
Total	228	2	285	283	274	32	221	1325

Table 3 - User’s and Producer’s Accuracy

	User's accuracy	Producer's Accuracy
Forest	0.5872	0.6371
No Data	0.0000	0.0000
Cloud	0.7677	0.5602
Water	0.8252	0.9406
Deforest	0.8206	0.4379
Reforest	0.8741	0.4690
Non-forest	0.3143	0.2750
Development	0.6113	0.6639

Table 4 - Deforestation Calculations

	r	P	q
Annual Deforestation Rate	-0.0082	-0.0078	-0.0081
Annual NET Deforestation	-0.0005	-0.0005	-0.0005

The three measures below are rates

$r = (1/(t_2-t_1)) \ln (A_2/A_1)$ - % deforested per unit time

$P = (1/(t_2-t_1))((A_2-A_1)/ A_1)$ - % of the original area of forest deforested per unit time

$q = (A_2/A_1) \wedge (1/(t_2-t_1)) - 1$ - % deforested per unit time

R and q are more similarly related with r being based on the compound interest law. I chose to use r because most deforestation will continue from areas of previous deforestation – a frontier of deforestation in all directions. While this does not figure into the actual calculations, it makes intuitive sense to use a compounding calculation. When deforestation is low, r & q are almost interchangeable, which is supported by my calculations. According to Puyravaud, P underestimates the annual rate of deforestation because it arbitrarily compares the current forest cover to the original. (Puyravaud 2003), and it does return a lower gross deforestation rate than r or q, but the net deforestation for all are the same.

Puyravaud, J. P. 2003. Standardizing the calculation of the annual rate of deforestation. Forest Ecology and Management **177**:593-596.

Table 5 - Protected Area Summaries

Park	**Country**	**IUCN Category**	**Date Created**	**Designate**	**Area (Sq. Km)**	**% Cloud Cover**	**Total sq km Deforested**	**Total sq km Reforested**
Abong-Mbang	Cameroon	Unset	1/1/1988	Forest Reserve	1597.47	14.56	2.86	7.35
Abumonbazi	DRC	Unset	1/1/1998	Unknown	5811.86	0.00	183.94	70.24
Andre Felix	CAR	II	1/1/1960	National Park	970.87	0.00	50.29	187.58
Aouk-Aoukale	CAR	IV	1/1/1939	Faunal Reserve	3491.11	0.82	54.94	196.26
Aubeville Boko Congo	Congo	Unset	1/1/1998	Unknown	525.94	11.47	100.56	85.13
Avakaba Presidential Park	CAR	IV	1/1/1980	Private Park	2927.15	0.25	238.32	37.05
Bamingui-Bangoran	CAR	II	1/1/1933	National Park	11256.22	0.27	256.66	622.60
Bangassou	CAR	Unset	1/1/1980	Forest Reserve	12245.91	0.00	117.33	656.29
Basse Kando	DRC	VI		Hunting Zone	341.50	0.00	0.29	106.70
Bateke	Gabon	Unset	9/4/2003	National Park	2036.41	10.75	16.29	17.30
Benoue	Cameroon	II	1/1/1968	National Park	1676.06	1.36	243.37	218.93
Bili-Uere	DRC	VI		Hunting Zone	33870.41	0.33	1265.68	880.65
Bombo lumene	DRC	VI	1/1/1968	Hunting Zone	3350.10	9.21	239.00	123.93
Bomu	DRC	Ib		Strict Nature Reserve	10988.03	0.12	616.59	908.21
BoubaNdjida	Cameroon	II	1/1/1968	National Park	2051.67	0.00	351.47	4.98
BoumbaBek2	Cameroon	II	3/21/2001	Faunal Reserve	991.45	9.93	0.00	0.00
Bushimaie	DRC	VI		Hunting Zone	2063.03	0.79	52.94	206.15
Douala Edea	Cameroon	IV	1/1/1932	Faunal Reserve	1295.05	8.13	11.22	5.73
Dzanga_Ndoki	CAR	II	1/1/1990	National Park	1143.59	12.10	37.84	10.78
Epi	DRC	Unset	1/1/1998	Hunting Zone	4528.54	0.08	186.48	126.82
Faro	Cameroon	II	1/1/1980	National Park	3428.91	1.10	1170.52	213.58
Fungom	Cameroon	VI		Forest Reserve	322.59	0.00	11.91	21.45
Ganala na Bodio	DRC	VI		Hunting Zone	8356.23	0.64	1167.93	318.23
Garamba	DRC	II	1/1/1938	National Park	5083.83	0.29	779.59	506.23
Gribingui-Bamingui	CAR	IV	1/1/1940	Faunal Reserve	4341.96	0.39	51.87	54.58
Ibenga_Motaba	Congo	Unset	1/1/1990	Unknown	6302.24	2.09	124.44	1.39
Ituri	DRC	VI	1/1/1992	Forest Reserve	150.21	5.84	0.95	13.58
Kaga Bandoro	CAR	Unset	1/1/1998	Forest Reserve	5019.39	0.00	0.00	251.51
Kahuzi Biega+A64	DRC	II	11/30/1970	National Park	5916.71	5.58	1044.31	690.16
Kalamaloue	Cameroon	II	1/1/1972	National Park	66.83	0.00	7.59	0.48

