THESIS

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2022

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Factors influencing the hibernation of juvenile hedgehogs (*Erinaceus europaeus)* in the wildlife rehabilitation centre of Luxembourg

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Budapest, Hungary
2022

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I) Introduction

The European hedgehog (Erinaceus europaeus) is a nocturnal mammal and one of the oldest animal living on earth (Neumeier, 2016). It plays a crucial role in the well functioning of our ecosystem (Tabitha, 2020) however these past years have seen a substantial decrease in the hedgehog population of several European countries (Mathews F and Harrower, 2020.). The causes of this decline are various, among them : climate change, loss of habitat, human activities, the use of pesticides, roads and traffic (Taucher and Gloor, 2020). Around the 1980s, in order to help the struggling wildlife, Europe has seen the development of the first wildlife rehabilitation centres (WRCs). In these places, ill, injured or orphaned wild animals of different species are taken in for care with the final purpose of being released in full condition back into the wild. Hedgehogs are among the most common patients in WRC, as they are easy to catch and adapt well to life in captivity. However, they also have a physiological sensibility that has to be taken into account during the rehabilitation period : they hibernate. The hibernation period starts in winter around November/December and lasts until March. It is essential for hedgehogs to reach a certain weight before the beginning of winter, to guarantee survival throughout the hibernation period (Mullineaux and Keeble, 2016). The winter period is a period of high mortality for hedgehogs (Kristiansson, 1990), especially for “autumn juveniles”, born from female hedgehogs giving birth later during the year (British, 2022). This phenomenon of late breeding may become more frequent in the years to come due to climate change and disturbances in temperatures. The latest newborns are growing at the dawn of winter, thus do not have enough time and food accessibility to reach the minimum required weight to survive the hibernation period. Such juveniles are predisposed to dehydration, deficiencies, illnesses and eventually die before the end of winter. If these juveniles are fortunate and are brought to a WRC before or during winter, they will receive the necessary care and spend their hibernation period in captivity until they are fit for release, around the months of March/April. The hibernation period - especially the first one for a juvenile - is a critical stage for hedgehogs (Morris, 1984). Some studies have been made to determine the factors influencing hibernation of hedgehogs in the wild (Bearman-Brown, 2020). However, studies concerning factors influencing hibernation inside WRCs are lacking (South et al., 2020). The aim is therefore to provide more informations on this subject by identify these factors and by observing wether they have a positive, negative or neutral influence on the animal's recovery and probability of survival. These factors may vary, from the animal's weight, to the protocols of medical treatments given in one specific WRC. To evaluate them, the daily weight gain and the survival rate datas of juvenile hedgehogs that spent their hibernation in the WRC of Luxembourg have been calculated. The analysis is done over three hibernation periods belonging to the years 2019, 2020 and 2021. The aim of my analysis is to orientate veterinarians and workers treating wild hedgehogs on how to optimise the care and the hibernation quality of hedgehogs in WRC in order to increase the recovery rates inside the WRC and to guarantee a successful survival rate in the released hedgehogs in Spring. In a second intention, this analysis aims to underline the role and importance of WRC in the conservation of hedgehog populations and participates in raising awareness about the current threats hedgehogs are facing in Europe.

II) Literature review

2.1 Biological characteristics of the hedgehog

2.1.1 Origin and history

The European hedgehog (Erinaceus europaeus) belongs to the Erinaceidae family which is a very diversified family. Its subfamilies gather up to 26 living species, found in very different habitats. Some of these animals, like the gymnures, only possess hairs, while others like hedgehogs are characterised by a spiny skeleton which contains about 5000 spikes that shed and regrow over the years (Robinson and Routh, 1999). The Erinaceidae family's origin dates from more than 60 million years ago, making hedgehogs one of the oldest mammals on earth (Zeng et al., 2022). Over this long time, hedgehogs have converted to a nocturnal and insectivorous lifestyle, but have not otherwise markedly changed (Hedgehog, 2008). Spiny hedgehogs species are native to Europe, Asia, Africa and New Zealand. Among these species, the West European hedgehog is nowadays distributed among western and eastern European countries, while it has been introduced to New Zealand (Moss and Sanders, 1990).

2.1.2 Habitat and diet

Hedgehogs favour areas that offer both a satisfactory food supply and nesting potential. For this reason, they are mostly found on green grounds in gardens and parks, as these sites offer a range of different natural materials such as hedges, bushes, leaves and thicket (Neumeier, 2016). Several recent studies have shown the preference of hedgehogs for towns and cities (Van de Poel et al., 2015), (Pettett, 2016), (Yarnell et al, 2014). Although they are very unlikely to be found on agricultural land (Yarnell and Pettett, 2020), some hedgehogs still survive in rural areas where they prefer pasture fields to arable and woodlands (Williams et al., 2018). Adult hedgehogs are usually solitary animals that possess several nests in their home range. The hedgehog being a nocturnal animal, the nests are visited at night during foraging. It is therefore considered abnormal for an hedgehog to be seen active during the day, far off any nests (Robinson and Routh, 1999). Hedgehogs are primarily insectivores with a very varied diet mainly consisting of caterpillars, earthworms and beetles, as well as their larvae (Yalden, 1976), slugs and snails. However, they are also considered to be opportunistic omnivores (Mullineaux and Keeble, 2016) as they sometimes prey on birds and their eggs (Jackson et al., 2004). In addition to this wide diet, humans strongly contribute to the hedgehog's diet by supplying it with artificial food (Robinson and Routh, 1999) when it visits their garden.

2.1.3 Reproduction cycle and autumn juveniles

The breeding season starts after the awakening of the hedgehog once the hibernation period is over, with a noisy and lengthy courtship (Mullineaux and Keeble, 2016). The female hedgehog produces about two litters a year and the average litter size is made up of four to five hoglets (Robinson and Routh, 1999). The gestation period lasts for five weeks (Mullineaux and Keeble, 2016) and shorter breeding season may produce larger litters (Kristiansson, 1981). If the female is disturbed during this time, she will likely kill or abandon her offsprings (Ranson, 1941). Young hedgehogs are weaned and fully independent around 5-6 weeks of age (Mullineaux and Keeble, 2016). They are sexually mature at 12 months of age, an age characterised by a full adult dentition (Morris, 1983).

Hoglets born later during the year, near to the start of the hibernation period, are often referred to as “autumn juveniles”. These hedgehogs do not rely upon their mother anymore and are able to look for food by themselves but they haven’t reached the required weight to ensure a safe hibernation. Since they are mostly from late-born litters, they are seen from September to the end of November, although they can be found foraging during the day from December to April (British, 2022).

2.2 Importance of hedgehog’s preservation

2.2.1 A key role in our ecosystem

To understand the importance of the conservation of the European hedgehog’s population, it is necessary to know why its presence in our environment is essential. The answer partly lies in its diet. As mentioned previously, most of the European hedgehog’s diet consists of various adult insects and larvae. By eating these insects, hedgehogs participate in the control of the pest population ensuring plants, fruits and vegetables a natural protection. One consequence of a possible hedgehog extinction would be a lack of pest control leading to a threatening disturbance in the food chain and environment (Yalden D.W., 1976**).**

Besides controlling pest, hedgehogs play a crucial role as an indicator specie in several different fields. They can be used as an indicator specie to assess the quality of the soil of a specific area. A decreased hedgehog population in an area can be related to a lack of food, therefore to a lack of insects living in the soil, which in turn reflects a poor soil quality. Some scientists have worked further with the indication potential of hedgehogs and have been able to identify and quantify the chemical pollution of certain areas mainly by analysing hedgehog’s hair and spikes and by calculating the amount of pollutants that has been absorbed by the animal (D’Havé et al., 2006). They have also been able to analyse the damages that these pollutants have on the hedgehogs’ internal organs (D’Havé et al., 2005). This gives critical informations about the levels of pollution in the environment, suggestions of ways to reduce them and illustrates the impact of their exposure on the animal’s health, which can be used to evaluate the potential effect on human health.

Moreover, hedgehogs are the perfect hosts to a lot of ecto- and endoparasites. Ticks and their pathogens have especially been analysed, since wild hedgehogs represent a big reservoir (Szekeres et al., 2019). The tracing of these ticks using hedgehogs represents valuable epidemiological informations regarding the distribution of infectious diseases. Some of the infectious agents that have been detected in hedgehogs are linked to important zoonotic diseases or diseases that can be transmitted to livestock. Among the most significant ones, we can cite : Campylobacter jejuni (Krawczyk et al., 2015), Salmonella (Keeble and Koterwas, 2020), influenza viruses (Delogu et al., 2020), coronavirus (Monchatre-Leroy et al., 2017) and toxoplasma gondii (Hofmannová and Juránková, 2019). Surveillance of these infectious diseases underlines the possible role hedgehogs play in the "one health" concept (Vinhas Jota Baptista C. et al., 2021). Thus, hedgehogs are not only indicators of the soil quality, but can also be indicator of environmental pollution levels and trace certain infectious diseases. Another field in which they can be of use as an indicator specie is climate evolution by retracing historical climatic and geographic conditions (Sommer, 2007).

Lastly, hedgehogs have been ideal candidates to observe in order to collect additional knowledge on antibiotic resistance, this has been the case with Methicillin Resistant Staphylococcus Aureus (Monecke et al., 2013) and Salmonella (Molina-Lopez et al., 2015). Identifying the presence of antibiotic resistant bacteria in a hedgehog could indicate that this bacteria has spread from humans and domestic species, to the wildlife (Plaza-Rodríguez et al., 2021), further contributing to the one health idea.

