Assessing Logging Concession Road Prevalence as a Mechanism for Land Use Change in the Republic of the Congo

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Introduction

What business does an urban planner have studying deforestation trends in Central Africa? Surprisingly, the vast majority of the world's urban population lives in small cities, not in the megacities we normally think of when discussing urbanity (Nations, 2001). It is also important to note that 50% of Africa's population will live in cities by 2035 (Nations, 2001). With this growth, questions arise concerning infrastructure, zoning, land use, and transportation. It is therefore vital as an urban planner to study the regions of the world that a) will be growing the most drastically over the next few decades and b) see how early stages of urbanization unfold in the twenty-first century according to governmental regimes, differing landscapes, land cover (or lack thereof), road prevalence, and resource exploitation.

Global Significance

In the Republic of the Congo (RoC), the growth rate of 2.849% is more than twice the worldwide average of 1.1% and it is on the rise. This country is one of six that are included in the Central African Congo Basin. Because this region is characteristically low density, many believe that much of the forest is uninhabited or that those who do live here have little to no customary rights (Lescuyer, 2012). Customary rights are used here as rights acquired by tradition, they differ from prescriptive rights in that the former belong to the inhabitants of a particular place or district while the latter are rights of individuals, regardless of their place of residence. This could not be farther from the truth. This massive tropical rainforest is currently home to more than 30 million people, many of whom use the surrounding forests as a means to acquire food, medicine, fuel, and other materials used to grow, industrialize, and urbanize (Zhang, 2006)**.** Rainforests like the ones that cover the Congo Basin are globally significant because they contain some of the highest biodiversity in the world (Megevand, 2013). This has positive impacts on local regions as well as on the global community (Norris, 2010). Rainforests contribute significantly to carbon capture, mitigating dangerous greenhouse gases in the atmosphere. Currently more than 30% of the forests in Central Africa are forested but only about 12% are protected (Laporte, 2007). The Congo Basin takes up the majority of forest cover in Africa: 70% (although this number is not stagnant and continues to fluctuate) (Megevand, 2013).

There are many regions in the Congo Basin where customary rights are applied to an area that the local people consider their own, regardless of internationally recognized governmental boarders. Such regions are known as "villages terroirs," which literally translates to local town (Lescuyer, 2013). Here, forest and agriculture zones are intertwined with human settlements and rights associated with a village terroir are legally recognized by many of the countries in the basin, although the existence of the "village terroir" is not formally recognized (Lescuyer, 2012).

Logging and Economic Importance

In many other regions in the world, the implementation of logging acts as a transition from one form of land use to another. In the Central African Congo Basin, this is not the case. Here, highly selective logging takes place in permanently forested areas. Forest logging makes up a considerable amount of local livelihoods and acts as a safety net for countries that face extensive obstacles in malnourishment and poverty (Megevand, 2013). The forest also acts as a buffer to climate change, as the Congo Basin makes up 25% of the total carbon stored in tropical forests worldwide. This alleviates some of the pressures from anthropogenic emissions (Megevand, 2013).

Although these forests are invaluably important, an injunction against logging in many parts of Africa is not an option. As mentioned previously, these forests play a very important role in the market economies of rural areas and of national GDPs. There are, however, intelligent ways to use the land and these resources. Although Sustainable Management Plans are implemented in logging concessions in the region, many scientists and spatial analysts who work in the regions debate whether or not these practices are the best way to handle deforestation. There is research that suggests that holistic, effective forest monitoring helps mitigate illegal harvesting and the consequential negative environmental impacts that go along with it (Bell, 2012).

Concessions and Logging Ecology

Because Congo Basin forestry is highly selective, the problems associated with logging concessions usually involve degradation (loss of biodiversity) rather than deforestation (loss of forests) (Bell, 2012). Only a relatively small number of species are logged and only a few felled per hectare (Zhang, 2006). Concessions of the Congo Basin mentioned in this paper follow the industrial forestry operations definition (Karseny et al, 2008). As Karsenty points out, 'industrial' in this context is sometimes confused with 'international' concession companies. Although it is true that five times more felled trees are associated with international companies in the region as compared to locally-based concessions (Brown, 2001), both local and international concessions are present and are grouped together in this paper. When discussing concessions, I use the word to describe any logging company that is present in the region, regardless of size or origin of the company.

Logging concessions have been present in the northern RoC for more than a century, although those that exist today vary greatly from the original concessions that mainly used forced labor from colonial rule (Karsenty, 2008). A concession is defined as "the granting of a territory to a concessionaire (here, a logging company) for their occupation and use" (FAO, 1999). It is a legal agreement that grants a private or public person (including commercial companies) exclusive rights to exploit the land. A legal contract called a "specifications book" (*cahier des charges*) is written up that details all of the obligations that the third party must abide by in order to continue the exploitation of the land (Karsenty, 2008). This book details all of the general laws that the concessionaire must abide by as well as regulations that are specific to that plot of land. These specifications include technical, fiscal, economic, social, and environmental issues. They also include a mandatory creation of a forestry management plan (FMP), establishing new jobs in the area, the delivery of goods and services to local administrators, specific taxes and fees that must be paid by the company, requirements to prevent poaching and illegal logging, and infrastructure building (Karsenty, 2008). Today, logging concessions provide and build much of the road networks around these often-rural areas because the state cannot afford to do so (Karsenty, 2008).

