HUMAN-WILDLIFE CONFLICT AND ROAD COLLISIONS WITH UNGULATES. A RISK ANALYSIS AND DESIGN SOLUTIONS IN TRENTINO, ITALY

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ABSTRACT:

This study investigates wildlife vehicle collisions with wild ungulates in the Italian Autonomous Province of Trento (PAT) located in the Eastern Italian Alps with a consistent anthropic population and pervasive summer and winter tourism. Both the populations of wild ungulates and vehicular traffic are increasing as well as road collisions leading to animals killed, vehicles damaged and human injuries and fatalities. The purpose of this work was to use FOSS4G to identify the road sections with a high number of collisions and then propose and design practical engineering solutions tailored to each of these hotspots. QGIS 3.16.6, GRASS 7.8.5 and GRASS 8.2 were used to standardize the data set, process georeferenced road collision with ungulates registered by local authorities, perform the hotspot analysis and the final maps. Field surveys were carried out to investigate the local morphology at each hotspot and once the more appropriate practical solutions were chosen, a specific detailed project was proposed including its costs. A cost benefit analysis comparing the cost of the infrastructures with the cost of roadkills shows that the infrastructures are effective in reducing the costs in the medium-long term. The construction of the five proposed infrastructures would reduce deer investments by 6% (about 250 collisions avoided in five years). Such solutions should be more numerous and widely distributed in order to have a greater impact. This FOSS4G procedure can be replicated elsewhere to plan the position of crossing structures, and for application to EU funds, thus mitigating Human-wildlife conflicts (HWC).

1. INTRODUCTION

Among the human-wildlife conflicts (HWC), wildlife vehicle collisions is one of the most evident to the general public. Human-wildlife conflicts can be defined as the breaking of a relationship of coexistence which occurs when the interaction between human and wild animals leads to undesirable consequences both for people and their resources, and/or wildlife and their habitats. The scientific approach to coexistence is challenging because it is fundamentally multidimensional and includes complex interactions and feedbacks. (König et al., 2021). Hill (2021) proposed that conflict should not always be viewed negatively and as something to be avoided, but should also be taken into account as a part of the experience of multi-species coexistence and as a force for change, facilitating long-term cohabitation and even sometimes peaceful coexistence between humans and wildlife. Nevertheless, conflict is source of tensions and of reactions that may lead to the reduction of biodiversity and loss of species. Our understanding of ecological network suggests that, among other issues, the loss of biodiversity may reduce the capability of ecosystems to survive to climate change (Newell et al., 2022).

Among the causes of HWC are land use change, particularly urbanization, with the construction of infrastructures that disrupt natural habitats, but also conversion of forests to agriculture and pastures, which results in crop damage and livestock predation, and increased human presence in wilderness areas for sport and recreation (Corradini et al., 2021a, 2021b). This problem is globally widespread (McGuire et al., 2021), both in those countries where the Land Use Change already occurred in historical times as well as where the land use change is ongoing at a dramatic pace (Delgado et al., 2018). In the last decades, in Europe there was actually a recover of large mammal populations, due to both the legal protection and afforestation caused by the abandonment of traditional agriculture (Chapron et al., 2014). However, the poor connectivity between ecosystems may limit dramatically the recovery of some populations (Bluhm et al., 2023). The increased number of large mammals lead to an increased human wildlife interaction, including roadkill and car accidents.

Roads can represent a major constraint since they condition animal movement (Basille et al., 2013), potentially limiting functional connectivity at multiple ecological scales and a recent study with GPS-tracked animals, showed that when road crossings occurred, they were more likely to occur in more forested areas (Passoni et al., 2021).

High mortality during crossing attempts would in the long term select for road avoidance, reducing the number of individuals killed on roads but leading to genetically partitioned subpopulations, a lack of gene flow and menacing the long term survival of the populations (Shepard et al., 2008).

According to many studies, the spatial and temporal drivers of roadkill rates appear to be taxon specific, thus encouraging the prioritization of the assessment of the efficacy of mitigation measures when they are present (Ascensão, 2021). According to some authors, a certain level of co-adaptation will be crucial in the long term (Carter and Linnell, 2016) but the present situation is definitely worrisome.