2.2.2 Reasons behind the recent population decline

The last few years have seen a population decline in hedgehogs of several countries around Europe. Many causes contribute to this worrying phenomenon. Collision and traumas with cars are one of the most common cause of death for hedgehogs living in urbanised areas (Wright et al., 2019).

Furthermore, hedgehogs are facing a loss and destruction of habitat (Taucher et al., 2020), as gardens and public parks become scarce in cities. The few remaining green areas are over-maintained with short grass, perfectly trimmed bushes, free from messy leaves and branches, leaving poor possibilities for a hedgehog to hide, build a nest or forage (Wilson, 2018). Further new threats to the hedgehogs' integrity are found in these urbanised green areas and include in particular electrical fencing, pools and automatic mowers (Wright et al., 2019). Other human buildings, such as roads, fences, barriers, walls or trains, have negatively affected hedgehog populations (Braaker et al., 2017) by restricting their movements from one place to another (Rondinini and Doncaster, 2002).

The above described habitat loss and dissolution does not result in a direct and immediate extinction of the hedgehogs but instead, creates smaller populations and smaller habitat regions, forcing inbreeding and isolation (Keller and Waller, 2002). Such situation feeds what has been described in previous studies as the “extinction debt” (Tilman et al., 1994).

In rural areas, hedgehogs declining populations are partially explained by the presence of predators, mainly badgers (*Meles meles*) (Van de Poel et al., 2015), (Hof et al., 2012). Beside being predators, badgers also share some of the hedgehog’s diet, making them food competitors and so their recent population increase in different countries (Judge et al., 2014), (Geiger et al., 2018), could cause in return a decline in hedgehog numbers. Other predators include domestic dogs and cats attacking young hedgehogs (Reeve and Huijse, 1999).

When not endangered by predators, hedgehogs’ health are at risk due to the extensive exposition to pesticides in the rural landscapes (Garces et al., 2020) and to rodenticides (Dowding et al., 2010). Hedgehog’s are not targeted by pesticides and rodenticides but can still be poisoned by these toxic substances by ingesting them directly or indirectly when eating a contaminated prey.

Per oral contamination while eating food submits hedgehogs to other types of environmental pollution (Talmage and Walton, 1991). Invertebrates like earthworms contain high levels of heavy metals such as lead and cadmium (Heikens et al., 2000) which are highly toxic, even at low concentrations. Some studies also suggest that contaminants could be an additional stress for the organism, increasing winter mortality and decreasing the body condition during fragile periods like the hibernation period (Rautio et al., 2010). Likewise, noise pollution due to human disturbances such as music festivals represents a considerable stressor to hedgehogs (Rast et al., 2019).

Finally, climate change is responsible for abnormal variations in summer and winter temperatures, disrupting the hedgehog’s hibernation in winter (Rasmussen et al., 2019) as well as limiting food and water availability in summer. A global decline in insect biomass has also recently been observed and is believed to have a consequent impact on the hedgehogs' access to food (Hallmann et al., 2017).

2.3 A hedgehog particularity : hibernation

2.3.1. Physiology of hibernation

The hibernation period of the hedgehog usually lasts from November/December to March (Mullineaux and Keeble, 2016). Environmental temperatures below 8°C trigger hibernation, although divers other components such as the photoperiod, food availability, and the quantity of fat reserve are also connected to the hibernation trigger (Reeve, 1994). Before hibernation, a special nest called hibernaculum is built. Hedgehogs may wake up occasionally to change nests (Morris, 1973) and to look for food, especially if there is a warming in temperatures (Robinson and Routh, 1999). During hibernation the body temperature falls below 10°C, the animals is in a hypothermic stage, the heart and the respiratory rates slow drastically (Reeve, 1994). Hibernation is a physiological process demanding a lot of energy (Burlington et al., 1972) and which main source comes from the catabolism of lipids (Al-Badry and Taha, 1981). Fat reserves before winter are therefore especially important (Konttinen et al., 1964) so it is vital for juveniles entering their first winter to weight at least 450 grams (Robinson and Routh, 1999) and ideally heavier than 550 grams (Mullineaux and Keeble, 2016).

2.3.2 Factors influencing hibernation in the wild

Hibernation is a critical period and a hedgehog can loose up to 40% weight on average during this time (Kristoffersson and Suomalainen, 1966). In the wild, the achievement of a successful hibernation depends on several factors, which themselves can be negatively affected by human driven factors such as agriculture and climate change (Bearman-Brown, 2020). This means that any additional stress during hibernation may increase individuals mortality or decrease the body condition.

Exposure to environmental toxins like heavy metals including magnesium, copper, lead and arsenic, has been recognised as a stress factor for the animal (Rautio et al., 2010).

Therefore, hedgehogs in polluted areas may need to gain more weight to survive the hibernation period.

Habitat also plays role in the hibernation success, as hedgehogs need specific materials to build their hibernaculum. As a result, different types of lands and management practices of the lands can influence winter nest positioning and their quality (Bearman-Brown, 2020). Also, hedgehogs are more likely to travel to residential gardens during hibernation, particularly if food is supplemented artificially by the public. Thus, supplementary feed disposed by householders is suspected to have a direct influence on hibernation and overwinter survival of hedgehogs (Gazzard and Baker, 2020).

Many unnatural situations also have a direct effect on the reduction of insects density and availability : very warm and dry summers, tightness of the soil due to agriculture machines, the use of pesticides and molluscicides. This decrease of the insect population prior to hibernation prevents the animal from gaining sufficient fat reserves to ensure a good hibernation (Berman-Brown, 2020). In addition, there have been further evidences that higher temperatures in winter due to climate change have an influence on the way hedgehogs hibernate (South et al., 2020). Unstable weather and climate, with especially warmer and wetter winters, forces hedgehogs to awake from their hibernation state to move and change nests more often than usual (Newman and Macdonald, 2015), consequently spending their fast reserves faster and increasing mass loss during hibernation making them more vulnerable (Yarnell et al., 2019).

Regarding the general health status of the animals, parasites lay at the centre of concerns as they absorb their host's energy. A high amount of parasites lead to high energy costs. Thus, instead of using energy for fat storage or growth, the host's energy is only able to maintain its basic body functions (Pfähle, 2010). Any factors, including climate change or the general health condition, increasing the risk of hedgehogs becoming infected with parasites (and other pathogens) could result in an increase in vulnerability and mortality (Pfähle, 2010). Furthermore, as mentioned in part 2.2.2, a fragmentation and reduction of the hedgehog's habitat increases the density of individuals in smaller areas which in turn eases the spread of parasites and pathogens between them.

Lastly, heavier males in the wild tend to hibernate for a longer time (up to 10 days) than females (up to 7 days), with the longest periods being during the months of January and February (Waldhovd, 1979). Individuals with higher body weight also tend to loose more mass during arousal than individuals with lighter weight, as their physiological processes costs them more (Rasmussen et al., 2019), (Jensen, 2004) (Morris and Warwick, 1994). It has been suggested that periods of awakening for hedgehogs that are not disturbed by any other external factors could be controlled by endogenous factors and individual variability (Waldhovd, 1979).

2.4 Wildlife rehabilitation centres and hedgehogs

2.4.1 Factors influencing hibernation in Wildlife Rehabilitation Centres

In several studies, it appears that hedgehogs that have undergone hibernation inside WRCs and that have been released after their hibernation period have had a successful rehabilitation (Morris and Warwick, 1994), (Molony et al., 2006) and have well adapted to the wild after the period of captivity and despite the change in the site of release (Robinson and Routh, 1999).

It has been mentioned previously that in the wild, a decrease in food availability and movements between nests consume noticeable amounts of energy. However, in WRCs the food does not lack and movements are restricted as hedgehogs are held captive in cages. This could reduce the duration and the intensity of hibernation (Robinson and Routh, 1999) and could prevent a weight loss during hibernation. A recent study has identified some awakening phases to be particularly long, showing that captive hedgehogs are not in a deep hibernation, possibly due to the WRCs environment (food, nesting materials, disturbance) (South et al., 2020).

The same study has provided further informations regarding the availability of food : if food is provided throughout hibernation, hedgehogs are able to feed every time they wake up. As a hedgehog wakes up to eat, the cost of the wakening can be neutralised by the food it ingests so less weight can be lost. This way, hedgehogs hibernating in WRCs have lower weight loss than in the wild and it is even possible for them to gain weight during their hibernation in captivity. Furthermore, this study provides evidence that hedgehogs of different weight do not hibernate in similar ways. Larger hedgehogs wake up more often during their hibernation but end up loosing less weight than smaller hedgehogs. This is however in complete opposition with what has been observed in hedgehogs hibernating in the wild. The study explains this contrast by the ready availability of food. Heavy hedgehogs wake up more often but feed more so loose less weight, hence it is relevant ti insist on the importance of monitoring food consumption during hibernation in WRCs (South et al., 2020). Animals that wake up less frequently and sleep for a longer time, end up loosing more weight than hedgehogs who wake up more frequently, which appears to be rather linked to the time spent asleep than to the frequency of arousal events. However, the constant access to food appears to generally reduce weight lost during hibernation for all captive hedgehogs. Concerning eventual other external factors influencing weight, this study has further established that the process of taking the weight of hedgehogs at WRCs during the hibernation did not have any influence on weight loss (South et al., 2020).

2.4.2 Most common causes of admission of hedgehogs into WRCs

The two most frequent reasons for admissions of hedgehogs into WRCs are healthy hedgehogs that have been casually found by the public in gardens or parks, and orphaned juvenile or unweaned hedgehogs (Martinez et al., 2014). Usually two peaks of juvenile admissions are observed : one between June and August and a second one around October and December, the latter corresponding to late litters (Bunnell, 2009). The rest of the admissions are less common and comprises hedgehogs with infectious or parasitic diseases and wounded hedgehogs due to predation attacks or road accidents (Wembridge et al., 2016).

