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Consequences and Solutions to Wildlife-Vehicle Collisions and Electrocutions: the case of the Alturas Wildlife Sanctuary

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Summary

Infrastructures affect wildlife survival in a variety of different ways: reduction of habitat connectivity leading to isolation, inbreeding and loss of genetic diversity; fatal attempts to cross roads due to traffic collisions for terrestrial animals and electrocutions for arboreal and flying animals. This is particularly evident in countries undergoing rapid development, such as Costa Rica, where there has been a surge in infrastructure construction in the last decade. Luckily, many localities nowadays have rescue centres where animals can be brought to by the general public to receive treatment and rehabilitation; the Alturas Wildlife Sanctuary, located in the Puntarenas Province of Costa Rica, is an example of this. As first part of the study, an analysis of the registries of the aforementioned sanctuary was performed to discover the main reasons for admission. Having learnt that two of these are vehicle collisions and electrocutions, the attention was focused on them and an examination of the lesions they cause and the possible mitigation solutions which exist was carried out. Included in this last point was also an analysis of the footage from the camera traps placed on the aerial bridges which the Alturas Wildlife Sanctuary installed above the main road in their area to understand their effectiveness. The conclusion which was drawn is that there are many options available to try and reduce the effect of roads and other infrastructures on wildlife and that the work of rescue centres, together with government bodies and other NGOs, are vital components for these to work.

Introduction

Infrastructures, and specifically roads, have been proven to have several negative impacts on wildlife populations. Some of these effects are visible only in the long term, while others become apparent within one or two animal generations [1].

Included in the first category is habitat fragmentation [2] , i.e. the splitting of a once large liveable habitat into smaller pieces which are no longer connected. This reduction of habitat connectivity leaves the animal subpopulations isolated one from the other and causes them to inbreed [2], i.e. breed with close relatives; this in turn leads to a loss of genetic diversity, as there is no new income of genes, culminating in "a decrease in the fitness of the subpopulations, as they are less likely to possess the genetic tools to survive environmental changes" [2].

In the fastly apparent consequences of infrastructures on wildlife, we can find fatal attempts to cross the roads. For terrestrial animals, this leads to death due to vehicle-collisions [2]; the animals try to cross but are too slow and get hit by oncoming cars. This can lead to a circle of death, since carcasses left on the road can attract scavengers which in turn get then hit by cars [3]. For arboreal and flying animals, instead, the main reason for fatalities is attempts to cross the roads using electrical wires; such wires, if not insulated, cause the death of the animals by electrocution [4].

These effects are evident worldwide, however, they are more obvious in countries where there are many new infrastructures built in a short amount of time; this is the case of Costa Rica, where there has been a surge in infrastructure building in the last decade [5]. This is mainly due to the increase in tourism, which calls for easier connectivity throughout the country leading to the construction of new and bigger roads. As new roads are built and more cars use them, the amount of wildlife roadkill also increases [6].

Luckily, however, there are a number of rescue centres throughout the country where animals which are found wounded or abandoned can be taken to receive medical attention and care, followed by a rehabilitation process, and, hopefully, release back into the wild. One of these is the Alturas Wildlife Sanctuary [7], a rescue centre located in San Martin Nortre, in the Puntarenas province. The Sanctuary has a 24/7 veterinary clinic where animals can be brought to, as well as a fully prepared staff ready around the clock to go and rescue animals following a phone call. Once the animal arrives at the clinic, trained veterinarians examine it and decide what the best course of action is. The Sanctuary keeps

registries in which all the animals admitted are reported, with the date, species, life stage, sex, reason for admission and decisions made.
As will be discussed in the dedicated chapter, most of the animals belong to the Aves class and are admitted for human-related causes.
Included in these human-related causes are vehicle collisions, electrocutions, dog attacks and orphaning. All these causes are related to infrastructure construction and its effects on wildlife. Vehicle collisions and electrocution have been previously explained. Dog attacks often occur when animals are forced to enter into open lands with human presence due to the lack of habitat connectivity [4]; for arboreal animals for example, this happens when trees are cut down to create space for farmland or new buildings: when the animals can't jump from tree to tree, they are forced to cross on the ground where they are susceptible to dog attacks. Orphaning can take place for a number of reasons; the mother can decide to abandon the baby if she is disturbed or she can be killed by dogs, cars or electric wires.
When the animals are lucky enough to survive vehicle collisions and electrocutions, they often have to carry with them the consequences of the lesions for the rest of their lives.
Traffic collisions mainly lead to bone fractures, abrasions, internal bleeding, brain damage and organ damage [8].
Bone fractures occur due to the blunt force received by the animal body when the car hits; the number of bones broken depends on the size of the animal [9] and sometimes can be so high that the best solution is to euthanize the animal. When the fractures are not too numerous and not too severe, they can be fixed through surgery, and after a long period of rehabilitation, the animal might be able to recuperate.
Abrasions occur when the animal lands on the road and its body is dragged on the tarmac for a certain length. This is due to the friction between the road surface and the animal and can cause several layers of the skin to detach [10]. These are often curable.
Internal bleeding happens when the hit involves internal organs and veins / arteries which rupture [11]. It can be so serious and unstoppable that it causes the death of the animal.
Brain damage takes place when the animal is either hit on the head by the vehicle or lands on its head after being hit. It can have severe consequences, such as the loss of the ability to move limbs or can interfere so much with the life of the animal that the best solution is euthanasia [12, 13].
Internal organ damage happens because of the blunt force given by the collision with the vehicle and mainly involves the liver, lungs, spleen and heart [14]. The organs in the thoracic cavity are more affected than the ones in the pelvic cavity due to the protection

given by the strong bone and muscle belt [10]. The organs affected generally rupture, leading to loss of function and internal haemorrhage which can lead to death [11].
Electrocution, instead, mainly leads to burns and internal organ damage [15].
The burns can be of several degrees of intensity corresponding to several degrees of damage. First degree burns only involve the outer layer of the skin, the epidermis [16], and can be easily medicated. Second degree burns involve deeper levels (epidermis and dermis) [16] and are more difficult to recuperate from. Third level burns penetrate even deeper (epidermis, dermis and underlying fatty tissue) [16] and often leave permanent scars if the wound manages to heal.
Internal organ damage occurs when the current travels through the body, from the entry to the exit point [15]. It can be caused by electroporation (i.e. osmotic swelling of the tissue) or electrothermal heating, depending on if the accident is low-voltage or high-voltage [17]. Organs can also rupture due to the blunt force trauma associated with falling from a height after electrocution [18].
If the intensity of the electrocution is high enough, the organs of the animal can shut down leading to almost immediate death [19].
As previously stated, unfortunately, these are some of the main reasons for admission to rescue centres in Costa Rica, but luckily, Costa Rica is also one of the countries with most mitigation solutions.
Mitigation solutions are ways to solve the issues of vehicle collisions and electrocutions through the construction of barriers or alternative crossing structures.
For vehicle collisions, these solutions can be separated into structures crossing the road or passing under it. Crossing the roads, it is possible to find arboreal bridges (natural, semi-artificial or artificial) and overpasses [20]. Passing under the road, there are underpasses, culverts, eco-viaducts and drains [20].
In addition to these there have been other methods implemented around the world, such as road signs, speed limits, speed bumps and fencing [3].
All the solutions have been tested in different designs with varying levels of efficacy; the most common result, however, is that designs intended for specific species tend to have the highest level of use by the animals [21].
These solutions allow animals to cross roads which fragment their habitat without the risk of coming into a collision with vehicles.
For electrocution, instead, the main solution is the insulation of energised parts, mainly electrical wires. This, however, can be very expensive [22], leading to the trial of other

methods which try to limit the access of animals to the wires and transformers, such as anti-climbing or anti-perching devices [23].

Arboreal bridges can also be seen as a solution for electrocution as they allow for an alternative route to cross the road [22].

As said before, Costa Rica is very ahead with the implementation of these solutions, so much so that they created a law stating that every new infrastructure built has to include in its plan a way to reduce its effect on wildlife [24].

The advanced level of understanding of the problem is also proven by the number of mitigation solutions, and especially arboreal bridges, erected in the country. This is made possible by the joint effort of rescue centres, government bodies such as ICE (the electrical company) and other NGOs. Their efforts go towards the construction of bridges but also to raising awareness within the communities, leading to an increment in the respect towards wildlife, which is especially important for drivers and electrical company workers.

A perfect example of this joint effort is the construction of several arboreal bridges by Alturas Wildlife Sanctuary in conjunction with Somos El Cambio [25], the NGO of the Envision Festival, and ICE, the governmental electrical company. Together, they have placed 2 bridges along the main road passing in their area, both made of a single line of rope, which lead from the mountain side of the road to the ocean side, allowing for animals to have these two portions of their habitat connected without having to risk their lives.

These bridges were installed in January 2024 and have ever since been monitored through the use of camera traps placed at one end. The videos recorded by the cameras show a relatively fast habituation of animals to the bridge: the first use was after only 45 days, in March 2024. The bridges are mainly used by capuchins, which play in the trees close to the bridge, use it to rest and also, as hoped, for crossing. The second species which most commonly uses the bridge is the woolly opossum which can be seen crossing the bridge several times during the night. Another species recorded using the bridge is the flycatcher, recorded as it was perching on the rope.

The use of the bridge by all these animals shows there is hope in mitigating the effect of infrastructures and other human disturbances on wildlife.

Thanks to all the studies on different solutions there is a continuous increase in knowledge on how to best design them for the species which most need them.

And thanks to the notion of the fact that working together, rescue centres, government bodies and other NGOs can have a real influence on the survival of wildlife populations, there is in fact proof that these mitigation solutions can be implemented and work successfully.

1. Analysis of Alturas Wildlife Sanctuary's Registries

As first part of the project an analysis of the registries kept by the Alturas Wildlife Sanctuary was performed.

