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Remote Sensing Methods for Detecting Deforestation and Illegal Logging in Bosnia and Herzegovina

Photos: Ana Gebert

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Department of Physical Geography and Ecosystem Science

Lund University

Sölvegatan 12

S-223 62 Lund

Ana Gebert

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Bachelor thesis, 15 credits, in *Physical Geography*

Supervisor:

Vaughan Phillips

Exam committee:

Fredrik Lagergren

Helena Borgqvist

Abstract

With the rapid and alarming rate at which forests are disappearing around the world, it is of great importance to effectively estimate loss of forest cover due to different causes. Among those causes illegal logging is a particularly enigmatic and dangerous one made well-known by the destruction of the tropical rainforests of South America and Southeast Asia. A less glamorous hotspot of illegal logging is Southeast Europe – whose forests are of a far more topographically and climatically dynamic nature than those of the tropics, and whose existence at the periphery of the European Union leaves it especially vulnerable as a tantalizingly near source of timber which is less regulated and financially weaker than its EU neighbors. Estimating illegal logging through remote sensing is difficult, and current methods, often developed specifically for the tropics, rely mostly on canopy disturbance as an indicator. This study used data obtained from the Global Forest Change as an estimation of deforestation to compare with official data received for the study area of Canton Sarajevo on annual amounts and locations of reported illegal logging from 2015 to 2018. The results showed conflicting relationships between deforestation and illegal logging, while visual corroboration showed very little areas of overlap between the two; spatial distribution appears mostly random with some concentration of illegal logging in the district of Hadžići. With a cumbersome political infrastructure and notorious problems with corruption, BiH's problem with illegal logging appears to be largely poverty-driven, and any action to combat it should take care not to target those who are most vulnerable.

Keywords: Bosnia and Herzegovina (BiH), Canton Sarajevo, illegal logging, remote sensing, deforestation, Global Forest Change (GFC)

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Contents

Introduction

Forests are a crucial and extensive component of the biosphere consisting of up to 31% of the Earth's land surface, and yet it is estimated that 75,676 km^2, or 0.2% of the total forested area, is lost annually due to deforestation (Hewitt 2005). With widespread effects ranging from a decreased and degraded water supply and reduced biodiversity to increased risk of landslides due to soil erosion, the negative impacts of a reduced forest cover are clear (Hewitt 2005).

In Western Europe the trend has gradually shifted from one of major deforestation at the beginning of the 20^{th} century due to urbanization and industrialization culminating around WW2, to one of mild afforestation due to intense re-forestation programs and abandonment of agricultural land resulting in a 30% increase in forest cover from 1950-2000 (Zanchi et al. 2007). The European Union (EU) is the world's largest market for timber and timber products valued at 61 billion USD, and consumption is increasing at a rate of around 1-2% annually (Hewitt 2005). At the same time it is the most strictly regulated market, with measures such as the Forest Stewardship Council (FSC) certification and the Forest Law Enforcement, Governance and Trade (FLEGT) increasing pressure on importers/producers to meet higher standards (Zanchi et al. 2007).

One of the major causes of forest degradation and deforestation in the world is illegal logging, which results in an estimated loss of 5 billion USD annually in tax revenue and a loss of 10 billion USD in profits for the legal timber industry according to the Global Forest Atlas, a Yale University organization which monitors illegal logging worldwide. The Global Forest Atlas also states that illegal logging is especially prevalent in developing countries where corruption works together with inadequate forest governance, leading to significant portions of the timber export being illegal – up to 70% in some countries. The difficulty in distinguishing illegal from legal activities creates problems in data collection and means that getting a grasp on the true proportions of the problem is near impossible. The EU enacted the EU Timber Regulation (EUTR) in 2013, which has greatly reduced imports of illegal timber into the European market, but the problem persists as the EUTR does not

cover all timber products and the legislation is still not being properly implemented in some exporting countries, especially those outside of the EU (Hewitt 2005). While much of the world's attention remains focused on the large-scale destruction of tropical rainforests in South America and Southeast Asia due to illegal logging, a more quiet destruction goes on closer to home in the economically unstable region of Southeastern Europe.

Southeastern Europe is often characterized by instability in comparison to Western Europe due to rapid changes in social and economic conditions following transitions from socialist to open-market structures (Knorn et al. 2012). Many countries in the region have not yet entered the EU and lag behind it in economic performance, with high levels of unemployment (14% in Serbia to 50% in Kosovo), and lower GDP per capita ranging from just 5% of the EU average in Kosovo to a high of just 46% in Montenegro (Markus-Johansson et al. 2010). This contributes to the exacerbation of illegal activities such as logging, which are generally the result of inadequate institutional capacities that can deal with the problem, a lack of consistent data, a lack of monitoring, corrupt practices and insufficient implementation of legislation (Markus-Johansson et al. 2010).

Bosnia and Herzegovina (from here forward BiH), is a small, non-EU country in Southeastern Europe with a population of around 3.5 million and a total area covering 51, 197 km^2, of which 53 - 63% (27,134 - 32,254 km^2) is forested, which is higher than the EU average of 42% (Republic Committee for Agriculture Forestry and Water of BiH 1986; World Bank 2013).

Forestry in BiH

The extensive forests in BiH have been a key resource in the development of the area going back many hundreds of years to the time Illyrian tribes inhabited the area, however its systematic exploitation was first documented during the era of the Ottoman Empire from the late 1400s to 1800s (Musić et al. 2013). During this period forests were considered a public good with no private owners, which changed when the Austro-Hungarian Empire conquered the area in 1878 and established forestry institutions with different categories of ownership and structured harvests (Musić et al. 2013). As time went on and regimes changed, different levels of legislation and ownership changed the structure of forestry in BiH, with large improvements after WWII and finally a law in 1993 recognizing forestry as a separate economic activity from timber processing. Today, the organization of the forestry sector is broken down on the level of three political administrative units created by the Dayton Accord after the war of the 1990s, each with its own legislation and structure; the Federation of Bosnia and Herzegovina, Republika Srpska and the District of Brčko (MOFTER 2018).

Of the 27,134 - 32,254 km^2 of forest cover existing in BiH, 12,919 km^2 are high forest, defined as forest originating from seed, and 9,178 km^2 of coppiced forest, which is continuously cut back and results in vegetative reproduction of a poorer quality for forestry purposes (UŠITFBiH 2019). The coppiced forest is largely a result of clear-cuts during the Austro-Hungarian Empire and wars of the 20^{th} century, and is further propagated by the large percentage occurring on private land where it is harvested often for firewood by the owners (UŠITFBiH 2019). Of the total forested area, 82% is state-owned and 18% is on private land, which is in stark contrast to the EU average of 40% state-owned and 60% private (Markus-Johansson et al. 2010). The total volume of timber stock in BiH is estimated at 291 million m^3, of which 183 million m^3 is deciduous and 108 million m^3 is coniferous, while the total annual volume increment is 7,942,000 m^3(UŠITFBiH 2019). The forests are majorly deciduous (around 60%) of which some 40% is beech (*Fagus sylvatica*) with significant populations of oak (*Quercus* spp.) and other broadleaf species, while the major coniferous species are spruce (*Picea abies*) and fir (*Abies*

spp.) with some endemic species such as *Pinus heldreichii hercegovinicum* found in the Mediterranean climatic region in the south (Markus-Johansson et al. 2010). Forestry is economically significant in BiH, contributing 2-3% of GDP (BHAS 2016).