State + Concession Relationships

Because these concessions are primarily agreements between the private operators and the state, logging concessions are often criticized for ignoring the interests of other stakeholders (Lescuyer, 2012). Although private concessions are required to implement the stipulations detailed in the *cahier des charges*, many do not. There is no incentive for private concessions to synchronize their production and conservation efforts when the local governments' consequences are arbitrarily given out and are often less severe than stated in the law (Nasi, 2012). There is no doubt that there are winners and losers in this system. This is especially apparent with the local populations, the vast majority of which existed before the state or concessions came into being (Lescuyer, 2012). There is much scientific and anthropologic debate about the validity of the management of these forests as dictated in the FMPs. As Lescuyer (2012) points out, not only have these plans stemmed from previous colonial rule, they also fail to address the problems that persist in these regions, including but not limited to: the displacement of human populations, lack of assistance to poverty stricken citizens in the area(s), the delegitimization of local authorities, and the continued poor governance of the forestry sector.

In many western countries, there are very specific protocols for road planning and construction. In developing countries, especially in less dense regions like a tropical rainforest, this is not the case and there are far fewer studies on the adverse ecological effects of these roads (Van der Hoeven, 2010). Roads can form barriers that render them impossible to cross for wildlife. This can separate the original populations into smaller sub-populations, which may result in the creation of metapopulations. Metapopulations are less able to adapt to changes in environments and are more prone to extinction than the original population (Forman, 1998). This argument, however, is convoluted by the fact that many concessionary roads are only open during a small time window and can reincorporate natural flora and fauna cycles. Arguments like this one further demonstrate the idea that more spatial analysis of differing levels must be applied to this region to better understand how the land is being used.

Research Questions

The primary question I would like to address in this paper is, what effect do these primarily concessionary roads have on the land around them (in terms of both land use and land cover change). I want to see to what extent it is affected in terms of distance. In other terms, I want to see how far out the land is affected by the building of roads. I also am interested in the different types of forests in the area and how the roads affect each differently (primary forests, secondary forests, and swamp forests). Although I might not be able to specifically address this question, I would also like to know to what extent the roads alone influence the change of this land or if there are confounding variables that are also affecting forest cover.

Study Area

This study area is located in the northern region of the Republic of the Congo. This area, 83,916 km^2 in size, encompasses approximately 25% of the entire country. It takes up the majority of the northern region of the country (**Figure 1**). This area is situated south of the border of Central African Republic, East of Cameroon and Gabon, and west of the Democratic Republic of the Congo. The two regions included in this study area are Sangha and Likouala. Two major protected areas are also included in this study area: Parc National d'Odzala-Kokoua and Nouabalé-Ndoki National Park. Ouesso is the largest city contained in this area. It is important to note that although this study contains 25% of the RoC, there is much less development in the northern section of the country. As previously mentioned, logging companies, not the state, develop much of the infrastructure that is currently in place in the area. This research cannot be extrapolated to the other sections of the country nor can it project the results to other regions in the Congo Basin as each has different governmental and non-governmental structures in place that could translate to different outcomes.

The Central African Forests and Institutions (CAFI) project at the University of Michigan informed the location that was used in this study. This project, funded by the National Science Foundation, studied logging concessions in Cameroon and the RoC. Research was conducted on the ways in which non-governmental organizations (NGOs), industries, and governments affect these logging companies. In order to consolidate certain information, I choose to only look at the Republic of the Congo portion of the CAFI study area.