The registries are compiled following the admission of an animal to the clinic and report all the basic information about the individual: species, conservation status, entry date, origin, sex, life stage, initial prognosis, final disposition, animal condition and cause for admission.

These data are first written by hand in a form handed to whoever delivers the animal and then copied by the veterinarians into an excel file as permanent records.

The registries analysed were separated into two excel files, one containing the information for all the animals admitted between 2014 and 2021 and a second one containing the information for those admitted between 2022 and 2023.

The first data examined was the Class to which the animals belonged, as can be seen in Figures 1.1 and 1.2.

For the 2014-2021 period the highest percentage was represented by the Mammalia class (981 individuals, 47%), closely followed by Aves (973 individuals, 47%) and Reptilia (117 individuals, 6%). For the 2022-2023 period the most represented were the Aves (462 individuals, 56%) and Mammalia (320 individuals, 39%), with Reptilia still being the least common (34 individuals, 4%).

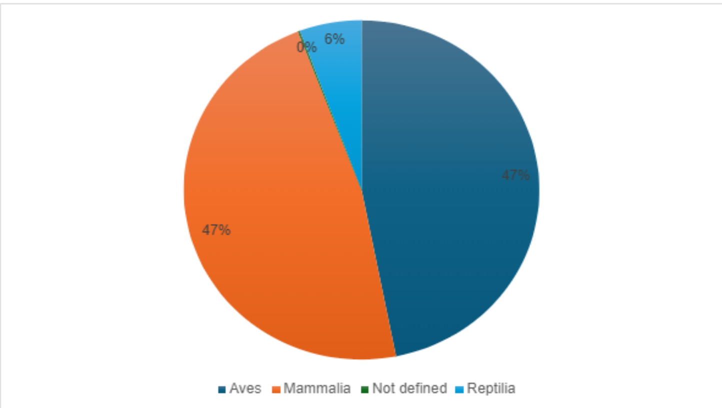

Figure 1.1: *pie chart showing the percentages of the various classes admitted in the 2014-2021 period.*

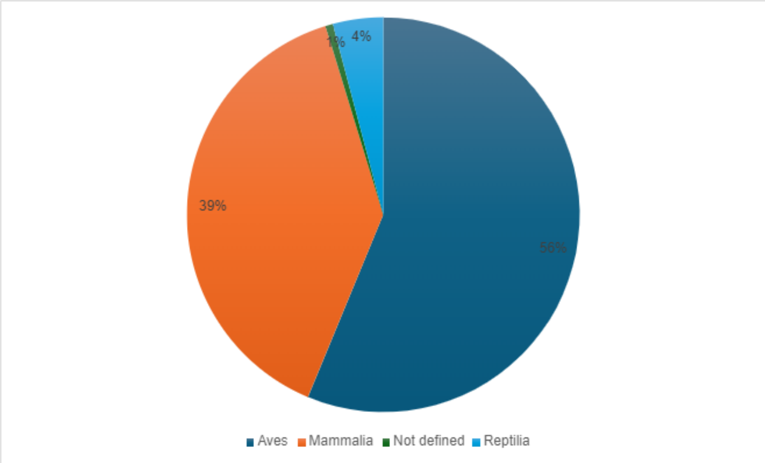

Figure 1.2: *pie chart showing the percentages for the various classes admitted in the 2022-2023 period.*

A further analysis of this information was then performed, summarising the number of different species admitted for each Class.
For the 2014-2021 period, the Aves received belonged to 140 different species, the Mammalia to 50 species and the Reptilia to 19. The most commonly affected Birds were the Red lored amazon, *Amazona autumnalis* (95 individuals), the Chestnut mandibled toucan, *Ramphastos swainsonii* (84 individuals) and the Fiery billed aracari, *Pteroglossus frantzii* (46 individuals). The most affected Mammals were the Common opossum, *Didelphis marsupialis* (151 individuals, also representing the most hit species overall for the time period), the Hoffmann's two toed sloth, *Choloepus hoffmani* (98 individuals) and the Variegated squirrel, *Sciurus variegatoides* (96 individuals). The most affected Reptiles were the Green iguana, *Iguana iguana* (44 individuals), the Boa constrictor imperator, *Boa imperator* (17 individuals) and the Scorpion mud turtle, *Kinosternon scorpioides* (13 individuals).
For the 2022-2023 period, instead, the total number of Aves admitted belonged to 86 species, the Mammalia to 36 and the Reptilia to 10. The most hit Aves were the Orange chinned parakeet, *Brotogeris jugularis* (72 individuals), the Red lored amazon, *Amazona autumnalis* (34 individuals), the Black bellied whistling duck, *Dendrocygna autumnalis*, and the Blue headed parrot, *Pionus menstruus* (last two both with 29 individuals). The most commonly admitted Mammals were the Common opossum, *Didelphis marsupialis* (76 individuals, again representing the most affected species overall), the Anteater, *Tamandua mexicana* (26 individuals), the Crab eating raccoon, *Procyon cancrivorus*, the Central american squirrel monkey, *Saimiri oerstedii* and the Hoffmann's two toed sloth, *Choloepus*

hoffmanni (last three all with 19 individuals). The most received Reptiles were the Hawksbill sea turtle, *Eretmochelys imbricata* (9 individuals), Green iguana, *Iguana iguana* (8 individuals) and Boa constrictor imperator, *Boa imperator* (6 individuals).

The next information analysed, the conservation status, was only reported in the file recording the data for the 2014-2021 period.

The majority of the animals, luckily, belonged to the Least Concern status (1736 individuals), followed by Vulnerable (175 individuals) and Near Threatened (125 individuals). Only a few animals belonged to the Endangered (14 individuals) and critically endangered (3 individuals) categories. Although this data may seem positive, it still shows how rescue centres can have a pivotal role in saving at-risk species since, especially for the Endangered and Critically endangered categories, the survival of every individual is essential.

The data for the entry date is summarised in Figure 1.3 where one can clearly observe how there are two main peaks in the trend.

The first peak is around March; this can be explained by the fact that the main tourist season for Costa Rica is from December to March, corresponding to the dry season. This increase in tourism leads to an increase in vehicles causing a rise in collisions with wildlife [6]; at the same time, it also brings a higher chance of injured or orphaned animals to be found and rescued.

The second peak around July can be explained in the same way.

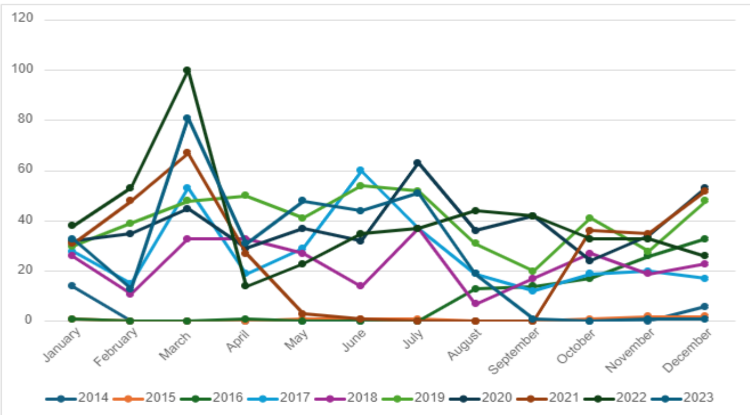

Figure 1.3: *line chart representing the trend for the entry date for the whole period (2021-2023).*

Regarding the location of origin of the animals, the main one for the 2014-2021 period was Bahia Ballena, followed by Perez Zeledon and Golfito. For the 2022-2023 period, instead, the main location was Perez Zeledon, followed by Uvita and Golfito. This data can be seen in Figures 1.4 and 1.5.

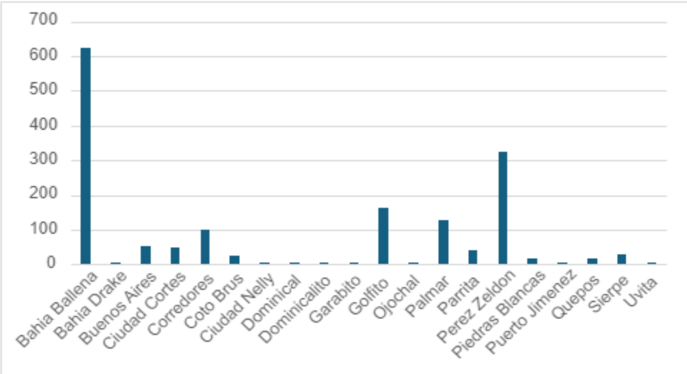

Figure 1.4: *histogram summarising the main locations of origin for the 2014-2021 period.*

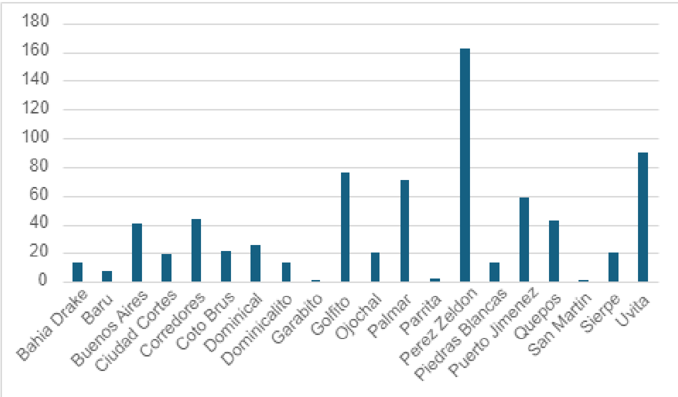

Figure 1.5: *histogram summarising the main locations of origin for the 2022-2023 period.*

Regarding the sex of the admitted animals, for both time periods the majority were male. Between 2014 and 2021, 448 males were admitted, while the females were only 378. Between 2022 and 2023, the males were 130 and the females 115.
For what concerns the life stage, for the 2014-2021 period mainly adults were received (744 individuals), followed by neonates (621 individuals) and juveniles (249 individuals). For the 2022-2023 period, instead, the majority were neonates (349 individuals), followed by adults (287 individuals) and juveniles (119 individuals).
The initial prognosis was reserved for the majority of animals (668 individuals, 32%) in the 2014-2021 period, followed by good (437 individuals, 21%), critical (399 individuals, 19%) and deceased (23 individuals, 1%). For the 2022-2023 period the trend was similar, with 355 reserved (43%), 248 critical (30%), 142 good (17%) and 13 deceased (2%). This data is shown in Figures 1.6 and 1.7.