Park	Country	IUCN Category	Date Created	Designate	Area (Sq. Km)	% Cloud Cover	Total sq km Deforested	Total sq km Reforested
Kimbi	Cameroon	IV	1/1/1964	Faunal Reserve	51.53	0.00	0.76	3.30
Kolwezi	DRC	Unset	1/1/1998	Hunting Zone	3387.05	1.67	126.47	65.95
Kotto	CAR	Unset		Forest Reserve	1011.60	0.00	82.90	25.75
Koukourou-Bamingui	CAR	IV	1/1/1940	Faunal Reserve	1139.03	0.14	17.78	97.20
Lac Tele	Congo	IV	10/5/2001	Community Reserve	1600.00	11.88	34.13	0.93
Lefini	Congo	IV	1/1/1963	Faunal Reserve	4766.60	1.08	288.22	163.62
Lobeke	Cameroon	II	1/1/1974	National Park	2174.69	7.71	143.92	96.71
Lomako	DRC	Unset	1/1/1991	Faunal Reserve	5823.77	6.39	783.41	374.45
Londela Kayes	Congo	Unset	1/1/1998	Unknown	186.29	14.23	41.59	18.10
Lossi Gorilla Sanctuary	Congo	Unset	10/5/2001	Faunal Reserve	571.33	4.70	0.00	0.00
Loudima 2	Congo	Unset	1/1/1998	Faunal Reserve	198.80	5.25	11.93	82.49
Luama	DRC	VI	1/1/1935	Hunting Zone	3566.00	2.36	21.62	353.74
Luama Shaba	DRC	VI		Hunting Zone	2616.02	6.80	143.68	184.39
Luki	DRC	Unset	1/1/1979	Forest Reserve	640.15	4.89	3.37	2.31
Luo Scientific Reserve	DRC	Unset	1/1/1990	Forest Reserve	509.24	10.94	76.66	27.79
Mai Mpili	DRC	Unset	1/1/1998	Forest Reserve	1133.60	10.47	142.71	26.99
Maika Penge	DRC	VI		Hunting Zone	2641.26	0.00	188.44	230.70
Maiko	DRC	II	1/1/1970	National Park	10617.29	5.69	106.57	0.00
Mangai	DRC	VI		Hunting Zone	11062.34	1.92	374.00	368.72
Maniema	DRC	Unset	1/1/1998	Forest Reserve	5294.81	2.02	409.55	0.00
Manovo-Gounda-Saint Floris	CAR	II	1/1/1933	National Park	19127.08	1.05	283.38	362.74
Mbam et Djeram	Cameroon	II	1/1/2000	National Park	4249.26	0.06	253.97	135.85
Mbambe	Cameroon	Unset		Forest Reserve	285.73	0.00	2.87	24.29
Mbulu Hills	Cameroon	Unset		Community Reserve	18.07	3.19	4.41	0.06
Mondo Missa	DRC	VI		Hunting Zone	1704.21	1.17	250.42	112.52
Mongokele	Cameroon	Unset	1/1/1988	Forest Reserve	576.74	7.80	25.94	0.83
Mont Namemba	Congo	Unset	1/1/1990	Unknown	4171.22	8.69	0.00	0.00
Monts Itombwe	DRC	Unset	1/1/1998	Faunal Reserve	7047.29	14.40	156.13	366.31
Mount Oku	Cameroon	Unset		Faunal Reserve	49.41	0.00	2.43	2.67
Mozogo-Gokoro	Cameroon	II	1/1/1968	National Park	17.17	0.00	8.38	0.14