To provide an order of magnitude in Europe: every year around 223 million of animals are roadkilled (194 million birds and 29 million mammals), around 300 humans lose their life and around

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30,000 people are injured, plus around 1 billion Euros in material damages (Grilo et al., 2020).
This study investigates wildlife vehicle collisions in the territory of the Italian Autonomous Province of Trento (PAT) 541,692 inhabitants, extending for 6,207 km2, a mountainous area interested by a significant summer and winter tourist presence. The province is located in the Eastern Italian Alps, around 60% of its territory is covered by forest ranging from Mediterranean to Alpine environment and hosts a large floristic and faunistic biodiversity including two Natural Parks, a national park and a series of protected areas in Natura 2000 (Tattoni et al., 2021a). Different species of mammals are present, among them various species of Ungulates (deer, roe deer, wildboar) and large carnivores including the Eurasian brown bear and wolf (Tattoni et al., 2021b). The ungulates are targeted by hunting activity that is carefully programmed and monitored by local hunting association and PAT bureaus. Despite the high percentage of forest cover the area is crossed by a dense road network that includes highways, heavy and medium traffic roads and forest tracks.
This work focuses on the two most common species involved in road accidents in the area, Roe deer (*Capreolus capreolus*) and Red deer (*Cervus elaphus*). In the last 10 years an average of 700 annual collisions with these ungulates were registered, the animals are often killed and the vehicles are heavily damaged leading to injuries and occasionally to human fatalities. A solution of the problem is becoming urgent in a highly anthropic environment like the Alpine one.
Different measures can be adopted to reduce the risks of collisions, e.g. underpasses, overpasses, viaducts and fly-overs, fences, animal detection systems, warning signs, nets, or also a combination of the former (van der Ree et al., 2015). The spatial positioning of these engineering solutions along the roads, as well as the integration of each intervention in the specific local terrain morphology adapting it to the animal behaviour are crucial to obtain effective results.
The main purpose of this work was to use FOSS4G to identify the road sections with a high number of collisions and then propose and design practical engineering solutions tailored to these hotspots. Field surveys were carried out to investigate the local morphology at each hotspot. Finally, the practical solutions that were more appropriate to each specific situation were chosen and when a specific project is proposed it included the costs to realize it.

2. MATERIALS AND METHODS

Initially the work focused on the spatial and statistical distribution of roads collisions with ungulates to determine their trends in space and time. The road sections characterized by a greater number of accidents were identified by combining GIS analysis and a detailed study of the morphology, land cover and other boundary conditions.
QGIS 3.16.6 (QGIS Development Team, 2022) was used to import data and standardize the data set, as well as to process data and produce heat maps, part of the analysis and most of the final maps. GRASS 7.8.5 and GRASS 8.2 (GRASS Development Team, 2022) were used to perform data integrity check fixing data errors, resample or recombine data from different sources and convert data from vector to raster or vice versa when necessary.
Different environmental covariates such as forest coverage, ecological corridors, roads and infrastructures were collected from the PAT service while others (e.g. contours and slope) were created starting from the Digital Terrain Model (DTM). Data about ungulates collisions were provided by the Wildlife Service of the Autonomous Province of Trento. Traffic data 2017-2022 were collected by Servizio Gestione Strade PAT (Road Management Service – PAT) and from the carthographic raster and vector PAT WebGis and ViabGis (see the Appendix section for all the addresses).
Since the January 2000, every road collision caused by ungulates reported by the Forest Service or by the Hunters Association or by the Road Service was stored in a geodatabase. This database records the date, the species of affected ungulate, the sex, an indication of the age and the geographical coordinates. Last update used for this study is from 08/2022. The dataset datum is ETRS89, frame ETRF2000, projection UTM zone 32 N.
To identify the most significant hotspots a series of heatmaps using the Heatmap (Kernel Density Estimation version 3.18) processing algorithm was used to create a raster from the point layer of registered roadkills. In our case the "radius" parameter has been set equal to 1450 map units (meters). The processing was initially carried out using all the time frame 2000-2022 data. However, there are many factors which can cause the most frequented crossing points to vary locally: construction of paraboulders or avalanche barriers, modification of the environment due to extreme weather events, and all these changes may deviate or interrupt some crossing paths. Therefore, after a careful examination, we decided run the processing using only the time frame data from 2017-2020 period, because in this way the identified hotspots reflect much more faithfully what is the present reality.
Once the areas of intervention were identified with QGIS we carried out on-site inspections to define the best solutions to be adopted in each specific case. GIS processing proved to be extremely informative both in the preliminary design phase and in the final design phase in which the works and interventions were defined in detail.

