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Effects of feeding practices on the performance of Eurasian elk (*Alces alces*) in European Zoos

Master thesis

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Declaration

I, Eva Čelakovská, declare that I have elaborated my thesis independently and all the sources have been quoted and acknowledged by means of complete references.

I agree that this thesis will be stored in Library of Czech University of Life Sciences Prague and would be used for study purposes only.

In Prague, 2018

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Signature

Bc. Eva Čelakovská

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Abstract

Eurasian elk (*Alces alces*) is a common species bred in European zoological gardens. The main problem in captive Eurasian elk is relatively low lifespan and survival rate of calves which are closely connected with feeding practices. Our study was designed to better understand the good practices in elk husbandry which may help to improve their performance in captivity. The data were collected in 22 zoological gardens in European countries, in 2016. In total, 79 individuals were included in the analysis. Data analysis were focused on feeding strategies and breeding management. For the statistical analysis based on the breeding management was also used information obtained from ZIMS in years 1986-2016, focused on breeding success, twinning success and average longevity. 70% of zoological gardens switched between the winter and summer diet. Tree preferences in captive Eurasian elk were as follows: willow 0.97, oak 0.69, birch 0.67, pine 0.64, maple 0.61, aspen 0.58. Oak consumption significantly affected seasonal changes in faeces consistency, reported birth rate and reported survival rate of twins. Scots pine had a positive effect on calculated breeding success over the last 5 years (2012 – 2016). Use of premixes positively affected reported twinning rate, reported survival rate of twins and reported birth rate. Twinning rate over the last 5 years (2012 – 2016) was positively affected by browsing ad libitum. 83.3% females gave a birth every year. Calculated longevity 6+ months was 4.1 years and calculated percentage of calves surviving up to the weaning age was 36.59%. Eurasian elk is very interesting animal, not only because of antlers and appearance, but mainly because of differences and strangeness in feeding strategies.

Keywords: Breeding success, twinning rate, feeding strategies, longevity, nutritional requirements, diet composition

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1 Introduction and Literature Review

For over than a half century, biologists have studied foraging behaviour and food habits of Eurasian elk (*Alces alces alces*; Linnaeus 1758). This species is one of the largest living ungulates which ranges throughout the boreal and temperate forestlands of the northern hemisphere of the Eurasian continent (Hoffman 1989).

They are classified as specialist herbivores because of their browsing preferences which predominantly consist of one tree species (e.g. *Salix*) (Crawley 1983). They are adapted for the different seasonal type of diet occurring during the fall and spring by changes in their digestive tract morphology and by reducing their metabolism (Clauss et al. 2009). Eurasian elk are mostly solitary animals and as a wild one also captive elk seek for the non-disturbed areas with water or marshy surfaces with plenty of aquatic vegetation (Anderson 1991). They browse throughout the day and require enough browse material all year-round. These facts make elk very special species which needs very high nutritional requirements.

Although after the Second World War the number of elk in nature still increase (Dziezciołowski & Pielowski 1993), their longevity in captivity is low and is mostly connected with poor breeding management. Because of this, it is very important to find out the best feeding and breeding practices and thus improve management of captive animal populations.

1.1 Natural history

1.1.1 Taxonomy

Grubb (2005) recognized two distinct species, Eurasian Elk (*Alces alces*) and Moose (*Alces americanus*), which differ in karyotype, body proportions, colouration, form of the premaxilla, and structure and dimensions of antlers (Geist 1998; Boyeskorov 1999). Groves and Grubb (1987) called them "semi-species". However, Geist (1998) recommended their separation at the subspecies level (i.e., *Alces alces americanus* (Clinton 1822) and *Alces alces alces* (Linneaus 1758). In fact, there is one more species which may be taken as a single species. Boyeskorov (1999) referred this species as *Alces americanus cameloides* with origin from the Manchuria/ Primorye region.

Hundertmark *et al.* (2002b) reported that analysis of mtDNA revealed three haplogroups, one primarily European, one entirely Asian and one primarily North American. Eight extant sub-species are recognized here (Hundertmark 2016):

Family:	*Cervidae*
Genus:	*Alces*; Gray 1821
Sub-species:	*A. a. alces* - Scandinavia, Finland, Baltic states and Poland
	A. a. americanus - E Canada (C Ontario to Newfoundland)
	A. a. cameloides - N Mongolia, Ussuriland, Nanchuria
	A. a. gigas - Alaska and Yukon
	A. a. andersoni - British Colombia to Minnesota
	A. a. buturlini - NE Siberia and Kamchatka
	A. a. pfizenmayeri - C Siberia and Stanovoy and Cherskiy
	A. a. shirasi - South Alberta to Wyoming and Utah
Common name:	Elk, European elk, Eurasian elk, Moose, Siberian Elk

This thesis is focused on *Alces alces alces*, which is the breeding subspecies common in European zoos.

1.1.2 History

The first remains of the species *Alces alces* were found back in Last Glacial Maximum, approximately 17 000-27 000 years ago in the refuge located in the north-western Balkans, northern Italy and in the areas of the Czech Republic and the Republic of Moldova (Sommer & Nadachowski 2006). After the Last Glacial Maximum, Eurasian elk population expanded to colonize almost the whole European continent. The maximum range of Eurasian elk in the Holocene was from the Pyrenees and Central Europe to Denmark and Great Britain. Elk populations declined and died out most of the sub-species until the Middle ages (Schmölcke & Zachos 2005). However, elk population were still numerous in Eastern Europe (Filonov 1983).

