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WILDLIFE-VEHICLE COLLISIONS VERSUS LANDSCAPE FRAGMENTATION

DIPLOMA THESIS

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DIPLOMA THESIS ASSIGNMENT

Pablo García Fernández

Forestry, Water and Landscape Management

Thesis title

Wildlife vehicle collisions versus landscape fragmentation

Objectives of thesis

The aim of the Diploma Thesis is use of GIS as a method to approach an issue of wildlife-vehicle collisions caused by the landscape fragmentation. Concretely, this study examines a relationship between the wildlife vehicle collisions and level of the landscape fragmentation in Czech Republic.

Methodology

Analysis of the level of landscape fragmentation using UAT methodology.

Identification wildlife-vehicle collision form the database of the Police of the Czech republic.

Identification of interaction between collisions and fragmented area.

The proposed extent of the thesis
50 pages

Keywords
Transport, accident, animal vehicle collision, barrier effect

Recommended information sources

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Declaration

I declare that I wrote my diploma thesis independently, and that I have stated all the information sources and literature I used. Neither this thesis nor any substantial part of it has been submitted for the acquisition of another or the same academic degree.

I consent to the lending of my dissertation for study purposes. By affixing his or her signature the user confirms using this dissertation for study purposes and declares that he or she has listed it among the sources used.

In Prague, / /2018

Signature:

Pablo García Fernández

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Abstract

Wildlife-vehicle collisions (WVCs) are a very important issue, that is getting worse in recent times. They produce loss of lives (both animals and humans) and huge economic costs. Besides, fragmentation, that is caused mainly by roads, act as a barrier for wildlife, what can lead to a decrease of their populations or even their disappearance.

In this work, they were examined WVCs in three regions of the Czech Republic (Ústecký, Liberecký and Středočeský Region) between 2007 and 2014. The data was taken from the Police of this country and analysed with ArcGis. Furthermore, the fragmentation of the landscape was studied, by dividing it in the unfragmented areas by traffic (UAT, what is the area of landscape with 100 km^2 or more that is limited by roads with an annual average traffic of at least 1000 vehicles/day) and the fragmented area, to see the influence of fragmentation on the crashes with animals.

The results showed a relationship between fragmentation and the number of collisions, as besides having a higher length of roads, and thus a higher surface where crashes can occur, in the fragmented zone the collisions per kilometer were also higher, and by each 100 kilometers of roads, there were 9 more accidents, on average, than in the unfragmented one.

By dividing the area of study in polygons formed by the major roads, the ones in the fragmented zone again had more accidents per kilometer than the polygons in the UAT. However, the collisions per square kilometer showed a higher number in the unfragmented zone, so it can be concluded that the collisions in the UAT are more concentrated in certain places, while in the fragmented one they are more widespread.

Keywords: WVC, accidents, animals, UAT, Czech Republic.

Abstrakt

Kolize dopravních prostředků s volně žijící zvěří (WVC) jsou významným problémem, který v poslední době nabývá na intenzitě. Tyto kolize mají na svědomí úmrtí (jak volně žijících živočichů, tak i účastníků silničního provozu) i ekonomické ztráty. Kromě toho, vyšší fragmentace krajiny, která je způsobena především dopravní infrastrukturou, působí pro volně žijící živočichy jako překážka, což může vést ke snížení počtu jedinců v populaci nebo dokonce k ohrožení životaschopnosti dané populace. V této práci byly zkoumány WVC ve třech regionech České republiky (Ústecký, Liberecký a Středočeský kraj) v letech 2007 až 2014. Údaje o kolizích byly převzaty od Policie ČR a analyzovány v programu ArcGis. Dále byla analyzována úroveň fragmentace krajiny pomocí rozdělení do oblastí fragmentovaných a nefragmentovaných dopravou (Unfragmented Areas by Traffic UAT, je plocha krajiny o rozloze větší než 100 km2, která je ohraničena silnicemi s průměrnou roční intenzitou dopravy nejméně 1000 vozidel/den). V rámci těchto území byl analyzován vliv fragmentace na incidenci WVC. Výsledky práce ukázaly vztah mezi fragmentací krajiny a počtem kolizí, V rámci nefragmentovaného a fragmentovaného území jsme pomocí rozložení hlavních silnic (dálnice, rychlostní silnice, silnice 1 a 2 třídy) vytvořili síť polygonů, Polygony nacházející se ve fragmentovaném území měly větší počet nehod na kilometr silnic než polygony nacházející se v UAT. Počet kolizí na kilometr čtvereční však byl v nefragmentovaném území vyšší, takže lze konstatovat, že srážky v UAT jsou na některých místech více koncentrované, zatímco ve fragmentované oblasti jsou více prostorově roztříštěné.

Table of contents

1.- Introduction

Wildlife-vehicle collisions (WVCs) are a major problem that is getting worse year by year, both for animals and for humans. Roads and other infrastructures act as barriers for fauna, which might stop their migration or risk their lives trying to cross them. Also, although to a lesser extent, some humans lose their lives because of this kind of collisions. And, besides the harms to living beings, economic losses have a great relevance, too. In Czech Republic, annual cost of vehicle reparation because of crashes with animals is estimated in 51 million euros. Furthermore, realising animals to the wild would cost around 122 million euros (Mrtka & Borkovcová 2013).

The importance of studying the causes and consequences of this issue is undeniable. This would lead to the root of the problem, trying then to find possible solutions to mitigate and reduce the number of accidents. Thus, it has been widely studied by experts but, however, the conclusions are not clear enough, as there are many contradictions among them. According to researchers, the most common factors involved in wildlife-vehicles collisions are locomotory activity of animals (daily and monthly), population’s density, season, traffic volume, speed limit, type of road and land cover. But they do not agree in which is the role they play in the crashes, or which ones are the most important to focus on. There is also controversy about how the mitigation measures should be applied, as some articles point out that the efforts have to be on drivers (by education campaigns or road signals), while other sustain that making wildlife avoid roads (using odor repellents or fences, for example) would be more effective.

Another relevant factor is the level of fragmentation of the landscape. This directly affects the possibility of migration of animals, causes habitat loss and might isolate populations. Mobility is essential for the survival of wildlife, as they need it to find mating partners, reach food and water sources or to move to new habitats (van Strien & Grêt-Regamey 2016). Furthermore, landscape fragmentation affects climatic conditions, soil, land cover, water balance and land use, besides the noise and pollution these human modified places produce (Jaeger et al. 2007).

Hence, the way the landscape is configured changes substantially the probability of collisions. Roads can be built parallel or in a grid; they might be placed altogether or distributed throughout the landscape; they can create many small patches of habitat or a few big ones. Besides, a large number of roads with little traffic might cause more or maybe less accidents than a few busy roads. For example, some articles point out that most crashes occur at intermediate traffic levels (Kušta et al. 2017; Thurfjell et al. 2015).

So, all these land planning decisions influence wildlife viability in different ways. But this has not been studied deeply, yet. On this survey I am going to focus on the relation between landscape fragmentation and wildlife-vehicle collisions, by using geographic information systems (GIS), which are an efficient tool to analyse the landscape.

2.- Aim

The aim of this Diploma Thesis is the use of GIS as a method to approach an issue of wildlife-vehicle collisions caused by the landscape fragmentation in Czech Republic. This will be achieved by following these particular aims:

- Analysis of the number of collisions in three regions of the Czech Republic (Ústecký, Liberecký and Středočeský Region) between 2007 and 2014.
- Analysis of the fragmentation of the landscape in these three regions by differentiating between unfragmented areas by traffic, fragmented areas by traffic and the border between them.
- Relationship between the localization of the collisions and the fragmentation of the landscape.

For a better understanding of the goals of this Thesis, I include the following scheme:

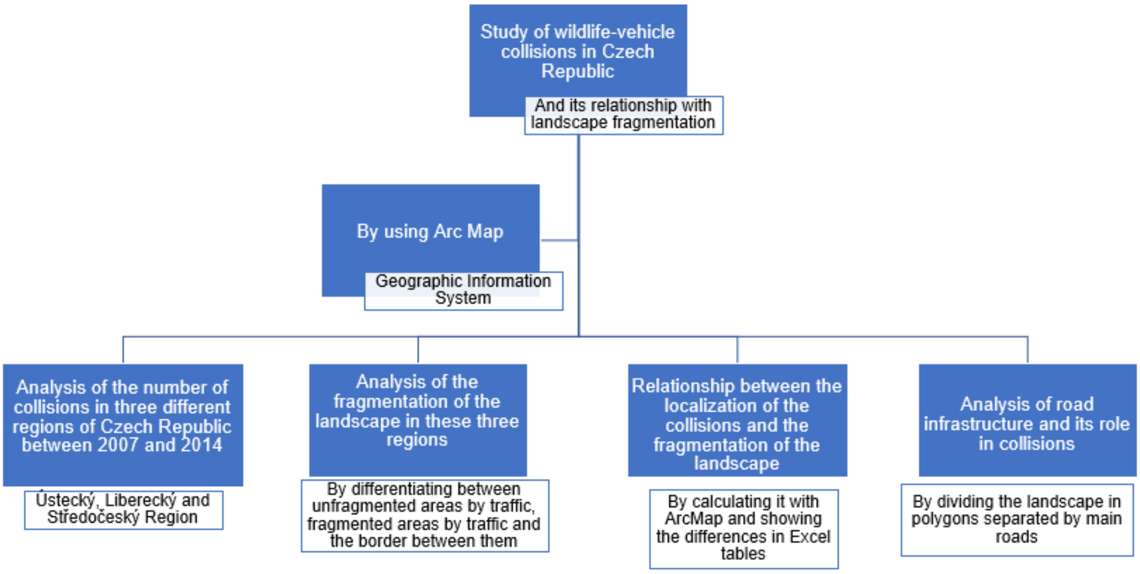

Figure 1. Scheme of the aims of the Diploma Thesis.

3.- Literature review

Since humans started to develop and grow cities and links between them, wildlife has been stopped by barriers that limit their displacements and migrations. Frequently, they are forced to cross roads to continue their way with the consequent risk, both for them and for the vehicles that are on the road. This causes huge economical and vital losses, implying the death of many animals and some humans; damages to roads and cars are also relevant.

It is such an important issue, that has been subject of many studies. It has been done research about the behaviour of the animals (usually monitoring them), the animals that are most commonly affected, the period of the day or of the year that has more wildlife-vehicle collisions (WVCs) and the possible mitigation measures to avoid them. However, much more research has to be done, as the number of accidents is increasing year by year. Here, I tried to gather information about the most important articles that deal with this problem.

3.1 General statistics and species involved

3.1.1 EU countries

There is no doubt that the figures of wildlife-vehicle collisions are alarming. According to RACC -Real Club Car of Catalonia- (2011) there are 507000 crashes with ungulates per year in Europe, with 300 fatalities and approximate cost of 800 million euros.

The species involved vary among zones. For example, in Belgium, in 78% of accidents were involved wild animals, mainly wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), in 13% domestic ones (principally dogs) and the rest were undetermined (Morelle et al. 2013). On the other hand, in Hungary 81,3% of all collisions affected red foxes (*Vulpes vulpes*), that is, 13 times more than roe deer

(Markolt et al. 2012). In Ireland, Haigh (2012) found out that the main species killed were rabbits (*Oryctolagus cuniculus*), hedgehogs (*Erinaceus eruopaeus*), badgers (*Meles meles*) and foxes.

In Galicia, situated at the North West of Spain, from 2006 to 2010, wild boar and roe deer collisions accounted, respectively, 62,8% and 36,5% of the WVCs (Lagos et al. 2012). And in Lublin region (Poland), 75% of the accidents with fauna were with roe deer (Tajchman et al. 2010).

A fact that reflects the importance of this problem is that in Sweden, 60% of all traffic accidents in the 90's were of this kind (Seiler 2004). In 1999, there were 24000 collisions involving roe deer and 4500 with moose (*Alces alces*). Fortunately, less than 5% of the collisions caused human injury; on the other hand, more than 90% of the animals died because of the collision; besides, the economic losses, that in Sweden are estimated in 100 million of euros per year. However, as not all accidents are reported, the estimations (supported by a questionnaire done to drivers) say that the true figures are more than double.

Figure 2. Moose crossing the road (photo by Larry Lamsa).

Morelle et al. (2013) observed a 21% increase in wildlife-vehicle collisions between 2003 and 2011 in Wallonia, Belgium, one of the densest road networks in the world.

87% of these accidents supposed car damages, while 13% entailed injuries for drivers, and 1% their death.

In Germany, a research compared deer-vehicle collisions with the rest of collisions, in a 10-year period study, from 2002 to 2011 (Hothorn et al. 2015). They found out that, while the accidents without animals decreased by 10% during this interval, the WVCs increased by 25%, probably because of the growth in deer densities.

In the case of Czech Republic, the figures of WVCs are also extremely high. Mrtka & Borkovcová (2013) made a questionnaire to more than one thousand drivers, resulting that 42% of them had reported a collision with mammals. The highest mortality rates corresponded to hare (*Lepus europaeus*), adding up 29% of the total, that is, 144000 deaths per year. This species was followed by roe deer, cat (*Felix catus*) and hedgehog.

In some species, mortality on roads exceeded the number of animals killed by hunting. Ungulates were the ones which supposed most frequent car damages, and the most expensive ones.

Mrtka & Borkovcová (2013) estimated the annual cost of vehicle reparation in Czech Republic in 51 million euros, and 122 million euros on realising animals to the wild.

However, not all the publications study this issue with mammals. Even though they are the most important ones because of being the biggest, other animals are also involved in WVCs. Colino-Rabanal & Lizana (2012) made a review of the interactions between roads and reptiles and amphibians (herpetofauna). In this case, the main impact is ecological, as they are not big enough to suppose a threat to humans. But this impact is huge, as it can affect the viability of populations, especially those from amphibians, which presented a high number of road-kills, besides being affected by pollution because of their permeable skin. Reptiles are also influenced by roads as they use them for thermoregulation, and herpetofauna in general is very susceptible to habitat fragmentation, caused mainly by roads.

3.1.2 Rest of the world

By studying the WVCs in USA between 1990 and 2008, Sullivan (2011) detected an increase of 108% of the crashes in this period.

Romin & Bissonette (1996) collected the information of the 43 state natural resource agencies of USA that answered their petition. They showed a high variability and inconsistence among the different agencies, but in most of them the number of collisions had increased in the previous decade (1982-1991), having around half a million of dead deer in 1991.