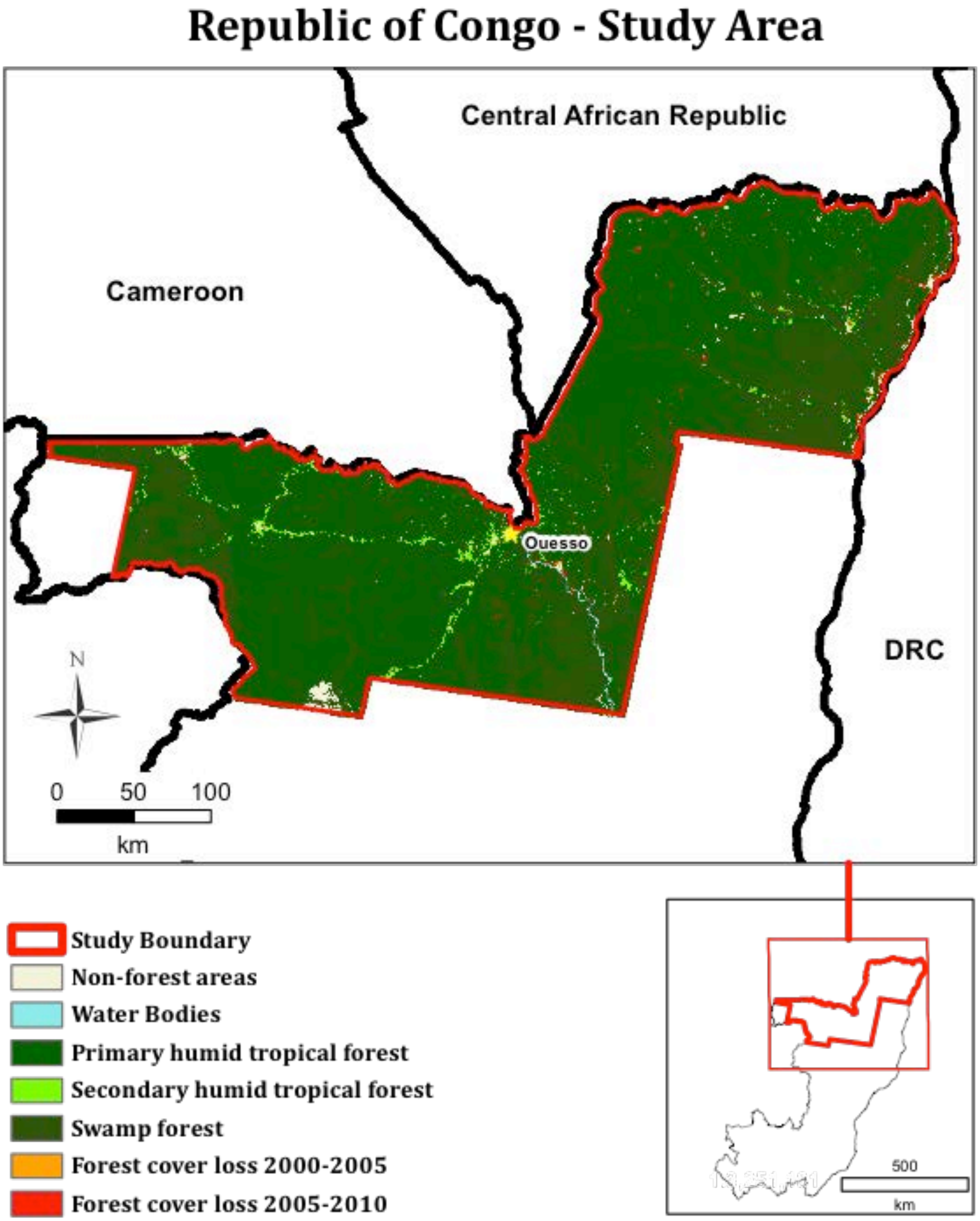

Figure 1 - Study Area

Methods

Geographical databases were made available by "Monitoring the forests of Central Africa using remotely sensed data set" (Foréts d'Afrique Centrale Évaluées par Télédétection) (FACET), which is led by Observatoire satellital des forets d'Afrique centrale (OSFAC) in collaboration with South Dakota State University and the University of Maryland, and supported by USAID CARPE**.** These satellite images are aggregates of multiple years of imagery (both 2000-2005 and 2005-2010) that use complex algorithms to find the clearest images of the land to be surveyed. The data was an "exhaustive mining of Landsat Thematic Mapper Plus (ETM+)," which totaled 8,881 images with less than 50% cloud coverage (Turubanova, 2012). The images used to create the roads data was the aggregate of Landsat images taken from 2005 through 2010. These images are mosaics based on ETM+

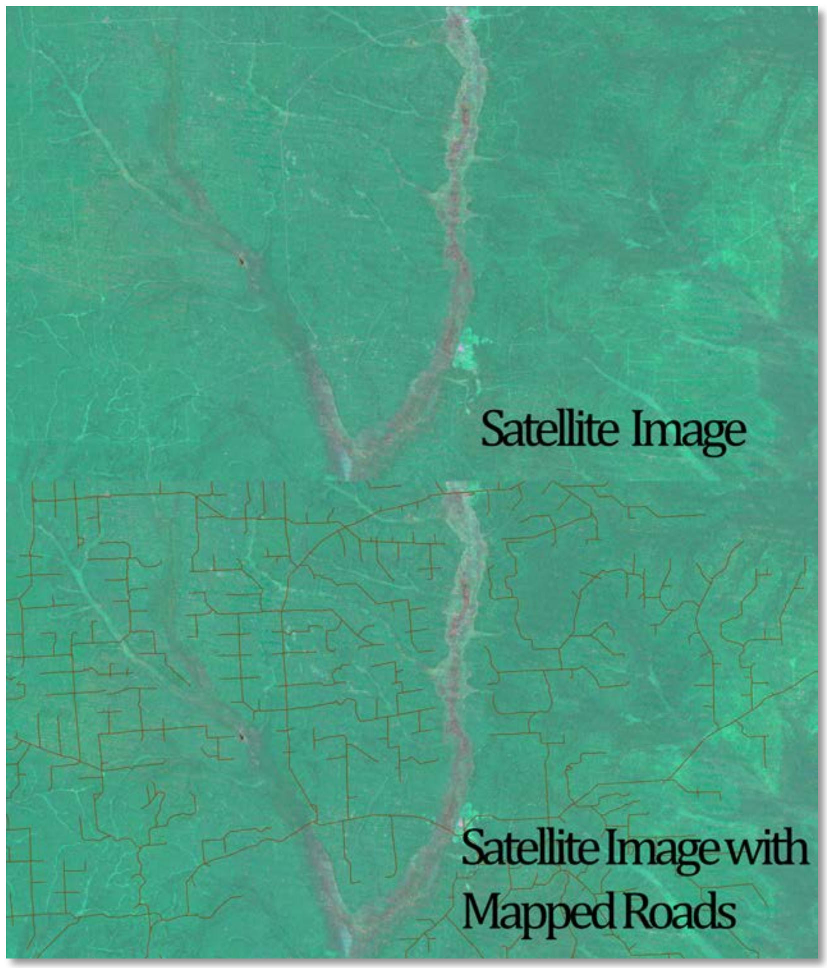

Figure 2 – Satellite Imagery (Bands 3, 2, 1) and Road Mapping Example

shortwave infrared (SWIR), near infrared (NIR) and Red spectral bands. The data were resampled to a 60m spatial resolution. Roads data was manually digitized using ArcGIS 10.1 (ESRI, 2011) and was modified specifically for this project from the CAFI data. The line segment tool was used to create individual roads. The methodology for determining whether or not to map a road was to first draw all major roads. Using the 6-band FACET satellite imagery with band combination Red: Band 3, Green: Band 2, and Blue: Band 1, all lines that appeared in white (which represents a lack of forest) were drawn in as roads. To help assist with less prominent road creation, I added settlement data into ArcGIS to assist with the formation of roads. This data came from digitized Landsat images. The settlements were named on the basis of information from topographical maps (IGN, CERGEC). This digitized data was then merged with the field data collected by CARP. Settlement data acts as a wayfinder to determine whether or not a road should be created. Although this settlement data helped to determine location of roads, most often, roads were discovered by the white land use found on the maps. If there was a clear lack of forest and no settlement data to match, roads were still mapped. Google Maps was also helpful at times when I was unsure or cloud coverage completely blocked my point of view. Because these large satellite images are aggregates, there is a possibility that some of the roads data is not completely accurate. A discussion of remote sensing drawbacks is located in the discussion section of this paper. An example of the satellite imagery and the roads mapped onto it is included in **Figure 2**.