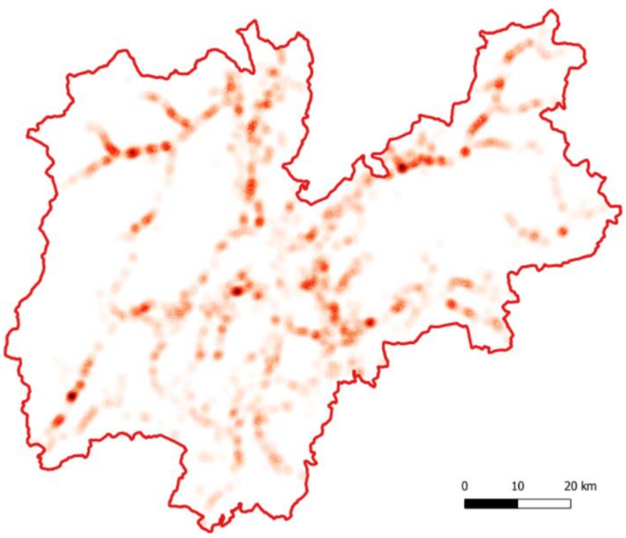

Figure 1. Heatmap of the roadkills 2017-2022 in the Autonomous Province of Trento.

For each case a specific analysis was carried out and a series of tailored interventions (underpasses, overpasses, viaducts and fly-overs, fences, road tunnels) and works aimed at mitigating road accidents with ungulates were identified. Each site was different and posed different construction problems and for each site we developed a specific solution. In addition, a first rough estimative metric computation is developed to determine the order of magnitude of the cost required to implement the recommended interventions.The rough estimation was carried out on the basis of previous works that calculated the economic impact of each collision, readapted to the local situation and converted in Euros (Huijser et al., 2009, Del Greco et al., 2022).

3. RESULTS

The results of our analyses are in line with other studies by national and international research, the ungulates are active mainly at dusk and dawn when the greatest number of investments are also recorded (Mayer et al., 2021). There is a certain seasonality of road accidents with ungulates (spring and autumn) although no time of year has such a low collision rate that it can be considered safe. Over the years the events have increased and such a trend does not appear to be destined to reverse itself. The populations of ungulates are increasing as well as vehicular traffic. Data for 2021 and 2022 show how the problem has worsened, in 2021 almost 1,000 accidents have been recorded. Speed traffic data shows a correlation between velocity and investment rate, thus highlighting how driving behaviour is one of the main causes of accidents. Speed limit of the roads in the hotspots are often disregarded.

The five hotspots chosen for intervention are located along four state roads and one provincial road and allowed to concentrate the designing effort where they were more needed.

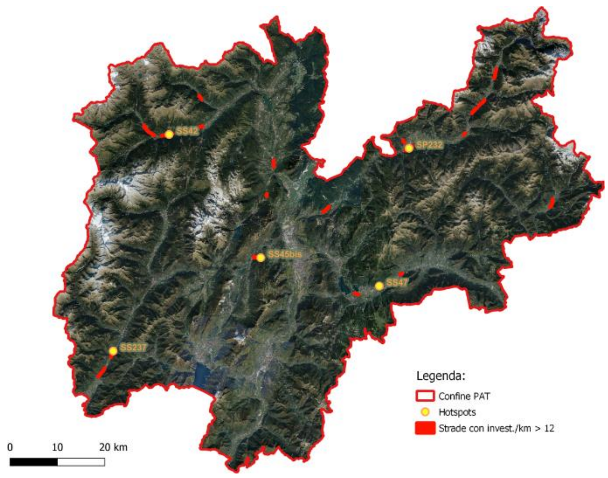

Figure 2. Map of the other 20 road tracts (in red) where the rate of road kills was more than 12 per year (the five chosen hotspots are represented in yellow dots) in the Autonomous Province of Trento.