Park	Country	IUCN Category	Date Created	Designate	Area (Sq. Km)	% Cloud Cover	Total sq km Deforested	Total sq km Reforested
Mpem et Djim	Cameroon	Unset		Faunal Reserve	1045.28	14.36	17.74	30.78
Mawne River	Cameroon	Unset	4/9/2002	National Park	454.40	3.00	28.89	0.14
Nana	CAR	Unset	1/1/1998	Forest Reserve	470.45	0.00	82.07	49.64
Nana Barya	CAR	IV	1/1/1952	Faunal Reserve	2363.38	0.00	187.06	96.80
Ngotto	CAR	Unset	1/6/1998	Forest Reserve	798.01	0.84	6.54	0.06
Ngotto Extension	CAR	Unset	12/13/2001	Forest Reserve	1363.95	1.77	23.98	0.25
Nouabale Ndoki	Congo	II	12/31/1993	National Park	4217.39	12.13	77.49	3.42
Okapi	DRC	II	1/1/1992	Faunal Reserve	111.45	2.37	0.70	8.35
Ouandjia-Vakaga	CAR	IV	1/1/1925	Faunal Reserve	7337.82	0.95	119.52	66.70
Rubi Tele	CAR	VI	1/1/1930	Hunting Zone	12384.93	10.49	329.68	0.00
Rutshuru	DRC	VI	1/1/1953	Hunting Zone	909.71	1.21	4.75	81.04
Salonga	DRC	II	1/1/1970	National Park	34895.33	2.77	1106.89	0.00
Santchou	Cameroon	IV	1/1/1964	Faunal Reserve	94.89	3.98	25.70	1.68
Shaba Elephant	DRC	Unset	1/1/1987	Faunal Reserve	531.10	5.53	56.04	21.19
Sources de Ogooue Zanaga	Congo	Unset	1/1/1998	Unknown	1457.45	0.52	29.09	18.21
Sud Masisi	DRC	Unset	1/1/1998	Forest Reserve	1684.81	3.57	316.02	58.23
Swa-Kibula	DRC	VI		Hunting Zone	1461.07	0.00	145.16	115.64
Takamanda	Cameroon	IV	1/1/1934	Faunal Reserve	617.34	1.64	80.34	0.03
Tchabal Mbabo	Cameroon	Unset		Faunal Reserve	3173.61	0.00	247.17	237.99
Tumba	DRC	Unset	1/1/1990	Unknown	1685.17	0.71	57.20	14.41
Upemba	DRC	II	1/1/1939	National Park	13983.91	0.00	78.85	3694.59
Vassako-Bolo	CAR	Ia	1/1/1960	Strict Nature Reserve	878.75	0.11	12.94	32.15
Waza	Cameroon	II	1/1/1979	National Park	1405.76	0.00	277.93	21.14
Wonga Wongoue	Gabon	IV	1/1/1972	Private Park	5064.65	9.29	0.00	0.00
Yangambi	DRC	Ia		Strict Nature Reserve	767.28	9.92	26.36	13.42
Yata Ngaya	CAR	IV	1/1/1960	Faunal Reserve	5117.94	0.00	431.33	569.06
Zone Pilote de la Sangba	CAR	Unset	1/1/1998	Forest Reserve	10698.72	0.22	234.50	525.82

Park	Annual Deforestation Rate	Annual Net Deforestation Rate	Borders Another Park	Roads Inside Park	Roads within 10KM	Roads as borders	Length of Road Inside PA (km)	Density of Roads in PA
Abong-Mbang	-0.0002	0.0004	No	Yes	Yes	Yes	130.61	0.08
Abumonbazi	-0.0042	-0.0026	No	No	No	No		
Andre Felix	-0.0160	0.0339	Yes	Yes	Yes	Yes	34.81	0.04
Aouk-Aoukale	-0.0035	0.0085	Yes	Yes	Yes	Yes	47.31	0.01
Aubeville Boko Congo	-0.0606	-0.0072	No	Yes	Yes	Yes	29.21	0.06
Avakaba Presidential Park	-0.0153	-0.0128	Yes	Yes	Yes	Yes	48.38	0.02
Bamingui-Bangoran	-0.0044	0.0059	Yes	Yes	Yes	Yes	145.60	0.01
Bangassou	-0.0013	0.0059	No	Yes	Yes	Yes	363.70	0.03
Basse Kando	-0.0002	0.0631	Yes	No	No	No		
Bateke	-0.0025	0.0002	No	No	Yes	Yes		
Benoue	-0.0215	-0.0020	No	Yes	Yes	Yes	54.86	0.03
Bili-Uere	-0.0070	-0.0021	Yes	No	Yes	No		
Bombo lumene	-0.0180	-0.0083	No	Yes	Yes	Yes	30.19	0.01
Bomu	-0.0116	0.0050	Yes	No	Yes	Yes		
BoubaNdjida	-0.0398	-0.0392	No	Yes	Yes	Yes	32.75	0.02
BoumbaBek2	0.0000	0.0000	Yes	No	Yes	No		
Bushimaie	-0.0066	0.0171	No	No	No	No		
Douala Edea	-0.0010	-0.0005	No	Yes	Yes	Yes	40.82	0.03
Dzanga_Ndoki	-0.0111	-0.0078	Yes	No	No	No		
Epi	-0.0109	-0.0034	No	Yes	Yes	Yes	70.11	0.02
Faro	-0.0608	-0.0466	No	Yes	Yes	Yes	26.77	0.01
Fungom	-0.0050	0.0038	No	No	No	No		
Ganala na Bodio	-0.0418	-0.0286	Yes	Yes	Yes	Yes	205.43	0.02
Garamba	-0.0528	-0.0155	Yes	No	Yes	Yes		
Gribingui-Bamingui	-0.0022	0.0001	Yes	Yes	Yes	Yes	62.63	0.01
Ibenga_Motaba	-0.0027	-0.0027	No	No	No	Yes		
Ituri	-0.0011	0.0130	Yes	Yes	Yes	Yes	9.92	0.07
Kaga Bandoro	0.0000	0.0075	No	Yes	Yes	Yes	286.10	0.06
Kahuzi Biega	-0.0323	-0.0098	No	Yes	Yes	Yes	48.41	0.01
Kalamaloue	-0.0352	-0.0325	No	Yes	Yes	No	16.06	0.24
Kimbi	-0.0044	0.0136	No	Yes	Yes	Yes	1.31	0.03
Kolwezi	-0.0052	-0.0025	No	Yes	Yes	Yes	50.96	0.02