Recently, an increase in admissions because of malnutrition, notably among late litter juveniles (Bunnell, 2009) has been seen and might be linked to habitat changes and decreased food availability (Hof and Bright, 2009). Late litters juvenile average weight has been found to be lower than for the required normal weight of a weaned hedgehog and late litters are more vulnerable to mortality. Additionally, a female hedgehog which had a successful first litter early during the year might see its resources depleted and will have difficulties to give her second litter the same support. On the other hand, hedgehog milk contains many essential antibodies and passive immunity plays a central role (Landes et al., 1998), so the second litter may be at risk of being weaker and more vulnerable, hence less likely to survive despite the care given in WRCs.

Ultimately, it has been proved that the increased number of hedgehogs admissions in WRCs these past last years is unfortunately not the result of better public education and awareness, but is simply due to an increased number of distressed hedgehogs (Burroughes et al., 2021).

2.4.3 Main treatment protocols reported in the literature

The literature is rich of various protocols for the treatment of different conditions in wild hedgehogs brought into WRCs.

Ampicillin and amoxicillin clavulanic acid (30 mg/kg) are broad spectrum antibacterial agents used subcutaneously (SC) or per oral (Po), particularly useful for respiratory tract infections, but also skin and soft tissues infections and enteritis (Mullineaux and Keeble, 2016). Clindamycin is used in a lower dosage (10-20 mg/kg) Po for anaerobic infections in wound cases, abscesses and dental infections. Marbofloxacin (10 mg/kg) and enrofloxacin (10-20 mg/kg) can also be used SC as broad spectrum bactericidals but their use should be avoided in young hedgehogs because of their side effects on growing cartilage (Mullineaux and Keeble, 2016). In any case, to maximise the success of wound healing, it is essential to ensure a homeostatic, and euhydrated state of the animal prior and during wound treatment (Hernandez-Divers, 2004).

The treatment of wounds in hedgehogs is identical than the one done in other small mammals. Nonetheless, two behaviour traits specific to hedgehogs are important to mention : hedgehogs are notorious self- mutilators so it is imperative to resolve wounds as fast as possible (Hernandez-Divers, 2004). Secondly, hedgehogs may exhibit a self-anointing behaviour termed "anting." Upon a non-familiar or foreign smell, they produce frothy saliva as a defensive mechanism and rub it on their dorsal, caudal, and flank spines and skin (MacDonald D., 2001). The veterinarian should be aware of these particularities when treating wounds topically and topical treatment should be limited whenever possible.

Most common anti-parasitic treatments comprise ivermectin, which can be given as a SC injection (0.5-3.0 mg/kg) or topically (0.2-0.5 mg/kg) as a spot on (Mullineaux and

Keeble, 2016). Ivermectin is efficient against most of the hedgehog's parasites (fleas, ticks, mites). Treatment can be repeated after 10 days if needed. Levamisole (27 mg/kg) SC is also a frequently used drug for hedgehog, it is especially the treatment of choice for lungworm with 3 injections given at 48 hours of intervals. Against cestodes and trematodes, fenbendazole (100 mg/kg) Po is used for 5 days (Mullineaux and Keeble, 2016). Finally, against coccidia, toltrazuril (25-50mg/kg) Po is used once and is repeated only if necessary.

Other frequently used drugs include dexamethasone (1-5 mg/kg intravenously (IV), intramuscularly (IM) or SC) a corticosteroid useful for parasitic bronchopneumonia. As analgesic and anti-inflammatory, Meloxicam (0.5 mg/kg) SC or Po is essential used as well as Ketoprofen (4 mg/kg IM, SC, Po) and Carprofen (5-10 mg/kg) SC or Po (Mullineaux and Keeble, 2016). For more severe pain (in case of traumatic injuries for example), opioids such as buprenorphine (0.02-0.05 mg/kg IM, SC) and butorphanol (0.2-0.4 mg/kg IM, SC) can be used (Mullineaux and Keeble, 2016).

Anaesthetic procedure varies from one centre to another. Theoretically, medetomidine (0.1 mg/kg IM), ketamine (10-20 mg/kg IM) and diazepam (1.0-3.0 mg/kg IV, IM) can be used in combination (Mullineaux and Keeble, 2016). Before general anesthesia, premedication with butorphanol (0.05-0.4 mg/kg SC) or buprenorphine (0.01 mg/kg SC) is recommended (Carpenter et al., 2001). But in practice the use of inhalation anaesthetic agents such as isoflurane or sevoflurane in oxygen is the most effective and advantageous method as it is safe and rapid in terms of induction and recovery times. They can be used and maintained via face mask or endotracheal intubation (Pye, 2001). Furthermore, a quiet environment is needed to ensure a successful sedation and anaesthesia of hedgehogs (Lightfoot, 1999).

Different routes of administration are possible in the hedgehog, although intravenous access is difficult and almost never done. On the other hand, most medications are administered via SC or IM injections. SC injections can be given between the spines, superficially or deep into the panniculus muscle (Robinson and Routh, 1999). IM injections are usually given on the ventrolateral face, at the border between the hair and spines, into the orbicular muscle or the purse string muscle, which is well exposed even if the hedgehog is rolled up (Robinson and Routh, 1999).

Finally, dehydration is detected by testing the skin turgor and fluids can be administered SC along the back of the animal. SC and intraosseous fluid administration in the tibia are the most practical routes (Lightfoot, 2000). In addition, hypothermia is common and hypothermic animals are cold to the touch. The normal rectal temperature ranges between 33.5-36.8°C (Herter, 1965) but it is not simple to measure it. Heat supplementation can be brought using a heat lamp, electric heat mat, a blanket or a heat pad/bag (Mullineaux and Keeble, 2016).

III) About the Wildlife Rehabilitation Centre of Luxembourg

3.1 Localisation and mode of operation

The WRC of Luxembourg is the only rescue centre for wild animals of the country. It is located in Dudelange, a town found in the south, near the border with France. Its location alongside a forest and the country side is ideal to host wild animals. Luxembourg is a country with a 2 586 km² area and 88.000 acres of forest (Administration, 2003). The country currently does not have a known population number of hedgehogs. The winters in Luxembourg are cold, with a daily average temperature around 2.9°C. Below 0°C temperatures are frequent during the night, with the maximum value reaching down to -10°C (Meteolux, 2021). The centre hosts a wide variety of wild animal species and treats between 3000 and 4000 animals every year. Among them, around 200 hedgehogs are taken in each year.

3.2 Hibernation environment and conditions

3.2.1 Bedding

There are four different types of cages for hedgehogs at the WRC of Luxembourg. Adults or young weaned hedgehogs that are in critical condition or that need to be under constant observation are placed in individual intensive care unit (ICU) cages. The bedding is made of newspapers and the grids are covered with a net to prevent flies from entering. The average room temperature in the ICU is around 18°C. Because it is indoor, lights are on during the day and turned off at night. If an hedgehog's body temperature is abnormally low or if the animal is very weak, a heating lamp can be fixed to the grid or a heating pad can be placed under the newspaper. Each individual cage contains a carton box in which the hedgehog can hide.

Young hedgehogs under circa 150g are kept together in the incubator. Hedgehogs are moved out of the incubator once they are able to eat by themselves. The temperatures inside the incubator vary according to the animals size and age. Newborns require a temperature between 32-35°C. The incubator temperature is decreased to 30°C once spikes start to appear and further down to 25°C once they start walking and attempt to eat soft food. The bedding is made of newspapers but it is further covered by a towel, which can be folded to give them possibilities to hide.

Juvenile hedgehogs that are too small to hibernate outside (200-500g) but too big to be in an incubator and that are healthy enough not to be in ICU, are kept in individual indoor cages. If hedgehogs arrived together with their siblings, they are kept together in one same cage. These hedgehogs also have newspapers as a bedding, covered by a thick layer of straw, allowing them to dig and hide. The average temperature of the juvenile room is around 10°C.

Finally, the fourth group of hedgehogs is made of the ones that are big and healthy enough to hibernate outdoors (weighting at least 600g) but that would not be able to to build a nest and find a place to hibernate in the wild, as the winter period has already started. These hedgehogs arrive in the centre from the end of October, throughout all of the winter period. They are kept in outdoor cages so they are exposed to the natural environmental temperatures, weather conditions and lightning. The cages host one or two hedgehogs and a grid covers the top. All the covered cages are placed inside an aviary structure for further protection. The bottom of the cage is covered by newspapers and a generous amount of straw is also available for them to hide and build their nest.

3.2.2 Diet and feeding schedule

All of the cages - except the incubators - always contain two bowls : one bowl with food and one bowl with water. All animals beside the unweaned hedgehogs are fed once a day, in the morning. The good functioning of the WRC depends on donations. As a result, the food brands used to feed hedgehogs may vary but the food itself remains the same. Weaned hedgehogs are offered three different types of food in one same bowl : dog or cat canned food, dog kibble food and dead insects. Dead insects are commercialised exotic pet food and contains the following species : cricket, pinkies, hermetia, wax moth larvae and mealworms. Some weak hedgehogs in the ICU may receive about 5 ml of an additional food supplement (Nutriplus) Po, several times a day.

Hedgehogs in the juvenile room are fed similarly but if they come from the incubator, between 3-5 ml of milk might be added to their food to help them transition to hard food. Hedgehogs in the incubator are fed puppy powder milk (Esbilac) with a syringe (cow milk is not used as it causes severe diarrhoea in hoglets). They receive milk ad libitum as they usually stop drinking once they are full. Newborn hedgehogs between 0-3 weeks of age are fed with the milk syringe every 2 hours, day and night. When they reach 3-4 weeks of age, they are fed 4 times a day with the milk syringe and soft food is offered to them in addition. Above 4 weeks of age, hedgehogs are weaned and receive only hard food. The milk is heated up to 39°C before feeding. Once they are fed, the excess of milk is wiped from their mouth and their lower abdomen is gently stimulated with a soft tissue.