Some of the interventions proposed in this work are relatively cheap, since they take advantage of existing structures or try to optimize upcoming projects and the total cost to be incurred for the construction of all the proposed five intervention in the five hotspots taken into consideration in this work is around 625,000.00 Euros.

As an example, we report the hotspot located in Valsugana in the stretch of State road 47 (Strada Statale 47, SS47) between Levico Terme and Campiello. The place identified as hotspot is located at the end of a wooded area which is crossed by the road. In the straight tract located on the SS47 in Valsugana, the maximum speed is set at 90 km/h and about 60% of the vehicles transit with a speed exceeding this limit, with a daily average of more than 19,000 vehicles per day.

The most affected species is the roe deer with 52% % of the collisions, followed by deer with 43% and wild boar with 5%. This combination of high number of vehicles and high speed means that the stretch of road is particularly critical also regarding the safety of drivers and passengers. Moreover, deer is a species very involved in collisions, and this animal often exceeds 120/130 Kg of weight. It is therefore essential to create a connection between the two sides of the Valsugana that allows animals to move without having to cross the SS47.

The roadkills are concentrated at the end of a wooded area crossed by the road. The morphology of the terrain presents a slope on the orographic left of the Brenta river with a funnel morphological conformation such as to convey the animals exactly in the direction of the wooded area, which appears to be the only one present in the section between Levico Terme and Novaledo (Figure 3).

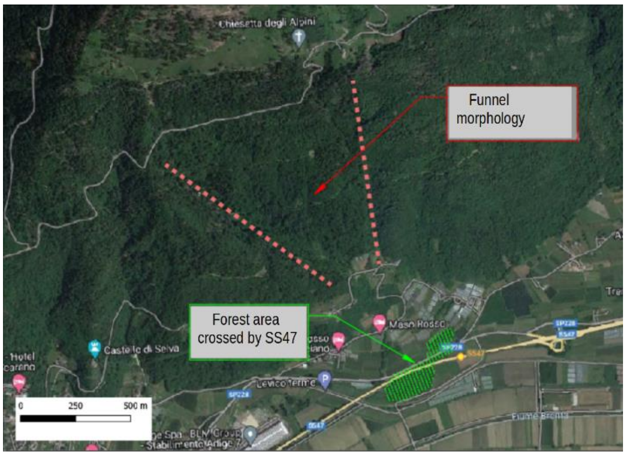

Figure 3. Funnel morphology leading ungulates to the crossing point in Levico Terme hotspot.

Furthermore, the on site inspection revealed how the location of the hotspot can be justified by the fact that the animals tend to move between one shelter area and another and they hardly walk long stretches in open areas, such as a pasture, where they are exposed to potential risks. The fauna is therefore attracted to the wooded area, which in that section extends on both sides of the road. On the orographic left, however, there is a retaining wall on which a rockfall net is installed (even if with reduced height) which prevents the passage of animals. These tend therefore, following the inclination of the land, to move parallel to the net until, at the end, they try to cross. It is at this point that the collisions are concentrated. Given the presence of this wooded area which acts as an "attraction", it was decided to design an overpass dedicated to the crossing of the ungulates of width equal to 7.0 m, width recommended for ungulates according to McGuire et al., (2021).

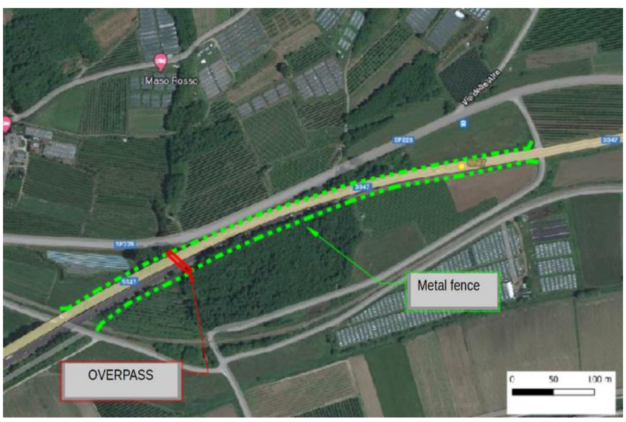

Figure 4. Designed Overpass (in red) and metal fence (in green) positioning in Levico Terme hotspot.