Similar conclusions achieved Langley et al. (2006) in USA, where they saw an increment of 78% of WVCs between 1995-2004, while the nonanimal-related events kept stable in this period. The patterns also differed depending if it was animal-related or not.

Figure 3. Dead roe deer on the roadside (photo by Zdeněk Keken).

3.2 General factors affecting WVCs

3.2.1 EU countries

There are many factors involved in WVCs. First, there must be a coincidence in space and time of a vehicle and an animal, and these coincidences are more frequent in some situations than others. Seiler (2004) revealed that the changes in the number of accidents in Sweden depended on ungulates' density and number of vehicles, taking also into account topography, road characteristics, habitat and vehicle speed, among others.

In Finland, Niemi et al. (2017) found a positive relationship between moose population size, traffic volume and number of collisions. Furthermore, they saw a decrease in the amount of crashes with personal injuries over time, probably because of the better safety measures in cars.

And in Czech Republic, Kušta et al. (2017) concluded that the most important factor affecting these crashes was the locomotory activity of the animals.

3.2.2 Rest of the world

Joyce & Mahoney (2001), in Canada, also identified moose density and traffic volume as the main causes of moose-vehicle collisions but, surprisingly, intermediate moose populations presented the lowest number of accidents, while small and big densities showed worse results.

It was also unusual to discover that the greatest amount of collisions was in dry conditions and straight roads, what implies that crashes are mainly drivers' fault.

All these articles analysed the relation between roads and wildlife. But there are other infrastructures that also cause fragmentation and death of animals because of the collisions. Trains are one of them, and they were studied by Visintin et al. (2018) in Australia. They developed a model to try to reduce collisions with kangaroos and found out that the main factors involved in these fatalities were the temporal variation in animal activity and train speed.

3.3 Spatial patterns

3.3.1 EU countries

Accidents are not randomly distributed, neither in time nor in space. Diaz-Varela et al. (2011) found some accident concentration sections in a road of Galicia (Spain), that hosted about 80% of the accidents, occupying only 10% of the network. Other authors distinguished more crashes at highways and major roads, probably because of the higher traffic density and allowed speed. Morelle et al. (2013) found out that, in Belgium, more than half of WVCs were on this kind of roads, despite representing only 14,6% of the road network. Similar results were obtained in Sweden, where roads that allowed higher speeds had 64% of the collisions, while they were only 29% of the total length (Neumann et al. 2012). They saw different results for crossings (which did not have the same patterns than the crashes), as they were mainly in old coniferous stands and forest roads.

To avoid this, in Hungary highways are fenced. Regardless, still 5% of the accidents involve wild animals (Cserkész et al. 2013). There is a clear clustering, as 43% of these accidents occur near interchanges (in a 100-meter radius from them), because there the continuity of the fence is interrupted. Another reason is that when animals cross accidentally the fence, they cannot return, so they continue along it until they arrive to an interchange, where they have to cross the road. This happened mainly for roe deer and red fox, while wild boars had their collisions near railways that were parallel to highways. Badgers were usually hit near places where the fence was not buried in the soil.

Contrarily, in the same country, Markolt et al. (2012) did not find any relation between underpasses or population densities and roadkill. Some species had more crashes near underpasses (like red fox) or were not affected by their presence (badgers). According to them, the main factor influencing WVCs is the habitat surrounding the road. So did Colino Rabanal et al. (2012) concluded studying wild boar in Spain. This species, the main one involved in wildlife-vehicle collisions in the Mediterranean region, together with roe deer, had most of the accidents near maize crops, where they eat and take refuge. This factor appeared to be more important than others like agricultural lands, forest areas and high speed or dense traffic zones. These results also stress the importance of difference among species and habitats, giving specific solutions to each situation, as this is not a homogenous issue and has very distinct variations.

Figure 4. Wild boar crossing tracks (photo by Zdeněk Keken).

An example of this could be the study of Kušta et al. (2014) in the Czech Republic, in which, surprisingly, the habitat surrounding the roads appeared to have no effect on the occurrence of accidents. But this could be explained because they did not distinguish within species, as the Czech Traffic Police did not have that data. This reinforces the necessity of study each species separately.

In the same country, Keken et al. (2016) analysed the role of landscape structural changes in WVCs, between 1950 and 2012. Czech Republic, because of its recent history, has had drastic changes in their landscape. The communist period (after

1948), transformed the way of managing agriculture, merging fields into large units, characterised by their homogeneity, which affected the migration potential of species.

Therefore, while in 1950 the landscape of hotspots was mainly grassland (34,99%), followed by forest (27,52%) and arable land (23,9%), in 2012 forest occupied 33,51%. Arable land also increased their surface up to 29,08%, while grasslands decreased substantially (6,19%).

The ecological migration potential irreversibly changed. The heterogeneity of 1950 decreased enormously and, thus, the possibility of animals to migrate. In almost all hotspots, the landscape structure was strongly modified.

In England, Nelli et al. (2018) made a mapping risk focusing on deer. Their most important factors related to the occurrence of a WVC were: traffic flow, average precipitation, and a combination of suburban areas and broadleaved forests. The habitat composition was also important, since a more diversified landscape decreased the number and risk of crashes. This model could be a tool to prioritize the intervention measures on the riskiest parts of roads.

3.3.2 Rest of the world

In Kansas, USA, Conard & Gipson (2006) also saw a relation between WVCs and land cover; contrary to what would be expected, riparian zones where the ones with more accidents, probably because they cross perpendicularly some roads. On the other hand, and unlike other surveys, agricultural zones appeared to be the safest zones.

According to Lao et al. (2011), the most important factors affecting collisions were speed limit, rural areas and species' habitat. However, high truck percentage, large number of lanes and male animals were considered to decrease the amount of accidents. Apparently, females require more response time, that is why males were less involved in WVCs. Similar results obtained Visintin et al. (2017) in Australia with 6 different mammal species and Danks & Porter (2010) in Western Maine, USA, studying the moose, the largest ungulate in most parts of North America and the North of Europe. These last ones demonstrated the effect of traffic (traffic volume was two times higher on average in collision points than in random ones) and speed limit (it was 6 km/hr higher at WVCs than at random points). The effect of landscape cover was also remarkable, and accidents took place mainly near cutover forest (36%). This may be because timber harvesting can enhance foraging habitat for moose. Coniferous forests were also important, unlike places with interspersion of cover types, because moose prefer the first habitat, and in the second one they do not have to move much between patches looking for forage and, thus, they cross less roads.

They revealed clustering at local and regional scale, but not at an intermediate one, where accidents were sometimes regularly distributed, sometimes randomly.

In California, Ha & Shilling (2018) developed a model that clearly showed the differences in the patterns of WVCs among several taxonomic groups. So, while ungulates were supposed to have more crashes in high forested areas with low road densities, birds and medium-mammals were more vulnerable in high road density areas, in both high or low forests.

Hurley et al. (2009) investigated the utility of expert-based knowledge in British Columbia, Canada, focusing on moose. Experts pointed out that the moose habitat classification was the most relevant factor explaining moose-vehicle collisions, as well as land cover and distance to water. Driver-related factors had less importance, and there were some discrepancies among experts, but the speed limit stressed as the most decisive one.

Both local and non-local experts achieved great results, but in the habitat criteria the local ones were slightly more precise. However, these conclusions are only valid for moose, as each species has a different behaviour, and their role and characteristics in WVC might be different.

A very different approach was followed by Rea et al. (2018). They used Dash Cam videos of YouTube™, that is, an onboard camera that records the view of the vehicle. This offers a great possibility to see what happened just before the accident, and to analyse the differences with those that avoided the collision. They observed 96 videos (52 collisions and 44 near misses) of moose, in different countries; most of them occurred during spring and summer, on dry roads, forested habitats, and with no oncoming traffic. As one might suppose, vehicles slowed more frequently in near miss videos than in crashes (in fact, this was the only significant variable that explained the difference between a WVC and a near miss). On the other hand, vehicles swerved more in the collisions. There was no evidence that the following variables had any influence in the collisions: surface conditions, roadside habitat type, cleared extension of the roadside, natural light conditions, season, oncoming traffic or the direction from which the moose entered the roadway.

Of course, these results should be considered with caution as it was a low sample and, for example, videos at night or including infractions are less likely to be uploaded.

3.4 Temporal patterns

3.4.1 EU countries

Like with the spatial analysis, the study of temporal patterns of WVCs shows a clear distribution for each species, that usually matches with the periods of highest activity of the animals.

In the case of wild boar, most accidents occurred during night (this was very significative in the study of Rodríguez-Morales et al. (2013), in which 94,5% of accidents happened when the light was gone and in the one of Diaz-Varela et al. (2011), with 91%). But many other surveys have demonstrated this (Colino Rabanal et al. 2012 and Lagos et al. 2012 in Spain; Markolt et al. 2012 in Hungary; Kušta et al. 2017 in Czech Republic; Thurfjell et al. 2015 in Sweden). This last article made a difference between crossings and collisions; crossings were more likely to occur at early hours in the morning between July-September and after sunset between September and December (in this second case, the probability that the crossing supposed an accident was higher).

Studying wild boar-vehicle collisions throughout the year, their activity is also a clue factor. There are more accidents during autumn and winter, that is, rutting season and litter dispersion (Colino Rabanal et al. 2012; Markolt et al. 2012; Diaz-Varela et al. 2011). Kušta et al. (2017) obtained different results, concluding that crashes were most frequent in spring and autumn, and less common in winter, probably because the lower traffic intensity, the worse conditions of the roads that make drivers reduce their speed, and the lack of vegetation that allows seeing the animals in advance. There were also some differences between roads, as motorways peaked only in spring, not in autumn.

Some articles also pointed out the possible influence of the hunting period, which is only allowed in Galicia (Spain) from late August to February, the months with higher number of collisions (Lagos et al. 2012; Rodríguez-Morales et al. 2013). Also Morelle et al. (2013) saw an increment of accidents during hunting season in Belgium.

Figure 5. Dead roe deer on the roadside (photo by Zdeněk Keken).

This could be an explanation for the differences among days of the week, too. Lagos et al. (2012) observed an increasing number of WVCs at weekends, especially on Sundays (day of the week when *batidas* take place, which is the way of hunting wild boar in Galicia). On the other hand, Rodríguez-Morales et al. (2013) separated the study of the patterns during the week into the hunting season and the rest of the year, but they did not see a clear relation. Both in wild boar and roe deer, the weekly patterns differed in hunting and nonhunting season, but there were not conclusive results.

The conclusions of the study of roe deer's patterns are very different. They have their crashes more homogeneously distributed thorought the day (46,4% at day and 53,6% at night), with peaks at dusk and dawn, their moments of maximal activity (Lagos et al. 2012; Rodríguez-Morales et al. 2013; Kušta et al. 2017; Diaz-Varela et al. 2011).

Furthermore, this species had their maximum in April and May, when the breeding occurs, so the fawns that had born the year before leave the group and wander alone, and the mothers move more distances finding food to improve their milk quality; July had also a high number of collisions, as it is the period for rutting, what makes them more sociable and bucks displace theirshelves looking for females to mate (Lagos et al. 2012; Rodríguez-Morales et al. 2013; Markolt et al. 2012; Diaz-Varela et al. 2011).

In the case of the moose, Neumann et al. (2012) found out that in Sweden there were important differences in space and time between crossings and crashes. While the first ones peaked in May, June and between November and January (period of moose migration), the accidents had their highest values in autumn and winter.

Nearby, in Finland, Niemi et al. (2017) surveyed the temporal patterns of moose-vehicle collisions, taking also into account the occurrence or not of personal injuries. This led to interesting results, as WVCs, in general, peaked in autumn and winter, like the previous study; but those including personal injuries peaked in summer. This could imply that factors affecting crashes might not be the same than factors affecting the severity of the crashes.

In Germany, a research compared deer-vehicle collisions with the rest of collisions (Hothorn et al. 2015). This kind of crashes were mainly after sunset and around sunrise, in early spring and mating season (July-August) (same results than Nelli et al. (2018)) and, surprisingly, were more common in weekdays than in weekends. Contrarily, general collisions occurred during the day, and mainly in December and January.

Haigh (2012) found out that the main species killed in Ireland were rabbits, hedgehogs, badgers and foxes, principally in May, August and September. The peaks differed among species, coinciding with their breeding and dispersal patterns. She pointed out that, for the most vulnerable species, like otter or marten, WVCs were one of the greatest threats.

In Czech Republic, Kušta & Keken (2017) realised the importance of the accidents involving trains and wildlife, but they were aware that quantifying them was very difficult, as few of them involved human injuries or property damage. This kind of collisions occurred mainly in winter, contrarily to those on roads, that, according to their results, were most often during spring, and winter was the season with less crashes.

3.4.2 Rest of the world

Joyce & Mahoney (2001) studied the spatiotemporal distribution of the accidents involving moose in Newfoundland, Canada. They concluded that most accidents (75%) were during dusk and dawn, and at that moments the possibility of human injuries was duplicate. At day scale, they did not see any differences between sex or age of the moose, but at a seasonal one there were changes depending on the age. Moreover, 70% of accidents were between June and October. Similar results than Danks & Porter (2010), who obtained a 81,6% of the WVCs between May and October, in Western Maine, USA. There was a peak in June (18,6%), which is the month of the parturition of moose, and when the mothers leave their calves. In the Dash Cam videos of Rea et al. (2018) the most risky seasons were spring and summer, too.

Figure 6. Dead young wild boar on the roadside (photo by Zdeněk Keken).

Conard & Gipson (2006) studied collisions with multiple species in Kansas, USA, and the seasonal study revealed a higher number of collisions during autumn, perhaps because the most frequent species in the analysis, Virginia opossum, moves more in this period of the year.

Like most studies, Sullivan (2011) concluded that both daily and seasonal patterns of collisions matched with the activity of deer. He observed more accidents in dusk and dawn, and in mating season (October, November), spring and summer.

Sullivan also discovered a relation between darkness and speed limit, as by each mile per hour allowed, there was a 2,3% increase in the probability of fatal accident. However, this relation was not so clear in the case of crashes of lower severity, probably because these are more difficult to mitigate, even with additional time to react (as the light would allow drivers to see the animal in advance); some crashes are, simply, unavoidable.