Forest management techniques vary greatly due to the decentralization of authority in the forestry sector, however overall they can be characterized as selective in nature, according to Prof. Čabaravdić (Faculty of Forestry in Sarajevo), and are often for sanitary purposes due to disease or forest fires while clear-cuts are rarely or never employed. Generally speaking, foresters are assigned tracts of forested land in units for regular monitoring, with responsibilities including reporting of illegal activities, estimating stock, and monitoring for disease. According to their official website, the cantonal public authority Sarajevo Forests still employ animals such as bulls to extract harvested timber in an attempt to reduce negative impacts on land from heavy machinery.

Background

Illegal Logging in BiH

Of the approximately 1.8 million m^3 of legal timber harvested in BiH in 2003, 41,000 m^3, or 2%, was reportedly illegally harvested, while an estimated value of 10-20 million USD is lost annually due to illegal logging (SAVCOR 2005; Markus-Johansson et al. 2010). Although this may sound relatively modest, the data was based on only one region of the country representing less than a third of the total area of BiH. Data regarding the problem is notoriously poor; as for example the second national forest inventory conducted in 2013 – the first to be conducted since before the wars of the 1990s – was never published due to political issues and suspected data manipulation by one of the entities (Lojo et al. 2008). Thus even data on the total forested area in the country depends on the source reporting it, as the unpublished data show 63%, while data from 2000 gives 53%.

The political division of the country into two autonomous entities; the Republika Srpska (from here forward RS) and the Federation of Bosnia and Herzegovina (from here forward FBiH), further complicates the problem as each entity has its own separate laws regarding illegal logging, and each has different divisions of authority responsible for implementation (Delić et al. 2016). In fact, FBiH currently doesn't have a law governing the forestry sector, as the entity-wide Law on Forests enacted in 2002 was declared invalid, upon which a temporary Forest Regulation enacted in 2009 expired in 2011, leaving the region without centralized legislation (Delić et al. 2016). A new law was proposed immediately, but, according to the General Secretary of the Association of Forestry, Wood-Processing and Graphics, the law has still not gained enough votes in parliament to be ratified. Instead, legislation and enforcement is left up to the individual "cantons", the federal units in FBiH of which there are 10 in total – each with its own separate laws. In the RS, the structure is more centralized with integrated entity-wide legislation.

Although BiH is under the scope of the EUTR and FLEGT regulations, the problem lies in proper implementation and enforcement (Markus-Johansson et al. 2010). FSC certification

has had some success in BiH, with 50% of state-owned forests having certification (FAO 2015). However, corruption can permeate every level of the process between the actual felling of the tree until actual processing and transport; even accredited sawmills may include illegally logged timber in legal quotas, forge documents, or obtain false documents from forestry officials, while politicians may be taking bribes to look the other way. This all may result in certification not being a guarantee of a legal process from start to finish (Blaser et al. 2005).

The problem is a complex one and cannot be easily explained by any single cause. The main motivating factors behind illegal logging are generally twofold: commercially motivated and poverty-driven (SAVCOR 2005). Poverty-driven logging is especially prevalent as a large portion of the population still depends on timber for fuel in BiH, consuming up to 8 m^3 of firewood annually per household (Markus-Johansson et al. 2010). An interesting note is that although the majority of forests are state-owned, according to the unpublished second forest inventory of 2013, the majority of illegal logging occurs in privately owned forests – around 600,000 m^3 (World Bank 2013). Although no official data supports the claim, a firsthand account and forestry experts from the public nationwide organization BH Forests explained that private owners are required to get approval from the local forestry administration to harvest on their own land, which can take months in the bureaucratic process. This is simply not feasible in remote villages which depend on timber for fuel and cannot afford to travel to administrative centers and wait for approval. Some firsthand reports even claim that foresters themselves, who are responsible for patrolling and protecting forestry units, are approving harvests on private land without permission by the owner. Commercially motivated illegal logging is more difficult to quantify, as it is more secretive and the timber may be processed/exported legally, as described above.

Quantifying Deforestation and Illegal Logging

Much research has been done to estimate deforestation as a spatiotemporal change in forest cover using various remote sensing methods (Broich et al. 2011; Hansen et al. 2013; Souza et al. 2013; Jovanović and Milanović 2015; Hermosilla et al. 2018). One of the most

extensive projects existing today is the Global Forest Change (GFC) project, which has been analyzing annual changes in forest cover for the entire globe starting from the year 2000 using Landsat satellite imagery at a resolution of 30 m (Hansen et al. 2013). Many studies also employ remote sensing methods for detection of logging, generally using satellite imagery to classify forest cover in conjunction with various indices to detect more subtle changes in vegetation such as the normalized difference vegetation index (NDVI), the modified soil adjusted vegetation index (MSAVI), tasseled cap indices which detect recently disturbed areas, and sub-pixel analysis to detect selective harvesting of single/few logs (Bhandari and Hussin 2003; Kuemmerle et al. 2009; Win et al. 2009; Knorn et al. 2012; Tritsch et al. 2016; Grecchi et al. 2017). It has proven more difficult to develop a method differentiating illegal from legal logging, though some studies have attempted it by associating illegal activities with road proximity (Auzel et al. 2004), examining deforestation within protected areas which are then clearly due to illegal activities (Knorn et al. 2012), and using official data on illegal logging to identify the locations (Bhandari and Hussin 2003; Tritsch et al. 2016).

The majority of these methods for detecting logging were developed for use in the tropical and subtropical regions of South America and Southeast Asia, and as such they are better suited to the logging techniques and environmental conditions of these regions. Namely, the generally insignificant seasonal variation in tropical areas and lesser topographical variation in comparison with the very hilly and continental nature of BiH enable a much easier differentiation of forest cover classes in the tropical regions. BiH has large seasonal and micro-topographical variation, which makes supervised classification techniques prone to error because of the difficulty of classifying spectral responses from complex terrain (Bahadur K.C. 2009). Forests in BiH are generally mixed, multi-layered and contain trees of various ages, which makes classification complex (FAO 2015). Another issue, according to Prof. Dr. Azra Čabaravdić (University of Sarajevo, Faculty of Forestry), is that the majority of logging, both legal and illegal, is relatively low in volume and takes place in the understory of the forest, resulting in low to nonexistent detection via even high resolution imagery, as the canopy remains undisturbed. Another problem fairly unique to BiH is that approximately 10% of forests contain landmines, a remnant of the war in the

1990s which makes field data dangerous or impossible to collect in areas (Bećirović 2018). Because of the above-named issues, it is of use to scrutinize the validity of using canopy-cover loss as a quantification of illegal logging under the specific conditions in BiH.

The purpose of this study is to compare areas of deforestation quantified by the GFC with recorded locations of illegal logging for Canton Sarajevo in order to see whether there is any relationship. Suggestions will be made as to how the process can be improved or adapted to the specific conditions in BiH, as it is hypothesized that locations of illegal logging may not coincide with areas of deforestation if canopy cover is left undisturbed.

Study Area

The area chosen for this study was Canton Sarajevo (Figure 1), located roughly in the middle of the country at 43°50'55.1"N, 18°21'23.18"E, with an area of 1,277 km^2 or 2.5% of the total area of BiH (Bećirović 2018). It was chosen as fairly representative of BiH in terms of forested area and structure. Canton Sarajevo is subdivided into nine districts: Centar, Hadžići, Ilidža, Ilijaš, Novi Grad, Novo Sarajevo, Stari Grad, Trnovo and Vogošća. The total forested area is 830.86 km^2, or 65.5%, and the elevation ranges from 511 m.a.s.l along the bottom of the valley, up to 2,088 m.a.s.l. at the highest point at the top of the mountain Treskavica (Bećirović 2018). The climate is continental temperate or Cfb according to the Köppen-Geiger climate classification. The average annual temperature in Sarajevo is 10.3 °C and average precipitation is 989 mm/yr. The canton is named for the capital city of BiH, Sarajevo, which is the administrative and cultural center of the country and has a population of 413, 593 as of 2013 (BHAS 2016). This area was subject to extensive deforestation during the war of the 1990s, when the capital city was under siege for years and residents with no access to electricity for months at a time resorted to felling trees within and in proximity to the city for fuel (Lacan and McBride 2009). Since the war, large re-forestation projects have been successful in restoring much of the vegetation and forest cover that was lost.