The best solution here is an overpass as the stretch of road is in a trench, i.e. the roadway is placed at a lower level than the ground on the sides (Figure 4).

The work is carried out in the uppermost section of the wooded area in such a way to make the most of the land embankments already present on the sides of the road. On the orographic left, the land rises rapidly until it reaches the SP228 road placed at a higher altitude of about 7.0 m. On the orographic right instead the embankment has a higher level, compared to the roadway, of about 3.5 m. In this case therefore in order to support the beams it is necessary to carry out earthworks to raise the ground level and create the access ramp. Indeed, the legislation provides that in roads such as the SS47 a clearance of 5.0 m must always be guaranteed. In addition, the position of the work is functional to the exploitation of the created ecological corridor from the riparian strip present around a stream that flows orthogonally to the road. Considering a carriageway width of 3.5 m and a shoulder of 1.0 m, the roadway has an overall width of 9.0 m. Therefore, we plan a simply supported steel-concrete composite overpass with a free span of 12.0 m (Figure 5).

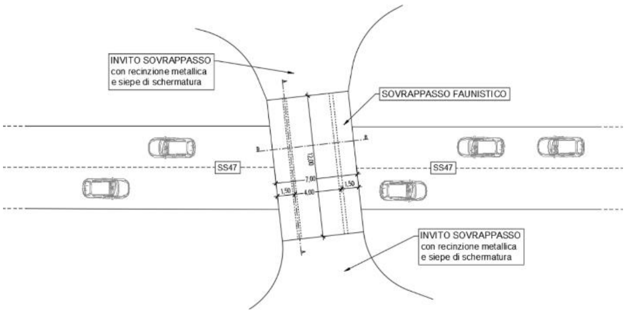

Figure 5. Designed Overpass in Levico Terme hotspot.

The deck is made of hot rolled steel profiles with a reinforced concrete lab. Above, the lab is waterproofed with a plastomeric membrane and is drained by laying a layer of expanded clay (10 cm). A further layer of soil (about 40 cm), is used to recreate an environment as natural as possible. This is obtained through the planting of bushes (with a non-tapping root system given the reduced layer of soil present) and creating a turf of native species by hydroseeding. Finally, the installation of a metal fence is envisaged to prevent the crossing of the roadway by ungulates on both sides outside the designated overpass. From the entrance of the overpass the wire network extends to the right and left for a length of about 400 m downstream and 150 m upstream, to accentuate the funnel effect. Finally, to slow down the vehicles in the section of the SP228 adjacent to the overpass, it is advised to install two speed bumps on the road, one downstream and one upstream from the overpass.

The forecasted total cost of the Levico overpass is reported in table 1 and is compared to the cost of the last 5 years of roadkills.

Species	Collisions (2017/2022)	Costs (Euro)
Roe deer	22	137,324.00
Red deer	18	296,874.00
Wild boar	2	32,986.00
Total costs of road kills (2017/2022)	42	467,184.00
Total cost Levico overpass		274,000.00

Table 1. Cost benefit analysis of the Levico Overpass, the cost of the infrastructure is compared to the cost of the last 5 years of roadkills.

Moreover, a set of maps that represents the rate of collisions at municipal level was produced. These maps provide very general indications on which are the municipalities where collisions with ungulates represent a significant problem. Their function is therefore to sensitize the administrations of these municipalities and to encourage them to take action to implement mitigation measures. In fact, from what has emerged from the meetings with local managers of the APT Wildlife Service, funds and incentives to try to reduce accidents with ungulates are already available (e.g. PSR funds Operation 4.4.3) but often the municipal administrations do not take action in order to produce the projects and the documentation necessary to take advantage of these loans. As an example we can cite that, although our work shows that roadkill phenomenon is clearly well spread in Trentino, only 4 Trentino municipalities took advantage of the PSR fund which provided for a loan of 50,000.00 Euros for the installation of anti-collision systems in 2022 (Figure 6).