3.5 Habitat fragmentation

Roads do not only affect wildlife because of collisions with vehicles, they also act as a barrier for populations. Mobility is essential for the survival of animal species: it is necessary to reach food and water sources, find mating partners or move to new habitats. It also plays an important role on plants viability, ensuring seeds or pollen dispersal (van Strien & Grêt-Regamey 2016). The division of the animals' habitat may force wildlife to cross roads to continue their way, with the consequent risk of a collision. Furthermore, landscape fragmentation affects climatic conditions, soil, land cover, water balance and land use, besides the noise and pollution these human modified places produce (Jaeger et al. 2007). Its impact also causes behavioural changes, reduced dispersal abilities and impediment to gene flow (Girvetz et al. 2007). The most affected species are those that require large areas.

An example of the consequences of fragmentation was showed by Patten et al. (2005), who realised that the differences in nesting strategies and females' survivorship of lesser prairie-chicken in different parts of USA were explained by their differences in habitats' fragmentation. The more fragmented landscape of Oklahoma supposed a threat for females, that were more likely to suffer a collision and, thus, their population persistence was much more endangered.

But fragmentation is not only caused by roads. Any impediment to the movement of animals contributes to it, like other human's constructions (agricultural lands, urban areas or railways), or natural barriers as rivers, lakes or alpine zones.

However, as I am studying WVCs, I am going to focus on the barrier effect caused by roads, which can be due to physical structures, such as fences, or to road avoidance behaviour. Although this can rescue individuals from road mortality to some extent, the negative consequences of habitat loss and fragmentation may be higher when such barrier effect is present, since road avoidance can lead to population isolation and to higher exposure to demographic and environmental stochasticity. Thus, reduced population abundance near roads may be due to direct road mortality, or due to road avoidance behaviour. Ceia-Hasse et al. (2018) studied both possibilities thoroughly. They developed a model that could simulate different scenarios, resulting that road mortality was much more decisive than the barrier effect for population size and persistence.

In the scenario of highest road density, only complete road avoidance led populations to extinction. In fact, road avoidance could also in some cases rescue populations under low to moderate road mortality from extinction. Even in the scenario with no road mortality and no road avoidance, the probability of extinction was higher, and the population size was smaller at higher road densities, suggesting an effect due to habitat loss. This is a clear example of the multiple effects of roads in wildlife populations.

Some studies also pointed out that animals avoided crossing a road when the traffic was intense. Kušta et al. (2017) and Thurfjell et al. (2015) obtained results that showed a high negative correlation between traffic and WVCs. They revealed that animals perceive roads as risky, so they only cross them if the reward (the other side of the road) worth it; for example, in the case of wild boar, this presumably happens with crop fields -when they are mature- or when acorns are available in deciduous forests. Thus, most accidents occur at intermediate traffic levels.

Some authors also analysed how the configuration of the road network influenced the degree by which wildlife populations are affected (Jaeger et al. 2005). They saw a clear relation, as their results suggested that, even though a population may show no negative response to a certain number or density of roads, a different configuration of the road network (with the same total length of roads) may cause the extinction of the population.

Furthermore, the population persistence was generally higher when all traffic was put on one road than when it was distributed on several roads across the landscape. They obtained similar conclusions by comparing the effect of clustering roads altogether or distributing them more homogeneously through the landscape. This happens despite the fact that clustering roads and traffic can have a stronger barrier effect.

Surprisingly, the model results also showed that, for animals that do not very strongly avoid roads, fragmenting the landscape into more patches was less harmful to population persistence. It was more important to preserve core habitats at a sufficient distance from roads than to keep the number of patches low. So, gridded pattern appeared to be less detrimental for animals than a parallel network, unless they had a high road avoidance, in which case they would be more isolated in the gridded pattern.

Different results obtained van Strien & Grêt-Regamey (2016), whose model revealed a negative correlation between habitat connectivity and the number of settlement patches. Several larger holes in the landscape network were better for the habitat connectivity than many smaller holes.

Furthermore, they surprisingly found out that, for tree frog and in landscapes with low proportions of settlement, there was a higher habitat connectivity for dense road networks than for sparse ones.

According to them, the objective of nature conservationists and traffic planners should be avoiding the construction of new roads by upgrading of existing roads and placing unavoidable new roads as close as possible to existing infrastructure, like other roads or railways.

McGarigal & Cushman (2002) called attention to the distinction between habitat loss and fragmentation, which most studies analyse like the same. However, despite the fact that they are very similar, they are independent processes with specific consequences. They also pointed out the importance of the study-scale, that should depend on the target of the research. This has to be larger than the area of the population that is subject to study, but if it is too large it might be difficult to investigate it realistically.

On the other hand, Van Der Ree et al. (2011) proposed a research in road ecology at larger scales, both temporal and spatial; they claimed to finish with the usual small-scale projects, because the complexity and interactions among the effects of roads and traffic are large and potentially unexpected. They believe in the necessity of a clearer integration between different studies.

In this kind of surveys, it is important to analyse landscape fragmentation taking into account natural borders, not political frontiers, as large unfragmented areas still exist in cross border regions. Walz & Schumacher (2005) concluded this after studying Saxon-Bohemian Switzerland national park, which involves two countries, Czech Republic and Germany. They also found out that the remaining unfragmented space in the Czech Republic was significantly larger than these space in the German part.

Until now, I have explained many causes and consequences of habitat fragmentation. From now on I am going to explain how to measure it. There are many ways to quantify it, and it can be done by selecting the single aspect of fragmentation that is of most concern to the question of interest, or to use several measures, which is more useful when concern is for the integrity of the entire ecosystem, rather than the impact on a single species with specific needs (Davidson 1998).

One common mistake is to use perimeter:area ratios to measure landscape fragmentation; it should not be used as it does not capture isolation. Furthermore, the choice of scale (both extent and grain) greatly affects analysis of fragmentation, but, according to Davidson, there is no one correct scale for analysis, each case has an optimal one.

Most methods to measure fragmentation can only be applied to specific aspects and cannot be used as a planning tool. However, effective mesh size can. It is based on the probability that two random points in a region will be located in the same non-fragmented area of land. It is an effect tool for transportation planners, to calculate the impact of roads, and it can also be used as an environmental indicator for ecological assessment of transportation system impacts (Girvetz et al. 2007; Jaeger et al. 2007).

Another article where effective mesh size is extolled is the one from Jaeger (2000), who compared it with two other methods: degree of landscape division and splitting index. The three methods characterize the anthropogenic penetration of landscapes from a geometric point of view and are calculated from the distribution function of the remaining patch sizes. They are based on the ability of two animals, placed in different areas, to find each other within the landscape. Comparing these three tools with old ones led to better results, for several reasons: their mathematical simplicity, their reaction to different fragmentation phases, the fact that they had ability to distinguish spatial patterns and their sensitivity to very small patches. The three of them were valid for the 6 phases of fragmentation (perforation, incision, dissection, dissipation, shrinkage and attrition), but the best one appeared to be effective mesh size.

Another useful method is expressing the unfragmented area by traffic (UAT), which is the part of the landscape which simultaneously fulfils two conditions: it is limited by roads with an annual average daily traffic volume higher than 1000 vehicles/day and it has an area greater than or equal to 100 km^2 (Kušta & Keken 2017). Unlike effective mesh size, that gives a numerical value of the fragmentation, UAT marks out a particular section of the territory, and it can be used, for example, to evaluate the migration potential of wildlife (Martolos et al. 2014).

Related to fragmentation is landscape connectivity, that is, the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993). A good method to measure it is cell immigration; this method is better than the two most common techniques to calculate landscape connectivity, dispersal success and search time, because they predict that landscape connectivity increases with increasing habitat fragmentation. This is because these measures are based on immigration into habitat patches and are therefore strongly related to the number of and mean nearest neighbour distance between habitat patches in the landscape. On the other hand, cell immigration measures the immigration into all habitat cells and, thus, solve this problem. Besides, it is highly robust to reductions in sample size (Tischendorf & Fahrig 2000).

3.6 Main issues with study designs

A common problem of wildlife-vehicle collisions' studies is the high rate of underreporting, as some collisions do not have enough damages for the drivers to report them. Furthermore, insurance policies, at least in Poland, do not pay the damages of the drivers if there was a 'Beware of wild animals' sign on the road (Tajchman et al. 2010).

Snow et al. (2015) researched about the effect of underreporting on prediction models, by simulating it randomly, excluding some WVCs. They found out that the relationship between the crashes and environmental factors was reliable even with a high rate of underreporting (up to 70%). Above this number, uncertainty doubled, but the positive thing is that underreporting is commonly under 2/3 (60%), so, in general, the loss of information is not a big problem. Besides, this survey was done with two different species and habitats: white-tailed deer in agricultural lands and moose in forested areas.

However, they recommend some caution with underreporting, as the accuracy is higher when the number of reports increases.

Santos et al. (2015) also reflected about study design, analysing how sampling frequency affected the accuracy of hotspots' identification. They realised that weekly sampling (or longer intervals) produced poor estimations, especially for small animals. Thus, they recommended to survey daily or every two days, in order to obtain precise results. They did this by comparing true hotspots with estimated ones with different sampling frequencies. They observed false positives (wrong estimated hotspots) and negatives (missing true hotspots) in the estimations with low frequencies.

3.7 Mitigation measures

Until now, I have compiled some of the main studies analysing the causes of WVCs and the factors which affect them most. From now on, I am going to collect information about the mitigation measures that should be done to reduce the number of this kind of accidents.

Romin & Bissonette (1996) found out that almost all the state natural resource agencies of USA tried mitigation measures, showing that the best ones were those that altered the behaviour of the deer. Fences, highway underpasses and overpasses contributed to solve this problem; while other techniques, such as deer-crossing warning signs, swareflex reflectors or general highway lighting failed in the reduction of crashes. However, some species of animals were driven away with some measures that others did not, showing the complexity of this issue.

In the Czech Republic, Kušta et al. (2015) studied the effectiveness of odor repellents in the reduction of WVCs. Despite their very questioned effect, they concluded that it was a useful tool, as it showed a 37% reduction in material losses between 2011 (without repellents) and 2013 (after two years applicating the measure).

The repellent was based on human sweat and predators' odor, and it wasn't tested in winter, as it has no effect during frosts. They asseverate that it was important to alternate the preparations to avoid animals get used to them.

Similar results obtained Bíl et al. (2018), also in Czech Republic. The reduction of WVCs was between 26 and 43% in their survey (despite the fact that odor preparation producers claimed to have up-to three times more effect).

Another usual measure is fencing. Clevenger et al. (2001) demonstrated their undeniable effectiveness in Canada, with an 80% decrease in WVCs after fencing, despite the increase on traffic volume. Moreover, the distribution of the crashes was not random, as most of them were within 1 kilometre from fence ends.

Figure 7. Road fencing (photo by Thomas Wiewandt).

In USA, McCollister & van Manen (2010) studied the effect of 3 underpasses and the associated fencing by implanting cameras and making track surveys before and after the mitigation measure. White-tailed deer (*Odocoileus virginianus*) represented 93% of all crossings, of the 9 species seen. They crossed 6,7 times more after the implement of the underpass; within fenced areas, mortality increased when the distance to the underpass did.

On the other hand, surprisingly, more WVCs were observed in fenced areas than in unfenced ones, probably because animals can transfer them, either from above, below or in their ends. Their advice was to build buried and continuous fences, at least between underpasses.

However, wildlife deaths were reduced by 58% after the construction of the underpasses, showing their effectiveness. The ratio of mortality of deer was extremely low (0,3%) in comparison with the number of crossings.

In Hungary, Cserkész et al. (2013) saw many accidents near interchanges because of fencing. So, they proposed some possible solutions, to try to avoid animals entering in interchanges. One measure could be the installation of cattle guards, that is, parallel tubes placed above a trench, so that cars can pass them slowly, but animals cannot. Acoustic repellents, or one-way gates, to allow animals to come back if they crossed accidentally the fence, could be other solutions.

Besides, they developed risk maps, which can be integrated in car navigation systems, alerting drivers of hotspots and at the most dangerous times of the day.

The use of warning reflectors is also quite frequent. Nonetheless, Ujvári et al. (2016) found them ineffective, in their case study with fallow deer (*Dama dama*). They saw an increasing indifference to the light reflections, as animals were getting used to them. They eliminated unmeasured factors, like vehicle noise and light, to test if the reflections changed the behaviour of the deer. They obtained different responses, but the common fact was that the reaction decreased day by day, showing that this measure is useless in the long term.

Similar conclusions obtained Benten et al. (2018), whose results after 2 years of recording showed that warning reflectors did not reduce the number of WVCs significantly.

And if that was not enough, Brieger et al. (2016) made a review of 53 articles that analysed light reflection devices between 1962 and 2013, coming to the same conclusion. They found differences among countries and type of studies (design, duration, length of the road), showing that short-term surveys revealed more positive effects of these devices than long-term ones. This might be because this kind of studies are carried out in peak years of WVCs, and after a peak there is always a drop in the number of crashes.

All these efforts were focused on animals' behaviour; but there is also the possibility to warn the other part involved in WVCs: drivers. Sullivan et al. (2004) studied the effect of temporary warning signs on roads during mule deer (*Odocoileus hemionus*) migrations in the United States. These were reflective flags and solar-powered flashing amber lights.

Their success was undeniable, as WVCs were reduced by 50%. Vehicles' speed was also reduced but its effect decreased in time, showing the importance of their temporality. So, they concluded that this measure was very useful in roads which have peaks in seasonal migration periods.

A similar approach was made by Neumann et al. (2012) who, after studying the different patterns between collisions and crossings, concluded that mitigation measures should focus on drivers, not on animal's behaviour; according to them, the main risks for the collisions are low light and poor road surface, not the probability of an animal crossing the road. Furthermore, they stressed the necessity of analysing not only the movement of the animals, but also collisions' data.

Joyce & Mahoney (2001) introduced a new idea in the mitigation measures: focusing on long term education programs. They support the idea that this is the only measure that works, besides the cheapest one. Furthermore, they proposed to use the local media, as radio or newspapers, to reduce costs and reach as many drivers as possible.

Another measure involving drivers is the installation of a Roadside Animal Detection System, that detects animals near the road and warns drivers with flashing signs. Grace et al. (2017) found them very effective during the tourist season, when they saw an important decrease on the cars' speed while the system was activated. Besides, this period is the one with the highest animal activity, so the effect on drivers is more significative.