Park	Annual Deforestation Rate	Annual Net Deforestation Rate	Borders Another Park	Roads Inside Park	Roads within 10KM	Roads as borders	Length of Road Inside PA (km)	Density of Roads in PA
Kotto	-0.0099	-0.0067	No	No	Yes	No		
Koukourou-Bamingui	-0.0028	0.0118	Yes	No	Yes	Yes		
Lac Tele	-0.0030	-0.0030	Yes	Yes	Yes	Yes	3.31	0.00
Lefini	-0.0145	-0.0060	No	Yes	Yes	Yes	155.19	0.03
Lobeke	-0.0270	-0.0081	Yes	No	No	Yes		
Lomako	-0.0175	-0.0088	No	No	Yes	No		
Londela Kayes	-0.0752	-0.0355	No	Yes	Yes	No	11.72	0.06
Lossi Gorilla Sanctuary	0.0000	0.0000	No	No	No	No		
Loudima 2	-0.0217	0.0767	No	Yes	Yes	Yes	35.67	0.18
Luama	-0.0017	0.0230	No	Yes	Yes	Yes	58.81	0.02
Luama Shaba	-0.0176	0.0045	Yes	Yes	Yes	No	97.53	0.04
Luki	-0.0006	-0.0002	No	Yes	Yes	Yes	38.26	0.06
Luo Scientific Reserve	-0.0255	-0.0155	No	No	No	No		
Mai Mpili	-0.0280	-0.0221	No	No	No	No		
Maika Penge	-0.0184	0.0037	No	Yes	Yes	No	60.38	0.02
Maiko	-0.0018	-0.0018	No	No	Yes	No		
Mangai	-0.0070	-0.0001	No	Yes	Yes	No	138.33	0.01
Maniema	-0.0136	-0.0136	No	Yes	Yes	No	40.38	0.01
Manovo-Gounda-Saint Floris	-0.0033	0.0009	Yes	Yes	Yes	Yes	223.28	0.01
Mbam et Djeram	-0.0091	-0.0041	No	Yes	Yes	Yes	1.18	0.00
Mbambe	-0.0012	0.0086	No	Yes	Yes	No	19.74	0.07
Mbulu Hills	-0.0433	-0.0426	No	No	No	No		
Mondo Missa	-0.0337	-0.0172	Yes	No	Yes	No		
Mongokele	-0.0124	-0.0120	Yes	No	No	Yes		
Mont Namemba	0.0000	0.0000	No	Yes	Yes	No	72.97	0.02
Monts Itombwe	-0.0049	0.0063	No	Yes	Yes	Yes	113.50	0.02
Mount Oku	-0.0070	0.0007	No	No	Yes	No		
Mozogo-Gokoro	-0.1564	-0.1503	No	Yes	Yes	Yes	2.31	0.13
Mpem et Djim	-0.0037	0.0027	No	Yes	Yes	Yes	1.96	0.00
Mawne River	-0.0079	-0.0078	No	No	Yes	No		
Nana	-0.0254	-0.0093	No	Yes	Yes	Yes	37.12	0.08