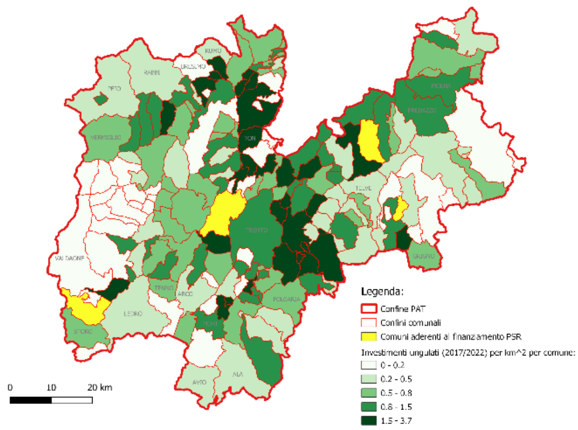

Figure 6. Map of collisions with ungulates per municipality. Light green represents the lower rates, dark green the higher rates of incidents. The only four municipalities that used the PSR funding are highlighted in yellow.

To further support and facilitate the possible application of the results of this study, a map representing the roads classified according to their roadkill risk was produced. A sample of this map is represented in Figure 7.

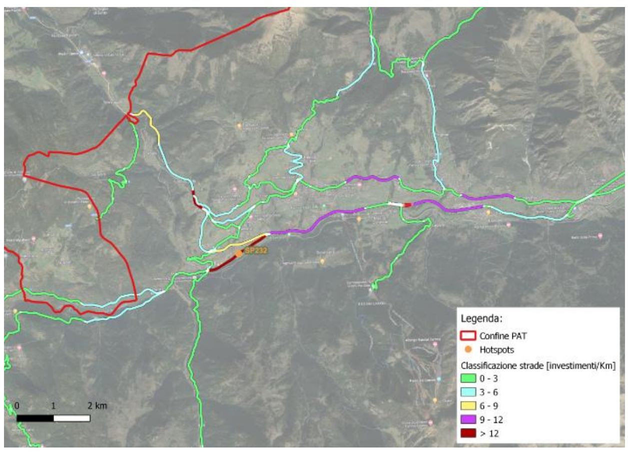

Figure 7. Map of road stretch according to the number of collisions. This map is centered on the hotspot along the Provincial road 232 (SP 232) near Cavalese (TN).

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Each road stretch is classified according the numbers of collisions and can easily be processed with other existing layers to create a risk classification that takes into account other factors.

4. DISCUSSION AND CONCLUSIONS

In this work, FOSS4G GIS were effectively used to identify the position of five roadkills hotspots, support engineering design in those points and create general maps that may be useful for policy and territorial planning.

It must be noted that the mitigation of the problem in the five hotspots suggested in this work cannot be considered the solution to the whole problem at the provincial level. Indeed, analyzing the data referring to the 2017/2022 period, the proposed interventions would have reduced accidents with ungulates by 6% (about 250 collisions avoided). If the interventions concerned 20 sections of road classified as high risk (i.e. where the investment per km are >12), the reduction of accidents, considering the same period, would have reached 16% (about 700 collisions avoided). The different interventions proposed in the various hotspots concern many of the types of works by available mitigation (fences, bollards, underpass and overpass) and these are been designed in a combined manner to obtain an overlap of the effects in the long term.

For this reason, we believe that the costs to be incurred for the construction of the proposed intervention in the 5 hotspots (about 625,000.00 Euros) are justified even in the face of a rather small reduction in collisions with ungulates at the provincial level. Furthermore, the number of annual collisions is continuously growing and the species classified as medium size (deer and wild boar) are rapidly increasing. This means that in the future the number of accidents with wildlife will be higher than today and the average general cost per each collision with an ungulate will be greater. In fact, it is recalled that in the period 2017/2022, in the 5 hotspots, the species involved were 41% small size and 59% medium size, thus involving an average cost for each single collision equal to approx 12,325.00 Euros. As an example, considering the case of Levico hotspot taken into account in this paper, the cost of the overpass proposed in this work is around 274,000 Euros, but the total costs occurred (calculated according to Del Greco et al., 2022) in the last five years due to roadkills in the same spot amounts to around 470,000 Euros (Table 1). Moreover, recalculating the costs using the parameters of another recent study (Sèbe et al., 2022) leads to the same conclusion.