The map used to calculate *deforestation* was an "Atlas of Forest Cover and Loss for 2000-2010 in the Republic of the Congo." This map also came from FACET. This map uses a "wall-to-wall" remote sensing method (as opposed to a sample-based method that many other spatial analysis studies use). It is an aggregate of 2491 Landsat ETM+ images that contained less than 50% cloud cover. The final FACET map that I used in my study contains thematic classifications of forest cover and forest cover loss for 2000-2005-2010 in the RoC. The FACET map that was used was clipped to the specific study area of this paper. An example area of the FACET map with the manually mapped roads can be seen in **Figure 3**. Notice how it differs from the map in **Figure 2.**

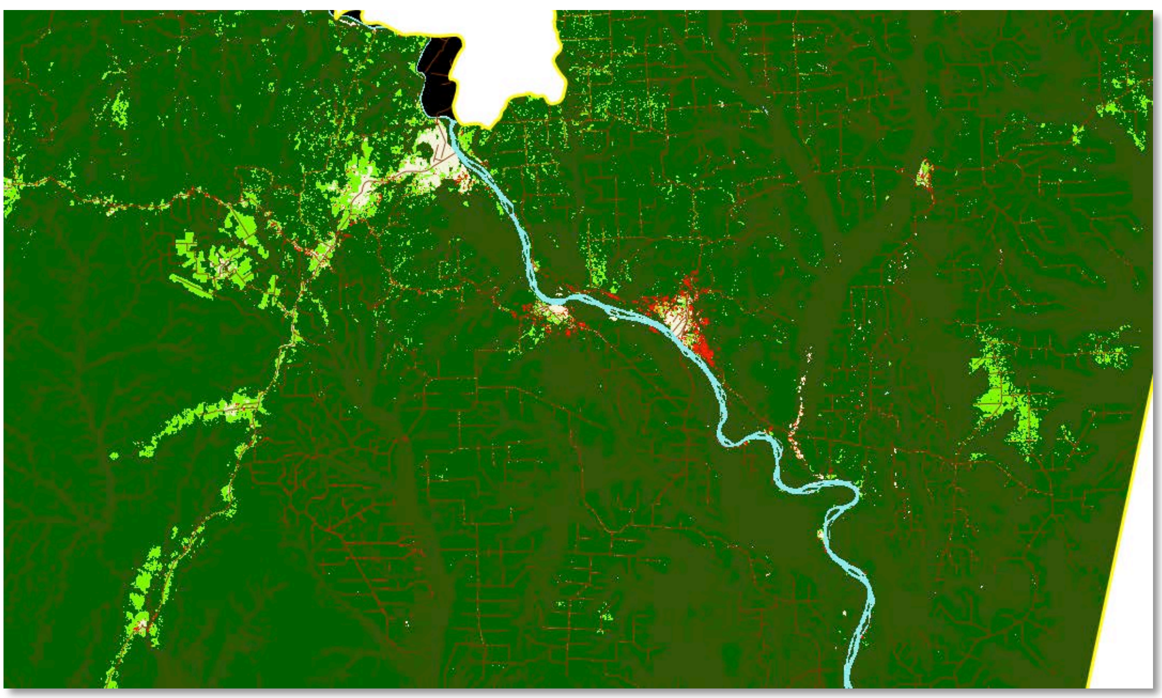

Figure 3 – Roads Overlaid onto FACET Map

The data described by the FACET map and listed in the legend of **Figure 1** are defined as follows:

- Forest is an area with trees at least five (5) meters in height and a canopy cover of at least 60% at a spatial resolution of 60 m. Forest areas have been divided into three categories: primary forest, secondary forest and swamp forest (swamp forest is a subset of primary forest)

- Primary forest is a mature forest, including old growth forest, plantations, mature trees, and forest galleries. Primary forests have a mature, heterogeneous canopy height and structure that extinguishes incoming light, reduces reflectance and makes these forests appear dark in satellite imagery

- Secondary forest includes recently regrown forests following a disturbance. Secondary forests are characterized by uniform canopies that increase reflectance, particularly in the near infrared wavelengths, when compared to primary forests.

- Swamp forest is primary forest occurring in wetlands. Wetlands are transitional lands located between terrestrial and aquatic systems where the water table is usually at or near the surface, or where the land is covered by shallow water.

- Other land cover types are considered non-forest.

- Forest cover loss was mapped by quantifying the change in forest to non-forest cover during the period under study. Permanent water bodies were mapped separately. (Turubanova, 2012).

Once the roads were manually mapped, I created buffers around the extent of all of the roads in the northern RoC region. Using the Multiple Ring Buffers tool, buffers made were one, two, three, four, and five kilometers from the road. This was primarily an arbitrary number but turned out to be viable because (as shown in the results section) land use was not very pervasive after 2 km out from any given road. These buffers completely wrapped around all of the manually mapped roads. “Dissolve Option: ALL” and “Outside Polygons Only: false” were selected in the options. This is shown in **Figure 4**.