Outdoor hedgehogs are only offered dog kibble once a day in the morning, in case they would wake up from their sleep.

3.2.3 Cleaning procedure

Every morning the animals receive fresh water and food in cleaned bowls. Cages are cleaned once a day, every morning before feeding. Ajax soap diluted with water is used to clean the inside of the cages. When the animals are suspected to have an infectious disease or when the cage is emptied and given to a new arrival, disinfection is done after cleaning with the soaped water. Disinfectants that are used are Bacillol (propanol and ethanol) and Neopredisan (preventol).

Incubators are rarely disinfected to avoid the toxicity of the strong fumes. When they are disinfected in between arrivals, the incubator is unplugged and left to dry for several hours before hosting new hedgehogs. The towels used for the incubator are washed at 90°C in a washing machine and are changed everyday.

For hedgehogs kept outdoor, only the food and water bowls are washed everyday. There is no cleaning of the bedding for hedgehogs hibernating outdoors.

3.3 Entry and examination protocol

Upon arrival to the WRC, all hedgehogs are registered on a paper sheet and in a computerised system. The animals are registered under an identification number specific to each individual. The registration sheet contains detailed informations about the place where the animal was found and in which condition. Further medical data (weight, clinical signs diagnosis, treatment plan and doses) is added by the veterinarian after the examination of the animal. The paper version of the registration sheet is attached to the front of the cage in which the said animal is kept.

Hedgehogs are examined upon arrival and if necessary, they receive the first dose of a treatment plan based on the diagnostic. Hedgehogs are weighted on arrival and gloves are usually necessary to manipulate adults. Their general physical appearance is evaluated: the amount of ectoparasites, the capacity of rolling up if touched, the level of reactivity, their body temperature, the absence or presence of clinical symptoms… Hedgehogs that either need a more thorough examination, an emergency intervention or that can not be properly examined because of excessive rolling up, are placed under isoflurane and oxygen. They are placed in a closed transparent plastic box which is linked to the anaesthesia machine by a tube where they receive 5% isoflurane for 2:30 minutes. They are then taken off the box and placed on a heating pad with a mask and keep receiving oxygen with isoflurane at a maintaining dose of 2%. A more precise examination can then be conducted.

IV) Treatment protocols of juvenile hedgehogs in Luxembourg

4.1 For healthy weak or unweaned animals

Hedgehogs coming in the WRC with no health issues upon examination by the veterinarian do not receive any medical treatment. Their care relies solely on diet and housing. Hedgehogs that show signs of weakness, dehydration and hypothermia receive a SC fluids injection containing : NaCl, butaphosphan and cyanocobalamin (catosal), vitamin B and Vitamin ADE complex for 3 days. In addition to the fluids supplementation, they receive a SC injection of meloxicam (metacam) SID for 3 days. Extremely weakened animals may be fed Nutriplus Po to help them recover faster.

4.2 For infectious diseases

4.2.1 Bacterial diseases

Hedgehogs are suspected of being infected by a bacteria when they show one or more of the following clinical signs : weight loss, anorexia, ataxia, lateral decubitus, dehydration, apathy, white or pale mucous membranes and hypothermia. These hedgehog will receive an antibacterial treatment together with a supportive treatment. Different antibiotics are used for different conditions.

Enrofloxacin (Baytril 50) in the centre is used SC for 5 days, in combination with the supportive treatment described above (3 days of Meloxicam SC SID and fluids SC). It is principally used in case of respiratory infections, enteritis and skin wounds. Enrofloxacin use is avoided in young dogs, especially from large breeds, as it can cause cartilage and joint damages but the effects have not been studied in hedgehogs and their growth in size is not as consequent as in dogs. Oxytetracycline SC is sometimes used for 5 days in a second intention in case of respiratory tract infection.

Amoxicillin clavulanic acid (Synulox) is used SC for gastrointestinal tract infection and enteritis for 5 days. It is used similarly in combination with meloxicam (Metacam) and fluids, with the addition of simeticon Po (SAB simplex) to decrease the excessive gas formation in the stomach and intestines. A spasmolytic such as metamizole (Novalgin) is also added SC for 3 days. When the enteritis is hemorrhagic, we may add ivermectin (Ivomec 1%) SC once to the treatment plan.

4.2.2 Parasitic diseases

Endoparasite eggs are detected using the flotation test. A hedgehog with a positive flotation test, such as for Capillaria eggs will receive ivermectin (Ivomec) SC diluted 1/10 with NaCl once. In addition to ivermectin, the hedgehog receives enrofloxacin (Baytril 2.5) SC for 5 days and meloxicam (Metacam) SC for 3 days. Coccidia positive hedgehogs are treated once Po with toltrazuril (Baycox bovis). A flotation test is done a week later to verify the efficiency of the treatment and if necessary, toltrazuril is repeated. For the treatment of nematodes and cestodes, fenbendazole (Panacur) is used Po for 5 days. Hedgehogs with a high amount of ectoparasites (ticks, fleas and mites) are sprayed using Flohspray which contains permethrin and pyriproxyfen, killing all stages of the parasites during its first contact.

In case of myiasis infections, ivermectin (Ivomec) SC is used together with an ivermectin wash where the skin is flushed with diluted ivermectin to kill the myiasis, along with the routine supportive treatment meloxicam (Metacam) SC and fluids SC.

4.3.3 Viral diseases

Viral diseases are not commonly diagnosed in wild hedgehogs (Mullineaux and Keeble, 2016). The clinical signs may be apparent to a bacterial infection and the treatment is mainly symptomatic (fluids, anti-inflammatory and antibiotics).

4.3 For wounds and traumatic injuries

A hedgehog that shows one or several wounds resembling bite injuries or with a clear anamnesis of bites, receives marbofloxacine (Marbocyl) treatment Po or SC for 5 days together with meloxicam (Metacam) SC and fluids SC for 3 days. For wounds other than bites, hedgehogs receive altogether enrofloxacin SC (Baytril 2.5), meloxicam (Metacam) SC and fluids SC for 5 days. In case of larger and severe wounds where a daily curettage is needed, amoxicillin clavulanic acid (Synulox) is given SC for 7 days together with meloxicam (Metacam) SC for 5 days and tramadol SC for 3 days. In parallel to the SC treatments, the wound is disinfected and if necessary zinc oxide cream with paraffin (Mitosyl), silver sulfadiazine cream (Flamazine) or propylene glycol (Intrasite gel) can be used. If the wound is infected with myiasis, amoxicillin clavulanic acid (Synulox) or enrofloxacin (Baytril) is used SC for 5 days together with meloxicam (Metacam) SC and fluids SC. In addition, the infected wound is flushed with NaCl and the animal receives an ivermectin wash.

An abscess or a deep wound needing suturing is firstly cleaned and flushed then a “wet to dry” bandage is used with an iodoform gauze, along with clindamycin (Antirobe) Po, meloxicam (Metacam) SC and fluids SC for 7 days. If no amelioration is seen, oxytetracycline BID SC is then used for 7 days.

Along with a typical anamnesis and evident clinical signs (traumatic wounds and injuries), a hedgehog suspected to have suffered from a traumatic accident (shock against a car, a fall…) is often presented with bloody nostrils or blood in the ears, fractures and/or dyspnea. With dyspnea as the only clinical sign, hedgehogs receive oxygen supplementation through a mask, enrofloxacin (Baytril) injections SC for 5 days, meloxicam (Metacam) for 5 days, rapidexon (Dexamethasone) SC for 3 days and fluids SC for 3 days. If dyspnea is accompanied by other traumatic clinical signs, the animal then receives tramadol SC for 3 days as well. Before a heavy surgery in case of a severe traumatic injury (for example an amputation), a deeper analgesic such as buprenorphine is used SC for 3 days.

Regarding the hedgehog’s eyes, if an ulcer is detected, ofloxacin (Floxal) drops are given for 5 days. In case of a superficial eye bacterial infection, tobramycin (Tobrex) drops are used for 5 days. In both cases, an antiseptic solution (Ocryl) is used to clean the eye and contains : benzylkonium chloride, methylene blue, boric acid and rose extract.

Table 1. Dosages and routes of administration of drugs used by the WRC of Luxembourg on wild hedgehogs.

Antibiotic	Parasiticide	Fluid	Anti-inflammatory	Muscle relaxant	Anaesthetic	Analgesic	Other
Amoxicillin clavulanic acid (Synulox 175 mg/ml) 0,25 ml/kg SC	Fenbendazole (Panacur) 2,5% 1 ml/kg Po	Calcium gluconate 10% 0,5 ml/kg IM	Dexadreson 1-1,5 ml/kg IV, IM	Diazepam injectable 0,2 ml/kg IM	Dolethal 1 ml/kg IV, IC	Buprenorphine 0.02-0.05 mg/kg IM, SC	Simeticon (SAB simplex) Po 0,5 ml/kg
Clindamycin (Antirobe) 0,5 ml/kg Po	Ivermectin (Ivomec) 0,3-0,5 **mg**/kg Po, SC	Catosal 0,5 ml/kg SC	Metacam (5mg/ml) 0,1 ml/kg SC	Diazepam drops (100 mg/ml) 0,1 ml/kg Po	Isoflurane	Metamizole (Novalgin) 0,1 ml/kg SC	
Enrofloxacin (Baytril 2,5%) 0,5 ml/kg Po SC, IM	Toltrazuril (Baycox bovis) 0,4 ml/kg Po	NaCl, G5, Ringer, Amynin 20-50 ml/kg / day SC, IV	Metacam (1,5 mg/kg) 0,35 ml/kg Po			Tramadol injectable 0,1 ml/kg SC	
Marbofloxacin (Marbocyl) 0,4 ml/kg Po, SC		Vitamins ADE 0,1 ml/kg IM, SC	Metacam (0,5 mg/ml) 1ml/kg Po			Tramadol drops (100 mg/ml) 0,05 ml/kg Po	
Ofloxacin (Floxal) topically		Vitamin-B complex 1 ml/kg IM, SC					
Tobramycin (Tobrex) topically							

V) Factors influencing hibernation of juveniles in the wildlife rehabilitation centre of Luxembourg

5.1 Materials and methods

The registration paper version allows caretakers and volunteers to write daily relevant observations concerning the animal's health. Animals are frequently weighted, sometimes up to once a day for young animals. The weight and dates of measure were recorded on each registration paper. The data that has been used for the following experiment has been extracted from the computerised system as well as from the paper versions of the registration sheets.