In Japan, Honda et al. (2018) studied the problem of urban deer. They differenced between the shy deer and the bold ones, which occupy anthropogenic environments, as they have low sensitivity towards human disturbance, increasing the probability of WVCs. Thus, their solution was to proceed with a culling, removing the bold individuals, what would suppose a reduce in crop damage and collisions.

As I have checked, wildlife-vehicle collisions have been widely studied. However, the information is not clear enough and there are many contradictions among articles. Besides, much more research should be done in order to decrease the number of this type of accidents.

4.- Methodology

4.1 Description of study area

Czech Republic is a country situated in Central Europe. I focused on three Northern regions of it: Ústecký, Liberecký and Středočeský Region), that have a total area of 19517,56 km^2.

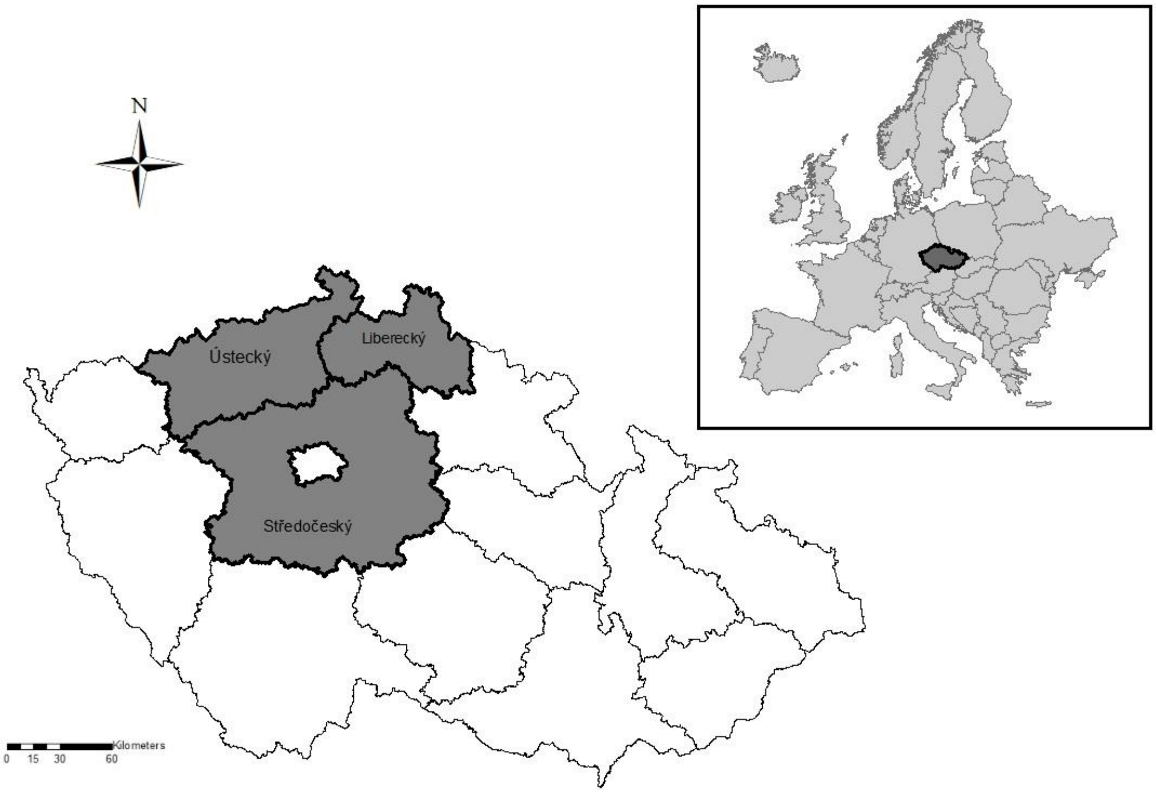

Figure 8. Situation of the three regions inside the Czech Republic and of this country inside Europe.

4.2 Data processing

I used the data of collisions of the Police of the Czech Republic. As some years were incomplete, I selected the largest period of years that had all the complete information, which was from 2007 to 2014. The number of collisions varied from 1189 crashes in 2009 to 2875 in 2014, with a total of 16092 collisions for the eight years' period. Thanks to the coordinates the file provided, it was possible to project the collisions to a Geographic Information System (GIS), specifically, ©ArcGis 10.3.1. The coordinate system used was S-JTSK Krovak East North.

To make the analysis in this program, I also took some layers from the National INSPIRE Geoportal. Using their WMS services, they provided me layers of the borders of the regions of the Czech Republic and of unfragmented area by traffic (UAT). UAT is the part of the landscape which simultaneously fulfils two conditions: it is limited by roads with an annual average daily traffic volume higher than 1000 vehicles/day and it has a core area greater than or equal to 100 km^2 (Kušta & Keken 2017).

So, with all this information, I separated the three regions of my interest and intersected all the other layers with this new area, in order to have the collisions (of each of the years) and the UAT reduced to my area of study.

Then I separated the collisions depending on where they had taken place: inside a UAT, in a fragmented area, or in the border between both (within 20 meters from it). To do this I used the tool *Select layer by location*, and the "Within_clementini" option for each of the three possible locations, and for each of the eight years. I separated every possibility in a new layer, obtaining 24 new layers.

I also obtained the layer of the roads of the Czech Republic.

4.3 Data analysis

With all these data I proceeded to analyse it. The first step was to calculate the number of collisions per year in each of the areas (again UAT, fragmented and border). Then I determined the area of the UAT and fragmented zones (as the border has no area), to calculate the number of collisions per square kilometer for each of the years (2007-2014).

After that, with the roads' layer, I differentiated between motorways, expressways, and first, second and third category roads, and calculated the number of collisions per kilometer. I merged all these layers except the last one, and created polygons with that polylines, dividing them between those which were in UAT and those in fragmented area. For each polygon, I obtained the value of its area, the length of the third category roads within it and the number of collisions inside it (including the collisions from all the years altogether). To do these two last steps the tool *Dissolve* was used.

I also calculated the value of collisions per kilometer and per square kilometer, separately for the unfragmented polygons and for the fragmented ones. Finally, I estimated the covariance between the fragmentation and the collisions/km and between the fragmentation and the collisions/km^2.

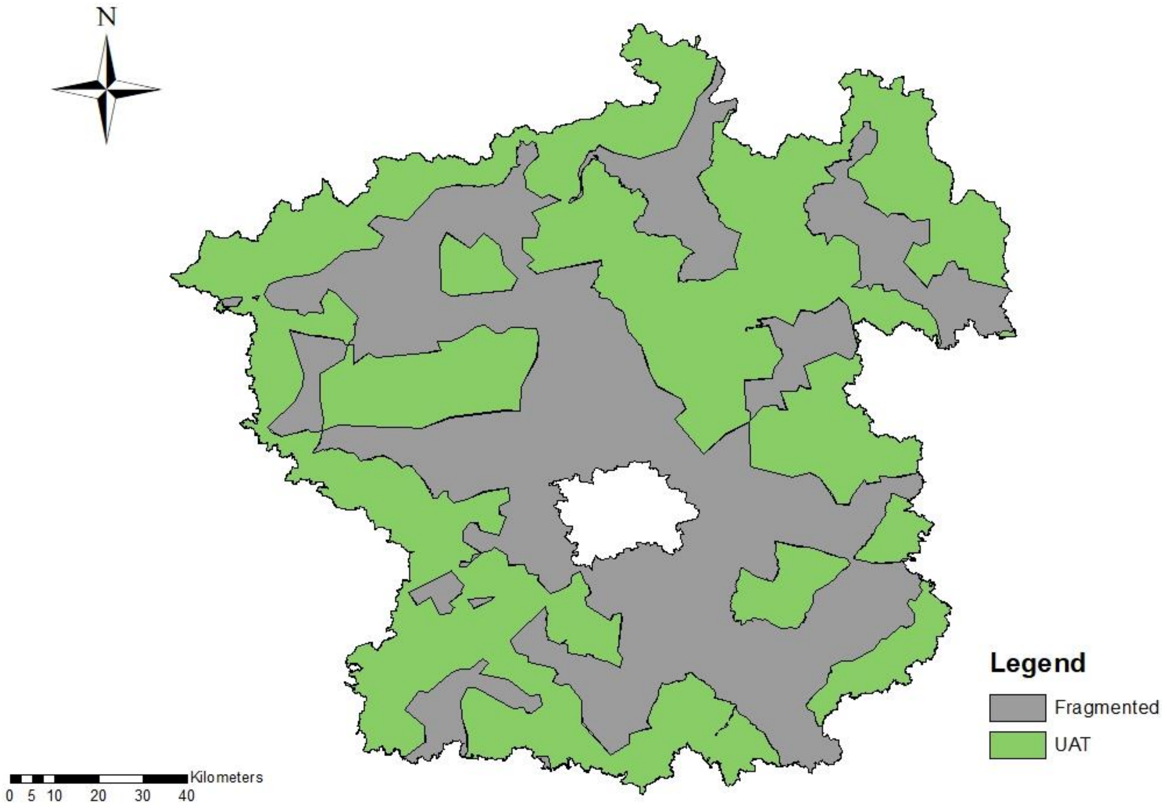

Figure 9. Division between the parts of the landscape that are fragmented and those that are unfragmented (UAT).

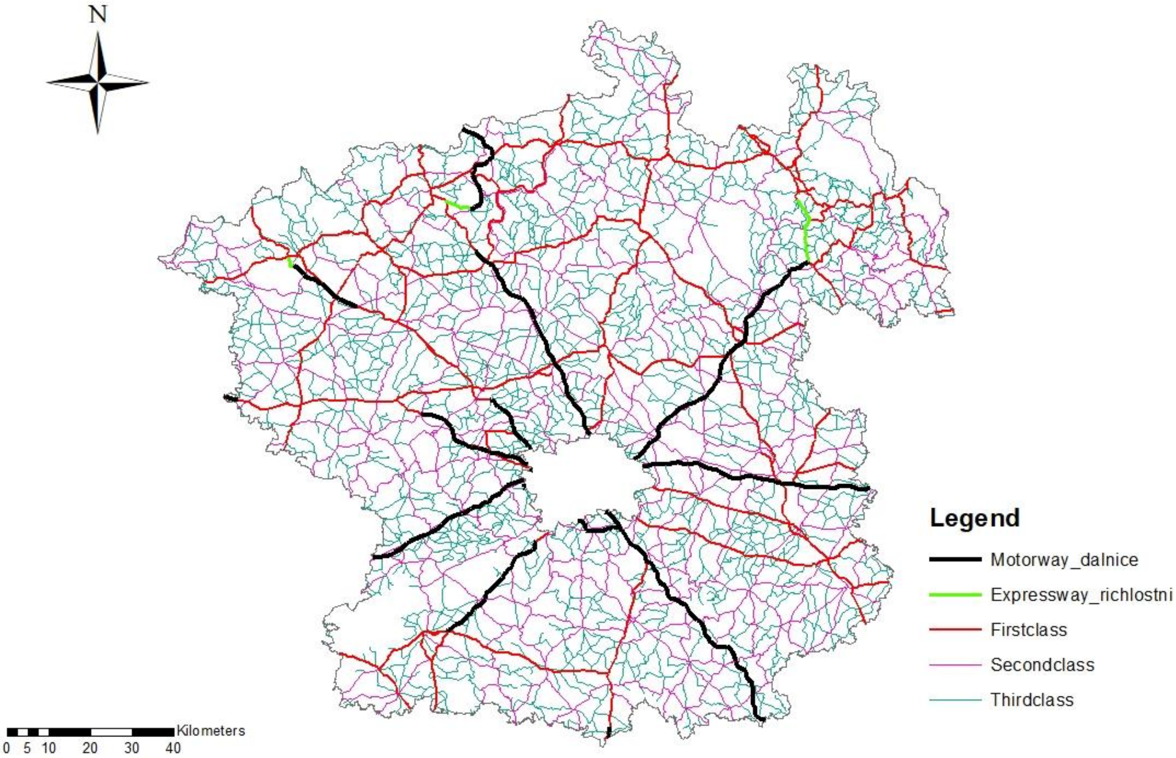

Figure 10. Motorways, expressways and first, second and third category roads in my area of study.

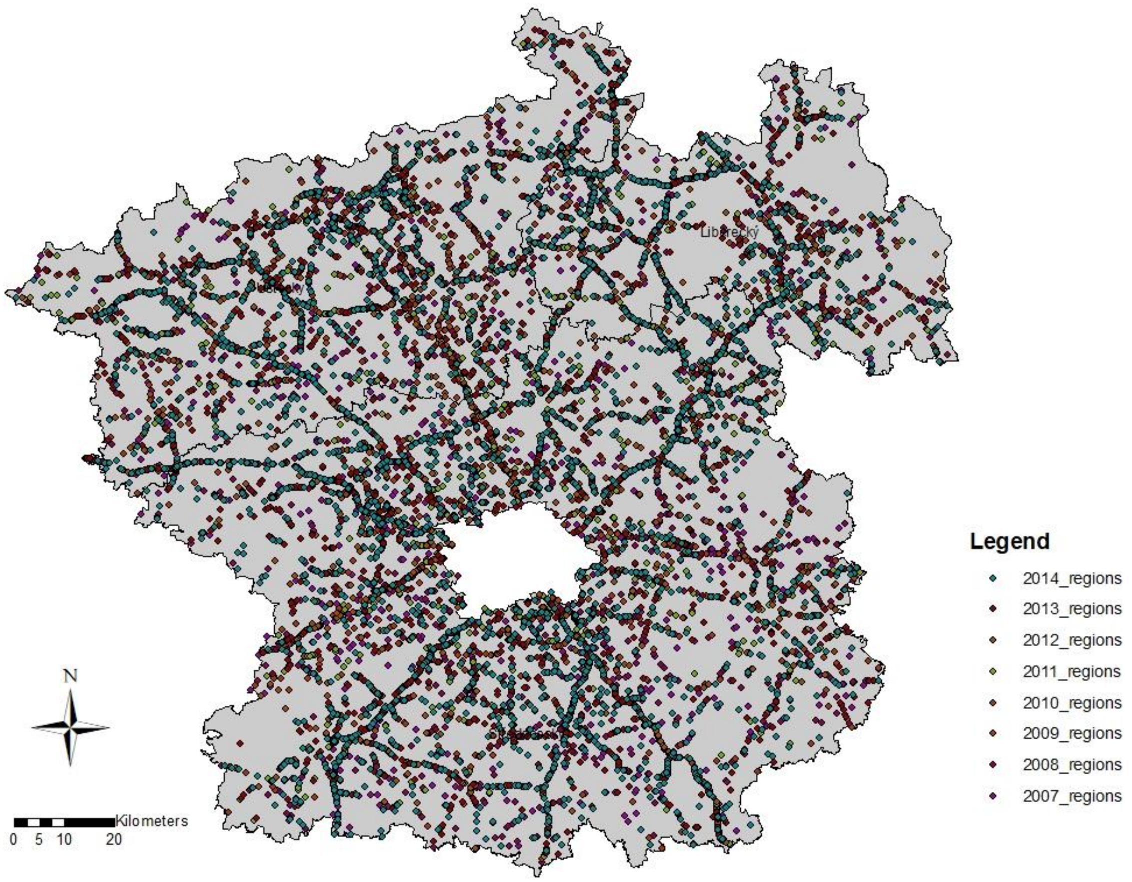

Figure 11. Distribution of collisions in the period 2007-2014.