I then rasterized all buffers separately using the Polygon to Raster (conversion) tool in ArcGIS. This allowed each buffer (1-km, 2-km, etc.) to act as a raster (rather than road data) that could pick up the information on the FACET map. Each pixel on the FACET map corresponds to one of seven categories (as previously described and shown in the legend of **Figure 1**). These rasterized files pick up the colors on the map and count the total number of different colors, sorting them into each category. Each pixel on the FACET map represents 60x60 meters of land. The “Tabulate Area” tool in ArcGIS calculated the amount of pixels picked up by each buffer.

The Statistical Package for the Social Sciences (SPSS) was used to analyze the data (IBM, 2011). The first test was an Analysis of Variance test (ANOVA) employed to see if a difference exists between the five different buffers’ rates of deforestation. An ANOVA test is appropriate here because it compares the differences between group means of all of the different sized buffers and tells us if one or more is significantly different. The null hypothesis would be that there is no difference in deforestation rates between the different buffers. The alternative would be that at least one of the buffers has a significantly higher or lower rate of deforestation. The second test was another ANOVA comparing the rates of deforestation between the three types of forest as defined by the FACET map (primary, secondary, and swamp forests). The null hypothesis here is that there is no difference in rates of deforestation between the different types of forest. The alternative hypothesis is that a difference exists between one or more of forests' rates of deforestation.

The last test performed was a paired samples T-Test. This test compared the rates of deforestation for all three types of forest and each buffer size for the years 2000-2005 with the same data for years 2005-2010. For example, the primary forest data for the 2-km buffer for years 2000-2005 was compared with the primary forest data for the 2-km buffer for rates of deforestation from 2005-2010. All 15 cells from the 2000-2005 data were compared with the cells from 2005-2010. Significance here (accepting the alternative hypothesis) would mean that there is a significant difference between the rates of deforestation between the two time intervals.

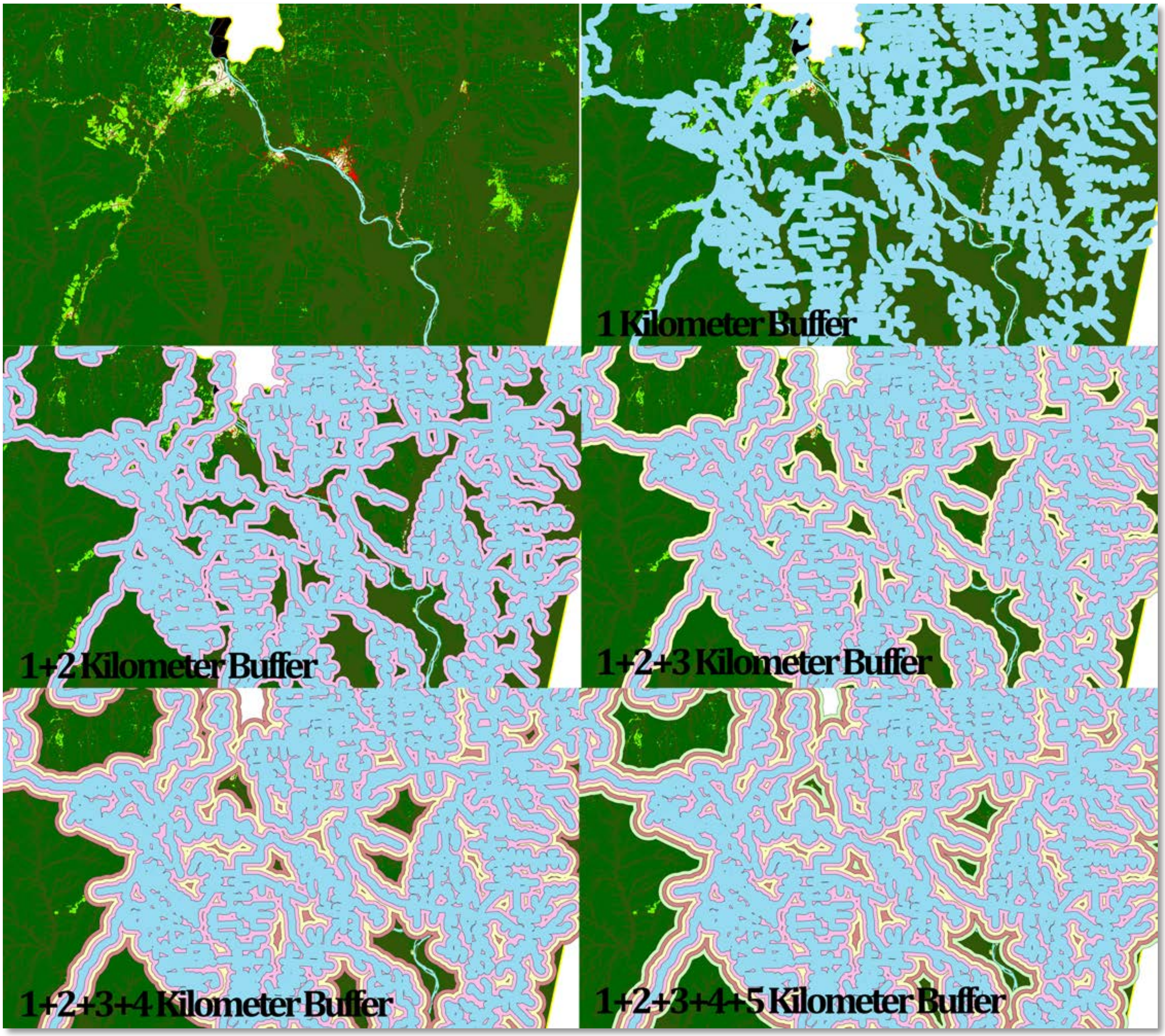

Figure 4 – Comparison of FACET Map with Roads Data to 1, 2, 3, 4, and 5-Kilometer Buffers