All the animals were grouped by the years. Table 1 shows the total amount of candidates per year that were used for this study. In first intention, the animals were grouped by the types of treatment they received and in second intention, they were grouped according to their weight on arrival in the WRC. A hedgehog that did not receive any medical treatment during its stay in the WRC is referred to the “No treatment” category. “Only fluids” means a hedgehog which received nothing else but SC fluids (NaCl, butaphosphan and cyanocobalamin, vitamins B, vitamins ADE). “Only ectoparasitic treatment” means a hedgehog which received nothing else but an ectoparasitic treatment (Flohspray containing permethrin and pyriproxyfen). The different treatment plans, drugs used and dosages are detailed in part IV.

In order to identify the factors that could have an influence on the hibernation quality of juveniles recovering in the WRC of Luxembourg, two values have been used : the percentage of survival and the average daily weight gain of a hedgehog. The survival rate is based on the amount of hedgehogs that have been released back into the wild at the end of their hibernation period inside the WRC. The survival rate percentage has been obtained by dividing the number of hedgehogs who survived by the total number of hedgehogs.

The second value used for the evaluation of the hibernation quality is the average daily weight gain (or loss if preceded by a negative sign). The calculation of the daily weight gain of an hedgehog during its stay at the WRC of Luxembourg uses three datas : the final weight, the arrival weight and the length of the stay. The final weight in grams is the last weight taken of the animal the day prior to the release into the wild or to the death of the animal. The arrival weight in grams is the weight taken on the first day of the animal entering the centre. The length of the stay in days is calculated using the date of arrival and the date of release or death of the animal. The difference between the final weight and the arrival weight, divided by the length of the stay gives the daily weight gain of a given hedgehog. The average daily weight gain of all the hedgehogs corresponding to the analysed factor is then calculated.

Table 1. Total number and sex of juvenile hedgehogs at the WRC during winters of

	Total	Sex		
		Female	Male	Unknown
Winter 2021	32	13	13	6
Winter 2020	26	6	10	10
Winter 2019	39	3	9	27

5.2 Results

5.2.1 Causes of entry and treatment types

Table 2. Survival rate according to causes of entry and treatment types.

	Winter 2021		Winter 2020		Winter 2019		3 winters together (2021, 2020, 2019)	
	Survived / Total	Survival rate (%)	Survived / Total	Survival rate (%)	Survived / Total	Survival rate (%)	Survived/ Total	Survival rate (%)
No treatment	8/9	**89**	10/12	**84**	7/7	**100**	25/28	**89**
Only fluids	1/4	**25**	2/3	**67**	1/2	**50**	4/9	**44**
Only ecto-parasiti-cide	0./1	**0**	0./2	**0**	4/5	**80**	4/8	**50**
Bacterial infection treatment	6/7	**86**	0./3	**0**	3/6	**50**	9/16	**56**
Endo-parasitic infection treatment	2/4	**50**	0./0	**No data**	15./15	**100**	17/19	**89**
Wounds/ trauma	5/7	**71**	3/6	**50**	2/4	**50**	10/17	**59**

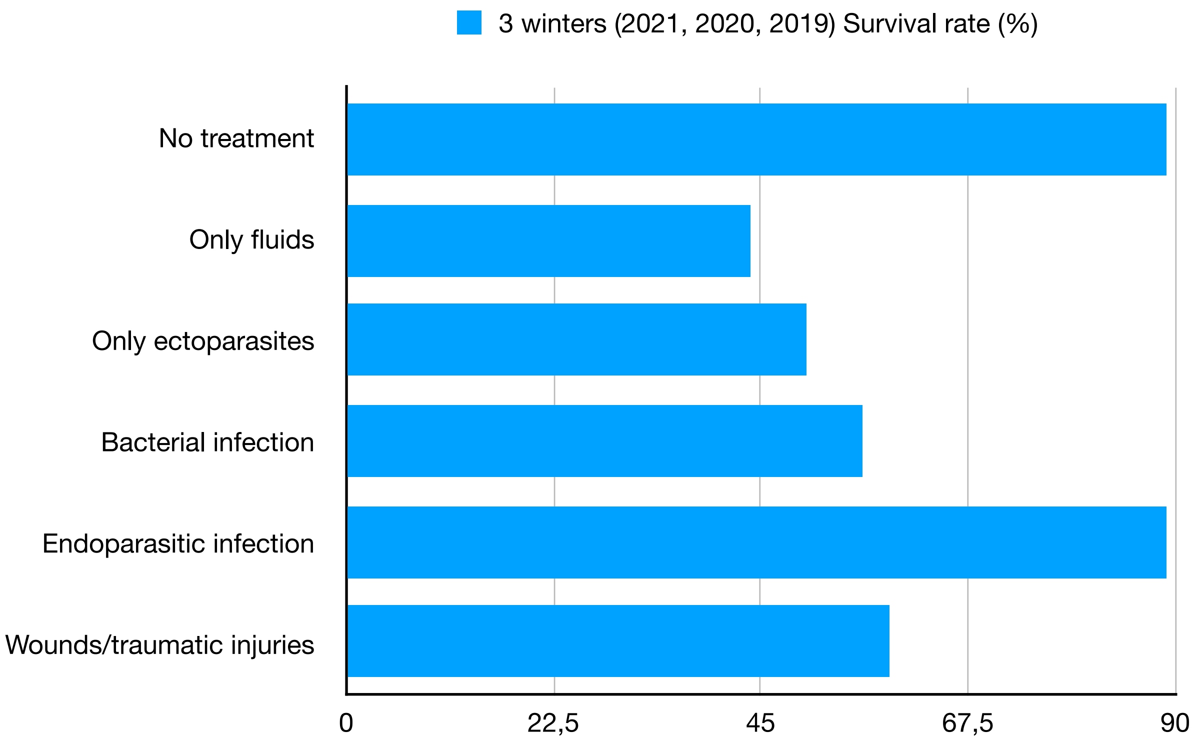

Figure 1. Survival rate (%) of hedgehogs over three winters with different treatments during their hibernation period at the WRC of Luxembourg.

Table 3. Average daily weight gain (g) of juveniles according to medical treatments.

	Winter 2021	Winter 2020	Winter 2019	Average of the 3 winters
No treatment	3,06	2,27	3,68	3,00
Only fluids	-28,98	2,38	3,24	-7,79
Only ectoparasites treatment	-7,00	-8,38	3,46	-3,97
Bacterial infection treatment	3,73	1,25	1,24	2,07
Endoparasitic infection treatment	2,67	No data	3,79	3,23
Wounds / trauma	5,28	-1,41	1,11	1,66

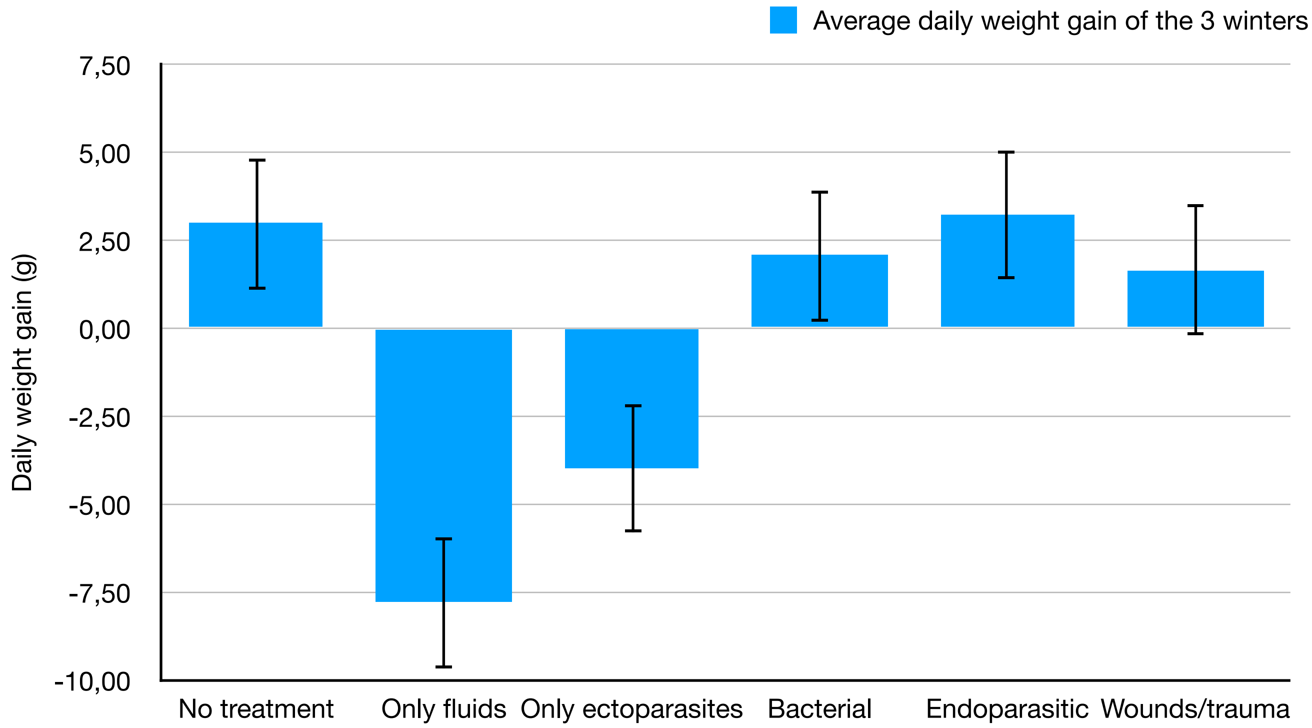

Figure 2. Average daily weight gain of hedgehogs over three winters with different treatments during their hibernation period at the WRC of Luxembourg.