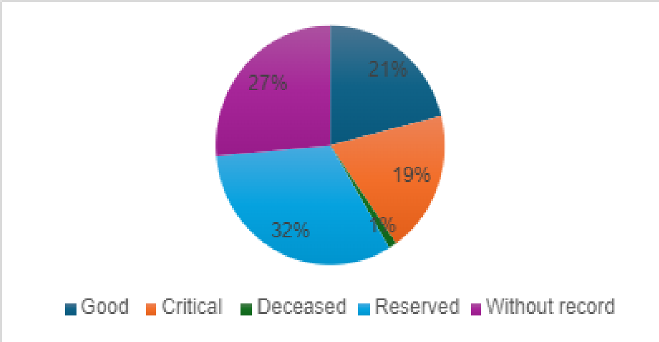

Figure 1.6: *pie chart showing the percentages of the various initial prognoses for the 2014-2021 period.*

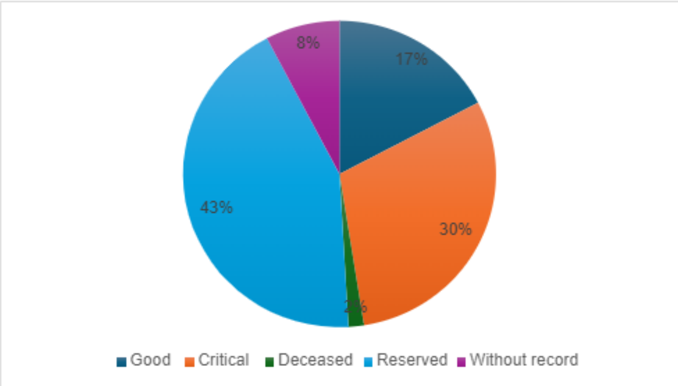

Figure 1.7: *pie chart showing the percentages of the various initial prognoses for the 2022-2023.*

The main final disposition for the 2014-2021 period was deceased (657 individuals), followed by euthanised (490 individuals) and released (479 individuals). 44 animals were admitted to the sanctuary.

For the 2022-2023 period, instead, the majority of animals died (404 individuals), many were released (159 individuals), part was relocated to another sanctuary (157 individuals) and some euthanised (63 individuals).

The high proportion of animals which died or were euthanised may be unexpected, but it is a daily event for rescue centres. For an animal to not flee upon approach and to be captured means it is in a very bad state; as a natural consequence many die from the condition or the most humane decision which can be made is euthanasia.

An analysis of the last two sets of data combined was also performed.

For the 2014-2021 period, of the animals admitted with a good prognosis 231 were released, 83 died, 65 were relocated, 9 were euthanised and 23 were admitted to the sanctuary. Of those admitted with a critical prognosis 272 were euthanised, 115 died and 8 were released.

Of those admitted with a good prognosis in the 2014-2021 period, 45 were relocated, 44 released, 37 died and 4 were euthanised. Of those admitted with a critical prognosis, instead, 178 died, 45 were euthanised, 21 released and 4 relocated.

This information is shown in Figures 1.8, 1.9, 1.10 and 1.11.

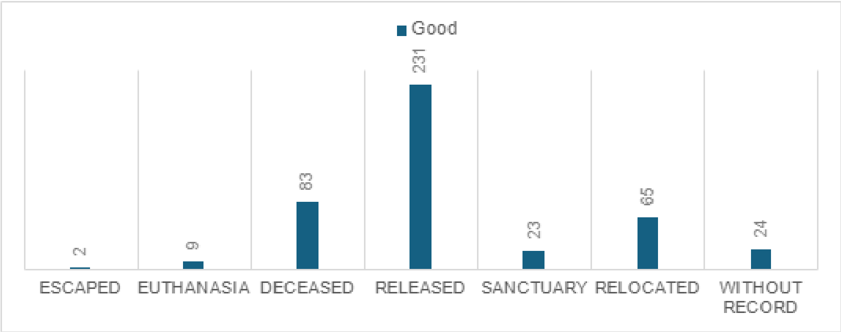

Figure 1.8: *histogram displaying the final dispositions for animals admitted with good prognosis in the 2014-2021 period.*

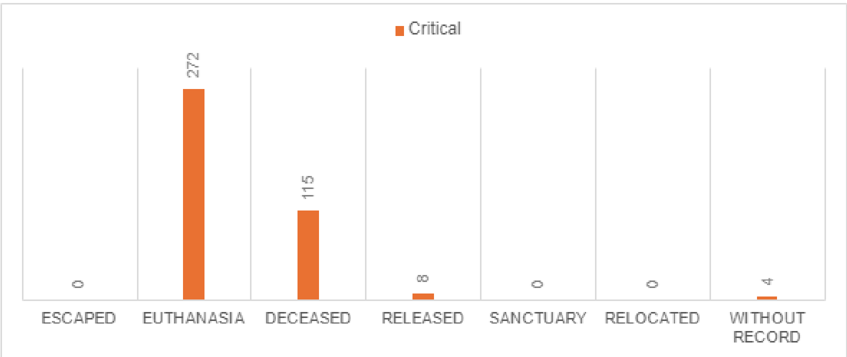

Figure 1.9: *histogram displaying the final dispositions for animals admitted with critical prognosis in the 2014-2021 period*

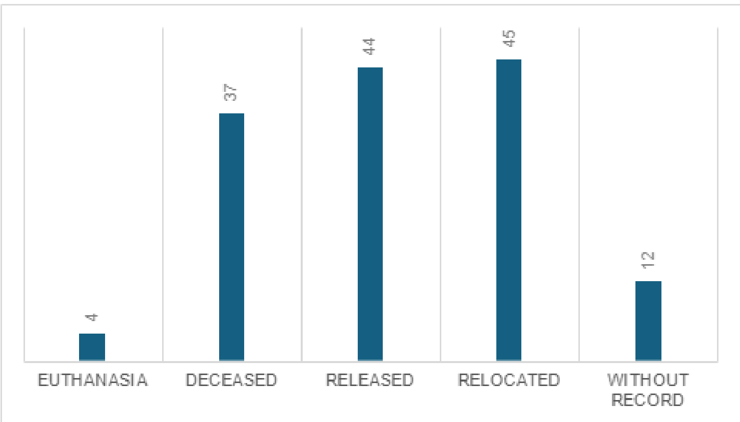

Figure 1.10: *histogram displaying the final dispositions for animals admitted with good prognosis in the 2022-2023 period.*

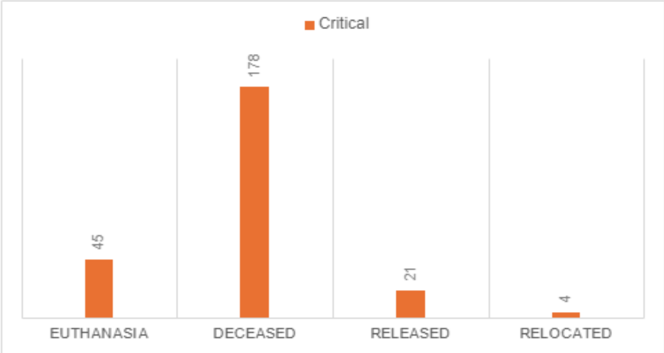

Figure 1.11: *histogram displaying the final dispositions for animals admitted with critical prognosis in the 2022-2023 period.*

As for the animal condition, between 2014 and 2021 most animals were admitted because of orphaning (573 individuals), followed by car accidents (362 individuals), confiscation from private owners (171 individuals) and dog attacks (111 individuals). Furthermore 84 individuals were admitted following electrocution.

Between 2022 and 2023 the main conditions were very similar: the majority of admissions were due to orphaning (291 individuals), confiscation (103 individuals), car accidents (101 individuals) and being beaten (94 individuals). 23 animals were admitted following electrocution.

This information is summarised in Figures 1.12 and 1.13.