CLASS	1 km Buffer	2 km Buffer	3 km Buffer	4 km Buffer	5 km Buffer
Non-forest areas	196.4	53.5	35.1	26.3	14.6
Primary humid tropical forests	12545.9	5064.6	3141.7	2523.9	2186.7
Secondary humid tropical forests	695.2	197.3	95.4	44.9	25.4
Swamp forests	3518.0	3685.7	2308.9	1702.8	1385.3
2000-2005 within primary forest	69.1	4.1	1.9	1.1	0.7
2000-2005 within secondary forest	21.6	2.7	1.3	0.5	0.3
2000-2005 within swamp forest	8.3	1.6	1.1	0.6	0.5
2005-2010 within primary forest	85.6	12.3	5.9	3.1	1.9
2005-2010 within secondary forest	31.4	5.9	2.7	1.5	0.7
2005-2010 within swamp forest	20.8	6.3	4.4	3.7	2.0

Table 1 – Raw Data from FACET Map pixels

Proportion (from total area)					
Land cover	1 km buffer	2 km buffer	3 km buffer	4 km buffer	5 km buffer
Primary humid tropical forests	32.1	12.9	8.0	6.5	5.6
Secondary humid tropical forests	1.8	0.5	0.2	0.1	0.1
Swamp forests	9.0	9.4	5.9	4.4	3.5

Proportion (from land cover class)					
Land cover	1 km buffer	2 km buffer	3 km buffer	4 km buffer	5 km buffer
Primary humid tropical forests	49.3	19.9	12.3	9.9	8.6
Secondary humid tropical forests	65.7	18.6	9.0	4.2	2.4
Swamp forests	27.9	29.2	18.3	13.5	11.0

Table 2 – Proportions of Buffers from Total Land Cover and Forest Type

Results

The raw data is shown in **Table 1**. With this, land use around these roads starts to become apparent. **Figure 5** shows the three types of forests as recognized by the FACET map: primary forest, secondary forest, and swamp forest. We can see that (at least for the area around established roads) the vast majority of the forest coverage is primary forest. There is a very small proportion of swamp forest. It also should be noted that these buffers are mutually exclusive of each other. In order to calculate these areas, it was best to not have aggregates of 1, 2, 3-km buffers (etc.) but rather separate areas for each buffer. Proportions of the data by both total area of all of the buffers as well as proportions of each type of forest are shown in **Table 2.**

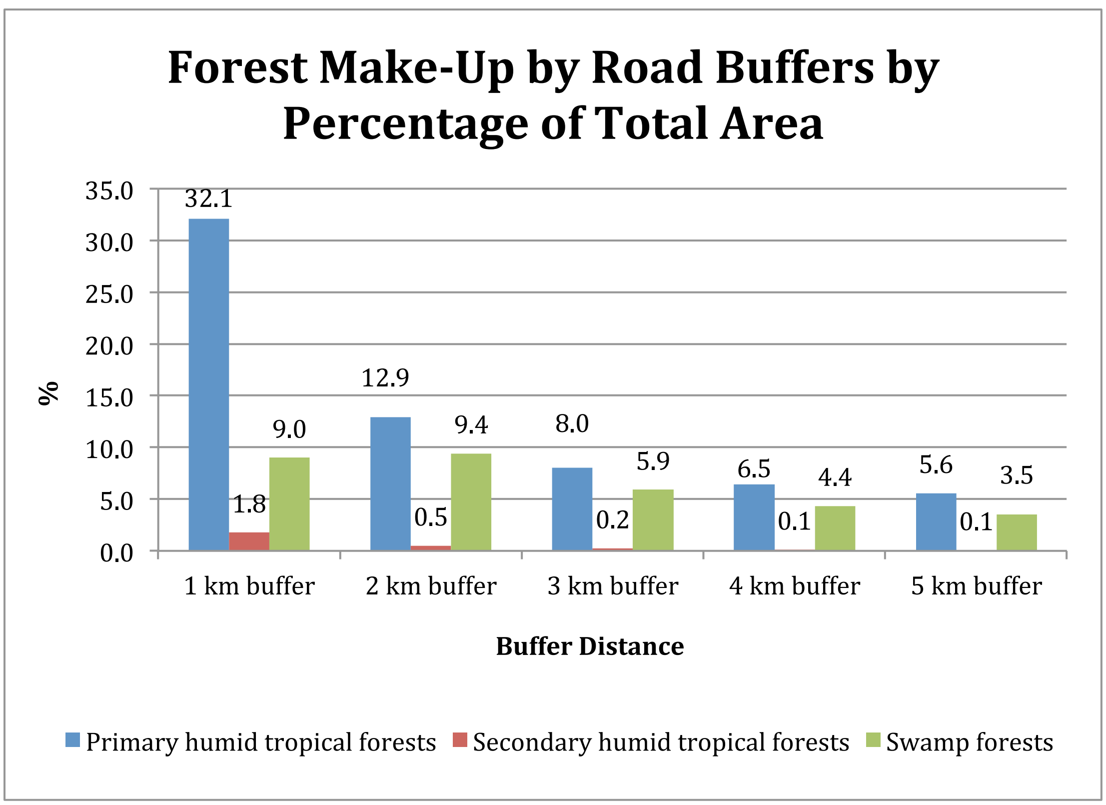

Figure 5 - Breakdown of Forest Type by Buffer

We can also see that, surprisingly, as the buffers get farther away from the roads, the proportions of primary to swamp forests get closer. This is intuitive: roads are not built near wet areas like swamps. It also should be noted that secondary forest coverage is almost impossible to see on this chart. This can be seen quantitatively in **Table 1**. This is also intuitive. There is less forest regrowth farther away from roads because the majority of this land is untouched by humans and therefore most of the forest is classified as primary forest.