5.2.2 Weight on arrival

Table 4. Weight on arrival and length of stay of juvenile hedgehogs during winters of 2021, 2020,

	Total	**Weight on arrival (g)**				**Length of the stay (days)**			
		< 200g	**200 - 300g**	**300 - 400g**	**400 - 750g**	**< 30**	**30 - 150**	**150 - 210**	**> 210**
Winter 2021	32	9	3	5	15	10	6	10	6
Winter 2020	26	7	6	3	10	8	3	9	6
Winter 2019	39	2	0	3	2	5	10	19	5

Table 5. The survival rate according to the arrival weight of juveniles at the WRC.

	Winter 2021		Winter 2020		Winter 2019		3 winters together	
Arrival weight	**Survived / Total**	**Survival rate (%)**	**Survived / Total**	**Survival rate (%)**	**Survived / Total**	**Survival rate (%)**	**Survived / Total**	**Average survival rate (%)**
< 200g	9/9	**100**	5/7	**71**	10/12	**83**	24./28	**86**
200g - 300g	1/3	**33**	3/6	**50**	6/6	**100**	10/15	**67**
300g - 400g	3/5	**60**	3/3	**100**	7/10	**70**	13/18	**72**
400g - 750g	9/15	**60**	5/10	**50**	9/11	**82**	23/36	**64**

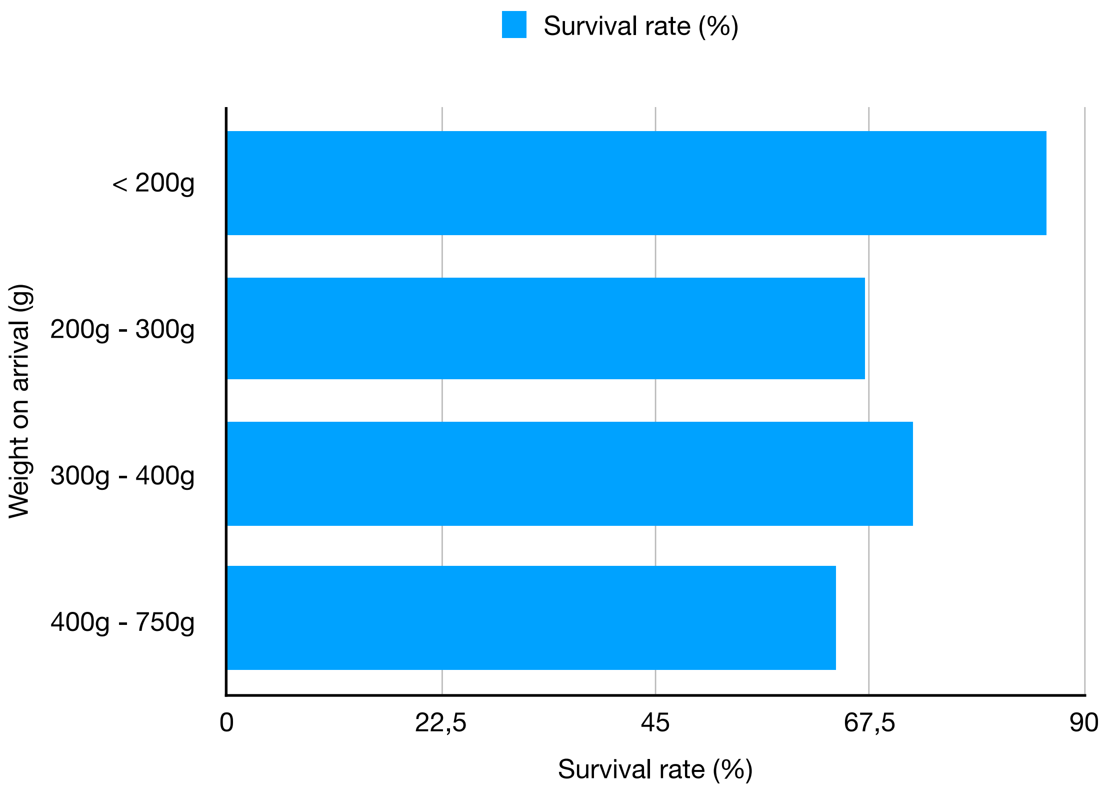

Figure 3. Survival rate (%) of hedgehogs over three winters with different arrival weight during the hibernation period at the WRC of Luxembourg.

Table 4. Average daily weight gain (g) according to the weight on arrival

Arrival weight (g)	Winter 2021	Winter 2020	Winter 2019	Average of the 3 winters
< 200g	4,25	2,77	2,90	3,31
200g - 300g	-2,92	-1,63	3,59	-0,96
300g - 400g	2,08	3,57	2,02	2,56
400g - 750g	0,76	-0,75	3,94	1,31

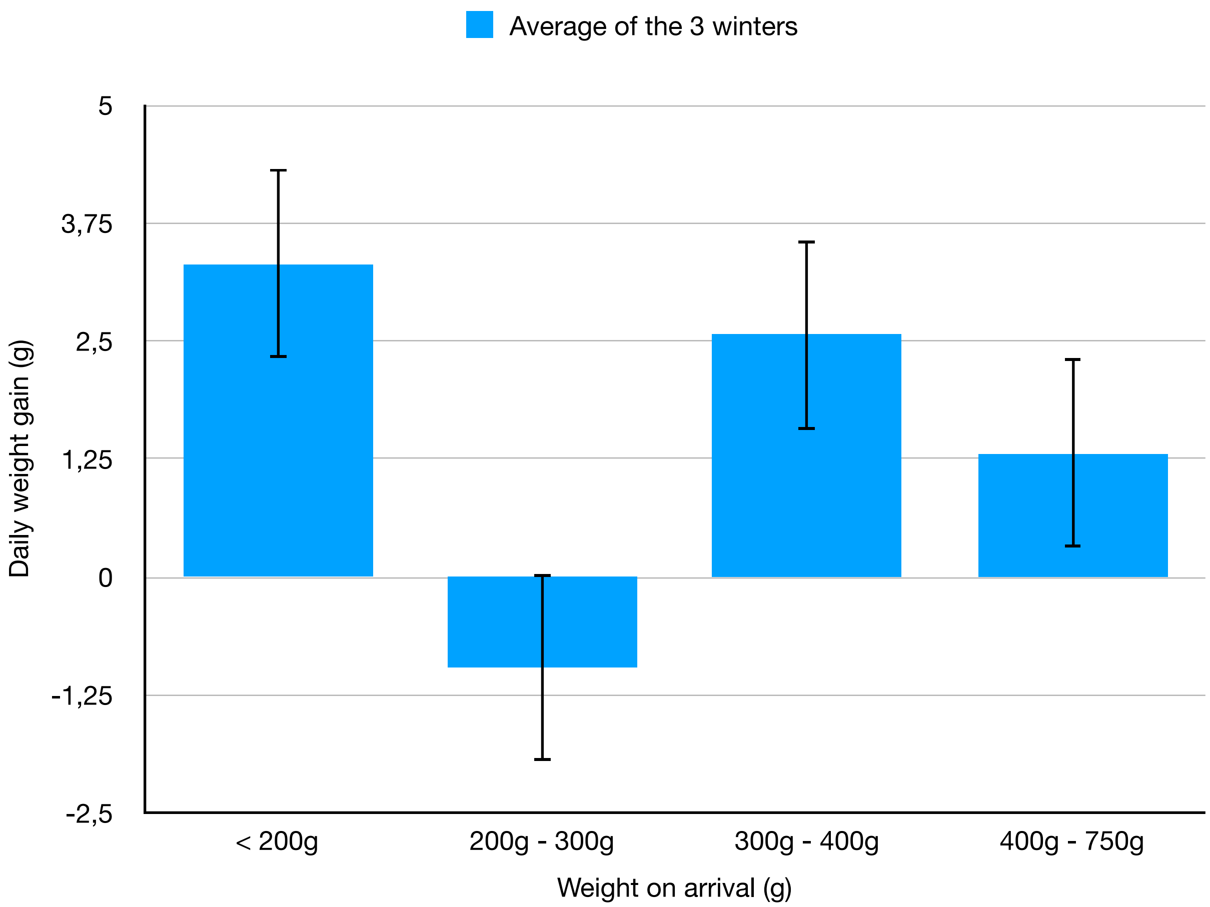

Figure 4. Average daily weight gain of hedgehogs over three winters with different arrival weight during their hibernation period at the WRC of Luxembourg.