Surely the single municipal administrations can’t finance these projects by themselves, but provincial planning must be performed through a cooperation between administrations involving municipalities, the Provincial Wildlife Service and the PAT Road Management Service.
It is essential to develop a long-term project, therefore planning a reduced number of interventions per year, positioning them on the most risky stretches of road.

Further reflection must be made regarding the future electrification of vehicles which could increase the number of collisions due to the fact that electric vehicles are less noisy than combustion engines cars. However, this technological evolution runs parallel the evolution of driver assistance systems integrated in vehicles. Some vehicles currently have a number of sensors that can recognize, monitor and digitally reconstruct the surrounding environment. This allows to provide support to the driver and, in some cases, to allow for auto-driving (in countries where this is permitted by law). The more advanced systems can detect the lateral and frontal presence of other vehicles or people (and animals) even at night thanks to radar and infrared sensors, and perform auto braking when the car system detects the risk of a collision. Dedicated software development could make it possible to recognize more and more accurately the presence of animals and intervene by slowing or stopping the vehicle if the driver does not notice the presence of an animal (ADAC, 2022). In addition, road anti-collision devices with sensors located on the roads could be developed in such a way that they could exchange information directly with the incoming cars and not only by activating the illuminated warning signs that are on the road. This would certainly draw more attention from drivers.

Finally, Open Source software has once more showed its potential in order to face long term challenges, like those posed by climate change (Baiocchi et al., 2021), biodiversity loss (Ciolli et al., 2017, Tattoni 2019) and habitat loss (Tattoni et al., 2019a, 2019b). A better definition of the real costs of a well defined HWC problem like roadkills could also help to consider the cost of HWC in the frame of ecosystem services (Nedkov et al., 2018, Piscopo et al., 2021), thus encouraging decision makers to act. The workflow of this paper and the proposed projects may create a guideline for the future politics of the provincial government, with the short term effect to foster the use of dedicated contributions like the PSR funds Operation.

Like many other issues related to HWC, to achieve a solution, the local governments must be receptive to research results, be proactive with management plans shared with researchers and technicians (Piscopo et al., 2021) and also create information campaigns to share the information with the public when this is particularly needed to guarantee the safety of the people and the animals.

Citizen science could also be explored in order to refine the data relative to all the animal roadkills, especially those related to other animals smaller than ungulates (Unger, 2022, Valerio et al., 2023) and many other research possibilities (Ostermann-Miyashita et al., 2021).
Sharing the capabilities of FOSS4G to experiment and improve the procedures in designing interventions that can reduce the collisions can inspire more researchers and technicians to experiment these solutions to plan the positioning of crossing structures, thus helping to mitigate Human-wildlife conflict (HWC).

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APPENDIX

Data for different features, Topography, DTM, Land Use, Urban Planning, Roads, Fauna, Cadastral Data, hydrography, in Shape file and other various format can be downloaded at the following addresses:

Provincia Autonoma di Trento - Urbanistica - Cartografia PUP, http://www.urbanistica.provincia.tn.it/pianificazione/piano_urbanistico_provinciale/cartografia/pagina161.html Accessed: 7 April 2023

OPENdata Trentino - http://sdi-pat.provincia.tn.it/. Accessed: 7 April 2023.

Servizio Foreste e Servizio Faunistico - Fauna selvatica https://forestefauna.provincia.tn.it/Fauna/Fauna-selvatica. Accessed: 7 April 2023.

Servizio Gestione Strade (WebGis) http://sdi-pat.provincia.tn.it/webgis/?bbox=595756,5044268,739244,5170732. Accessed: 7 April 2023.

Servizio Gestione Strade, sdi-pat.provincia.tn.it/ http://sdi-pat.provincia.tn.it/. Accessed: 7 April 2023.

WebGIS PAT, www.protezionecivile.tn.it http://www.protezionecivile.tn.it/territorio/webgis_downloadcarte/. Accessed: 7 April 2023