5.- Results

First of all, I show the area of the unfragmented area by traffic and the fragmented one in the regions of the study:

Table 1. Area of fragmented and unfragmented area by traffic in the three regions (km²).

	Area (km²)
UAT	10757,18
Fragmented	8760,38
TOTAL regions	**19517,56**

The division of the collisions between those which were in fragmented areas, those in UAT and those in the border is presented in the following maps:

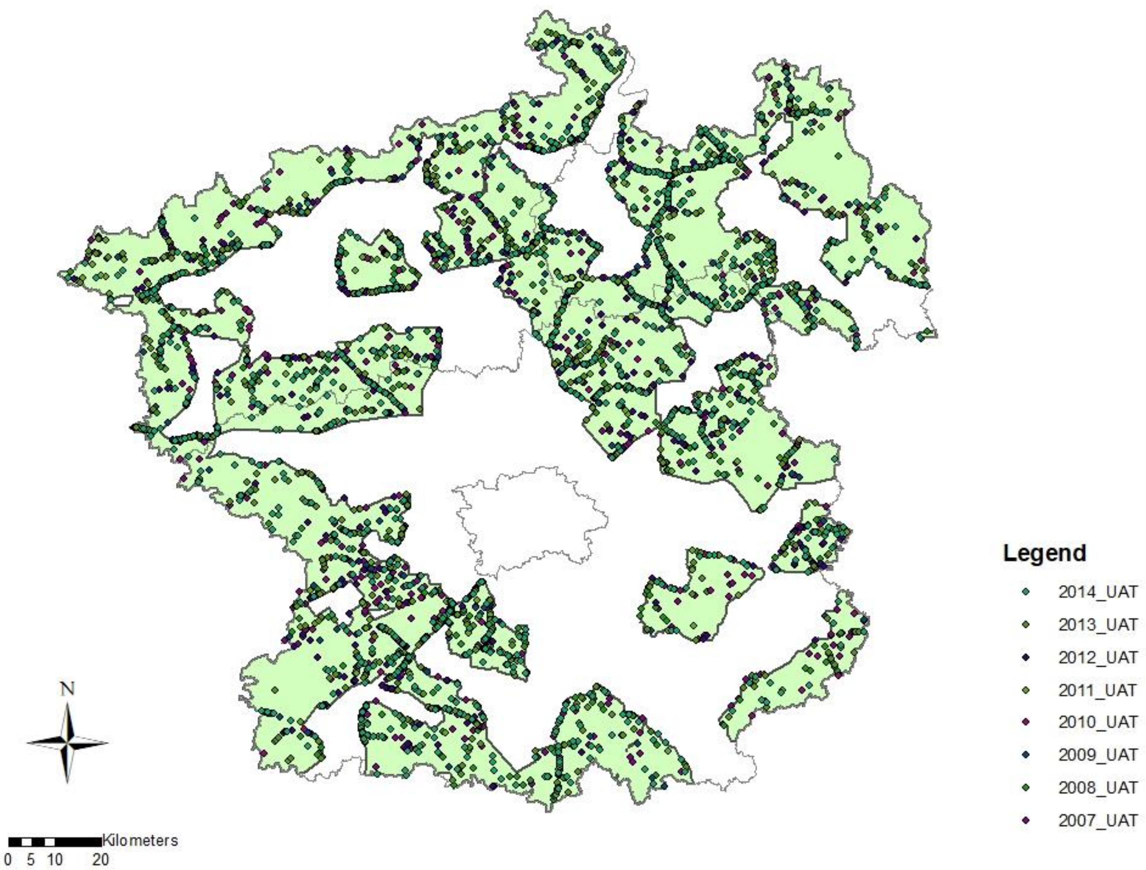

Figure 12. Distribution of the collisions in the unfragmented area by traffic, for each of the years (2007-2014).

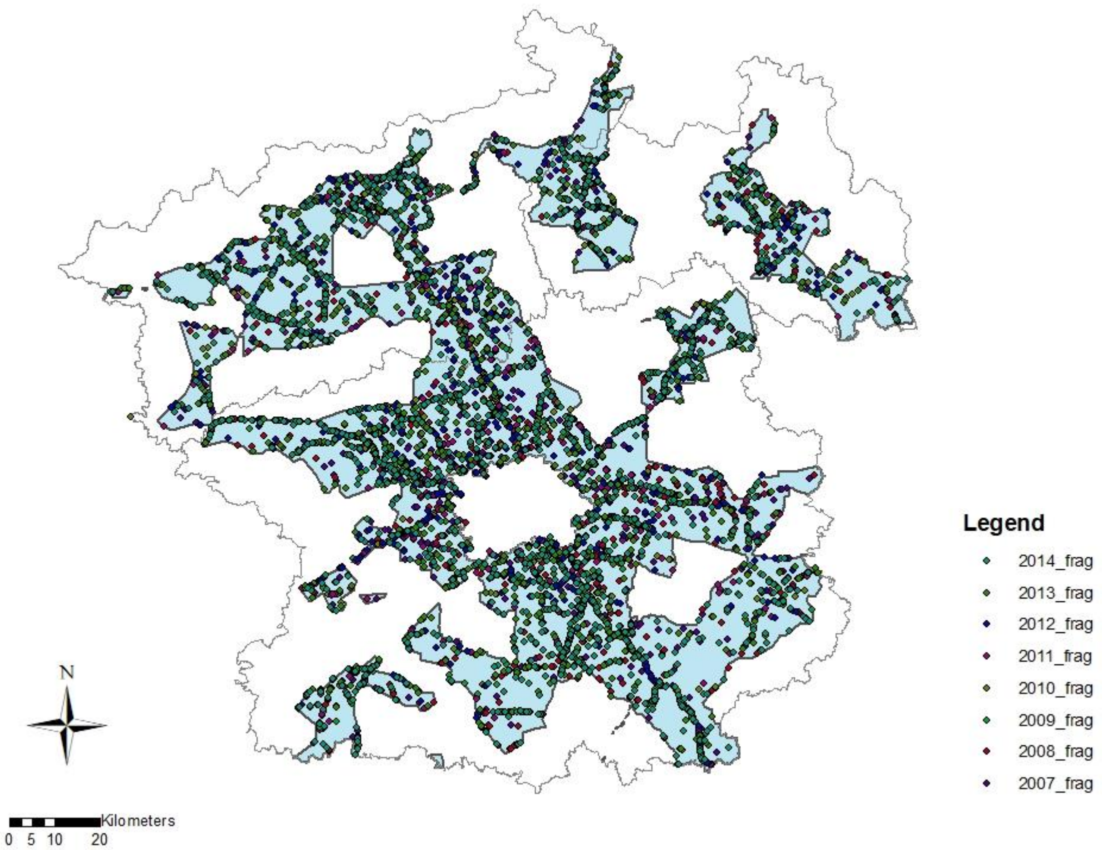

Figure 13. Distribution of the collisions in the fragmented area, for each of the years (2007-2014).

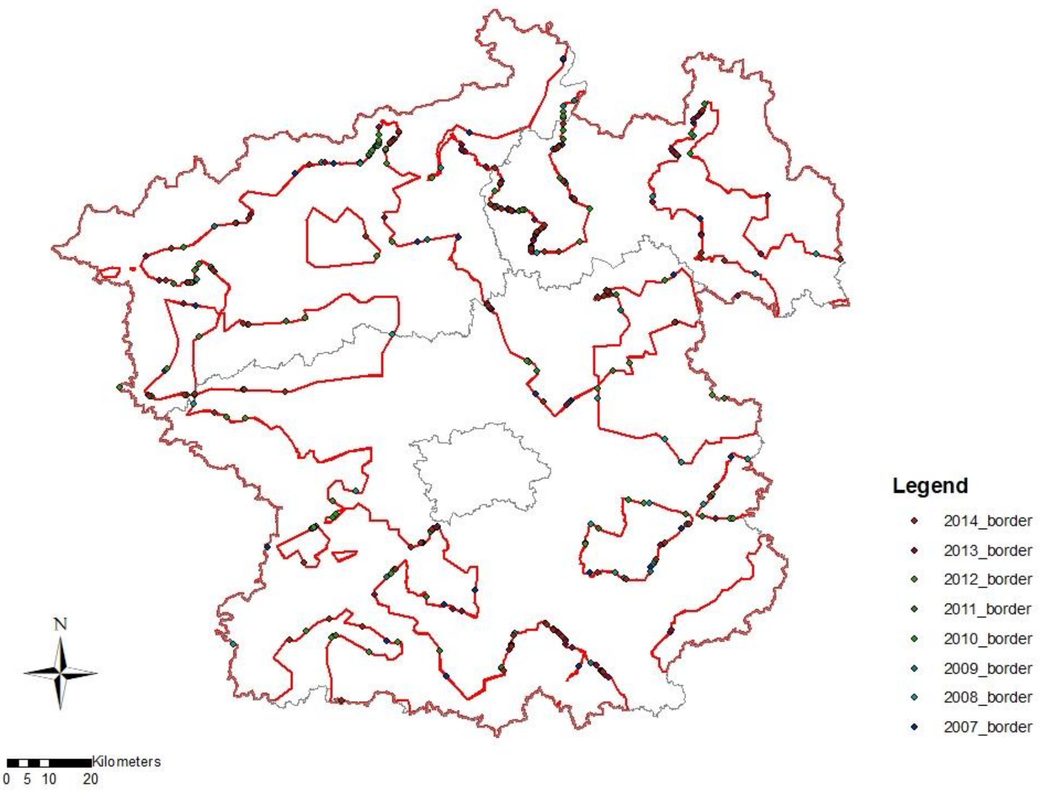

Figure 14. Distribution of the collisions in the border between UAT and fragmented area, for each of the years (2007-2014).

And in the following table you can visualize the number of collisions year by year, also sorted in UAT, fragmented area and border.

Table 2. Number of collisions in the period 2007-2014, sorted by level of fragmentation.

	COLLISIONS IN:			
YEAR	**UAT**	**Fragmented**	**Border**	**TOTAL**
2007	972	1505	88	2565
2008	901	1356	77	2334
2009	409	740	40	1189
2010	459	765	44	1268
2011	551	796	47	1394
2012	794	1171	89	2054
2013	940	1386	87	2413
2014	1114	1670	91	2875
TOTAL	6140	9389	563	**16092**

For a better visualization, this table is also showed as a graph:

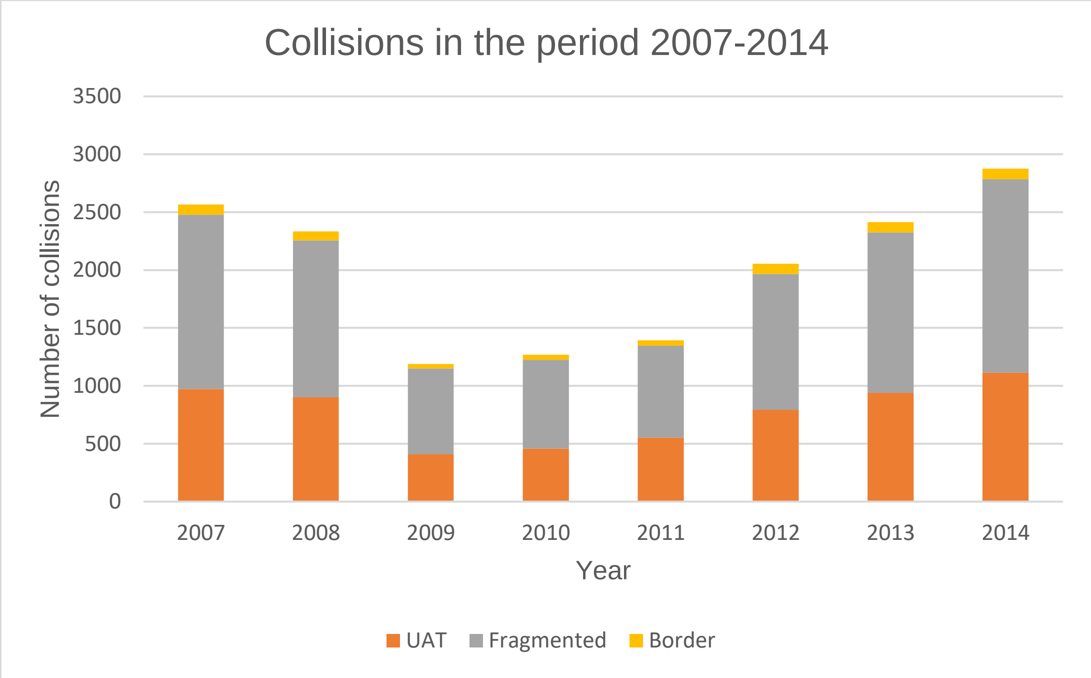

Figure 15. Number of collisions in the period 2007-2014 sorted by level of fragmentation.

As you can see, the total number of collisions was 16092, and most of them occurred in the fragmented area (9389 crashes). The collisions per year ranged from 1189 to 2875.

In the analysis of the collisions per square kilometer in fragmented and unfragmented areas by traffic the results were:

Table 3. Collisions per square kilometer in fragmented and unfragmented areas by traffic in the period 2007-2014.