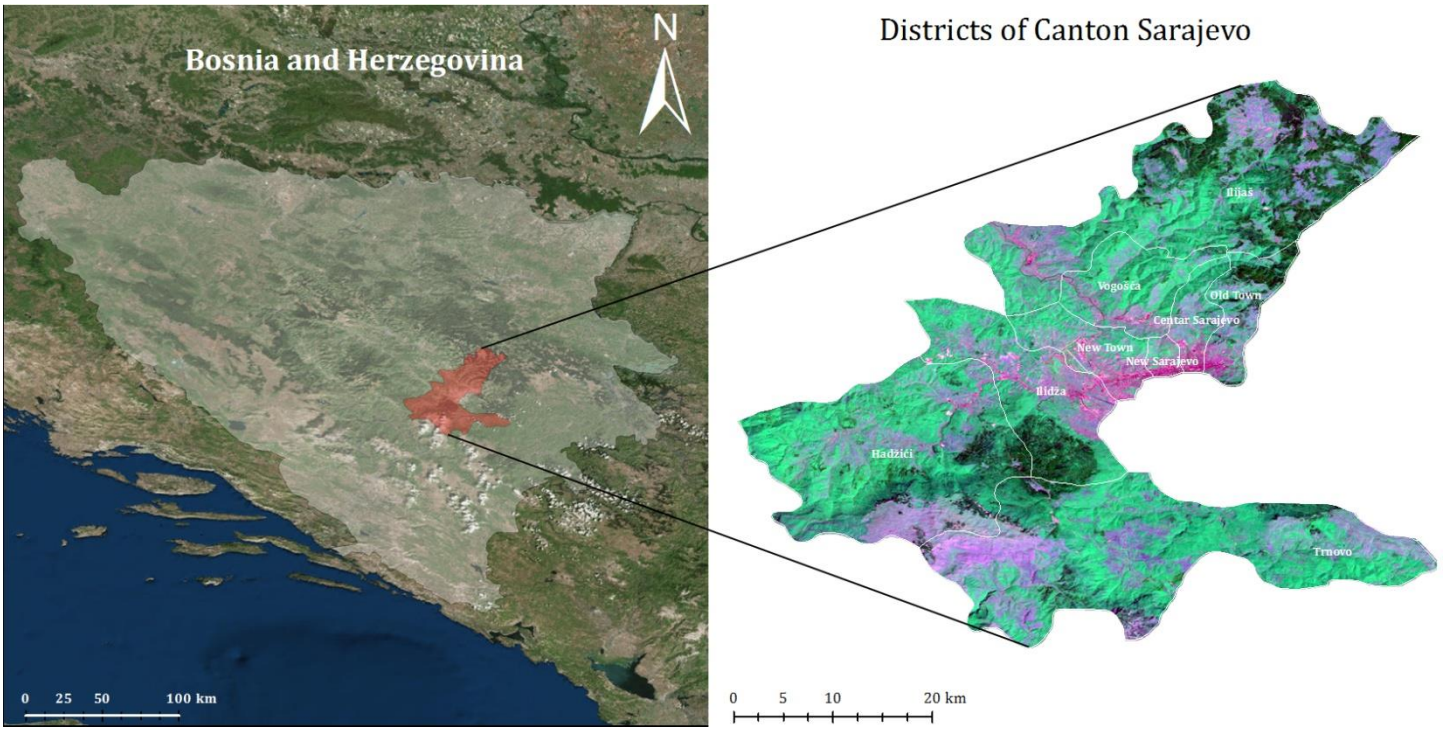

Figure 1: The study area Canton Sarajevo, a canton of Bosnia and Herzegovina. The canton is further sub-divided into 9 districts. Maps created in ArcGis 10 using administrative boundaries obtained from ESRI (2019).

The situation in Canton Sarajevo as regards illegal logging is more positive than many regions of BiH, partly due to it being more financially and institutionally advanced than the rest of the country, and partly due to the comprehensive Operative Plan to Protect Forests from Illegal Activities in Canton Sarajevo enacted in 2012 (Žigić and Budimlić 2017). The Operative Plan considers three main categories of illegal activities: illegal harvesting of timber, illegal transport of timber and illegal sawmills. It combats them through various monitoring techniques and practical measures. A study done by local criminologists Budimlić and Žigić (2017) uses official statistics for Canton Sarajevo about reported illegal logging and actual court decisions to illustrate the still-existing gap between reports of illegal logging and actual consequences for those committing the crimes. According to the same study, during the period of 2010-2014 the number of reported ecological crimes was 1,219 in total (of which the authors cite that the majority is related to illegal logging) an amount which is staying the same or mildly increasing annually, while the number of convictions (just 254 total) and investigations is in fact decreasing – pointing to an inability or lack of interest of the court to punish these crimes. Interestingly, Budimlić and Žigić

highlight the lack of adequate punishment, as the highest forms of punishment are imprisonment or large fees and yet in the period of 2010-2014 the enormous majority of court decisions resulted in mere warnings; only three decisions ended in fees and none in imprisonment. Figure 2 is adapted from the 2017 study, depicting the amount of timber recorded as illegally logged from 2010-2015, along with the total amount reported by court decisions; the large gap between the two, in conjunction with the previous statements, illustrates the ineffective and even disturbing lack of court sanctions.

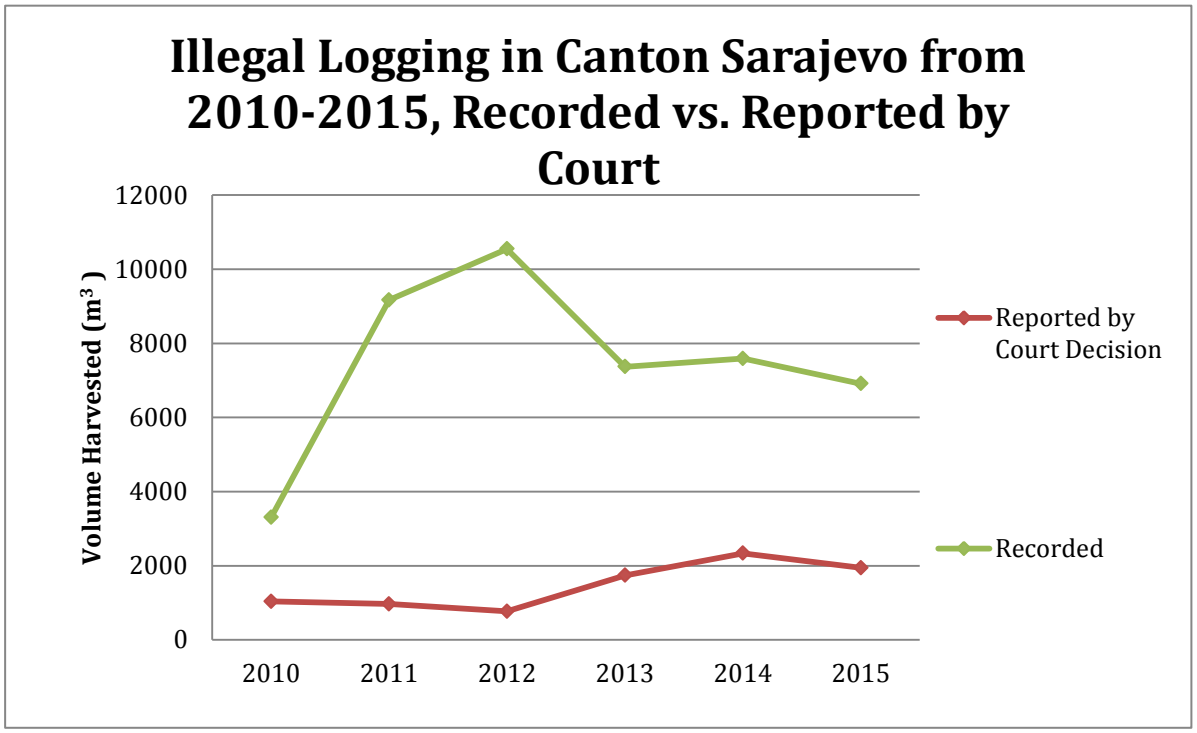

Figure 2: Illegal logging in Canton Sarajevo (2010-2015): recorded amount and amount reported by court decisions (m^3). Adapted from (Žigić and Budimlić 2017).