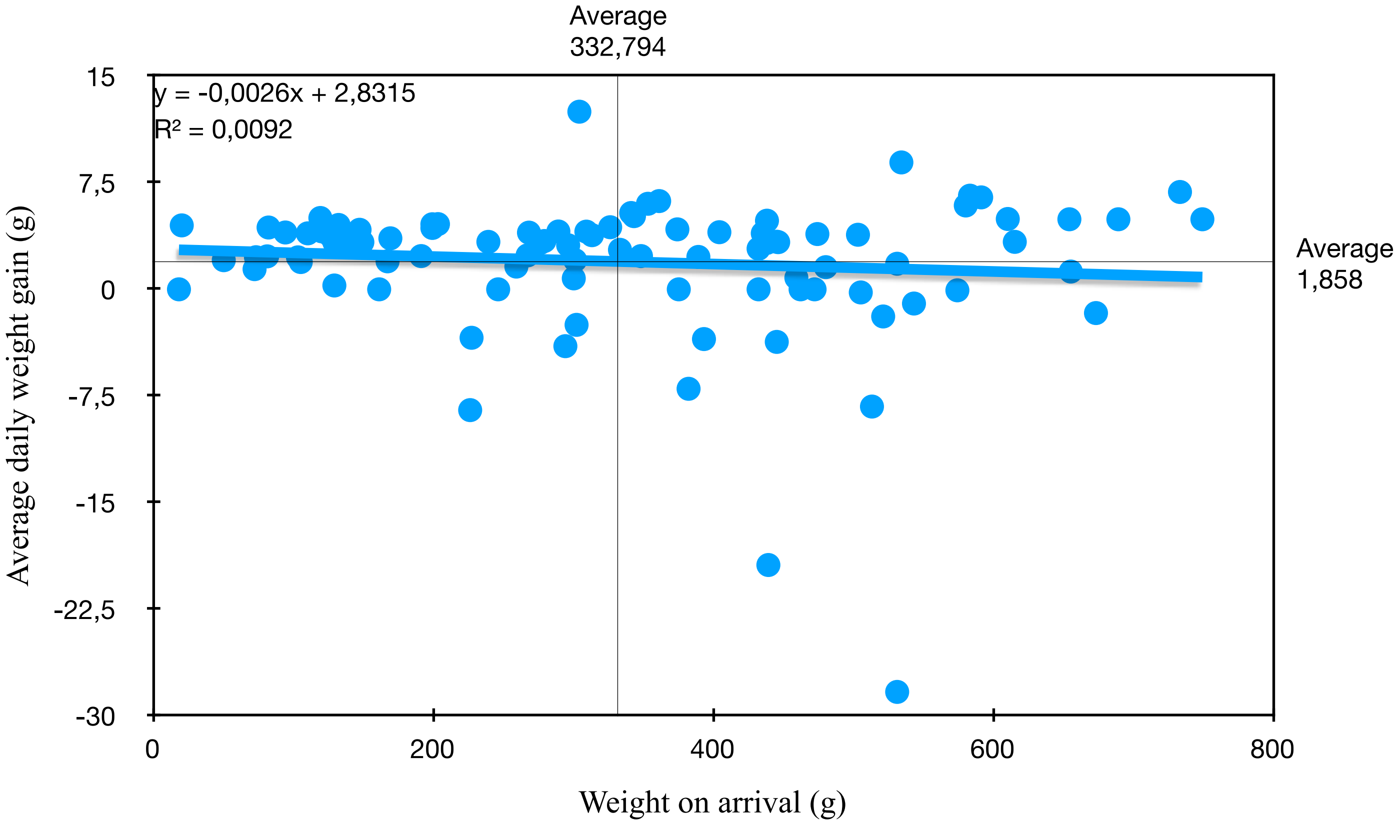

Figure 5. The average daily weight gain (g) of all the hedgehogs during hibernation over 3 winters according to their weight on arrival (g).

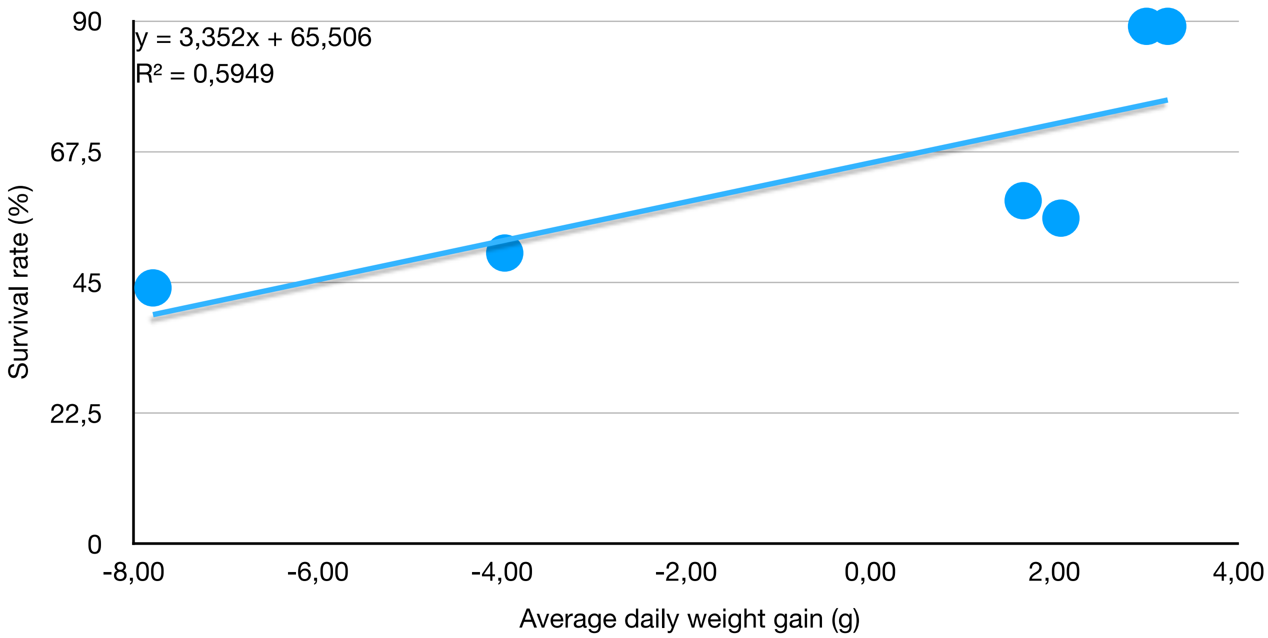

Figure 6. Relationship between the average daily weight gain and the survival rate of hedgehogs over three winters spent at the WRC of Luxembourg.

VI) Discussion

The study focuses on juvenile hedgehogs that have spent a part, if not all, of their recovery in the WRC of Luxembourg during the hibernation period. We define the start of the hibernation period in November and the end of it in late March, beginning of April of the following year. Hedgehogs under 750 grams of weight before or during the hibernation period are considered being underweight juveniles. The data has been collected over the winters of the years 2019, 2020 and 2021. In the interest of easing results interpretation, we consider these three winters equal in terms of environmental and climatic conditions.

If we look at the total number of hedgehogs who spent their hibernation at the centre the last three winters in table 2 and Figure 1, the hedgehogs with the highest survival rate percentage are the ones who did not receive a treatment at all and the ones who received an endoparasitic treatment. Hedgehogs that did not receive a treatment were healthy and so it logically explains their highest survival rate. It further suggests that their environment conditions and the food they received during this period was adequate as it kept them healthy and alive. In addition, we could assume that healthy hedgehogs had the least interactions with the veterinarians since they did not need any treatment or follow up, which meant that they were exposed to less stress factors than hedgehogs who did received a treatment. Hedgehogs that received an endoparasitic treatment had one of the highest survival rate too. Most of wild hedgehogs live fine with a few endoparasites and thus the high survival rate could be primarily explained by the general healthy states of these hedgehogs. The results support the idea that endoparasite infection may have a less damaging impact than a bacterial infection or wounds and traumatic injuries on the hedgehog's health and recovery during its hibernation period. It may also indicate that the treatment containing a parasiticide such as ivermectin and an antibiotic such as enrofloxacin does not have a negative effect on hedgehogs.

Hedgehogs that had the lowest survival rates where hedgehogs that received a minimal supportive treatment. These hedgehogs did not show strong clinical signs that would have justified a stronger treatment with the use of antibiotics, parasiticides or anti-inflammatories. It has been proven (Pfähle, 2010) that ectoparasites could represent a great loss of energy and weaken the animal. The results in table 2 may suggest that killing ectoparasites in an animal severely infected might not be enough. A better care that would include an additional supporting treatment with fluids, antibiotics or parasiticide, food supplementation may be needed to increase the survival rate, especially since severe infections generally happen when the immune system is weak. It may also be that the active substances (permethrin and pyriproxyfen) of the spray used to treat ectoparasites were negatively influencing the hedgehogs.

Animals that received only fluids were animals that were weak and that only received a supportive treatment. However, their survival rate was among the worst ones as shown in Figure 1, which indicate that weak animals may need to receive stronger medications despite not showing any other clinical signs. Hedgehogs with a bacterial infection and the ones who suffered wounds or traumatic injuries show an average survival rate. The results are good enough (higher than 50%) not to question the treatment plan efficiency and may have been lowered by the cause itself. In fact, a bacterial infection or a traumatic injury has more serious consequences on the health of the animal and naturally makes it harder for them to recover, despite being given the right care.