	COLLISIONS/KM^2	
YEAR	**UAT**	**Fragmented**
2007	0,09	0,17
2008	0,08	0,15
2009	0,04	0,08
2010	0,04	0,09
2011	0,05	0,09
2012	0,07	0,13
2013	0,09	0,16
2014	0,10	0,19
Mean	0,07	0,13

The differences between the fragmented and the unfragmented zone were increased here, with an average of 0,13 collisions/km^2 in the first one, and 0,07 collisions/km^2 in the UAT.

In the study of the roads, then you can see the length of the different types of roads that were studied.

Table 4. Length of the different types of roads in the area of study.

Type or road	Length (km)
Motorway	431,93
Expressway	27,16
Primary	1443,48
Secondary	3638,18
Tertiary	6517,65
TOTAL	**12058,40**

From the total more than 12000 km of roads, 6517,65 km were third class roads, and there were only 27,16 km of expressways.

The length of the total roads (including all types of roads, even the minor ones) depending on the level of fragmentation of the area was higher on the UAT zone:

Table 5. Total length of roads sorted by level of fragmentation.

	Length of roads (km)
UAT	6802,79
Fragmented	5786,58
Border (+/- 20 m)	513,27

The collisions per kilometer in these three different zones were:

Table 6. Collisions per kilometer in the period 2007-2014, sorted by level of fragmentation.

	COLLISIONS/KM		
YEAR	**UAT**	**Fragmented**	**Border**
2007	0,14	0,26	0,17
2008	0,13	0,23	0,15
2009	0,06	0,13	0,08
2010	0,07	0,13	0,09
2011	0,08	0,14	0,09
2012	0,12	0,20	0,17
2013	0,14	0,24	0,17
2014	0,16	0,29	0,18
Mean	**0,11**	**0,20**	**0,14**

Again, in the fragmented took place most of the collisions (0,20 crashes per kilometer, on average), followed by the border (0,14) and the UAT (0,11).

It was obtained the following map with the polygons formed by the motorways, expressways, and first and second category roads. Third category roads are drawn in green.

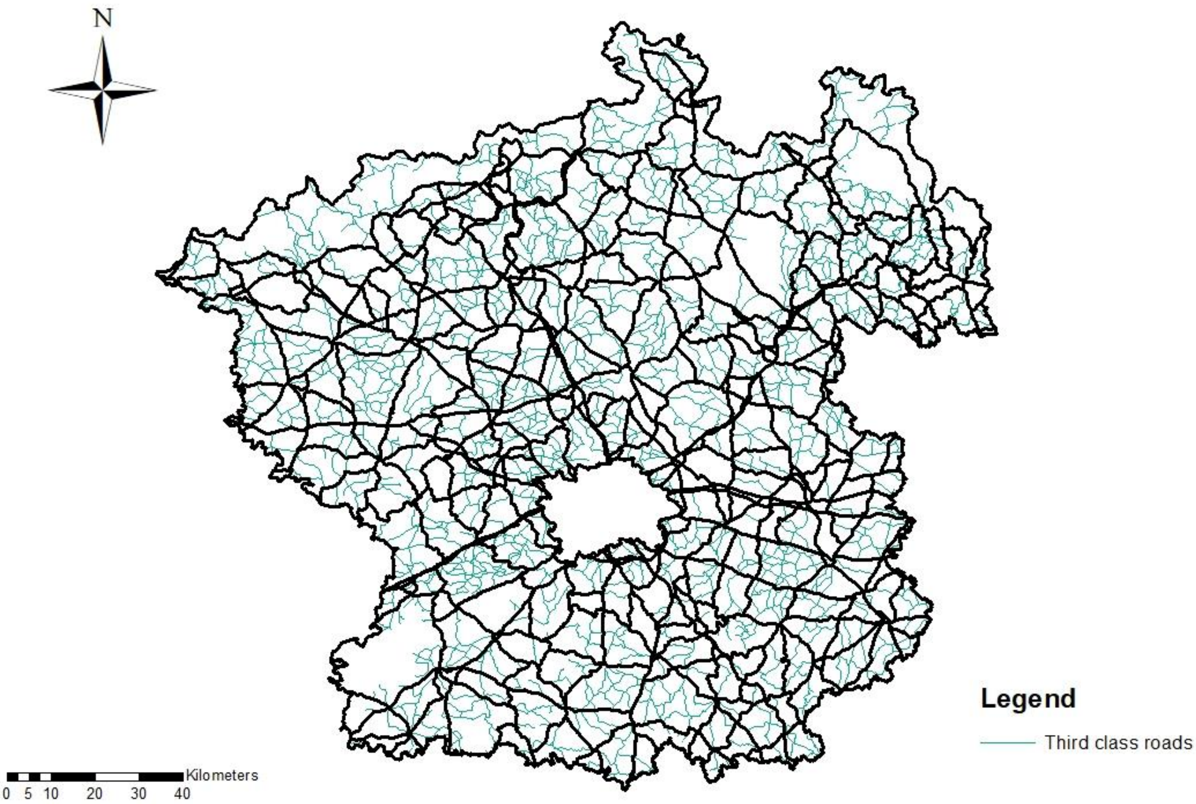

Figure 16. Polygons formed by the major roads. Also, third category roads in green.

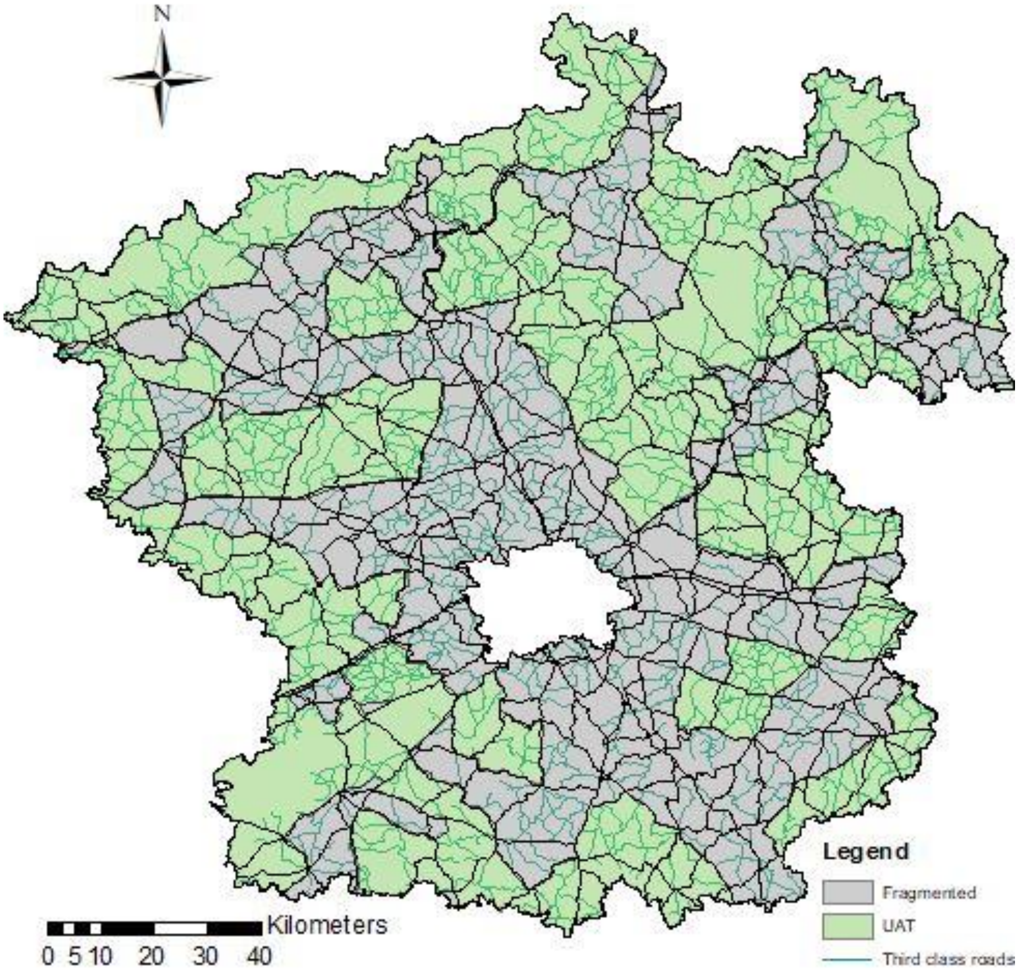

Figure 17. Polygons formed by the major roads, and the fragmented and unfragmented area by traffic. Also, third category roads in green.

In the next table you can observe the summary of the table with the information of each polygon (that is, if it was in unfragmented or fragmented area, its area, the length of the third category roads inside it, and the number of collisions in its core). The complete table is on the appendix 9.2.

Table 7. Summary of the information of the polygons formed by the major roads.

Polygons		Area of each polygon (km^2)		
Fragmented	**Unfragmented**	**Min**	**Max**	**Mean**
242	145	0,01	838,88	50,47
387				

Table 8. Second part of the summary of the information of the polygons formed by the major roads.

Length of 3rd class roads (km)			Number of collisions in each polygon		
Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
0,00	266,38	16,84	0	417	41,58

From the total 387 polygons, which had an average area of 50,47 km^2, 242 were in the fragmented zone and 145 in the unfragmented. The length of the third category roads inside them ranged from 0 to more than 260 km, with a mean of 16,84 km, and there were up to 417 collisions in one polygon, with an average of 41,58 collisions/polygon.

The summary of the calculation of the collisions/km and collisions/km^2, dividing the polygons between the fragmented and the unfragmented zone, led to the following results:

Table 9. Summary of the collisions/km in the fragmented and the unfragmented area by traffic.

Collisions/km		
Unfragmented		
Min	Max	Mean
0,05	207,36	6,92
Fragmented		
Min	Max	Mean
0,25	138,76	8,79

Table 10. Summary of the collisions/km^2 in the fragmented and the unfragmented area by traffic.

Collisions/km^2		
Unfragmented		
Min	Max	Mean
0,00	172,22	4,97
Fragmented		
Min	Max	Mean
0,09	50,24	2,29

You can observe that the collisions/km^2 have a wide range of values, especially in the unfragmented zone, reaching up to more than 170. The mean is also higher in the UAT. On the other hand, despite the fact that the maximum value of the collisions/km is also higher in the unfragmented area, the mean is greater in the fragmented one.

The covariance between fragmentation and collisions/km^2 was -0,6282, and between fragmentation and collisions/km: 0,4485.

6.- Discussion

These results are quite new, as the relationship between wildlife-vehicle collisions and landscape fragmentation, in spite of being pretty predictable, has not been studied widely, yet. However, some of my findings agree with other surveys that analysed the spatial patterns of WVCs.

6.1 Different methodology used to analyse fragmentation

I have chosen three regions of the same country, Czech Republic. This differs with the opinion of Walz & Schumacher (2005), who defend the importance of analysing landscape fragmentation using natural borders, not political ones. However, despite the fact that I agree with their belief, I only had access to the Police data of the Czech Republic, being impossible to procced in another way. Furthermore, it is very probable that my data does not reflect the real number of collisions, as underreporting is very common, and those crashes in which the Police is not involved in, are not reported. Nevertheless, according to Snow et al. (2015), the effect of underreporting is only relevant above 70%, and I consider that I am below this limit.

For the study of fragmentation, I used the unfragmented area by traffic (UAT), that is, the area of at least 100 km^2 that is limited by roads with an annual average traffic of 1000 vehicles/day or more. It has been used in other studies, such as the one from Kušta & Keken (2017) about railway ecology, or the one from Martolos et al. (2014), where they tried to optimize the measures to prevent collisions. I selected it because of its simplicity and clarity, and for how accessible it was.

However, effective mesh size would have been a good option, too. This tool was used, among others, by Girvetz et al. (2007) and Jaeger et al. (2007), as it is also very effective for transportation planning and as an environmental indicator. The difference is that, while effective mesh size just gives a value of fragmentation, unfragmented area by traffic divides the area of study in fragmented and unfragmented zones, what was more useful in my case.

6.2 Real effect of fragmented area on WVCs

First of all, in table 1 you can realize that the area of the unfragmented area by traffic is slightly higher (55,12%, with 10757,18 km^2) than the fragmented area (which represents 44,88% of my study area). It is lower than the value obtained by Anděl et al. (2005), who obtained 70% of UAT for the whole Czech Republic. That means that the regions I studied are, on average, more fragmented than the country in general. Indeed, they are at the level that was predicted by Anděl et al. (2010) for Czech Republic for 2040.

In spite of the fact that unfragmented areas occupy more than a half of the territory, this is still a high percentage of fragmented zones, what agrees with the conclusions of Keken et al. (2016), that revealed a very transformed landscape in Czech Republic because of the communist period, resulting in a reduce of the ecological migration potential. Some articles also pointed out the importance of the landscape in WVCs (Conard & Gipson 2006; Markolt et al. 2012; Colino Rabanal et al. 2012). According to them, the habitat surrounding roads is one of the main causes of the crashes with animals.

The fragmented zone, despite having a lower surface than the other two parts (UAT and the border between them), had the highest amount of collisions, as you can clearly see on the maps 12,13 and 14. This intuition is demonstrated by looking at the table 2. There you can observe that, in the period 2007-2014, 9389 collisions out of 16092 took place in the fragmented area, representing 58,38% of the total. In the UAT, that has a larger surface, only occurred 38,15% of the crashes with animals (6140). Finally, the remaining 563 collisions, that is, 3,5% of the total 16092, took place in the border of these two areas. On average, there were 2011,5 collisions per year.

You can see as well that the superiority of accidents in the fragmented zone is constant during all the years, but with variation of their proportion. In the following table you can observe the different percentages:

Table 11. Percentage of collisions in UAT, fragmented area and the border during the period 2007-2014.

	% COLLISIONS IN:		
YEAR	**UAT**	**Fragmented**	**Border**
2007	37,89	58,67	3,43
2008	38,60	58,10	3,30
2009	34,40	62,24	3,36
2010	36,20	60,33	3,47
2011	39,53	57,10	3,37
2012	38,66	57,01	4,33
2013	38,96	57,44	3,61
2014	38,75	58,09	3,17

The differences are very small among years, with an approximate maximum of 5% of variation (34,40% of accidents in UAT in 2009, 39,53% in 2011; and 57,01% in fragmented area in 2012 and 62,24% in 2009). In the border, the percentage is even more stable.