Materials and Methods

Some of the information used in this study originates from interviews with members of the Faculty of Forestry in Sarajevo (Profs. Azra Čabaravdić, Mersudin Avdibegović, Jusuf Musić, and Dženan Bećirović), as well as the Chamber of Economy of FBiH (General Secretary of the Association of Forestry, Wood-Processing and Graphics Šemsa Alimanović), Canton Sarajevo Forestry Administration (Director Kemal Starogorčić and Jasmin Mameledžija) and BH Forests. All spatial analysis was conducted using ArcGIS 10.5, all statistical analysis was performed in Microsoft Excel and Google Earth was used for visual support.

Deforestation: Global Forest Change (GFC)

For the purposes of this study, deforestation data was taken from the Global Forest Change project. This extensive project uses supervised classification techniques on Landsat 7 and 8 images of 30 by 30 m resolution from the year 2000 to the year 2018, with any change registered in a pixel during the time period resulting in a classification of either forest gain or loss (Hansen et al. 2013). The exact methodology is not publicly available, however the basic steps consist of using Landsat images which were first masked for cloud cover and other atmospheric disturbances, upon which they were normalized and converted to top-of-canopy reflectance. Then to create the forest loss map, a supervised bagged classification tree algorithm created by the authors and using input training data resulted in a given pixel being classified as a "loss" if it was completely changed from forest to non-forest. The publicly available data used in this study was the forest loss year products from 2015 to 2018. A forest loss was defined as a change from forest to non-forest and was registered in binary form – either loss or no loss. For the purposes of this study, the forest loss products were clipped to the study area and used to identify areas of deforestation for each year from 2015 to 2018 in order to compare them to the locations of illegal logging recorded in the same time span.

Areas of Illegal Logging

Data on volumes of illegal logging (m^3), and locations were obtained from the Canton Sarajevo Forestry Administration for the years 2015-2018. The locations were digitized as polygons to be compatible with ArcGIS to enable further analysis, with each polygon representing any forestry unit which registered any amount of illegal logging occurring at any time during the year for the whole of the respective year. The forestry units vary in sizes not exceeding 1 km^2, and correspond to areas patrolled by foresters who are responsible for reporting any illegal activity within the area. The polygons were compared to the GFC maps of forest loss for the years 2015-2018 by converting them to pixels to enable direct comparison.

Contingency Tables and Odds Ratios

The resulting frequencies of pixels for each categorical variable were put into a contingency table, which is a cross-tabulation of frequency distribution, for each year from 2015 to 2018 according to the layout in Table 1. They show basic relationships between categorical variables and can be used for some further statistical tests.

Table 1: Layout of the contingency tables.

Year				
Deforested	**Illegally Logged**			
		yes	no	TOTAL
	yes	a	b	a+b
	no	c	d	c+d
	TOTAL	a+c	b+d	a+b+c+d

Upon creating contingency tables for each year, odds ratios (OR) were calculated to indicate the strength of the relationship between the two categorical variables. The odds ratio is calculated according to the equation found below (Eq. 1), where OR > 1 indicates

that deforestation has a higher chance of occurring where there is illegal logging, OR = 1 indicates that they are not at all related, and OR < 1 indicates that deforestation has a lower chance of occurring where there is illegal logging.

$$OR = \frac{a/c}{b/d}$$

(Eq. 1)

Results

The spatial distributions of the areas of deforestation defined as forest loss for all years between 2015 and 2018 according to the GFC are seen in Figure 3 below.

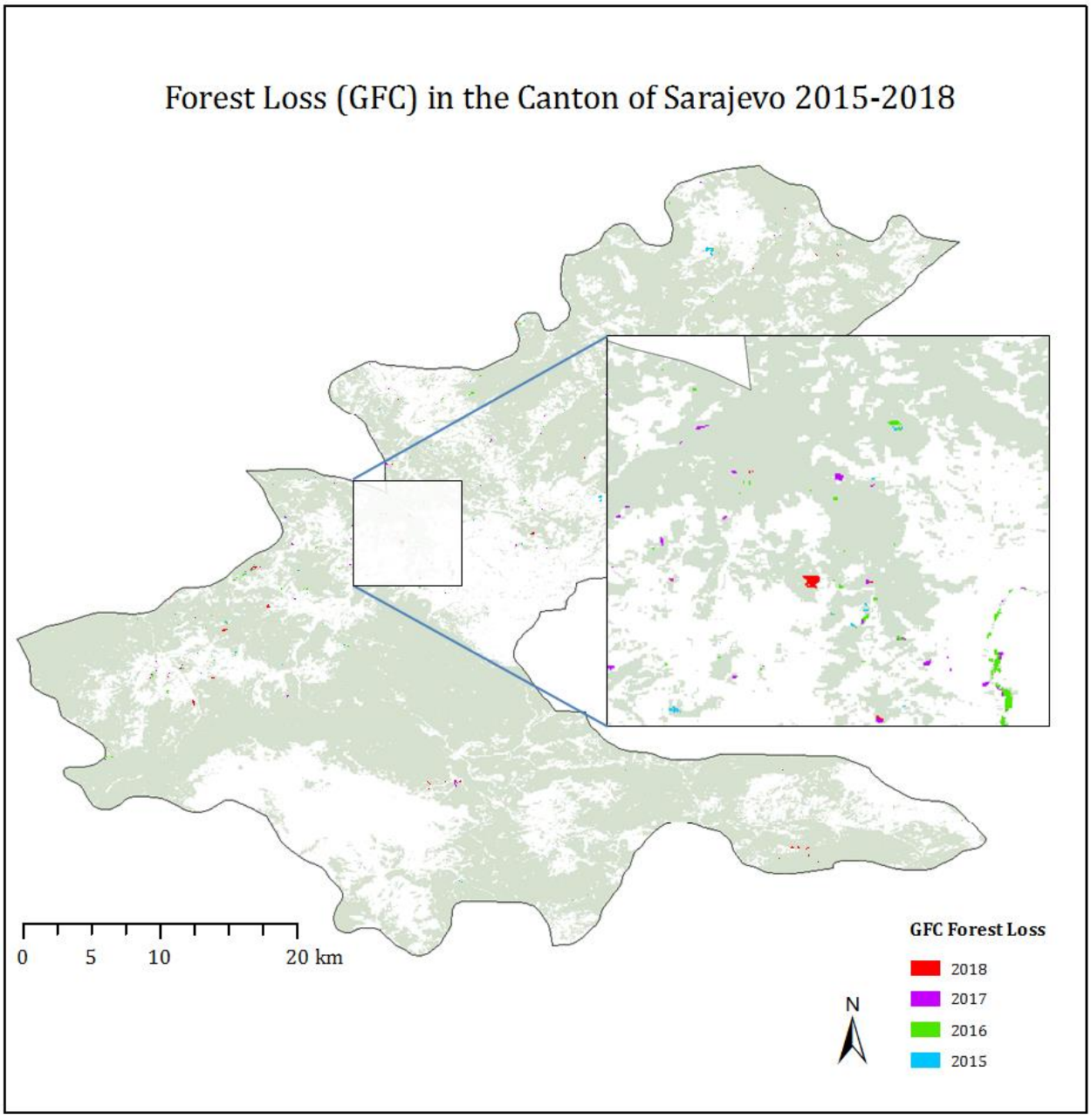

Figure 3: Areas of deforestation in Canton Sarajevo according to the Global Forest Change (Hansen et al 2018) for the years 2015-2018. Darker green areas represent forest cover as of 2000. Map created by the author.