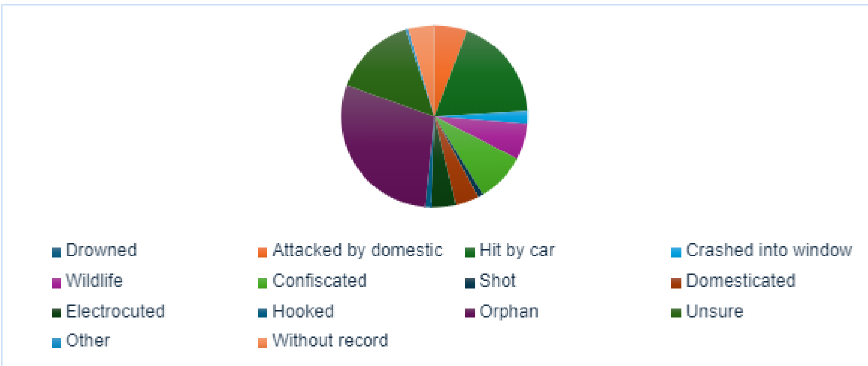

Figure 1.12: *pie chart summarising the animal conditions on arrival for the 2014-2021 period.*

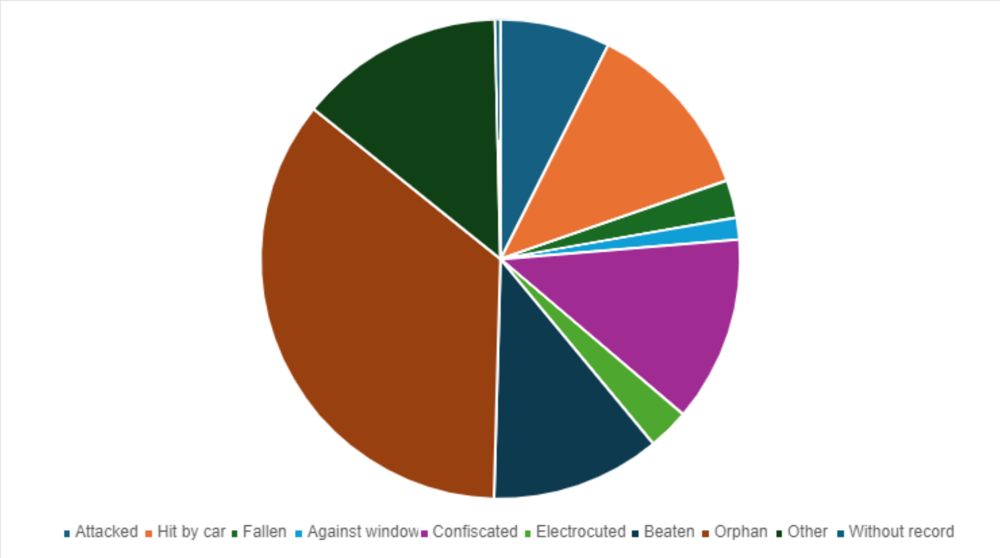

Figure 1.13: *pie chart summarising the animal conditions on arrival for the 2022-2023 period.*

For the 2014-2021 period, the main lesions endured by the animals were also registered. The majority of the animals had no lesions (483 individuals), followed by fractures (297 individuals), internal haemorrhage (153 individuals) and serious injuries (140 individuals), as can be seen in Figure 1.14.

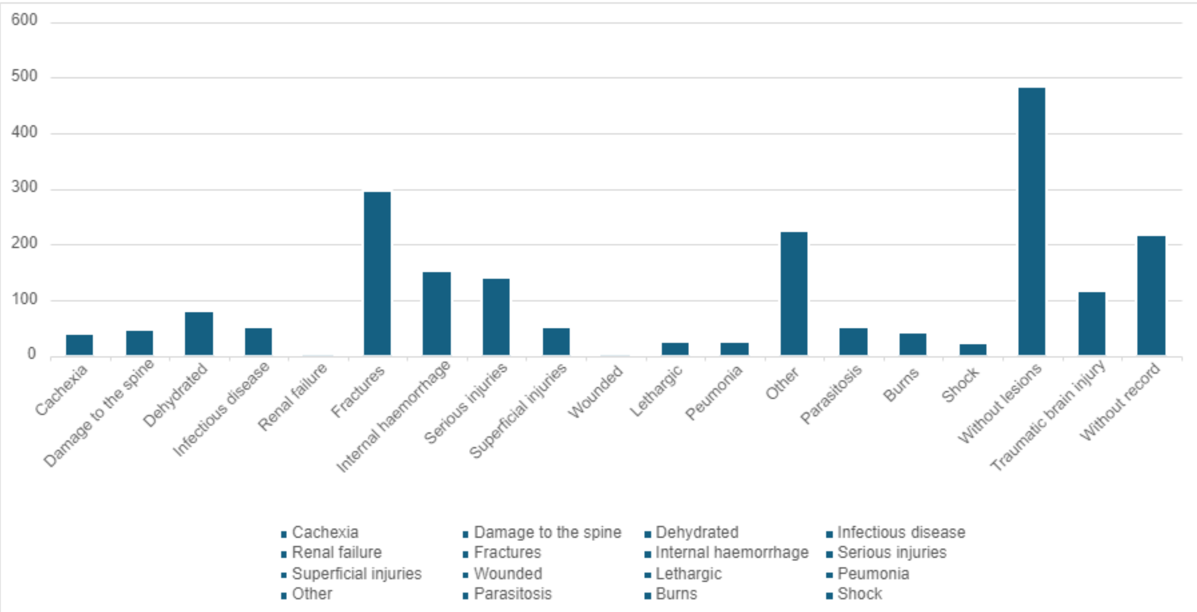

Figure 1.14: *histogram showing the main lesions endured by animals for the 2014-2021 period.*

For both time periods the main causes were human-related, as can be seen in Figures 1.15 and 1.16. Between 2014 and 2021, 1023 animals (49%) were admitted for human-related causes, and only 321 (16%) for natural ones. Between 2022 and 2023, 372 individuals

(45%) were received following human-related causes, and 196 (24%) following natural ones.

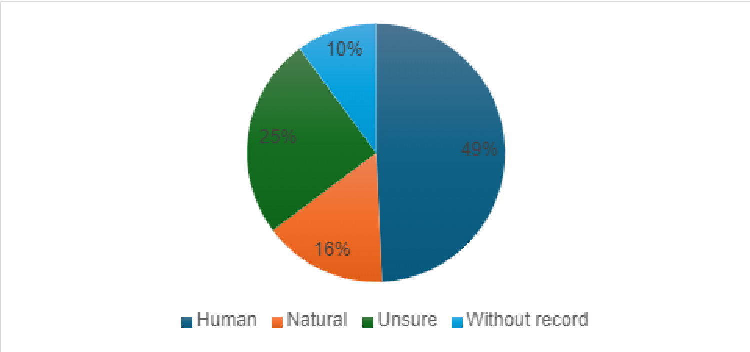

Figure 1.15: *pie chart representing the main admission causes for the 2014-2021 period.*

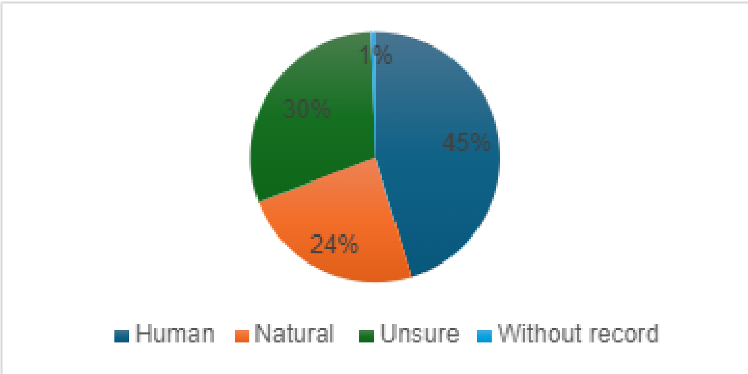

Figure 1.16: *pie chart representing the main admission causes for the 2022-2023 period.*

Following the analysis discussed above, an interest in learning more about vehicle collisions and electrocutions was born, leading to research on the lesions they cause and the possible existing mitigations methods. The results of this study are presented in the following chapters.

2. Main lesions following vehicle collisions

When animals are forced to cross roads they can be hit by oncoming vehicles, following which they can suffer from several injuries.

These injuries affect different areas of the body with different percentages; the most affected body segment in large, medium and small mammals is the abdomen/pelvis, followed by the chest, head/neck and extremities [14]. The higher percentage of lesions present in the mammalian pelvis is most likely due to the escape reflex of the animals: when they sense a vehicle approaching, they attempt to flee, leading them to be hit in the caudal part of the body [11]. In birds it mainly affects the extremities, i.e. the wings and legs, and the coelomic cavity [26, 11].

Most animals are injured in more than one anatomical area, while some have only one area affected [11].

The injuries can be of various nature, mainly abrasions, lacerations, bone fractures, head and spinal trauma and rupture of internal organs with associated internal bleeding [8].

The blunt force trauma and the complications which derive from it can also lead to death in very severe cases.

2.a. Bone fractures

As previously stated, one of the most common lesions following vehicle collisions is bone fracture, especially in birds due to the fact that their bones are hollow and thus more fragile [11].

It is important to note that all the fractures which follow the collision occur at the same time, thus, if the animal survives, they will all be in the same healing stage; this can be a very useful tool, since, upon histological examination, it can be used to differentiate these kinds of fractures from those following abuse, as in the latter case one will most probably find fractures in different healing stages [10].

Most animals present multiple fractures, especially if they are of small size; animals of medium size present a lower frequency of fractures, and large animals even less [14].

Based on the locomotion and agility of the animals they can have a higher percentage present in the cranial or caudal portion of the body: animals with plantigrade locomotion and low agility, such as the Northern tamandua, *Tamandua mexicana*, are often hit in the frontal lateral position, while animals with a higher agility, such as dogs and cats, are most often hit in the caudal position [9].

The most affected bones in the cranial portion of the body are the temporal, occipital, parietal, mandible, frontal and nasal bones, along with the ribs and the forelimb [14, 11].

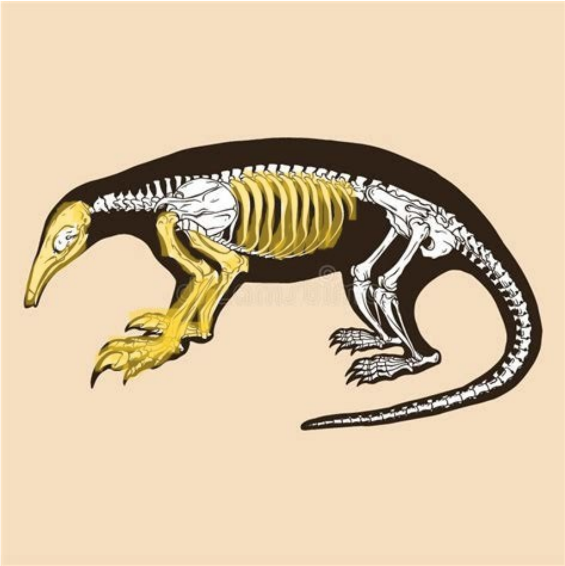

Figure 2.1: *schematic representation of a Northern Tamandua, Tamandua mexicana, skeleton. The main bones fractured in a vehicle collision are highlighted. Image from "Skeleton Northern Tamandua Vector Illustration Stock Vector - Illustration of Vertical, Habitat".*

The most commonly fractured bones in the caudal portion of the body are the pelvic bones and those of the hindlimb [14, 11].