Park	Annual Deforestation Rate	Annual Net Deforestation Rate	Borders Another Park	Roads Inside Park	Roads within 10KM	Roads as borders	Length of Road Inside PA (km)	Density of Roads in PA
Nana_Barya	-0.0147	-0.0068	No	Yes	Yes	Yes	9.82	0.00
Ngotto	-0.0009	-0.0009	Yes	Yes	Yes	Yes	20.17	0.03
Ngotto Extension	-0.0019	-0.0019	Yes	Yes	Yes	Yes	93.82	0.07
Nouabale_Ndoki	-0.0039	-0.0037	Yes	No	No	Yes		
Okapi	-0.0010	0.0101	Yes	Yes	Yes	No	13.05	0.12
Ouandjia-Vakaga	-0.0057	-0.0025	Yes	Yes	Yes	Yes	216.16	0.03
Rubi Tele	-0.0039	-0.0039	No	Yes	Yes	Yes	90.15	0.01
Rutshuru	-0.0012	0.0171	Yes	Yes	Yes	No	12.74	0.01
Salonga	-0.0035	-0.0035	No	No	Yes	No		
Santchou	-0.0526	-0.0482	No	No	Yes	Yes		
Shaba Elephant	-0.0386	-0.0222	Yes	No	No	No		
Sources de Ogooue Zanaga	-0.0052	-0.0019	No	Yes	Yes	No	68.19	0.05
Sud Masisi	-0.0464	-0.0361	No	Yes	Yes	Yes	4.19	0.00
Swa-Kibula	-0.0408	-0.0071	No	No	No	No		
Takamanda	-0.0162	-0.0162	No	No	No	No		
Tchabal Mbabo	-0.0133	-0.0005	No	No	Yes	No		
Tumba	-0.0040	-0.0030	No	No	No	No		
Upemba	-0.0021	0.0658	Yes	No	Yes	Yes		
Vassako-Bolo	-0.0027	0.0039	Yes	No	Yes	No		
Waza	-0.0334	-0.0304	No	Yes	Yes	Yes	77.60	0.06
Wonga_Wongoue	0.0000	0.0000	No	Yes	Yes	No	433.90	0.09
Yangambi	-0.0046	-0.0022	No	Yes	Yes	Yes	24.26	0.03
Yata Ngaya	-0.0158	0.0045	Yes	Yes	Yes	Yes	147.04	0.03
Zone Pilote de la Sangba	-0.0035	0.0042	Yes	Yes	Yes	Yes	203.46	0.02

Park	Transmission Lines	Transmission Line Length in PA (km)	Density of Transmission Line in PA	Perimeter (Km)
Abong-Mbang	Yes	9.67	0.01	191.91
Abumonbazi	No			281.75
Andre Felix	No			141.99
Aouk-Aoukale	No			394.63
Aubeville Boko Congo	Yes	19.34	0.04	83.91
Avakaba Presidential Park	No			264.74
Bamingui-Bangoran	No			693.74
Bangassou	No			545.04
Basse Kando	No			82.69
Bateke	No			284.62
Benoue	Yes	11.38	0.01	241.03
Bili-Uere	No			1617.92
Bombo lumene	Yes	66.42	0.02	303.62
Bomu	No			1214.60
BoubaNdjida	No			210.67
BoumbaBek2	No			343.14
Bushimaie	No			185.85
Douala Edea	Yes			404.20
Dzanga_Ndoki	No			197.98
Epi	No			332.83
Faro	No			250.07
Fungom	No			78.95
Ganala na Bodio	No			668.33
Garamba	No			410.78
Gribingui-Bamingui	No			491.22
Ibenga_Motaba	Yes	53.02	0.01	342.17
Ituri	No			437.50
Kaga Bandoro	Yes	74.91	0.01	291.77
Kahuzi Biega	Yes			595.26
Kalamaloue	Yes			37.71
Kimbi	No			39.07
Kolwezi	Yes	101.96	0.03	213.90