The pixels are mostly occurring along the edges of forested areas, covering areas of usually much less than 1 km^2. Much of the pixels are concentrated near the urban periphery of

Sarajevo, in many cases due to clearing for urbanization purposes such as new roads or construction, as seen when examined for the year in question using high-resolution satellite imagery from Google Earth. The areas with reported illegal logging for each year

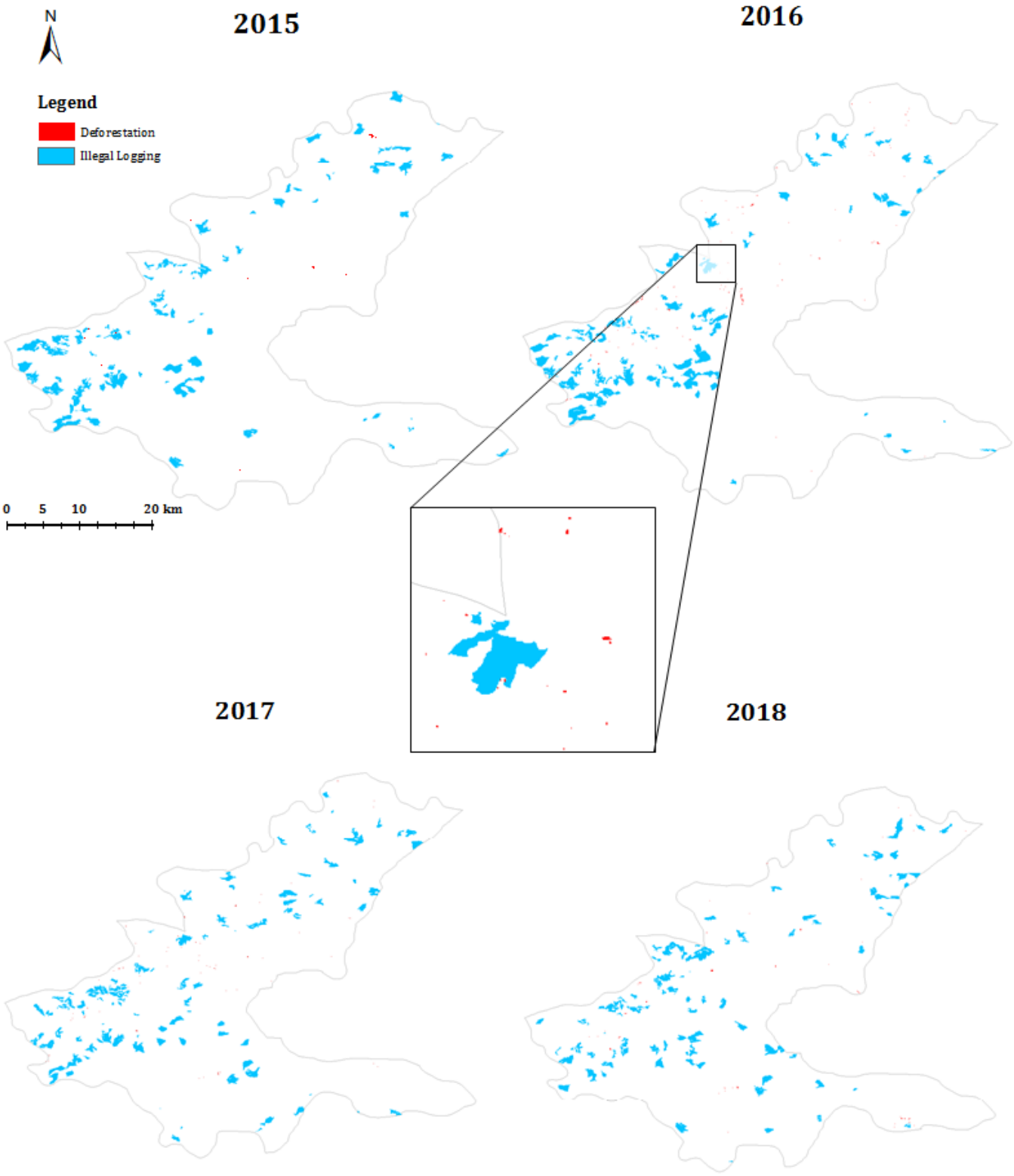

Figure 4: Areas of deforestation according to the GFC (Hansen et al 2018) overlaying areas of illegal logging in Canton Sarajevo for 2015-2018.

were combined with the GFC deforestation areas to produce Figure 4, and can be seen in more detail in appendices 1-4.

The illegal logging is represented by individual areas which correspond to forestry units of usually less than 1 km^2 which were registered as a whole if any illegal logging was reported to have occurred within the forestry unit at any time during the year. It can be seen that the area with the highest concentration overall tends to be the southwest corner, lying within the district of Hadžići, which is enumerated in the study conducted by Budimlić and Žigić (2017) as one with some of the highest rates of illegal logging within the canton. The data as presented this way visually shows very few areas of deforestation overlapping those of illegal logging.

Contingency Tables and Odds Ratios

The contingency tables for each year from 2015 to 2018 can be found in Tables 2 through 5, respectively. They contain the frequency of pixels pertaining to either the illegally logged areas or deforested areas defined as forest loss by the GFC. It can be immediately noted that the total frequency of pixels being both illegally logged and deforested is very low in comparison to totals, as in fact the total amount of deforested pixels is much lower than that of illegal logging.

Table 2: Contingency table for 2015.

2015				
Deforested	**Illegally Logged**			
		yes	no	TOTAL
	yes	35	613	648
	no	85404	2165101	2250505
	TOTAL	85439	2165714	2251153

Table 3: Contingency table for 2016.

2016				
Deforested	**Illegally Logged**			
		yes	no	TOTAL
	yes	16	1477	1493
	no	98332	2151328	2249660
	TOTAL	98348	2152805	2251153

Table 4: Contingency table for 2017.

2017				
Deforested	**Illegally Logged**			
		yes	no	TOTAL
	yes	5	741	746
	no	86482	2163925	2250407
	TOTAL	86487	2164666	2251153

Table 5: Contingency table for 2018.

2018				
Deforested	**Illegally Logged**			
		yes	no	TOTAL
	yes	36	797	833
	no	77923	2172397	2250320
	TOTAL	77959	2173194	2251153

The OR calculated according to Eq. 1 for each year can be seen in Table 6 below. The years 2015 and 2018 have ratios higher than 1, indicating that deforestation has a higher chance of occurring where there is illegal logging, while the years 2016 and 2017 with ratios much lower than 1 indicate that deforestation has a lower chance of occurring in the same area as illegal logging.

Table 6: Odds ratios (OR) for 2015-2018.