Figure 6 shows the proportions that each buffer takes up by forest type. The amount of land that each buffer covers is not equal. The 1km buffer of land contains 16,7759 km^2 of land, the 2km buffer contains 8948 km^2, the 3km buffer contains 5546 km^2, the 4km buffer contains 4272 km^2, and the 5km buffer contains 3597

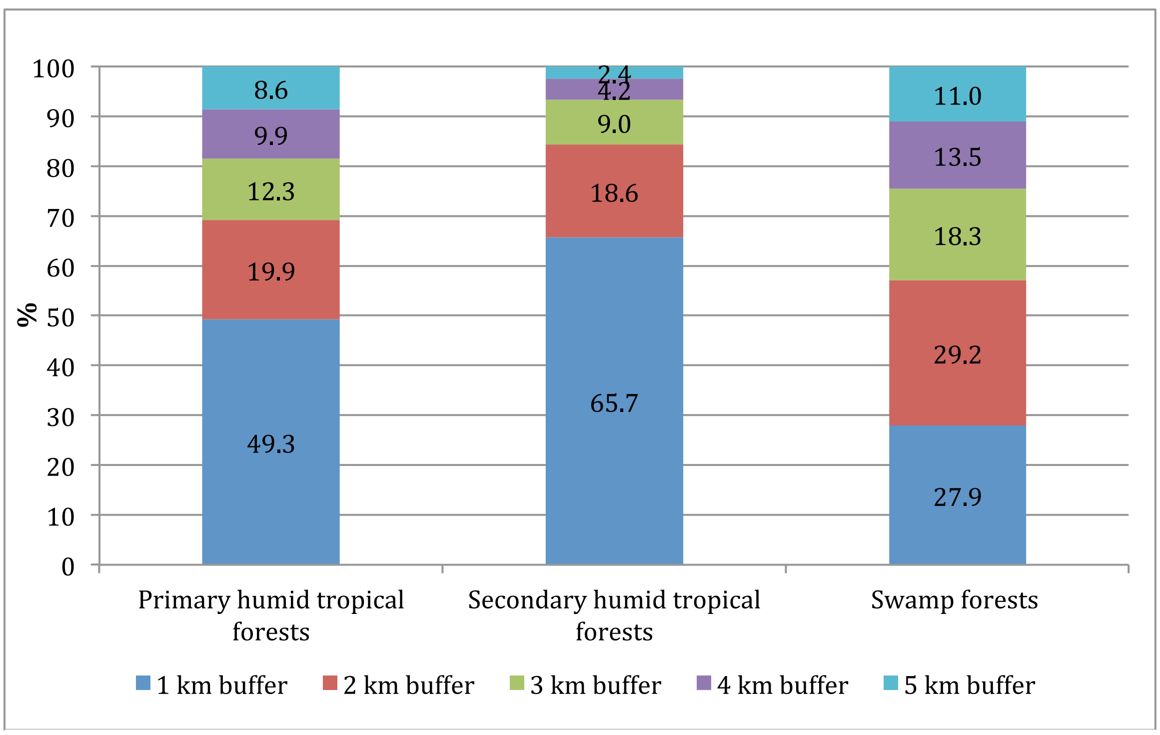

Figure 6 – Proportions buffers by Forest Type

km^2.

This FACET map provides data of deforestation for 2000-2005 as well as 2005-2010. As discussed in Mertens (467), land use change is best when observed over multiple periods of time. This gives more depth to a study, as there are multiple points of reference to compare to the current state of the land use. In **Figure 7** we see the trend continue. Primary forest loss was the highest of all of the types of forest loss for both the 2000-2005 and 2005-2010 time periods. Secondary forest was then the second highest, followed by swamp forest loss being the lowest normative value (swamp forest is hard to exploit so many companies do not log in these areas). We can also see that for all three primary, secondary, and swamp forest categories in the northern RoC, km^2 of forest loss increased significantly from 2000-2005 to 2005-2010.