Park	Transmission Lines	Transmission Line Length in PA (km)	Density of Transmission Line in PA	Perimeter (Km)
Kotto	No			127.34
Koukourou-Bamingui	Yes			200.79
Lac Tele	No			392.47
Lefini	Yes			431.60
Lobeke	No			238.23
Lomako	No			397.29
Londela Kayes	Yes	13.72	0.07	49.91
Lossi Gorilla Sanctuary	No			99.82
Loudima 2	Yes	37.38	0.19	76.64
Luama	Yes			305.58
Luama Shaba	Yes	118.86	0.05	275.64
Luki	Yes	21.55	0.03	106.56
Luo Scientific Reserve	No			104.93
Mai Mpili	No			128.07
Maika Penge	No			295.19
Maiko	No			569.73
Mangai	Yes	71.49	0.01	747.96
Maniema	No			267.59
Manovo-Gounda-Saint Floris	Yes	128.64	0.01	1008.92
Mbam et Djeram	No			354.06
Mbambe	No			70.20
Mbulu Hills	No			16.44
Mondo Missa	No			207.82
Mongokele	No			102.60
Mont Namemba	No			288.49
Monts Itombwe	No			389.53
Mount Oku	Yes			25.61
Mozogo-Gokoro	Yes			16.72
Mpem et Djim	No			136.72
Mawne River	Yes	14.40	0.03	134.12
Nana	No			105.90

Park	Transmission Lines	Transmission Line Length in PA (km)	Density of Transmission Line in PA	Perimeter (Km)
Nana_Barya	No			279.52
Ngotto	No			133.71
Ngotto Extension	No			276.27
Nouabale_Ndoki	No			341.33
Okapi	No			426.92
Ouandjia-Vakaga	Yes	56.43	0.01	682.28
Rubi Tele	No			536.81
Rutshuru	No			179.38
Salonga	No			1343.12
Santchou	Yes			46.89
Shaba Elephant	No			151.28
Sources de Ogooue Zanaga	No			137.58
Sud Masisi	Yes			228.59
Swa-Kibula	No			221.16
Takamanda	No			175.53
Tchabal Mbabo	No			286.43
Tumba	No			156.50
Upemba	No			711.48
Vassako-Bolo	No			137.49
Waza	Yes	44.40	0.03	165.79
Wonga_Wongoue	Yes	63.01	0.01	466.45
Yangambi	No			107.85
Yata Ngaya	No			573.73
Zone Pilote de la Sangba	Yes	139.34	0.01	422.79