Going back to the global figures, the year with more accidents was 2014, with 2875 collisions, and the one with less 2009 (1189 crashes).

Also, in spite of the fact that from 2007 to 2008 there was a slight decrease, from 2009 to 2014 there was a continuous increase of the number of collisions, as you can clearly observe in the figure 15. This increment of the accidents over time has been a common conclusion in most of the studies in different parts of the world (Hothorn et al. 2015 in Germany; Sullivan 2011, Romin & Bissonette 1996 and Langley et al. 2006 in USA; Morelle et al. 2013 in Belgium; etcetera). The huge difference between 2008 and 2009 is explained by the fact that the conditions for Police reporting of crashes were changed during that period.

It could seem obvious that the number of collisions was going to be greater in the fragmented parts of the landscape, because there the traffic and density of roads is, by definition, higher. However, if you look at the collisions per kilometer (table 6), their number keeps higher in the fragmented area, which is a very revealing result. This means that, in the most fragmented zones, in addition to increasing the overall probability of a collision because of having a greater number of places where it can occur, the likelihood of an accident also increases proportionally. So, by each 100 kilometers of roads in fragmented areas, there are, on average, 9 more accidents per year than in unfragmented areas (20 versus 11, that is, almost double). There are also more collisions in the border than in the UAT, with 14 collisions by each 100 kilometers.

Jaeger et al. (2005) revealed the importance of the configuration of road network. Thus, while one configuration could cause the extinction of the population, another one with the same road length might not have any effect on the population.

Their results agree with mine, as for them the best configuration was the one with the lowest number of roads, that is, with the less fragmented landscape. They concluded that it was better to have all the traffic in one road (or in several clustered roads), than having many roads with low traffic distributed throughout the landscape. This is coherent with my findings that showed that fragmentation increased the number of collisions per kilometer.

Many other authors stressed the importance of road traffic in the probability of occurrence of a WVC. Niemi et al. (2017) in Finland, Joyce & Mahoney (2001) in Canada and Danks & Porter (2010) in Western Maine, USA, found a positive relationship between moose-vehicle collisions and traffic volume. Indeed, in this last study, traffic volume was two times higher in average in collision points than in random ones. However, some other surveys found a negative correlation between traffic and WVCs (Kušta et al. 2017; Thurfjell et al. 2015). That might be explained because animals avoid crossing a road when the traffic is intense, as they perceive it as risky. According to their findings, most accidents occur at intermediate traffic levels.

In table 4 you can observe that, from the total 12058,40 kilometers that have the analysed roads, more than a half (6517,65 km) correspond to third class roads. They are followed by secondary roads (3638,18 km), primary (1443,48 km), motorways (431,93 km) and, finally, expressways, with only 27,16 km.

Some authors concluded that most collisions occurred at highways and major roads, like Morelle et al. (2013), that found out that more than a half of the crashes in Belgium were on this kind of roads, despite being less than 15% of the road network. In Sweden, the results of Neumann et al. (2012) do not differ much from this, as 64% of the accidents were in major roads (that represent less than 30% of the total length of the roads).

Surprisingly, by surveying the length of all the roads of my study -table 5- (even the minor ones that were not mentioned above) depending on the level of fragmentation, the roads situated in the UAT had a higher length (6802,79 km) that the ones placed in fragmented areas (5786,58 km). But their number is very similar, and this can be explained because UAT had a greater extent in my study. Indeed, by calculating the kilometers of roads per square kilometer in both zones, the fragmented area had a relative higher value of roads than the unfragmented one (0,66 km/km^2 versus 0,63 km/km^2).

Finally, in the border there were 513,27 kilometers of roads.

Analysing now the accidents per square kilometer (table 3), the differences are the expected, considering that the UAT had a greater surface and a fewer amount of collisions. So, by each square kilometer, there were almost twice as many accidents in the fragmented zone (0,13 collisions/km^2) than in the unfragmented one (0,07).

After dividing the landscape in polygons, whose limits were defined by motorways, expressways, and first and second-class roads, you can see in tables 7 and 8 that, from the total 387 polygons in my area of study, 242 were in the fragmented zone, while the other 145 were in UAT. This is a quite high number of polygons, what means a very fragmented landscape. However, according to the results of Jaeger et al. (2005), this could be good for population persistence (in the sense of migration potential, of course not for the WVCs, as we saw that the fragmentation increases the number of collisions). They surprisingly concluded that, for animals that do not strongly avoid roads, it was better to have a fragmented landscape, with many patches in a gridded pattern, that having a few large patches. Nevertheless, van Strien & Grêt-Regamey (2016) obtained different results, as for them there was a negative correlation between the number of patches and the habitat connectivity, what is more coherent. Similarly, Ceia-Hasse et al. (2018) reflected the important effect of high road densities in reducing populations, by producing population isolation, besides the deaths in the roads. In my regions, the fragmentation showed high values, and corresponded with a much higher number of WVCs; this adds to the obstacles that fragmentation supposes in the way of the animals. A larger number of roads means that, either the animals have to stop their migration with the drastic consequences that this might have, or they try to cross the road, risking their life. The results of Jaeger et al. (2005) were only for animals that do not avoid roads, so roads are not a barrier for them. However, they are more likely to die because of a collision.

The area of the polygons varied from 0,01 to almost 900 km^2, and, despite the fact that some of them had no third category roads inside, other had up to 266 km of this type of roads. The average of their length in the core of the polygons was 16,84 km. Something similar happened with the collisions, that ranged from 0 to 417 accidents in a single polygon, with a mean of 42.

By last, after calculating the collisions/km in each polygon, separating those in fragmented area from those in UAT (table 9), again the fragmented area had a higher mean (8,79) than the unfragmented (6,92), although the UAT had a greater maximum value (207,36 versus 138,76). However, surprisingly, in the analysis of the collisions/km^2 in the polygons (table 10), the average was higher in the UAT (4,97 versus 2,29).

These results were supported by the values of the covariance between fragmentation and collisions/km (0,4485, that is, a positive relationship) and the covariance between fragmentation and collisions/km^2 (-0,6282, a negative relationship, that means that the fragmented polygons had less collisions per square kilometer, on average, than the UAT ones).

The conclusion of this surprising result is that there is a clustering of collisions in some unfragmented zones, while the crashes in the fragmented zone are more widespread. This is the only possible explanation of why the global values of collisions per square kilometer were almost double in the fragmented zone (0,13 versus 0,07 in UAT) but, after dividing the area of study in polygons, the value is higher in UAT. This means that some polygons of the unfragmented area by traffic have very high values (as you can check in the appendix 9.2 and in table 10, where the maximum of collisions/km^2 is 172,33, more than triple than in the fragmented polygons), increasing the average of UAT. So, it is very important to pay attention to these polygons in UAT, where many collisions take place.

6.3 Possible measures to mitigate collisions

There are many possible efforts to try to solve this enormous problem. Some of them were proven ineffective, like warning reflectors (Ujvári et al. 2016; Benten et al. 2018 and Brieger et al. 2016), but many other appeared to have a great impact in the reduction of WVCs. They are often based on preventing animals from crossing the road, like odor repellents (which showed a 37% decrease of crashes in the study of Kušta et al. (2015)) or fencing (80% of diminution in the research of Clevenger et al. (2001)). But there are other measures focused on drivers, as some authors like Neumann et al. (2012) think that is the best solution. These can be, for example, temporary warning signs on the roads (Sullivan et al. 2004) or Roadside Animal Detection Systems (Grace et al. 2017).

From my point of view, the first step to prevent wildlife-vehicle collisions should be a sustainable land planning. We have to satisfy our needs, but we have to think and act globally and, first of all, reflect about the convenience and need to build a new road. We should not forget the barrier effect that it might cause to animals, and the important that is for them to displace. Also, it is essential to keep in mind the causes and drastic consequences of WVCs. If there is no other solution than building a road, then the previous mitigation measures should be carried out. It would be important as well to pay attention to those zones with clustering of collisions, especially those in UAT that were found out in this analysis, but also in the fragmented area.

Anděl et al. (2005) remarked the idea of considering UAT polygons before planning the construction of a road, too. They advise to, firstly, update the fragmentation maps with the last information of traffic volume. Then to try to rout roads outside this unfragmented areas by traffic, and if this is not possible, to take into account the number of polygons affected, the reduction of area in each one and if the road divides the polygon into two new ones or it removes it (for example, by dividing it in two polygons smaller than 100 km^2). They also suggest calculating the overall reduction of territory inside UAT. Another document to follow instructions of land planning is the one of Anděl et al. (2006), where they assess the permeability of the territory, proposing guidelines to make routes with the least environmental impact.

Similarly, van Strien & Grêt-Regamey (2016) called attention to the importance of upgrading existing roads, instead of building new ones, that would entail to an increase of the fragmentation of the landscape, with the consequent rise of WVCs.

Finally, the construction of migration passages to allow the free movement of wildlife was thoroughly analysed by Hlaváč & Anděl (2001). They proposed to divide the landscape in areas according to the species that host and the periodicity of their presence: areas of exceptional importance (in which they recommended the minimum possible of new constructions), areas of increased importance, areas of medium importance, areas of low importance and unimportant areas.

6.4 Suggestions for further research

To execute a sustainable and worthy land planning, the most important thing is to have as much knowledge as possible. WVCs are such a relevant issue, that any little mistake could have huge consequences, both economic and material. To prevent this, and to proceed in the most optimal way, much more research should be done. The investigation is the most decisive measure that could be carried out and, probably, the cheapest one.

Future research could focus on a deeper analysis of the relationship between fragmentation and collisions. An exploration and monitoring of the unfragmented zones where I saw a concentration of crashes, studying their causes and trying to mitigate them, would be a very effective solution to decrease the number of WVCs. Examining separately the species might also lead to better conclusions, as each category of animals behaves differently; the analysis of the best configuration of the road network to avoid collisions could influence land planners as well, or the investigation of the differences on the patterns in the distinct types of land cover. Finally, a larger area of study, considering natural borders and not frontiers would give a more global and complete vision of the issue.

7.- Conclusions

After analysing wildlife-vehicle collisions in Czech Republic, and their relationship with landscape fragmentation I can conclude that, as anticipated, there was an increasing number of collisions between 2009 and 2014. By dividing the area of study in three zones: unfragmented area by traffic (UAT), fragmented area and border between them, I found a connection between WVCs and fragmentation. This was demonstrated by the fact that the total number of collisions was higher in the fragmented areas than in the UAT, but this also happened with the collisions per square kilometer and per kilometer. Indeed, in this last analysis I found out that, by each 100 kilometers of roads in the fragmented area, there were 9 more accidents on average than in the unfragmented area by traffic.

Besides, the results showed a clustering of crashes in some UAT, that was reflected by the higher mean of collisions/km^2 that the polygons of the unfragmented zone obtained, despite having a lower total value this zone than the fragmented one.

These results should be taken into account in land planning, before building new roads in unfragmented areas, considering the consequences that a fragmented landscape can have in wildlife displacements and in WVCs.

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List of tables

List of figures

9.- Appendices

9.1 Appendix 1: map with the numbered polygons.

Here I will show you the map with the polygons and its corresponding number, and the complete table with the number of the polygon, if it is fragmented or not, its area, length of third category roads and number of collisions inside it.

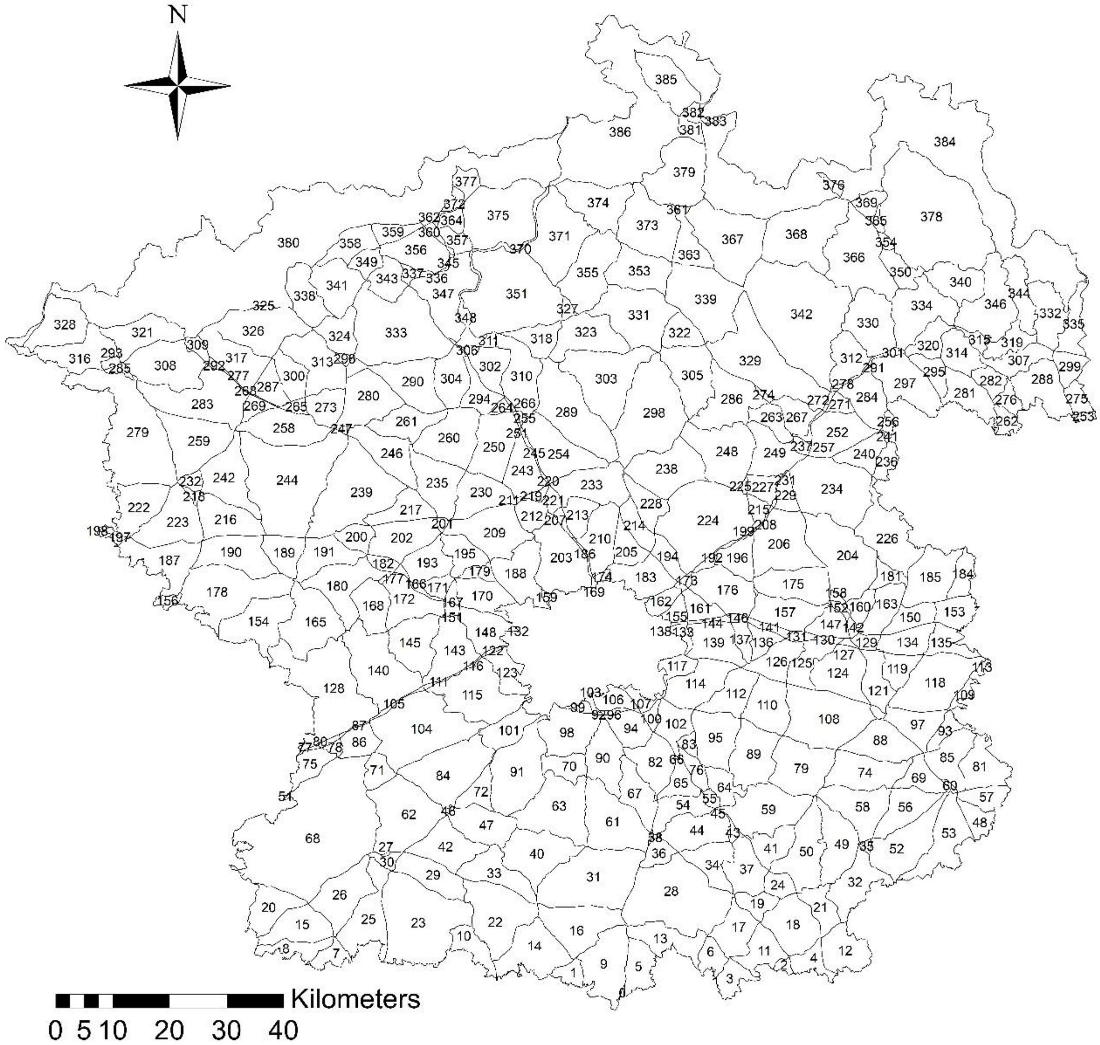

Figure appendix 9.1 Polygons made by motorways, expressways and first and second-class roads with their corresponding number.