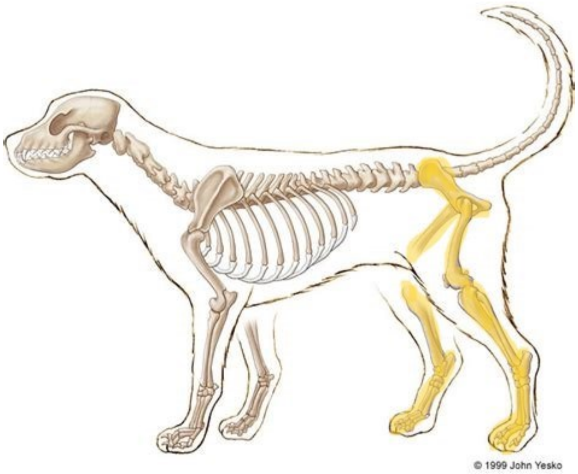

Figure 2.2: *schematic representation of a Dog, Canis familiaris, skeleton. The main bones fractured in a vehicle collision are highlighted. Image from Diagram of Skeletal System of Dog Pt. 2 | Quizlet.*

Also, the vertebrae can be fractured, with consequent spinal cord lesions [11].
Animals can also present cutaneous lesions associated with the fracture point, such as lacerations, abrasions and avulsions [11].

2.b. Abrasions

Vehicle collisions mainly lead to two types of abrasions: scrape abrasions and pattern abrasions.

Scrape abrasions are almost always found and are characterised by "an area of epidermal detachment larger than the surface area of the object" [10]. They are more frequent in larger animals, probably due to the higher resistance of the body mass to the tangential force [10]. Grossly they appear as areas of exposed dermis, usually with broken hair shafts in haired animals [10]. Histologically they are characterised by "focal epidermal detachment, often with disruption and haemorrhages in the dermis" [10].

Figure 2.3: *Capybara, Hydrochoerus hydrochaeris. Cutaneous abrasion haemorrhage in right forelimb. Image from [14].*

Pattern abrasions are common in humans involved in car accidents, but are infrequent in animals, and only seen in animals with short fur or in sparsely haired regions [10]. They reflect the shape of the object which caused the lesions [10].

2.c. Internal bleeding

Internal bleeding is another common consequence of the blunt force trauma due to vehicle collisions.

It can be identified due to abnormalities in the mucous membrane colour, such as paleness [12, 27].

It is mainly observed in large animals, followed by medium-sized and small ones [14].

The most commonly found haemorrhage is in the lungs, as well as in the oral cavity, nostrils and brain [14]. Haemoperitoneum, i.e. the presence of blood in the peritoneal cavity, and haemothorax, i.e. the presence of blood in the pleural cavity, are also very common findings [14, 27]; with the former being more frequent than the latter [11]. The higher prevalence of blood in the peritoneal cavity compared to that in the pleural cavity is most probably due to the high resistance given by the ribs, especially in young animals [11].

Figure 2.4: *Giant anteater, Myrmecophaga tridactyla. Haemoperitoneum. Image from [14].*

Haemoperitoneum is most commonly due to the rupture of the spleen and liver, organs which can't dissipate the energy they absorb, making them more susceptible to rupture [11]. Haemothorax, instead, is most commonly caused by the laceration of the lung and heart and the rupture of the great vessels [11].

In some cases, the presence of blood in the body cavities could be due to unidentifiable vessel rupture or to postmortem autolysis of the carcass [11].

2.d. Brain and Nervous system damage

Brain damage can be a consequence of vehicle collisions.

Head trauma can be indicated by bruising or haemorrhage on the mucous membranes in the mouth [12].

Cranioencephalic lesions include cranial skull fractures and intracranial haemorrhage, which can also be present without bone fracture [11].

Figure 2.5: *Brown brocket deer, Mazama gouazoub. Multiple fractures of temporal and parietal bones with rupture and haemorrhage of brain. Image from [14].*

Head trauma is associated with an increased risk of no survival, since cerebral hypoxia and hypotension can contribute to secondary brain injury and higher mortality [13]. These latter two derive from the alteration of haemodynamic stability and tissue oxygenation coming from severe concurrent injuries [13].

In raptors, road traffic accidents also often result in damage to the radial nerve, which can cause permanent wing paralysis leading to the bird being unreleasable [12].

2.e. Internal organ damage

Many internal organs are affected by the blunt force trauma deriving from collisions with vehicles.

The rupture of visceral organs has a higher frequency in large animals, followed by medium-sized and small ones [14].

The lungs can have grossly significant damage which can be associated with extensive bruising and bulla formation with potential subsequent pleural rupture [10]. These organs can also be lacerated by bone fragments when the blunt force causes rib fractures; this can lead to leakage of air and pneumothorax [10].

The diaphragm can rupture, event which can be followed by herniation, i.e. displacement, of the abdominal organs into the thoracic cavity following abrupt increase in intra-abdominal pressure [10].

The heart has also been reported to rupture, mainly due to bone perforation, but non-perforation rupture of the interventricular septum or atrium has been described too [14].

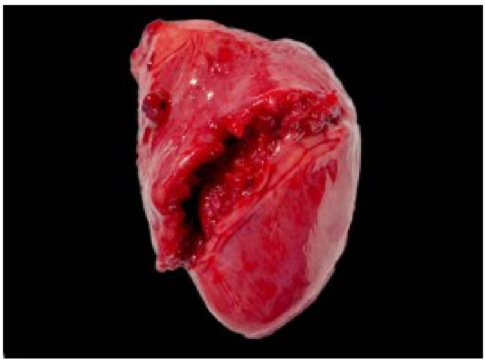

Figure 2.6: *Crab-eating fox, Cerdocyon thous. Myocardial rupture along interventricular septum. Image from [14].*

The organs in the pelvic cavity are relatively protected thanks to the strong bone and muscle belt, however, spleen and liver ruptures have been reported [10].

Figure 2.7: *Puma, Puma concolor. Rupture of liver parenchyma. Image from [14].*

Skeletal muscles can lacerate with bone dislocation, due to trauma being associated with vigorous compression and stretching of muscle fascicles [10].

Organ damage can lead to the presence of blood in body cavities, as discussed in the previous section of this chapter.

Organ evisceration with blunt exposition of abdominal organs has also been observed [11].

2.f. Death

Death following car accident can be frequently caused by hypovolemic shock resulting from multiple traumas [27]. Hypovolemic shock is "the clinical syndrome that results from inadequate tissue perfusion; the most common form of it results either from the loss of red blood cell mass due to trauma or internal haemorrhage and plasma from haemorrhage or from the loss of plasma volume alone due to extravascular fluid sequestration within the body or lost from the body or gastrointestinal, urinary and insensible losses" [27].

3. Main lesions following electrocutions

Wildlife, especially arboreal mammals, when faced with roads interrupting their habitats, may try to cross them by using power lines. When the animal's body bridges the gap between two energised parts or between an energised part and a grounded metal part, it completes the circuit and the electricity travels through it [28]. As a consequence, it can undergo electric shock, i.e. the body serves as a path for electric current, but the animal is not killed immediately, or electrocution, i.e. the animal is killed immediately upon serving as a path for electric current [29].

In either case, the passage of the current through the body can produce a range of effects, from localised spasm to fatality with extreme severe burning [30]. The main injuries which animals suffer from are burns and internal organ damage, as well as central nervous system damage, skeletal injuries leading to limb loss or the need for amputation, eye damage and lacerations. The longer the duration of contact of the body with electricity, the more energy can cause electrothermal heating of tissues, which increases the degree of tissue destruction [15].

The most important factor determining the development of electrical injuries is the amount of current which flows through the animal; other determinants include type of circuit, resistance, size of contact area and current pathway through the body [17]. Regarding resistance, in birds it is important to note that dry feathers provide substantial resistance, but wet feathers have 10 to 15 times less resistance [18], reason why bird electrocutions are more frequent during periods of rain and snow [28].

3.a Burns

Burns are the major injury which animals suffer from following electrocution.

This is because skin is the main resistor to the current flow into the body, for which a 3-phase response was found [17]. "In the first phase, there is a slow rise in current as a result of the progressive destruction of the skin barrier. The second phase is characterised by an abrupt current increase after complete breakdown of the skin. In the third phase, the current ceases to flow after the tissue fluids are volatilised by electrothermal heat, resulting in desiccation and carbonisation with increasing resistance" [17].

Burns can be categorised by severity or degree. First degree burns are those which only affect the epidermis, i.e. the top layer of the skin [16]. Second degree burns penetrate the epidermis and can extend into the dermis; these can be further categorised into mild and severe, where mild ones fully penetrate the epidermis but just barely reach into the dermis, and severe ones extend deeply into the dermis but never reach the underlying fatty tissue [16]. Third degree burns are those in which all the tissue of the epidermis and dermis is destroyed, and also the fatty tissue below is affected [16].