Year	OR
2015	1.45
2016	0.24
2017	0.17
2018	1.26

Relative Trends in Illegal Logging and Deforestation

Figure 5 below depicts the relative trends of three different datasets: the illegally logged areas in pixels, the areas of deforestation defined as forest loss by the GFC in pixels, and total volumes of reported illegally logged timber (m^3) extracted for each year from 2015 to

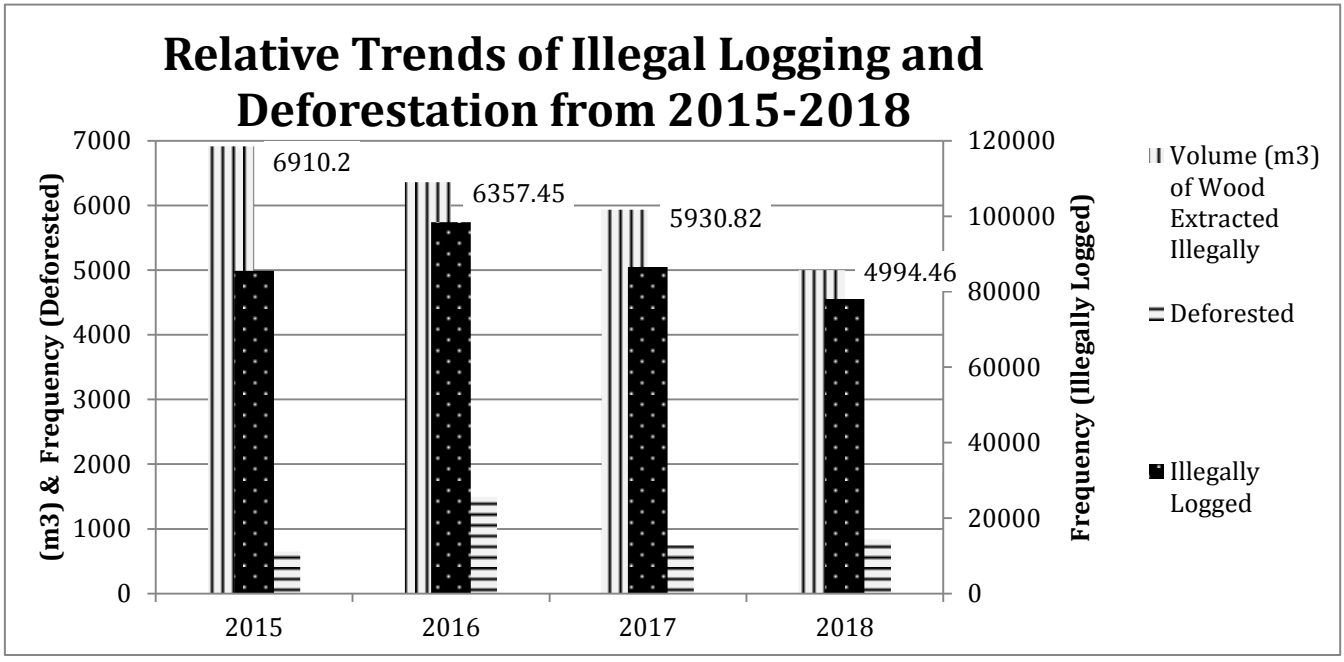

Figure 5: Relative trends of illegal logging and deforestation 2015-2018. Volume of timber and deforested areas correspond to the primary axis, and illegal logging as an area corresponds to the secondary axis.

2018. The actual values are largely irrelevant; instead the axes are adapted to show clearly trends from year to year of each dataset. It can be seen that the actual volume of timber reported as illegally logged each year appears to be steadily decreasing from a maximum in 2015 of nearly 7,000 m^3, to a low in 2018 of 5,000 m^3. In comparison, the trends for deforestation and illegal logging (in pixels) are more random, with deforestation increasing and decreasing in turn, and illegal logging similarly increasing and then decreasing in 2018.

Discussion

The results show that the locations of the illegal logging occurring from the years 2015-2018 are not strictly corresponding to the purported locations of deforestation according to the GFC forest loss maps. These results are most likely due to the issues mentioned earlier in this study; namely that the structure of forests in BiH tend to be mixed, multi-layered and of various ages, and that the logging, both legal and illegal, tends to be selective in nature and leaves the canopy intact as it targets understory growth. This method of logging contrasts with methods generally employed in countries where comparable remote sensing studies have been conducted such as Brazil, Indonesia, or even Europe, where forest management techniques favor clear-cutting techniques over selective logging, according to studies and monitoring by organizations such as Earthroots (Lundmark et al. 2014). Because the existing methods for quantifying illegal logging depend on canopy disturbance, they simply cannot be utilized with any confidence under the conditions present in BiH. Upon consultation with various interest groups currently working in the field on this specific issue, it has become clear that the largest problems associated with illegal logging in the country are organizational/structural and political in nature.

The truth of the matter is that the average annual volume increment for the entire country (7,942,200 m^3/yr) is in fact greater than the 5,763,000 m^3 amount of reported timber felled in 2017 – some data even including illegal logging under the category "human influence"(FAO 2015; Institute for Statistics of FBiH 2018; Institute for Statistics of RS 2018). Of course these numbers undervalue the amount of illegal logging and the volume increment is largely in the coppiced area, however, this illustrates that forest resources in BiH are great and have potential for sustainable logging – as highlighted in the FAO report of 2015 which concludes that forest resources should in fact be utilized at an even greater rate than is currently maintained. Additionally, as found by the (unpublished) second national forest inventory, the majority of recorded illegal logging occurs on private land (despite its constituting a fraction of total land area in BiH at 18%), indicating that the majority of illegal logging is by the owners of the forests themselves and is therefore an issue of inefficient organizational structures and is largely poverty-driven rather than for

commercial gain (World Bank 2013). This suggests that the root of the problem of illegal logging itself is legislative and structural in nature rather than because it is an enticing option for commercial profit. Regardless of the causes, any activity which is illegal should of course be addressed, and this calls for, first and foremost, a comprehensive method for quantifying the problem and monitoring it.

Limitations

The greatest limitation in this study was the lack of high quality empirical data, especially on the actual amounts and locations of illegal logging, as found by the criminology study as well (Žigić and Budimlić 2017). Data is not publicly available and requires a relatively arduous bureaucratic process to obtain, while the results are often unreliable due to underreporting and inadequate monitoring methods. Any numbers should be considered estimations. In this light, the most telling result of this study is the trends of each of the three datasets examined in this study. The trend of deforestation according to the GFC was completely random, increasing and decreasing from year to year, illegal logging as an area was similarly random albeit slightly decreasing overall, and the third dataset in the form of total volumes of illegally logged timber per year was steadily decreasing from the beginning of the study period to the end. The two datasets on illegal logging were obtained from the same source; the Canton Sarajevo Forestry Administration, so it is telling that while the actual amounts of timber being illegally logged appear to be decreasing, the spatial distribution is the same or even becoming more scattered.

Another limitation was that the results of the odds ratios are directly conflicting with each other, making it difficult to draw any conclusions. Two years showed a correlation and the other two years showed a directly opposite correlation. This is clearly due to the large population size while the number of pixels corresponding to illegal logging or deforestation is very small, in some cases less than 10 pixels out of 2 million, skewing the results numerically. The method applied to calculate the ratios is estimation at best, as the areas representing illegal logging are not representing volumes of timber extracted, and thus cannot be directly compared to the deforestation which has a clearly defined spatial extent. The spatial extent of the illegal logging and specific amounts remain unquantifiable and

therefore are of much less use. If specific amounts of timber logged illegally were known in conjunction with a specific location such as coordinates, further analysis would be much more accurate.

A smaller issue is that the deforestation as quantified by the GFC can be due to any cause, and these methods are not sensitive to new-growth situations, as was observed at several locations in the study area which classified immature tree growth as a forest loss, and many areas on the city periphery which were due to urbanization.