Image 1 – Ngotto and Ngotto Extension forest reserve

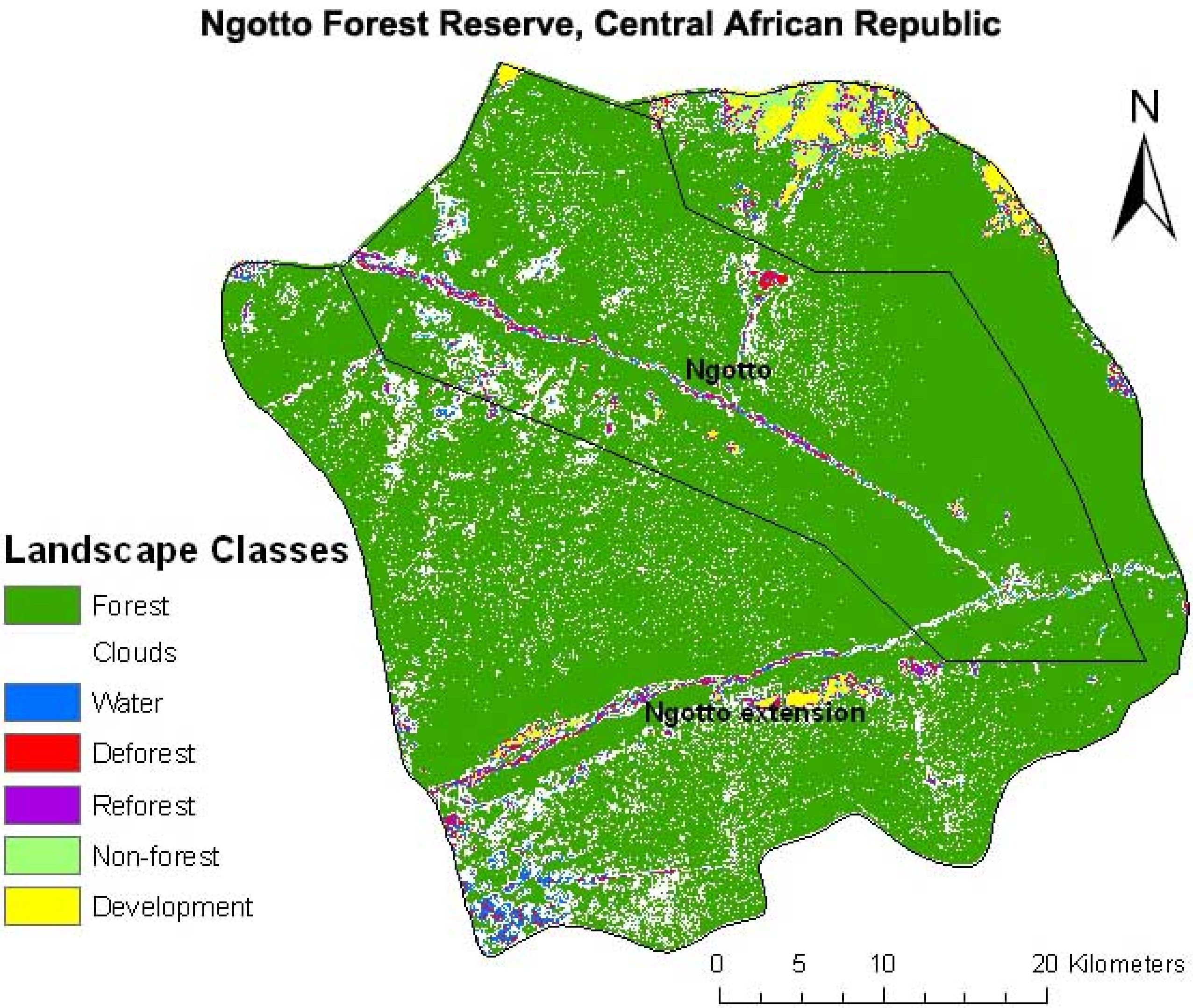

Image 2 – Ngotto Forest Reserve with roads and rivers