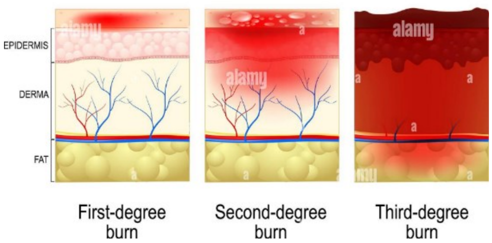

***Figure 3.1**: Schematic representation of first, second and third degree burns. Image from Skin Burn. Layers of the Skin. First, Second and Third Degree Skin Burns Stock Vector Image & Art - Alamy*

The smallest of the skin lesions, so-called current marks, are described as crater-like elevations of the skin around a sunken center [17]. Macroscopically, they are surrounded by a pale zone and have a raised border [17]. Microscopically, dermal collagen appears hyalinised with abnormal staining properties. Intra- and subepidermal blister formation is a common finding [17].

Figure 3.2: *Current mark, skin of a toe, raptor. Image from [17]*

In birds, burns are mainly seen on the wings distal to the elbow, lower legs and feet, as well as on the ventral body or face [31]. This is because feathers are poor electrical conductors, but if contact is made between points on the skin, talons, or beak, or if the feathers are wet, conduction can occur [28]. When the feathers are burnt, the edges curl or twist and light-coloured ones may be discoloured brown or charred [31]. Burns on the skin, instead appear as dry blisters, particularly on the scales of the feet or legs, the margins of which may be brown or charred [28].

Histopathological findings at burnt sites specific to electrocution cases include "intraepidermal and subepidermal separation, epidermal coagulation necrosis, smudging of dermal collagen, loss of differential staining of affected layers, and elongation of epidermal nuclei" [31].

It is important to note that burns can be small and obscured underneath feathers or can be mistaken for dirt or blood staining [31], which means an accurate search must be conducted during necropsy, especially when electrocution is suspected. Moreover, fully skinning the body is recommended as it may reveal larger burns in the underlying tissue and help to pinpoint the location of small contact points [18].

In mammals, burns in severe electrical accident cases can appear as depressed, yellow-grey, punctuated areas with central necrosis [32]. The main areas of the body affected are those which come into contact with the electrical source and the ground, namely the hands, head and neck, thorax, thighs and heels [33, 32].

Figure 3.3: *Severe injuries from four individuals of mantled howler monkeys, Alouatta palliata, that suffered from electrical burns. Image from [15]*

These injuries, depending on their severity and if the animal survives, can require prolonged hospitalisation and have multiple complications [33].

3.b. Internal organ damage

As electricity travels through the animal body, it can have an impact on the internal organs. The pathway of the current from the entry to the exit point determines the number of organs affected and, as a result, the type and severity of the injury [15].

Internal injuries can be caused by two different mechanisms: electroporation and electrothermal heating. Electroporation occurs in low-voltage accidents and involves the osmotic swelling of the tissues, vacuolization, and necrosis of cells following structural damage to the cell membranes [17]. Cells with larger surface areas, such as neurons and myocytes, appear to be more severely affected by this mechanism [18]. Electrothermal heating, instead, occurs in high-voltage accidents and prolonged contact durations in low-voltage accidents and involves the generation of heat within the tissues [17, 18]. The distribution of this type of injury depends on the pathway of the current [17]. Although there is an overlap between the two types of damages, electroporation usually occurs directly along the path of the current, while thermal injury is visible in areas of higher resistance, even if these are not along the pathway [18].

Commonly reported internal organ injuries include rupture of viscera [18], muscle damage and secondary renal damage [15]. Frequent findings in the heart are blood clots and petechial haemorrhages of the epicardium [32]; the latter are also found in the trachea, lungs and mucosa of the stomach [17, 34].

Since blood is a good conductor of electricity, current can flow along the blood vessels, causing damage to endothelial cells and myocytes resulting in thrombosis and haemorrhage [17]. This type of lesion may develop at any time after the accident, even after several weeks [17].

Common complications in survivors are rhabdomyolysis, i.e. the destruction of striated muscle cells, and myoglobinuria, i.e. the presence of myoglobin in urine, or haemolysis, i.e. the rupture of red blood cells, and haemoglobinuria, i.e. the presence of haemoglobin in urine, with resulting renal injury and failure [17]. Rhabdomyolysis and compartment syndromes as a result of vascular ischemia and muscle oedema may develop far away from the contact points and may be severe even in cases with minimal external evidence [17].

Internal organ damage also occurs following blunt force trauma due to the animal falling from the poles or lines after being electrocuted [35, 18]. Liver, pectoral girdle and rib fractures may be present in birds, as well as vascular tears causing haemocoelom, haemorrhage around the base of the neck, and/or haemopericardium [18].

3.c. Death

Death is a common occurrence following the contact of animals with electrical wires; for sloths, for example, the mortality rate can be as high as 70% [19].

It typically stems from multi-organ failure after the animal's core body temperature rises to over 43°C [19].

The main mechanism is cardiopulmonary arrest and subsequent oxygen deprivation: the electrical current causes universal stimulation of the nervous system and universal stimulation and contracture of the musculature, including the heart, for as long as it flows through the body; when the flow ceases, all muscles, including the heart, relax [29].

In high-voltage electrocutions, death results from the passage of current through the cardiac and/or respiratory centers of the brain or directly through the heart [18]. Depending on variables such as contact points, cardiopulmonary arrest may be caused by brainstem damage, paralysis, muscle spasm and/or direct injury to the heart [18]: current from the limbs to the head affects the brainstem and upper cervical cord, arm-to-arm or left-arm-to-leg current involves the heart [32]. In this type of accident, ventricular arrest is not preceded by fibrillation as occurs in cases of low-voltage electrocution [18].

In low-voltage electrical accidents, established mechanisms of death include "disturbances of cardiac T-wave, direct introduction of fibrillation by multiple high-frequency pulses, and long-term high-rate electrical cardiac capture causing sufficient ischemia to lower the ventricular fibrillation threshold" [17].

Death can also occur due to secondary traumatic injuries, such as those in the head and neck due to fall after electric shock, or due to multiorgan failure following severe burns [32].

3.d. Others

Two other relevant consequences of electrocution are central nervous system damage and skeletal injuries, with subsequent limb loss or amputation.

Central nervous system signs are common in victims of electrical accidents if the current pathway travels through the brain or spinal cord [17]. Animal models show that electrocution can lead to "pyramidal cell loss, reduction in Purkinje fibres, leptomeningeal haemorrhages and disruptions, and haemorrhages, disruptions, cavities and neuronal loss in the spinal cord" [17].

Skeletal injuries can occur when electric current only passes through the limbs but not the central nervous system; this can lead to limbs or limb function to be lost without associated cardiac arrest [29]. Moreover, femoral fractures due to strong muscle contractions or falling are sometimes seen [17]. Severe burns can also extend through the integument to cause fractured legs, digits or wings in birds [31]. In these animals, in fact, some of the more striking injuries associated with electrocution are fractures resulting in traumatic amputation; the ends of the amputated bones and skin are often charred [18].

Figure 3.4: *Bald eagle, humerus. The wing distal to the fracture site was avulsed during electrocution. Image from [18].*

When amputation is part of the rehabilitation process of an injured animal, such as that needed to remove the damage caused by gangrene following burns, it leads to the animal being unable to be returned to the wild and in need of being permanently kept in captivity [28].

4. Mitigation solutions: General

Following the above discussed research on the consequences of vehicle collisions and electrocutions on wildlife, an interest in the possible existing mitigation solutions arose, leading to the study which will now be explained.

4.a. Mitigation solutions for vehicle collisions

Three main mitigation solutions for vehicle collisions were found: overpasses, underpasses and fencing. Overpasses and underpasses can be grouped into the bigger category of wildlife crossing structures, i.e. "physical structures which increase the permeability of the road or other linear infrastructure by facilitating the safe passage of animals over or under it and, in the case of roads and railways, preventing collision with vehicles" [36].

Overpasses are structures which allow the passage of animals above the road; five main types were found: landscape bridges, wildlife overpasses, multi-use overpasses, canopy crossings and glider poles [36].

Landscape bridges are also known as eco-ducts or wildlife bridges [36]. They are wide bridges which extend over the road, typically covered in soil and planted with vegetation [36]. Their large size allows them to be used by the greatest diversity of wildlife and they can be adapted for amphibian and reptile passage [20].

Figure 4.1: *Example of landscape bridge. Image from Ecoduct | Ecopedia.*

Wildlife overpasses are also bridges covered by soil and/or a vegetation layer, but they are smaller than landscape bridges [37, 20]. They are designed exclusively to meet the needs of a wide range of species, from small to large [20]; ones specifically for crab crossing have been built on Christmas Island [38].

Figure 4.2: *Crab overpass on Christmas Island. Image from [38].*

Multi-use overpasses are narrow bridges designed for mixed wildlife-human use [36, 20]. They are best adapted in human disturbed environments and species used to human activity and disturbance are those which benefit the most from them [20].

Canopy bridges are ropes suspended above the road, either from vertical poles or from trees, designed for semi-arboreal or arboreal species which use the canopy cover for travel [36, 20]; they can be artificial, semi-artificial or natural.

The simplest artificial canopy bridge design consists of a single thick rope strung between two trees on opposite sides of a road; a good way to make this design more economical is to employ ropes previously used by climbers or to moor boats [21, 39]. More complex designs include double rope bridges, with the second rope either above the first one or beside it [24, 21], and triple rope bridges, with two ropes side by side on the horizontal plane and the third one above them; spider monkeys especially can benefit from the latter as it allows all hands, feet and tail to be in contact with the ropes [24]. Another form is a rope ladder bridge, with two external ropes always straight and two internal ones interlaced forming an "X" between each rubber hose step [40], or a vertical ladder bridge, with two ropes one above the other and vertical rope intervals [5]; to determine the appropriate distance between the top and bottom lines of this last design, the average back-limb to tail-tip of adult, juvenile and infant animals should be considered [24].