Suggestions for Further Studies

Further studies should explore the possibilities of obtaining more specific data on exact quantities and locations of illegal logging. This is at the moment not possible with the existing data collection methods employed by the authorities responsible, as they are not uniform across all those who register illegal logging and do not include detailed data on locations and amounts. Further statistical analysis of the data calculating proper threshold values for significance would be of use, however the magnitude of frequencies makes it difficult to find appropriate statistical tests to perform. Additionally, proximity to roads and social demographics of illegal logging hotspots could provide further insight as time constraints didn't allow for this analysis.

In order to combat illegal logging, a proper monitoring system is essential for quantifying and evaluating the extent of the problem and providing the first step toward any further tackling of the issue (Markus-Johansson et al. 2010). Effective monitoring programs exist in many countries, for example the PRODES project in Brazil which uses remote sensing and has been in place from as far back as 1988 and has proven effective in that region (Shimabukuro et al. 2012). There have been multiple attempts at creating a monitoring program for BiH or the wider region which have so far proven ineffective, such as the Action Plan to Combat Illegal Activities in the Forest and Wood Processing Sectors in Bosnia and Herzegovina (2005) which faded without a trace due most likely to bureaucratic and political issues (Markus-Johansson et al. 2010). There is currently another attempt ongoing called the Regional Action for Combatting Forest Crime and

Corruption, which is developing a monitoring program and working with the national governments in the region to establish good practices. This project is, among other aims, investigating different methods for quantifying illegal logging through remote sensing techniques in real-time.

One possibility is participatory GIS (PGIS), which is a real-time, open-access form of geographical system which enables users with rudimentary knowledge of GIS software to access and input data themselves (Poudyal et al. 2015). PGIS enables real-time users such as foresters or even casual passersby to mark locations they observe of illegal logging (for example) or other changes they see in the landscape. This method was found to be effective by a study in Sweden in 2015, with the largest limitations being initial resistance to adoption due to perceptions that it would be difficult to learn the software, however often those with the highest interest such as the local populace or foresters have higher levels of adoption and participation (Poudyal et al. 2015). This approach to monitoring the state of forests is flexible, involves many stakeholders, involves the public, and importantly for BiH specifically, doesn't depend on official data or bureaucratic processes and doesn't rely on canopy cover as an estimation of forest loss.

Conclusion

The major conclusion which can be drawn from this study are that the current methods existing worldwide for estimating illegal logging using remote sensing are most likely inadequate under the environmental and social conditions specific to Bosnia and Herzegovina. This study used data obtained from the Global Forest Change as an estimation of deforestation in the region of Canton Sarajevo to compare with official data received from the Canton Sarajevo Forestry Administration on annual amounts and locations of reported illegal logging from 2015 to 2018. The results showed conflicting relationships between deforestation and illegal logging, while visual corroboration showed very little areas of overlap between the two – spatial distributions appear mostly random with some concentration of illegal logging in the district of Hadžići. Upon consultation with several local interest groups working in forestry in the region, it became clear that the reliance of current methods for estimating illegal logging on canopy cover disturbance simply cannot reflect the real situation due to difficulties in estimating deforestation. This is because of the complex topography and high seasonal variation in vegetation characteristic of the area, as well as the tendency of logging techniques, both illegal and legal, to be selective in nature –targeting undergrowth and leaving canopy cover undisturbed. Considering this environment, an effective monitoring program would likely have more success by relying on real-time reporting by individuals on the ground, for example using a PGIS system.

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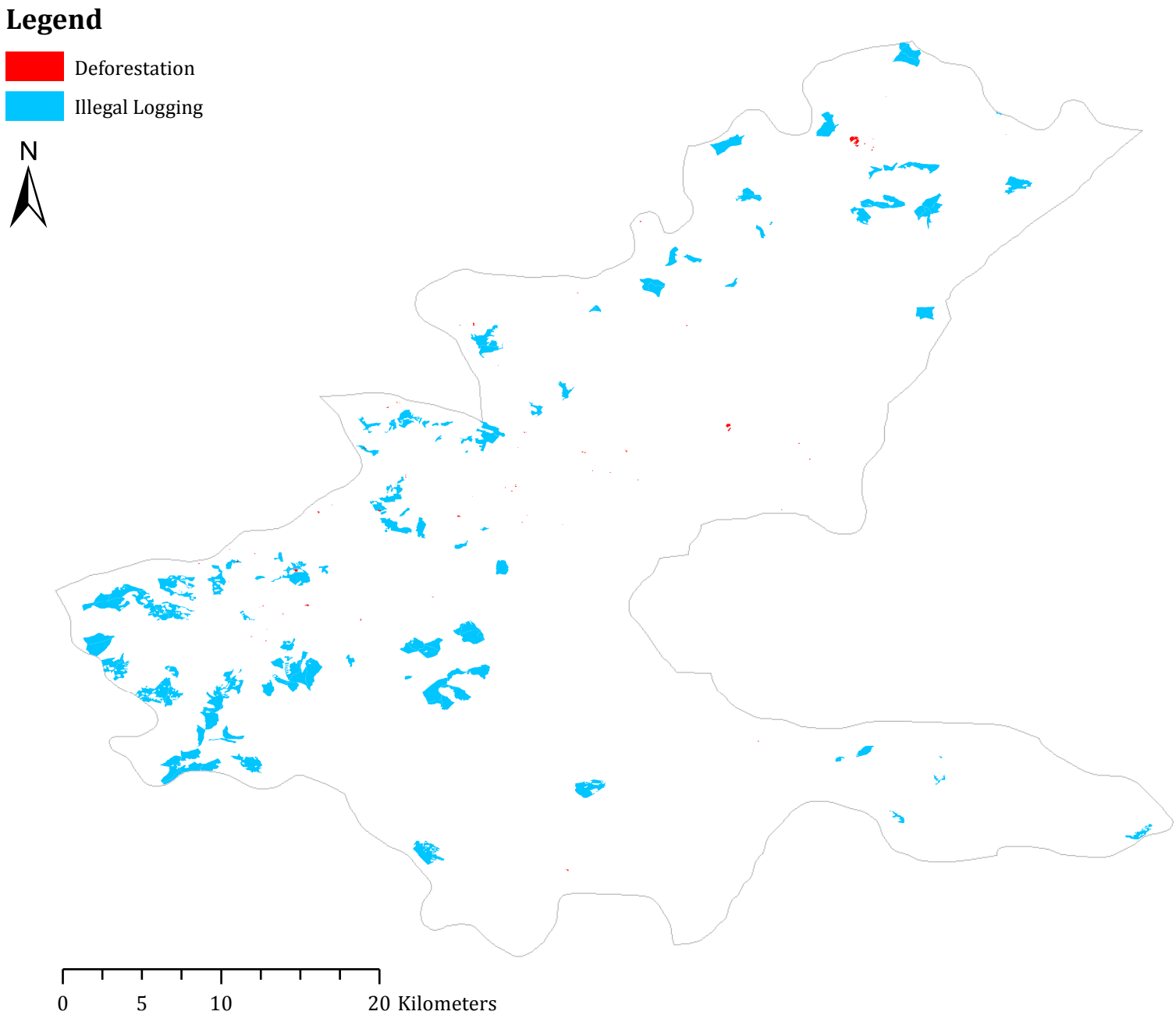
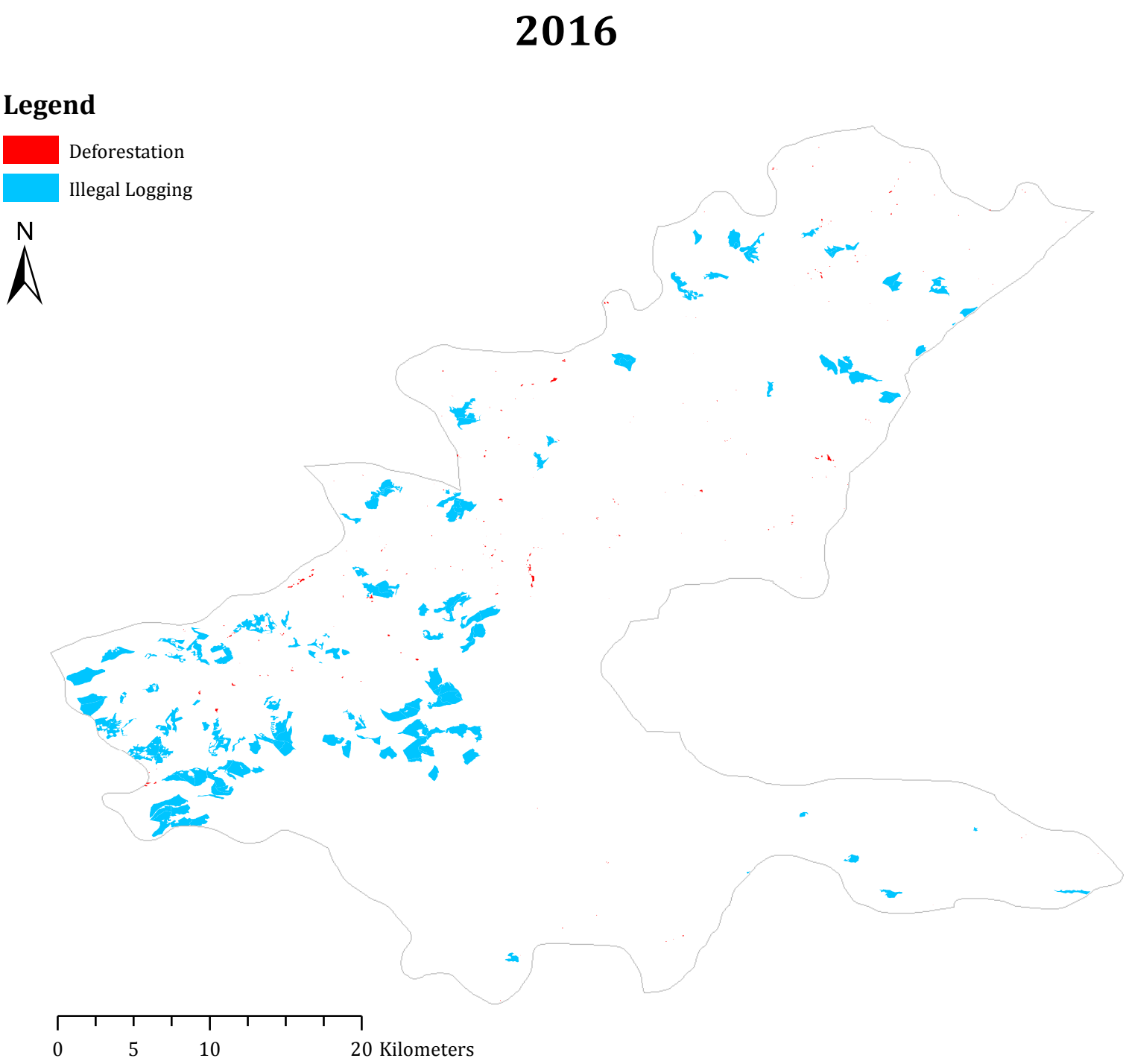
Appendices