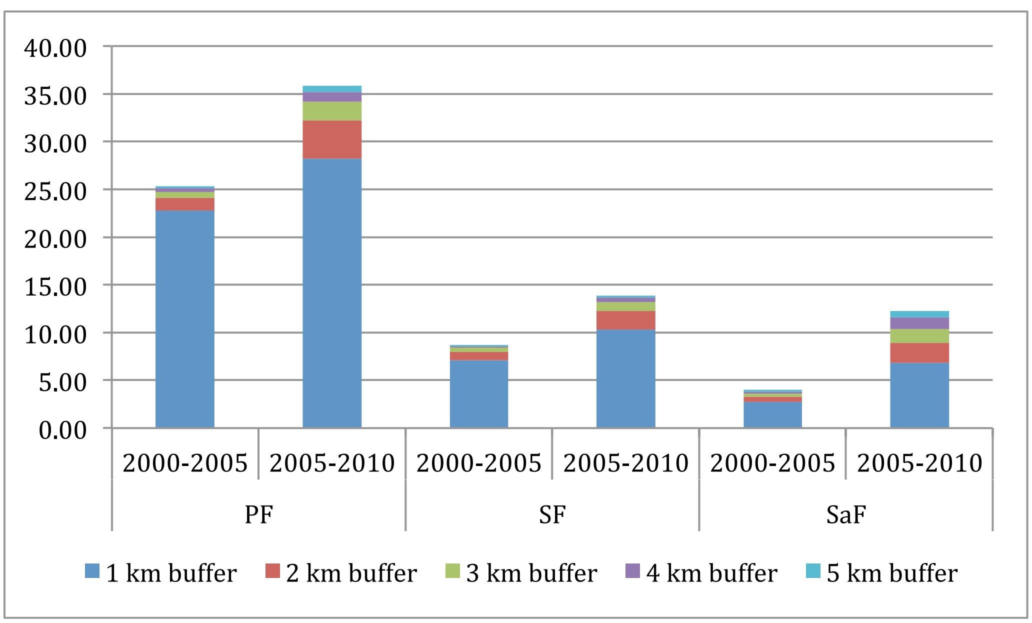

Figure 7 – Proportion of Deforestation by Total Area

For statistical analysis, three models were tested and compared. The first test was a one-way analysis of variance (ANOVA) comparing the dependent variable of deforestation rates from **Table 1** separated by the "factor" of the five different buffers. The final significance was .000 (with an F-value of 8.478 and 4 degrees of freedom). This output is shown in **Figure 8.** This means that there is a significant difference between the rates of deforestation between the buffer zones. When we compare this to the **Figure 7** of forest cover loss by year, we can see that the buffer zone closest to the roads (1000 km) is significantly more deforested than the others.

ANOVA

Area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6527.465	4	1631.866	8.478	.000
Within Groups	4812.323	25	192.493		
Total	11339.788	29			

Figure 8 – ANOVA Output for Rate of Deforestation between Each Buffer

The second model tested was also an ANOVA, this time analyzing whether or not there was a significant difference between the three types of forests in the region: primary forests, secondary forests, and swamp forests. This comparison of the means would tell us whether the rates of deforestation are significantly higher in certain forests than others. This is not the case. The p-value for this test was .255 (with a F-value of 1.436 and 2 degrees of freedom). The output for this test is shown in **Figure 9**. There is no significant difference between deforestation in the different types of forest around these roads. This does not mean that the rates of deforestation between the different types of forest are the same. It is also important to note that, as mentioned previously in the paper, logging around these areas is almost exclusively done through legal logging and is very selective.

ANOVA

Area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1090.338	2	545.169	1.436	.255
Within Groups	10249.450	27	379.609		
Total	11339.788	29			

Figure 9 – ANOVA Output for Rate of Deforestation between Forest Type

The last test performed was a paired samples T-Test. The two-tailed significance was .001 (with a T-value of -3.940 and 14 degrees of freedom). There is a significant difference between the two pairs. According to the output in **Figure 10**, we can conclude that the deforestation rates are higher for the “2005” year. The mean for this data, which is the aggregate data from 2005-2010, is higher, meaning land cover change was higher in the 2005-2010 period than the 2000-2005 period.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Y2000	7.6960	15	17.84405	4.60731
	Y2005	12.5467	15	21.88538	5.65078

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Y2000 & Y2005	15	.992	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	Y2000 - Y2005	-4.85067	4.76840	1.23120	-7.49132	-2.21001	-3.940	14	.001

Figure 10 – Paired T-Test Statistical Output for Rate of Deforestation between Both Time Intervals

Discussion

It is unfortunate that there are so many confounding variables involved in the exploitation of natural resources of the Congo Basin. From this study, it is not explicitly clear why the rate of deforestation has increased in the northern portion of the RoC over the past 15 or so years. It can be inferred, however, that it is likely a mix of 1) increasing the number of allowed concessions in the area, 2) human population increase (more people hunting bushmeat, felling trees illegally, etc.), and 3) easier access for people to exploit these resources as more and more roads and infrastructure are built in the otherwise rural forest.

One of the main limitations of this study was that the sample size was not as large as it should have been for both ANOVA tests. It is my understanding that all other conditions were met for the ANOVA to be valid, except that there should have been at least 50 different observations, of which there were only 30. Additionally, the roads that were mapped and then analyzed followed the FACET map of satellite images that aggregated to "2010." This means that there could have been roads that did not exist in the 2000-2005 map that were still analyzed for deforestation in the 2000-2005 year. This road mapping was also done with the human eye so it was not as accurate as it could have been with more sophisticated road mapping tools. Deforestation was not analyzed for areas that were farther than 5km away from roads but it would be interesting to see how the rest of land in this study area is used. From just observing the maps, I can see that there are certain pockets that have vast clearing that are not close to roads (most of these are along large or major rivers).

More and more scientists are using remote sensing to study areas with global significance and it would behoove us all for them to continue to do so. Many authors cited in this paper maintain that the more we use remote sensing to understand land use, the more we will know about certain regions of the world and the better equipped we will be to handle changes in landscape. It is true that we need to study how these forests are changing so that we can best prescribe theories for fixing them, but these theories should be taken with a grain of salt. Writing a scientific paper is good practice for the skills required to do spatial analytics, but I did not travel to Africa and do not want to come across as an academic trying to assert his findings on a region or group of people.

I have learned a great deal from my research, but I am in no way going to tell the people of the Republic of the Congo how to use their land and resources. Although there are many scientists and researchers who have been to the area, it's one thing to comment on trends, but it is another to study a region for a few months and try to recommend ways that things can be changed. As mentioned earlier in this paper, many of the people living in the Congo Basin have customary rights that they live by. These villages terroirs have social structures that go back centuries. Governmental regimes change, but the idea of "ownership of land" that many western cultures believe in so deeply doesn't hold the same weight in Central Africa. This ownership originates in feudalism and is still fueled by colonialism.

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