Figure 4.3*: Example of single rope artificial canopy bridge. Image from (Kimbrough).*

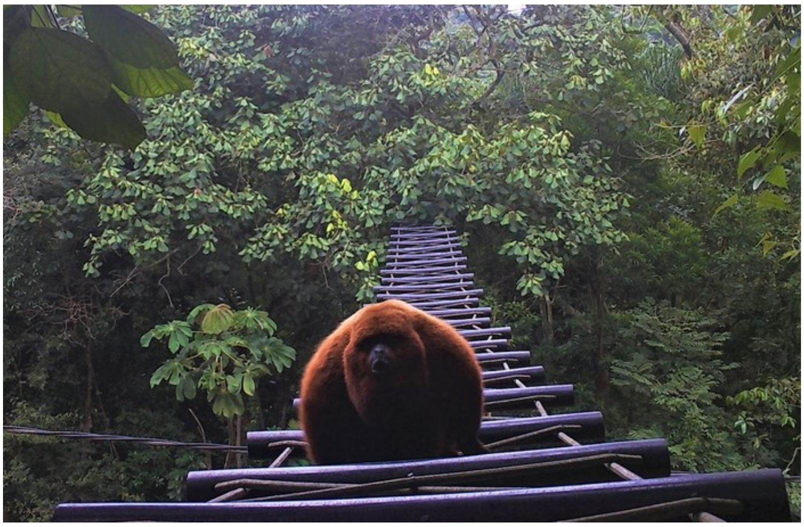

Figure 4.4*: Example of rope ladder bridge. Image from (Kimbrough).*

Semi-artificial canopy bridges can be constructed in two main ways, one cheaper and one more expensive. The most simple and cheap design consists of a single rope secured between two trees, over which chosen species of native vine are grown; the main drawback of this design is that a single rope can only cover a predetermined length, generally of about 30 meters [41]. The more expensive form consists of support posts and a flat metal grid, along which plants and vines are grown; this allows for added stability and vegetation cover, making it an optimal choice for wildlife [41].

Figure 4.5: *Example of semi-artificial canopy bridge. Image from NFR To Install Canopy Bridges in Hollongapar Gibbon Sanctuary - The Hills Times.*

Natural canopy bridges are simply branches from trees on either side of the road which overlap allowing for animals to cross [21]. These are always preferred by rainforest species and are also the cheapest kind of design [42]. To allow for these crossings to persist it is important to preserve connecting branches, reason why it is recommended that all linear infrastructure projects in forests with arboreal mammal populations include the maintenance of these canopy bridges [20, 43].

Glider poles are vertical poles placed in the centre median or on the road verge providing species which glide intermediate landing and launching opportunities [36]. The beams can either be sideways-pointing or vertical-pointing, with the latter being preferred by some species such as sugar gliders and squirrel gliders, possibly due to the fact that this design allows to shorten the glide distance [44].

Figure 4.6*: Example of glider pole. Image from Glider Poles Successful in Helping Animals Jump across Australian Highways | News.Com.Au — Australia's Leading News Site.*

Underpasses are structures which allow the passage of animals below the linear infrastructure [36]; there are seven main types, which will now be described.

Small- to medium-sized mammal underpasses are one of the smaller wildlife crossing structures passing under roads [20]. They are primarily designed for small- and medium-sized mammals, but use depends on how they are adapted for the specific needs of the species [20].

Large mammal underpasses are the largest of the underpass structures designed specifically for wildlife use [20]. They are primarily designed for large mammals, but small- and medium-sized mammals often use them too [20].

***Figure 4.7**: Example of large mammal underpass. Image from (Ament).*

Multi-use underpasses are similar to large mammal underpasses, but they are designed for co-use between wildlife and humans [20]. They may not be adequate for all species, and usually result in use by generalist ones common in human-dominated environments [20]. Larger structures can be built to accommodate the need for more space for both humans and wildlife [20].

Underpasses with waterflow are structures designed to accommodate for the passage of moving water and wildlife [20]. They are frequently used by some large mammal species, but this depends largely on how the structures are adapted for the specific crossing needs of the species [20]. Small- and medium-sized mammals can also use these structures, particularly if riparian habitat or cover is retained within them [20].

All of the four types described so far can have different shapes, such as arched, square, round, elliptical or rectangular, and different furnishings, such as logs and rocks to provide cover and simulate the forest floor, or escape poles and ropes to provide haven for arboreal species needing to escape from predators [37, 42].

Viaducts, also known as eco-viaducts or flyovers, are the largest of underpass structures, but they are usually not built exclusively for wildlife movement [20]; in fact, they can be built for three main reasons: specifically for wildlife use, specifically for human use or retrofitted to be used by wildlife [37]. Their large span and vertical clearance allow for use by a wide range of wildlife and they can also be adapted for amphibians and reptiles, as well as for semi-aquatic and semi-arboreal species [20]. They can be sloped, i.e. having a slope on each side of the crossing, or walled, i.e. having a vertical wall on each side [37].

Other variables of the design are the construction material, which can be concrete or natural materials, flooring covering, which can be soil or vegetation layer, and open median, i.e. they can have an open mid-section [37]. Ungulates, large carnivores and small carnivores are more likely to use this type of structure compared to both overpasses and other types of underpasses [37].

Figure 4.8*: Example of Viaduct. Image from Glista et al.*

Modified culverts or drains are crossings which are adaptively designed for use by small- and medium-sized wildlife associated with riparian habitats [20]. They are typically precast concrete cells or arches made of steel, square, rectangular or half-circle in shape [36]. They may be built for fauna passage or drainage, or a combination of both [36]. They are generally used by aquatic species, amphibians, small- and medium-sized mammals and carnivores [20]. Adapted dry platforms or walkways are typically constructed on the interior walls above the high-water mark [20]. Included in this category are oversized drains, i.e. drains in the middle of water courses and small rivers which are of a bigger size than that needed simply for water passage, in order to allow for enough space for the passage of wildlife [45]. Those of rectangular shape are typically more used, as they provide more space for the movement of fauna compared to large tubular shaped ones [45].
Lastly, amphibian and reptile tunnels are crossings designed specifically for the passage of amphibians and reptiles, although other small- and medium-sized vertebrates may also use them [20]. Many different designs have been attempted to meet the requirements of each species or taxonomic group [20].

All these wildlife crossing structures just described have been shown to achieve a huge reduction in collisions, in some cases up to 85% or 99% [46]. An example of this reduction can be seen in the 3km section of Route 34 passing through Hacienda Baru National Wildlife Refuge, Costa Rica, where 33 wildlife-crossing structures (29 underpasses and 4 overpasses) were installed; this area, in fact, was shown to record "only 26% of the mean mammal roadkill per monitoring survey for all transects along the 42 km segment (0.1875 vs 0.7129 roadkills per transect per monitoring survey)" [21]. Based on this comparison with other segments of the highway, and the higher mortality rate seen in the same area during the period when the animals were still learning to use the wildlife crossings, it was declared to be "reasonable to postulate that the lower rate of collisions mortality on the 3 km Hacienda Baru stretch of Route 34 [...] is attributable to the presence of the 33 wildlife-crossing structures that enable wildlife to travel safely from one side of the highway to the other" [21].

Another important mitigation method found is fencing. It is important to note that this alone can increase the barrier effect of roads and cause further habitat fragmentation, reason why it should always be combined with safe crossing opportunities for wildlife, i.e. the wildlife crossing structures discussed above, and/or escape opportunities, i.e. wildlife jump outs, for animals which end up in the fenced road corridor [47]. Fencing can also have different designs, such as having a concrete foundation or barbed-wire outriggers, or being angled towards the road [47, 48]. Furthermore, it can be designed to take into consideration the climbing and burrowing ability of animals, such as having top extensions or smooth vertical surface for climbing animals and a buried base or with a skirt for burrowing animals [49].

Figure 4.9: *Example of fencing. Image from "National Road Fencing".*

The large-scale implementation of this method requires a big investment, but it is likely to pay off in 16-40 years for the mitigation of full roads and in 9-25 years for hotspots of mortality, with the calculation of these times being based on vehicle damage costs [50]. Overall, fencing can be seen as a win-win solution for increasing traffic safety for humans and reducing road-related negative effects on wildlife; for the latter, it has been shown that this mitigation method, with or without crossing structures, can reduce road-kill by up to 54% [50, 49].

It is important to bear in mind that it is a lot easier, and cheaper, to build in these mitigation methods during road construction than it is to retrofit existing ones [51].

Other secondary mitigation methods can be divided into those which modify the behaviour of motorists, and those which modify the behaviour of animals.

The behaviour of drivers can be modified by local traffic management, i.e. devices to reduce the speed or volume of traffic, such as temporary road closures during species' migrations, chicanes, warning signs alerting to potential animal crossings, speed bumps and speed limits [36, 52, 4]. An example of the effectiveness of these methods can be seen in Jasper National Park where The Parks Canada Drivers for Wildlife combined public education with two digital signs recording speed and advising drivers to slow down to obtain a decrease of the number of road-killed animals by about 15% within the first 10 months [3]. Other methods include animal detection systems, which have been shown to provide a 57% reduction in large mammal road-kill, and ways to increase the visibility of animals to drivers such as roadway lighting, vegetation removal and wider stripings, as well as environmental education at the community level [47, 3, 52].

Figure 4.10: *Example of warning sign alerting to animal crossing. Image from mytravelcurator.*

The behaviour of animals, instead, can be modified through measures which scare them away, increase the attractiveness of areas away from the road or decrease the attractiveness of the road [49]. These include reflectors and mirrors, audio signals in right of way or attached to vehicles, olfactory repellents and electro-mats to scare them away [49, 3, 1]; intercept feeding, i.e. "strategically placed supplemental food sources in an attempt to divert the animals away from roadways", to increase the attractiveness of distant areas [20]; carcass removal and reduction of the amount of organic garbage thrown out of car windows to decrease the attractiveness of the road [3]. For the case of intercept feeding, for example, researchers in Utah found that this mitigation method may have reduced deer-vehicle collisions by as much as 50% [3].