9.2 Appendix 2: Complete table with the information of the polygons.

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
0	0	0,92	0,39	1
1	0	17,35	5,11	4
2	0	6,25	0,08	4
3	0	26,46	10,01	2
4	1	25,83	5,87	24
5	0	40,00	11,01	42
6	0	23,22	0,00	0
7	1	20,16	6,59	4
8	0	29,29	4,20	5
9	0	83,68	32,80	30
10	0	32,80	4,64	4
11	0	41,06	8,14	13
12	1	54,00	27,00	45
13	0	53,14	8,07	16
14	0	81,72	22,72	26
15	0	57,87	8,86	7
16	1	83,78	23,82	49
17	0	49,20	11,83	9
18	1	71,95	23,86	59
19	1	23,60	6,27	20
20	0	49,01	2,62	15
21	1	34,23	7,65	41
22	0	106,25	36,83	66
23	0	177,71	65,55	80
24	1	19,75	5,24	29
25	1	76,11	29,40	97
26	1	74,66	31,81	67
27	1	0,66	0,00	8
28	0	179,70	77,88	100
29	1	54,24	12,84	58
30	1	10,02	1,10	19
31	1	150,80	75,17	83
32	0	61,03	20,18	15
33	0	57,06	14,95	61
34	1	45,62	8,17	24
35	0	3,36	0,00	3
36	1	20,46	4,89	30
37	1	51,53	11,41	23
38	1	1,60	0,26	3

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
39	1	0,25	0,00	1
40	1	86,13	19,77	28
41	1	37,33	6,40	40
42	0	65,52	23,80	115
43	1	5,85	0,00	26
44	1	62,74	19,94	55
45	1	0,26	0,00	4
46	1	1,82	0,00	4
47	1	59,87	6,00	36
48	0	24,74	8,53	6
49	1	68,55	24,34	10
50	1	79,31	20,88	28
51	0	0,23	0,13	1
52	1	85,28	32,29	14
53	0	74,06	32,03	16
54	1	37,46	6,61	62
55	1	7,17	0,00	29
56	1	54,47	16,77	18
57	0	27,52	9,15	8
58	1	71,92	20,65	27
59	1	93,90	33,11	57
60	1	2,62	0,00	1
61	1	98,27	37,35	62
62	0	117,62	44,18	148
63	0	106,14	27,28	88
64	1	27,68	2,83	26
65	1	26,00	6,88	63
66	1	0,39	0,00	6
67	1	47,58	1,33	97
68	0	386,96	70,42	119
69	1	32,91	10,00	20
70	1	29,61	0,00	22
71	0	24,02	0,00	9
72	1	27,83	4,18	40
73	0	0,35	0,00	4
74	1	71,34	30,10	25
75	0	29,01	10,44	26
76	1	18,17	3,20	33
77	0	1,36	0,63	2
78	1	5,95	3,34	18
79	0	85,46	52,74	9

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
80	1	3,49	0,00	15
81	0	53,03	22,95	15
82	1	55,15	7,50	116
83	1	9,78	0,00	15
84	0	113,51	9,58	130
85	1	52,99	9,18	31
86	1	30,45	16,01	18
87	0	0,89	0,22	45
88	1	62,50	23,45	42
89	0	74,85	19,75	31
90	1	59,80	12,45	61
91	1	110,32	35,82	146
92	1	0,63	0,00	1
93	1	18,92	0,00	13
94	1	37,34	17,48	68
95	1	67,54	33,50	30
96	0	3,72	0,70	17
97	1	46,66	10,51	37
98	1	70,01	31,73	83
99	1	6,05	3,03	7
100	1	9,19	0,00	14
101	1	40,48	13,05	79
102	1	38,18	14,09	78
103	1	3,15	0,79	9
104	0	154,27	128,41	136
105	1	4,60	0,84	13
106	1	22,74	11,65	47
107	1	12,62	6,82	28
108	0	125,63	91,76	29
109	0	10,40	4,30	3
110	1	61,30	20,56	23
111	0	2,68	0,55	57
112	1	48,79	21,53	85
113	0	3,43	1,50	5
114	1	66,05	30,90	86
115	1	104,04	61,86	85
116	1	1,31	0,00	16
117	1	21,07	8,75	42
118	0	104,55	50,23	77
119	1	29,15	4,89	34
120	0	0,32	0,00	3

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
121	1	39,72	0,00	52
122	1	2,26	1,16	2
123	1	33,34	14,44	29
124	1	70,50	26,24	43
125	1	36,88	3,48	12
126	1	41,99	5,77	28
127	1	2,88	0,73	7
128	0	175,89	68,29	42
129	1	11,27	2,23	12
130	1	6,85	0,64	16
131	1	4,56	0,00	15
132	0	0,02	0,00	1
133	1	9,35	2,11	8
134	1	38,47	7,64	13
135	0	30,70	12,84	19
136	1	20,45	0,00	18
137	1	16,76	0,00	8
138	1	1,34	0,39	4
139	1	56,56	9,64	54
140	0	115,99	40,18	88
141	1	9,24	0,00	40
142	1	4,66	0,00	2
143	1	67,22	13,78	70
144	1	4,88	1,03	9
145	0	68,18	24,60	42
146	1	4,28	0,00	5
147	1	27,95	0,00	12
148	1	48,54	22,32	93
149	1	1,16	0,00	4
150	1	31,04	0,00	17
151	1	5,75	0,00	11
152	1	4,57	0,00	8
153	1	33,57	12,17	3
154	0	81,22	26,54	12
155	1	13,98	4,89	36
156	0	8,10	0,31	1
157	1	57,64	11,12	37
158	0	3,46	0,82	1
159	1	2,55	0,00	10
160	0	19,35	0,00	2
161	0	23,53	0,00	29

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
162	1	18,50	9,09	26
163	0	42,04	4,94	19
164	1	2,10	0,00	9
165	0	92,07	22,07	21
166	1	5,02	1,83	26
167	1	6,74	0,17	24
168	1	47,30	0,00	11
169	1	1,34	0,00	9
170	1	48,64	27,26	40
171	1	15,38	4,54	29
172	1	55,74	22,98	93
173	1	3,64	0,00	8
174	1	3,45	0,00	4
175	0	68,11	25,03	18
176	1	69,07	0,00	42
177	1	2,69	0,97	18
178	0	127,90	34,15	39
179	1	12,49	4,76	18
180	1	75,01	10,24	69
181	0	17,68	0,00	3
182	1	11,47	0,00	35
183	1	54,69	32,64	50
184	0	24,96	8,42	1
185	0	72,63	26,41	29
186	1	2,93	0,73	22
187	0	73,32	13,98	70
188	1	68,61	43,32	88
189	1	39,12	11,07	22
190	1	72,65	23,07	26
191	1	52,47	14,07	66
192	1	8,50	2,71	73
193	1	44,63	23,81	71
194	1	23,45	0,00	40
195	1	36,48	14,92	55
196	1	35,38	5,96	14
197	0	4,89	0,00	32
198	0	0,01	0,00	1
199	0	0,44	0,00	2
200	1	24,28	5,78	27
201	1	3,81	0,00	4
202	1	66,17	16,61	65

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
203	1	92,46	45,22	84
204	0	119,95	48,08	37
205	1	29,91	12,85	52
206	0	97,12	24,68	95
207	1	6,16	0,74	28
208	0	1,90	0,44	65
209	1	84,83	49,66	67
210	1	57,98	30,29	70
211	1	1,35	0,00	6
212	1	25,68	5,60	19
213	1	28,63	11,44	34
214	1	27,34	0,00	34
215	1	13,50	0,00	18
216	0	61,24	18,26	65
217	0	41,55	14,85	48
218	1	4,37	0,00	9
219	1	5,97	0,00	9
220	0	0,03	0,00	2
221	1	9,47	2,55	19
222	0	64,56	23,41	49
223	1	78,41	22,13	77
224	0	175,83	67,41	167
225	0	2,81	0,00	8
226	0	87,37	47,53	42
227	1	21,73	0,00	10
228	1	35,00	0,00	42
229	1	18,90	4,01	19
230	1	57,16	37,05	27
231	1	1,97	0,85	99
232	1	10,53	4,36	13
233	1	70,09	25,58	42
234	0	133,17	60,12	89
235	0	68,56	44,15	33
236	0	18,52	9,80	9
237	1	7,05	0,00	5
238	0	89,80	30,91	83
239	0	157,73	48,48	83
240	0	34,57	10,17	28
241	0	1,77	0,00	2
242	0	75,13	25,82	29
243	1	49,46	22,52	38

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
244	0	218,51	126,19	116
245	1	5,07	0,49	32
246	0	61,76	11,87	53
247	1	2,60	0,00	4
248	0	98,67	38,17	38
249	0	57,03	21,92	57
250	1	74,07	21,31	24
251	1	1,68	0,00	9
252	1	64,90	32,45	117
253	0	4,78	0,85	3
254	1	83,22	39,52	72
255	1	2,59	0,00	17
256	1	6,45	0,00	3
257	1	5,20	2,04	37
258	1	72,59	31,90	70
259	1	89,61	37,41	32
260	0	82,92	23,14	35
261	0	49,48	13,74	13
262	1	15,82	4,24	14
263	0	27,57	2,26	38
264	1	6,26	0,00	20
265	1	8,49	2,61	12
266	1	1,63	0,00	16
267	1	31,87	15,40	42
268	0	0,73	0,00	3
269	1	14,08	4,34	38
270	0	0,12	0,00	1
271	1	11,75	0,00	20
272	1	2,53	0,00	35
273	1	35,89	5,78	35
274	0	3,13	1,48	16
275	1	17,94	7,30	15
276	1	16,03	0,00	2
277	0	0,60	0,00	6
278	0	3,24	0,00	34
279	0	195,04	110,01	67
280	1	74,91	27,75	35
281	0	49,42	25,71	18
282	1	21,76	0,00	15
283	0	113,56	29,83	60
284	1	52,67	12,59	25

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
285	0	6,16	0,00	19
286	0	81,23	28,74	107
287	1	28,96	0,00	12
288	1	67,87	25,46	15
289	1	125,67	62,37	132
290	1	80,40	31,97	83
291	0	1,46	0,00	11
292	0	3,80	0,00	20
293	0	5,08	0,00	16
294	1	31,60	8,50	38
295	0	24,73	8,11	36
296	1	4,09	0,00	15
297	0	77,44	44,08	50
298	0	157,09	79,58	86
299	1	24,50	0,00	28
300	1	33,84	4,07	14
301	1	4,42	2,71	42
302	1	39,24	15,29	43
303	0	122,13	37,43	91
304	1	50,50	25,00	42
305	0	78,08	25,11	19
306	1	3,90	0,00	8
307	1	37,94	0,00	13
308	1	89,49	2,56	124
309	1	10,98	2,36	37
310	1	70,29	18,90	105
311	0	5,63	0,00	3
312	0	44,94	18,50	16
313	1	74,50	20,86	70
314	1	41,03	11,76	47
315	0	10,56	0,00	6
316	0	67,86	27,02	24
317	1	64,80	4,62	73
318	1	35,25	7,07	28
319	1	29,42	3,75	15
320	1	31,00	15,02	29
321	0	60,02	14,17	58
322	1	31,93	3,95	57
323	0	71,45	13,07	23
324	1	39,70	16,36	48
325	0	0,29	0,00	24

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
326	1	93,38	17,69	120
327	0	6,62	0,00	11
328	0	67,69	30,70	24
329	0	162,03	25,88	127
330	0	78,14	45,19	69
331	0	107,42	35,53	165
332	0	55,52	18,30	1
333	0	175,20	91,28	96
334	1	85,57	46,81	108
335	0	36,45	11,82	29
336	0	0,18	0,00	1
337	1	9,69	1,05	49
338	1	50,88	9,49	62
339	1	122,95	21,55	161
340	1	52,91	34,92	32
341	1	62,87	10,53	54
342	0	259,05	61,35	99
343	1	35,91	13,52	44
344	0	43,13	11,96	13
345	0	1,46	0,00	12
346	0	91,53	63,85	39
347	1	89,06	32,38	104
348	1	20,98	0,00	39
349	1	20,32	4,56	24
350	1	28,36	12,29	61
351	0	195,45	115,12	164
352	0	1,15	0,00	10
353	1	65,86	19,79	98
354	1	5,15	1,10	4
355	0	90,19	38,17	48
356	1	59,20	20,93	116
357	1	16,85	3,39	73
358	1	37,95	12,23	136
359	1	21,11	8,39	33
360	1	5,35	0,00	63
361	0	0,02	0,00	1
362	1	2,49	0,00	58
363	1	39,35	9,32	114
364	1	14,32	0,00	51
365	1	6,14	2,15	9
366	1	124,18	49,76	130

Number of polygon	Fragmented (1) vs Unfragmented (0)	Total area (km^2)	Length of 3rd class roads (km)	Number of collisions inside the polygon
367	0	124,84	56,06	172
368	0	127,04	36,66	127
369	1	17,89	0,24	12
370	1	11,42	0,38	38
371	0	111,13	30,57	39
372	1	8,69	0,00	19
373	1	97,31	42,77	142
374	1	76,36	31,03	88
375	0	130,99	63,88	96
376	0	5,75	0,58	10
377	1	18,23	0,00	36
378	0	300,65	84,35	102
379	1	99,87	32,96	112
380	0	838,88	266,38	327
381	1	14,14	0,00	15
382	1	8,27	0,00	7
383	1	4,35	0,00	32
384	0	624,49	187,12	417
385	0	65,43	23,58	33
386	0	383,78	136,72	143
TOTAL		**19530**	**6516**	**16093**