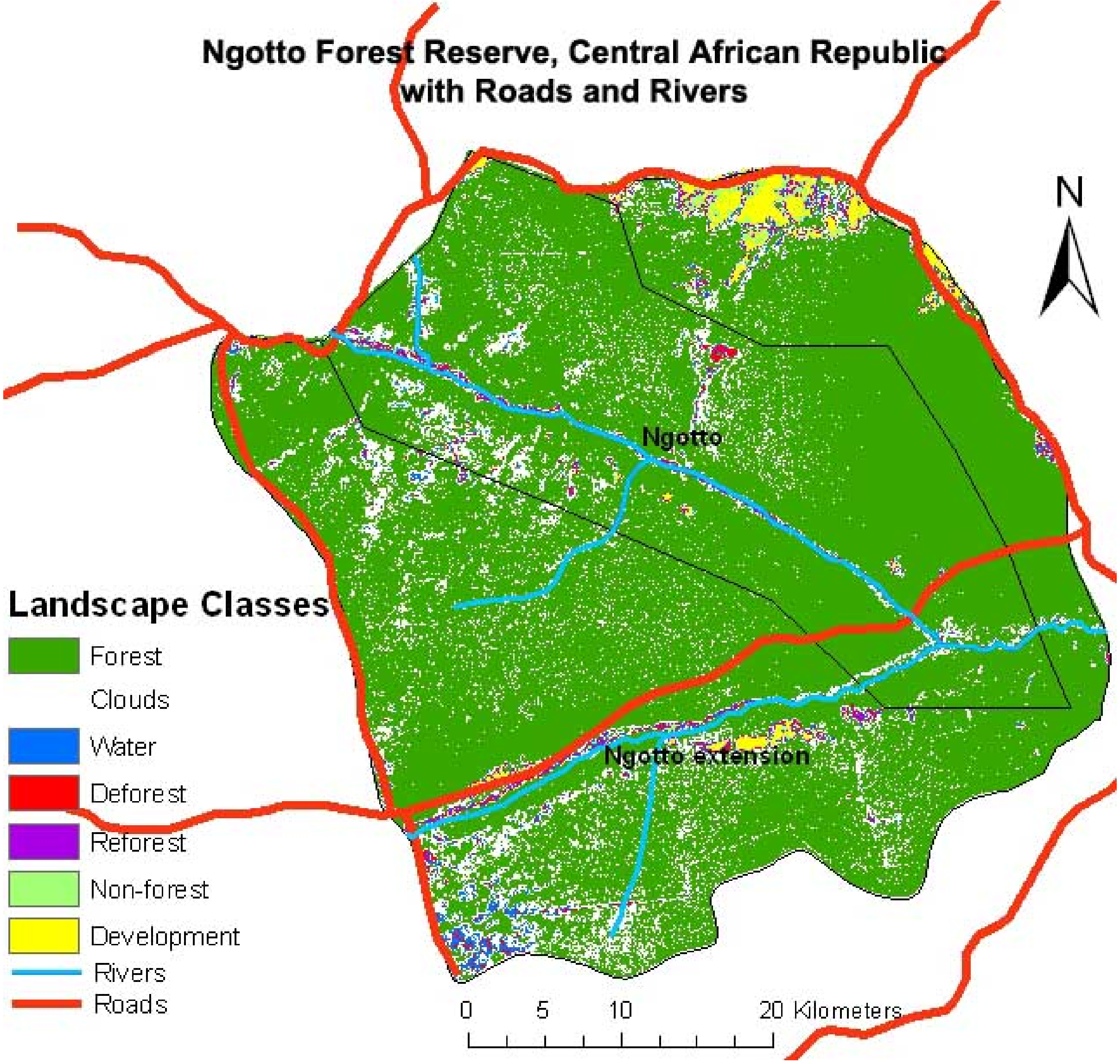

Image 3 – Ngotto Forest Reserve, Satellite image from 2000

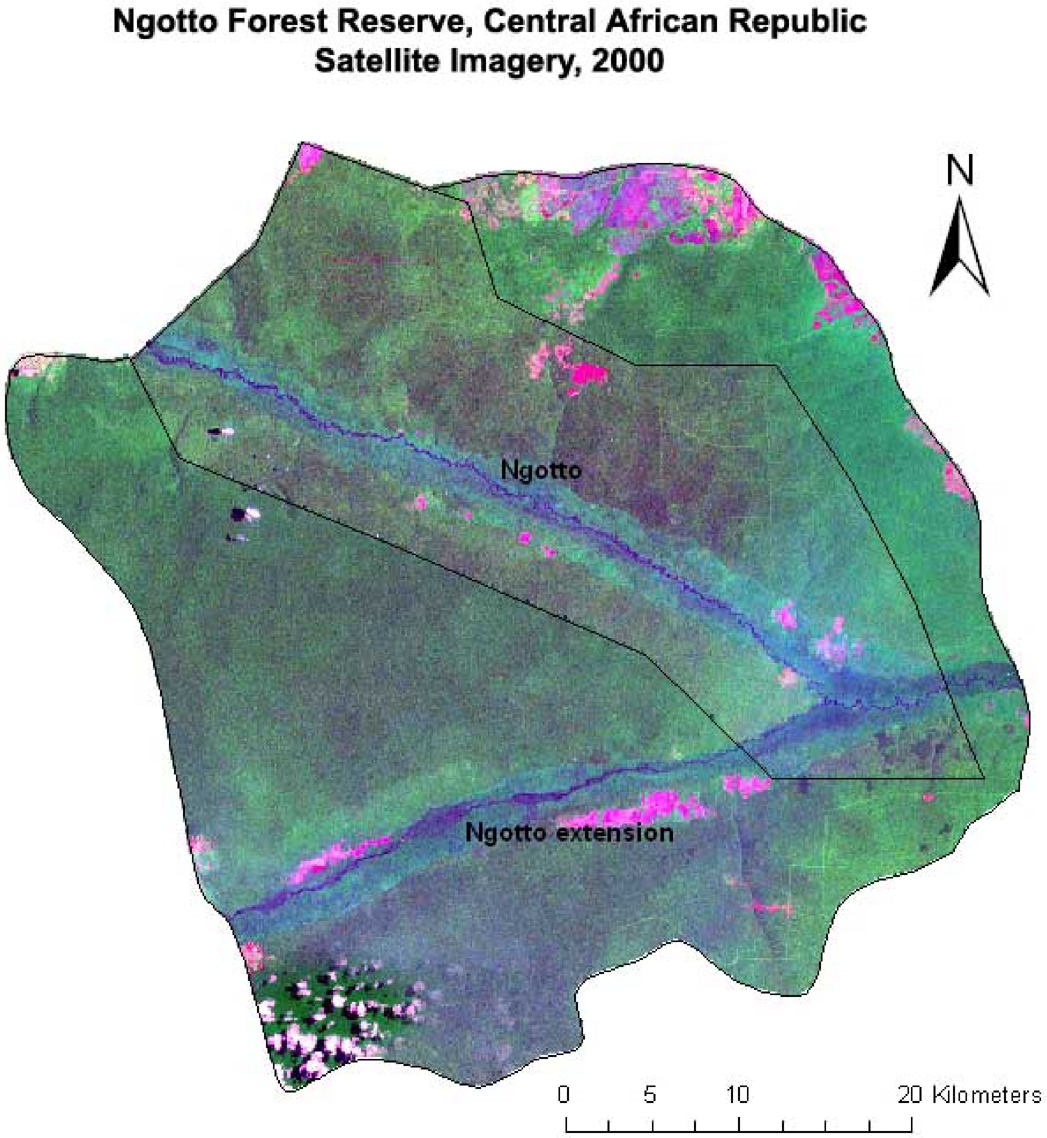

Figure 1 – Cloud cover elimination figure