The treatment types influencing hibernation have been further analysed using the average daily weight gain of each individual over the three winters. The results illustrated by Table 3 and Figure 2 are lining up with the ones obtained previously in Figure 1: hedgehogs that received only fluids and an ectoparisiticide treatment were the ones with the highest daily weight loss. All the other hedgehogs gained weight during their hibernation period. Hedgehogs that did not receive any treatment and the ones that received an endoparasiticide had the highest daily weight gain, just as they had the highest survival rate. Despite bacterial infection and traumatic injuries implying serious health conditions, hedgehogs with other medical issues still managed to gain weight during the hibernation period. Figure 6 shows a clear correlation between the weight gain or loss and the survival rate, which could encourage veterinarians to take weight during the hibernation as a surveillance measure, especially as the process hasn't been linked to negatively influencing the animal's hibernation quality (South et al., 2020).

Concerning the survival rate according to the weight on arrival, Tables 4-6 and Figure 3 do not show evident differences among the arrival weights. Hedgehogs with the lowest weight and therefore the youngest had the best survival rate. This could be explained by the fact that they received a very good nutritional and environmental care during their early days - which were shown to be the most crucial days (Landes et al., 1998) -, making them become stronger and more resistant hedgehogs. In fact, older hedgehogs may have been weakened by the time spent in the wild where they could not get the support needed and this may have impacted their recovery capacity in the center. Also, it may be that younger hedgehogs were usually the ones that were unweaned and orphaned, thus did not suffered from any medical conditions. While older juvenile hedgehogs that were not able to put on the required amount of weight or kept losing weight during hibernation, may be the ones suffering from more serious medical issues such as infections or wound injuries.

It has been previously mentioned that the survival rate of animals that have accumulated sufficient fat reserves before hibernation is likely high (Bearman-Brown, 2020), which is the case of young hedgehogs that have grown and been raised at the WRC. These trends are confirmed when looking at the average daily weight gain in Table 6 and Figure 4. A study mentioned the fact that hedgehogs of different weight hibernate differently, in particular larger hedgehogs wake up more frequently during hibernation but loose less weight that lighter hedgehogs (South et al., 2020). This theory does not appear evidently on Figure 4. Hedgehogs between 200-300g on arrival show the highest daily weight loss, despite a good survival rate. A daily weight loss during hibernation for this weight group could suggest that these hedgehogs are prone to losing more weight than the others, especially if they have been exposed to an additional stress that has not been identified (Kristoffersson and Suomalainen 1964). They should therefore be given more attention regarding their care. Finally, Figure 5 confirms that there is no relation between the average daily weight gain and the weight on arrival, so the weight variations during hibernation do not depend on the hedgehog's arrival weight at the WRC.

In both cases, Figures 2 and 4 show that hedgehogs in hibernation could put on weight (on average, hedgehogs at the WRC gained 1.86 g daily during hibernation), which matches the results found in previous studies (Morris, 1971), (South et al., 2020). This study shows that the WRC centre of Luxembourg has a good overall survival rates among its hedgehogs that spent their hibernation in captivity. Hedgehogs that arrived in poor conditions or as healthy juveniles both showed good rehabilitation results. However, hedgehogs that did not show clinical signs that could suggest them being affected by a serious disease consequently did not receive much medications and were the ones with the least favourable survival rates. This could suggest that hedgehogs might not always show if they are sick or not as they might be affected by a serious internal disease despite the lack of clinical signs. Thus, as a general rule it could be interesting to treat all arriving hedgehogs with an anti-parasitic treatment and fluids supplementation, regardless of the presence or absence of clinical symptoms. This way, hedgehogs looking healthy even though they have a hidden internal problem, could be guaranteed better survival chances.

VII) Summary

The survival rate and the average daily weight gain have been used to identify and study the influence of different factors on the hibernation of hedgehogs kept inside the wildlife rehabilitation centre of Luxembourg during the winters of 2021, 2020 and 2019. The factors that have been observed to see if they influence or not the hibernation quality of recovering juveniles in the WRC are the following : the type of treatment a hedgehog received during its stay and the weight on arrival of a hedgehog. Medical treatments given to hedgehogs during their hibernation period at the WRC did influence their survival rate and daily weight gain, although it is difficult to separate the influence of the cause of admission from the influence of treatment itself. Hedgehogs that did not receive any treatment showed higher survival rate than those who did. Hedgehogs who received only a supportive treatment showed the worst survival rates. It would be interesting to see if these survival rates could be increased if the concerned hedgehogs were given a stronger treatment implying an antibiotic or an anti-parasitic drug. Furthermore, the average daily weight gain has been positively linked to the survival rate, which means that closely surveilling a hedgehog's weight during its hibernation period could help predicting its overall survival chances. No link has been found between the weight on arrival of a hedgehog to the WRC and its survival rate, although it appeared that youngest hedgehogs (under 200g) had the highest survival rate. In the majority of the cases, hedgehogs in the WRC did gain weight during their hibernation period, as shown in previous studies. The quality of care given by the wildlife rehabilitation centre during the hibernation period is proved by the successful results and highlights the importance of such centres in the conservation of the specie, at a time where the hedgehog populations are declining in

Europe and are at threat to worsen in the next decades. Hibernation is a complex process that may be influenced by many other factors, such as the interactions with the animal workers and veterinarians, the route of administration of treatments, some drug active substances used in the treatments, the type of food given and the temperature conditions. Further investigations on other possible influencing factors on hibernation could be of interest.

VIII) Osszefoglaló

Luxembourg-ban a vadvilág rehabilitációs központban (WRC) 2019, 2020, 2021 telén kutatók a túlélési arányt és az átlagos napi súlynövekedést használták fel arra, hogy megállapítsák és tanulmányozzák a különböző hatásokat a vadrehabilitációban belül tartott sünök hibernációja közben. A faktorok amelyekről információt gyűjtöttek, hogy megállapítsák: van-e hatása a hibernáció minősége a hibernáció közbeni gyógyulási folyamatra melyet fiatal sündisznókon figyeltek meg. Ezen megállapítások a következőek: A kezelés típusa melyet a sündisznók kaptak a tartózkodásuk alatt az érkezési tömegük alapján állapították meg. A hibernációs időszakban kapott kezelés hatással volt a sündisznók túlélési aránya és a napi súlygyarapodásukra, bár nehéz külön választani a probléma hatását a kezelés következményeitől. Azok a sündisznók melyek részesültek kezelésben magasabb túlélési arányt produkáltak azokhoz képest mint akik nem részesültek kezelésben. Azok a sündisznók melyek csupán a tüneteikre alkalmas kezeléseket kapták produkálták a legrosszabb túlélési arányt. Érdekes lenne látni, hogy ezek a túlélési arányok növelhetőek lettek volna-e ha az érintett sündisznók erősebb kezelést kapnak mint például antibiotikum kúrát vagy parazita prevenciós kezelést. Továbbá az átlagos napi súlygyarapodás pozitívan kapcsolódik a túlélési arányhoz ami azt jelenti, hogy szorosan figyelemmel kell kísérni a sündisznó súlyát a hibernációs időszak alatt mert segíthet megbecsülni a túlélési esélyüket. Nem találtak kapcsolatot a rehabilitációm központba bevitt sündisznók súlya és a túlélési arányuk között. Úgy tünt, hogy a fiatalabbak (200g alattiak) túlélési aránya a legmagasabb. Az esetek többségében a rehabilitációs központban levő sünök híztak a hibernációjuk alatt ahogyan azt előző tanulmányok kimutatták. A vadrehabilitációs központ által nyújtott ellátás minősége a hibernációs időszakban bizonyítja a sikeres eredményeket és rávilágít az ilyen központok fontosságára a természetvédelemben egy olyan időszakban, amikor a sündisznópopuláció csökkenő tendenciát mutat Európában és ez veszélybe sodorja a sündisznókat a következő évtizedekben. A hibernáció egy összetett folyamat amelyet sok más tényező is befolyásolhat, mint az állat gondozókkal és állatorvosokkal való interakció. A kezelés típusa és folyamata, a kezelések közben használt egyes gyógyszerhatóanyagok, az élelmiszerek fajtája továbbá a hőmérséklet is lehet befolyásoló tényező. További kutatások a lehetséges faktorok feltérképezéséről érdekes lehet.

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X) Acknowledgements

I would like to thank the following people who have helped me in completing this project:

My supervisor Dr. Nógrádi Anna, for believing in my ideas and guiding me through the writing of this thesis with a lot of patience, support and precious advices;

The Wildlife Rehabilitation Centre of Luxembourg for their contribution to data collection, and in particular Jill Gaasch, Céline Bertrand and Dr. Lena De Baets for their time and explanations; the workers and volunteers of the centre for their dedication and hard work in preserving wild animals' lives;

Dr. Valentina Ossola for introducing me to wildlife medicine, for sharing with me her vast knowledge with love and passion and for teaching me countless rules but above all confidence and self-belief;

To all of my teachers throughout these past five and a half years, for transmitting their knowledge and for helping me to become what I have always dreamed of;

To my many precious friends from Budapest and from home, whose unconditional love, support and generosity have helped me thrive on my veterinary student journey;

To my dear family, who has never failed to believe in me and whose infinite love and presence have been crucial to help me achieving my goals;

To Clementina and Dino, for their infinite love, kindness and for guiding me from above;

To my lovely dog for his moral support and companionship;

And finally, To my parents Valérie and Fabrice and to my brother Sandro, for their absolute love, endless support and encouragements, and without whom I would never have been able to be where I am today.

Appendix 4. Supervisor counter-signature form

I hereby confirm that I am familiar with the content of the thesis entitled FACTORS INFLUENCING THE HIBERNATION OF JUVENILE HEDGEHOGS (ERINACEUS EUROPAEUS) IN THE WILDLIFE REHABILITATION CENTRE OF LUXEMBOURG

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which I deem suitable for submission and defence.

Date: Budapest, 16 day 11 month 2022 year

ANNA LINDA NOGRADI DVM PHD

Supervisor name and signature

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