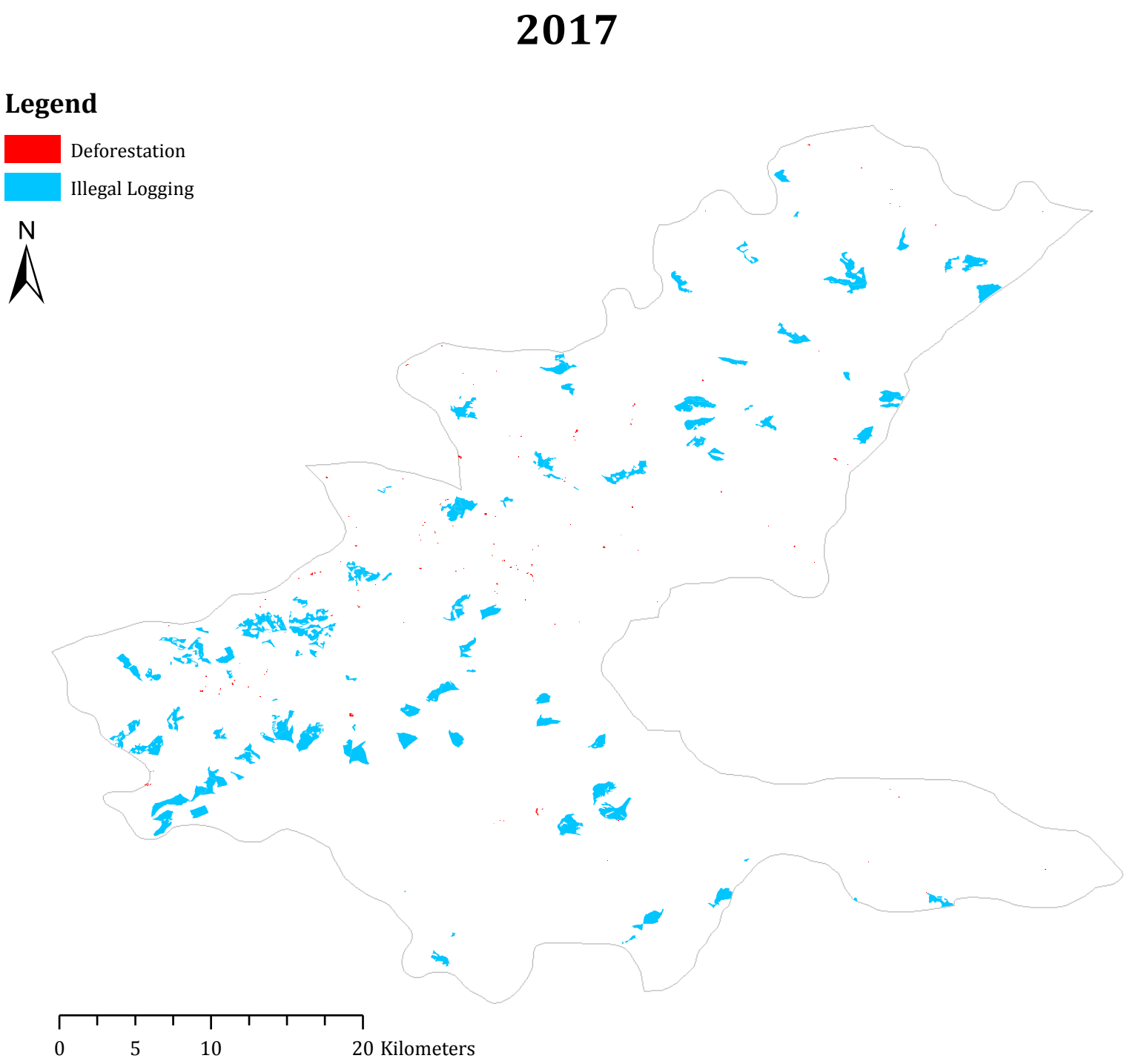
Appendix 1. Areas of deforestation according to the GFC overlaying areas of illegal logging in Canton Sarajevo for 2015.



Appendix 2. Areas of deforestation according to the GFC overlaying areas of illegal logging in Canton Sarajevo for 2016.



Appendix 3. Areas of deforestation according to the GFC overlaying areas of illegal logging in Canton Sarajevo for 2017.



Appendix 4. Areas of deforestation according to the GFC overlaying areas of illegal logging in Canton Sarajevo for 2018.