An important consideration is that all these mitigation methods have a variety of benefits; the most relevant from the point of view of this discussion is the conservation of threatened species, but they also provide for an increase in human safety and a reduction in costs associated to vehicle collisions [47]; all these reasons put together show the great importance of these structures both for wildlife and people, reason why they should always be considered when the building of a new infrastructure is being planned.

4.b. Mitigation solutions for electrocutions

The main mitigation solution for electrocutions is the insulation of power lines. This involves the "covering of high- and low-tension cables with thermoplastic or thermoset insulation, which prevents conduction" [24]. This can be very expensive, reason why it could be a good idea to concentrate only on specific areas, as there is evidence in some localities that electrocutions occur in hotspots and insulation in these zones greatly reduces the number of electrocutions overall [22]. Insulation, though, can deteriorate over time and it loses effectiveness with damage, plus it does not guarantee 100% protection [24, 53]; for these reasons it should be combined with the installation of wildlife crossing structures, such as rope overpasses. An example of the effectiveness of this mitigation method can be see in Playa Hermosa, Guanacaste, Costa Rica, where the combination between power line insulation and the installation of a canopy bridge allowed to achieve a decrease in fatalities of mantled howler monkeys, *Alouatta palliata palliata*, from five to one annually in the period between 2015 and 2021 [5].

***Figure 4.11**: Example of insulated power lines. Image from (Australia).*

Another solution would be the installation of power lines underground. This is in fact the only long-term solution to prevent wildlife electrocutions in the future [19]. This process, though, is extremely costly, lengthy and requires the agreement of the electricity institutes; so, in the meantime, a more affordable and rapid solution is to insulate the existing lines, poles and transformers which are currently without insulation, as discussed above [19].
A further mitigation method is the installation of protection devices of barrier type, to avoid the fauna getting onto equipment or powerlines [23]. These include anti-climbing devices, such as rectangular plates of stainless steel placed on the anchor cables of posts, revolving devices, which avoid animals accessing electrical lines or having enough stability to hold on, and anti-perching devices, such as triangles of rigid plastic or rotating-mirror perch deterrents [23, 54].

***Figure 4.12**: Example of rotating-mirror perch deterrent. Image from (Mitigation – Bird Electrocution)*

Devices to increase the visibility of power lines might also help to reduce the number of electrocutions by deviating the flight of birds [23]. These include PVC spirals, reflective or not, placed on transmission and distribution lines [23].
Additional methods include habitat management, such as trimming branches which touch the lines while maintaining natural canopy crossings, or improving the habitat away from the wires to reduce the need for animals to use the power lines [22, 53].
A relevant note is that telephone cables don't directly pose a threat to animals, but they are usually connected to the same poles as electric wires so they can inadvertently bring them close to dangerous structures such as uninsulated power lines and transformers; but if the electrocution risk is low, for example if the wires are insulated, these cables might actually benefit arboreal species by providing a safe crossing away from traffic and other threats on the ground [22].

5. Mitigation solutions: the Alturas aerial bridges

The Alturas Wildlife Sanctuary, whose registries were analysed at the beginning of this dissertation, installed two artificial aerial bridges on the 26th of January 2024 to attempt to protect wildlife from the negative consequences they may suffer while trying to cross roads.
These bridges are 6.5 m high at their lowest point, and 20 m wide. One, hereafter named "Bridge 1", is a double rope bridge, with the second rope above the first one; the other, hereafter named "Bridge 2" was constructed according to the simplest possible design, i.e. one single thick rope made of plastic green material. The design for the first bridge was chosen with the intention of allowing animals to walk on the bottom rope while holding onto the top one with their tails. Both are attached to metal posts then connected to trees by a secondary bridge; in the case of bridge 2 the secondary bridge is connected to a fruit tree, in order to try and attract more animals.

Figure 5.1: *Double rope bridge installed by the Alturas Wildlife Sanctuary in collaboration with Somos El Cambio and ICE. Image from Alturas Wildlife Sanctuary | Facebook.*

Both of these bridges are located over route 34, Costanera Sur highway, between the towns of Dominical and Uvita, area from which many animals have been saved by the rescue centre (see Figures 1.4 and 1.5). When the highway was built, it cut through pristine jungle, separating the mountains and the oceans, and interrupting the biological corridor used by animals to move from north to south [55].

The bridges were installed in collaboration with Somos El Cambio, the non-profit organisation associated with the Envision Festival and ICE, Instituto Costarricense de Electricidad - the Costarican institute of electricity [55]. The Alturas Wildlife Sanctuary provides Somos El Cambio with their data generated on roadkill, which is then combined with the non-profit organisation's own data on road accidents and electrocutions, in order to identify the main areas for concern, which are the ideal locations to install safe crossings for the local wildlife.

During installation, camera traps were placed at one end of both bridges, in order to observe which animals use the crossings and to monitor their effectiveness [55].

Bridge 1 was first used after only 7 days, on the 2nd of February 2024, by a Panamanian white faced capuchin monkey, *Cebus imitator*. This event was closely followed by the first crossing, on the same day at 17.28, only 9 minutes after the first use of the bridge, again by the capuchin monkey. During the following month and a half, 80 videos were recorded by the camera trap; of these, 48 showed the bridge being used by Panamanian white faced capuchin monkeys and 9 showed its use by Derby's woolly opossums, *Caluromys derbianus*. In the two months after that, the settings of the camera were changed, leading it to record both photos and videos, adding up to a total of 2618 images, of which 285 showed Panamanian white-faced capuchins, 3 showed great kiskadees, *Pitangus sulphuratus*, and 206 showed Derby's woolly opossums using the crossing.

Figure 5.2: *Panamanian white faced capuchins, Cebus imitator, using bridge 1.*

These numbers show that the bridge is in a correct position for it to be used by wildlife as a safe crossing far away from the dangers present on the ground. However, the original design was not used as intended: the idea was for the animals to walk on the bottom rope and hold onto the top one with their tails, but instead they all simply walked on the top rope. This last fact, though, can be seen as a positive piece of information, as it demonstrates that the simplest design, with a single thick rope, can be sufficient for the bridge to be used by animals, making the addition of a second rope a redundant expense which can be easily avoided.

The use of bridge 2 was only analysed for the period between the end of April and the beginning of July. During this time, the camera trap recorded 203 videos, of which 2 showed a black iguana, *Ctenosaura similis*, 2 a variegated squirrel, *Sciurus variegatoides*, 3 showed common opossums, *Didelphis marsupialis*, 3 great kiskadees, *Pitangus sulphuratus*, 1 a green iguana, *Iguana iguana*, 1 a kinkajou, *Potos flavus*, and 43 Derby's woolly opossums, *Caluromys derbianus*. Most of these, though, only recorded the animals using the branches at the end of the bridge, rather than the crossing itself; in fact, only 7 videos showed any sort of interaction of the animals with the bridge: 1 showed a black iguana with one foot initially touching the bridge, 1 recorded a Derby's woolly opossum sniffing the bridge, 2 showed a Derby's woolly opossum using the bridge as leverage to push itself up the tree trunk, 1 showed a Derby's woolly opossum climbing down from the bridge and up the branch, 1 showed a Derby's woolly opossum climbing down the branch, onto the tree trunk and then onto the bridge and 1 recorded a Derby's woolly opossum climbing down the branch, up the trunk and onto the bridge, where it then took a couple of steps before stopping.

Figure 5.3*: Derby's woolly opossum, Caluromys derbianus, using bridge 2 to push itself up the tree trunk.*

This data demonstrates that the bridge has been placed in an optimal spot for wildlife, as many different species clearly inhabit the area. However, the lack of animals actually using the bridge to cross can be seen as a negative piece of information, and is possibly due to an incorrect placement; it was suggested to move the rope from the outside of the trunk to the bifurcation between the trunk and the branch, in order to hopefully allow easier access to the bridge by animals; the putting into practice of this suggestion has yet to occur.

Overall, the camera trap monitoring shows that the bridges placed by the Alturas Wildlife Sanctuary are useful as safe animal crossings and thus as mitigation methods for wildlife-vehicle collisions and electrocutions. The effectiveness of these overpasses also demonstrates how the collaboration between rescue centres, other NGOs and government bodies is an essential ingredient for mitigation methods to be put into place, especially in an efficient manner.

Conclusion

The purpose of this study was to show how roads and other linear infrastructures can have several negative consequences on wildlife, including habitat fragmentation leading to genetic isolation and inbreeding of populations, as well as wildlife-vehicle collisions and electrocutions as the animals attempt to cross the roads. This causes many animals to need the help of rescue centres, which, luckily, exist and often run around the clock.

When the animals arrive at the clinics they can have severe lesions, including bone fractures, internal organ damage and internal bleeding following car accidents and burns or internal organ damage following electrocutions. Some of these lesions are curable and allow the animal to be released back into the wild following a rehabilitation process, but others can be so severe that euthanasia is the best solution or that body parts essential for survival in the wild are either missing or needing amputation, causing the animal to become unreleasable and in need of permanent housing in an animal sanctuary.

There are, however, mitigation methods which are being implemented globally to try and reduce the problem at its origin, by diminishing vehicle collisions and electrocutions. The main solutions for vehicle collisions include overpasses, such as landscape bridges and canopy bridges, and underpasses, such as viaducts and modified culverts, along with fencing. For electrocutions, instead, the main mitigation can be achieved through the installation of power lines underground and / or their insulation. The installation of these mitigation methods should always be considered when a new linear infrastructure is being planned, and should be carried out through the collaboration of different institutions, such as rescue centres, other NGOs and government bodies, in order to allow for an efficient sharing of information leading to appropriate location and design choices, as can be seen by the example of the aerial crossings installed by the Alturas Wildlife Sanctuary alongside Somos el Cambio and ICE discussed above.

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