The smallest range of Eurasian elk was in the middle of 19th century and at the beginning of 20th century. At that time elk survived only in some areas in Poland, Belarus, Scandinavia, Lithuania and Latvia (Ryman et al. 1977; Filonov 1983; Dziezciołowski & Pielowski 1993; Schmölcke & Zachos 2005). During the 19th-20th centuries, the only large elk population existed in Russia (Filonov 1983). After the Second World War, the number of elk increased (Dziezciołowski & Pielowski 1993).

1.1.3 Geographical distribution

Nowadays, the range of Eurasian elk covers the central, eastern and northern parts of the European continent (Figure 1).

Figure 1. Eurasian elk distribution (IUCN: http://maps.iucnredlist.org)

They are found in the Baltic states, Scandinavia, European Russia, Poland, Belarus and northern Ukraine. Small populations of elk exist also in the Czech Republic (Homolka 1998), especially in the south and north part of Bohemia (BioLib 2018). The species is occasionally recorded in Hungary, Germany, Croatia and Romania. The population range from sea level up to 1 500 meters in Europe (Henttonen et al. 2007).

1.1.4 Population

Eurasian elk is an abundant species in Europe. The European population is in the range of 0.5 million individuals, while global population is close to 1.5 million individuals (Bauer & Nygrén 1999). An approximate calculation of the population in European countries includes the following: Czech Republic – a maximum of 50 individuals, Poland – 2,800 individuals, Lithuania – 3,900 individuals, Estonia – 10,000 individuals, Latvia – 21,000, Finland – at least 110,000 individuals, Norway – 110,000 individuals, Sweden – 340,000 individuals (Andersen et al. 2010; Ruusila & Kojola 2010).

1.1.4.1 Conservation

Eurasian elk is listed on Appendix III of the Bern Convention. There is a large number of protected areas where Eurasian elk occurs (Wemmer 1998). Eurasian elk is protected under national legislation in several countries (e.g. Germany). The conservation sites were identified over the entire range. According to Ruusila and Kojola (2010), the species is also subject to intense management in some countries, such as Finland, through hunting quotas. The main conservation concern is extensive landscape and regional scale habitat change.

1.2 Morphology

1.2.1 Body description

Eurasian elk are the largest living ungulates in *Cervidae* family not only because of their size but also because of their height. Elk are highly sexually dimorphic, with females being more than 40% lighter than males (Bowyer et al. 2003). Their massive bodies are kept by long, slender legs. They have a large, prolonged head kept by humped shoulders with a thick neck. Reach a weight from 320 to 450 kg in males and from 275 to 375 kg in females (Hoffmann et al. 2008). Their height ranges from 1.7 to 2.1 meters measured from the hoof to shoulders. Lengths of both sexes range from 2.0 to 2.9 meters with a tail length up to 10 cm (Bubeník 2007; Hoffmann et al. 2008).

One of the most conspicuous features of the species is its bulbous, long, drooping muzzle. The upper lips of elk overhang the lower lips. Between the nostrils is a triangular patch of bare skin. Under the neck is a flap of furred skin called the bell. This "bell" may or may not be present in a female. Elk do not have upper incisors or canines. Because of it, elk must bite off plants between their lower incisors and a bony upper palate (Wilson & Ruff 1999; Bubeník 2007).

1.2.2 Antlers

Antlers are carried by males only and can weigh as much as 20 kg with spreading up to 1.5 m. They grow mostly during the spring from March to April, mature in time for the rut from September to November and they cast from January to February. Antlers can grow extremely fast with rate up to 4-6 cm per day (Hoffmann et al. 2008; Chapman et al. 1975). The most common type of antlers in Eurasian elk is a cervine-shape type (see Figure 2) mostly without palmation contrary to American moose which has palmate antlers (Engan 2001). The frequency of palmate antlers increases to the north and with increasing body size (Engan 2001; Sæther & Haagenrud 1985). The largest antlers are found after six-years of age (Solberg et al. 2006).

Figure 2. Antlers of Eurasian elk (rejser.guide.dk)

1.2.3 Pelage

Pelage is generally dark brown or greyish black, with the lower legs being a lighter brown, greyer on flanks and underside. Pelage becomes browner during the summer and greyer and woollier during the winter. On their neck grow hairs 15 to 25 cm long and serve as a thermal insulation (Novak 1999; Hoffmann et al. 2008). Young individuals have rich reddish pelage and do not have the spots like the other young in *Cervidae* family (Novak 1999).

1.3 Reproduction

The Eurasian elk are seasonal polyoestrous mammals. Their mating takes place during the autumn. During the mating females and males attract each other by scent marking trees and making vocalizations (Schwartz & Hundertmark 1993). The oestrus period occurs during late September and early October but may vary with the age of individuals and within regions (Malmsten 2014; Garel et al. 2009), and lasts from 24 to 25 days. The gestation period lasts for 243 days and the female gives birth to one or two calves (Garel et al. 2009). Females give birth in spring, from May to June. The calving place is often an undisturbed area. The calves are very vulnerable during their first few weeks. According to AnAge (2017), the average weight of healthy calf after birth is 12.8 kilos with weight gain approximately 1 kg per day. Nursing of calves occurs immediately within the first few hours after birth. While the offspring are young, only females take care of them. Calves are weaning approximately at the age of three to five months (100 days) with an average weight of 94 kg, and stay with the mother until shortly before the new calves are born (Malmsten 2014; AnAge 2017; Schwartz 2007).

1.3.1 Twinning rate

Variation in twinning has been attributed to differences in body condition of elk (see Figure 3). However, according to Boer (1992) and Schwartz and Franzmann (1991), it is supported that such a relationship is linked to indirect feature (e.g. correlation with habitat quality or population density). In the research done by Testa and Adams (1998) in Sweden, 11 (23%) from 48 pregnant females had twins. Another research was done by Jones et al. (2017) during the years 2014-2016 in North USA, where twinning rates were measured through direct observation by stalking yearlings, and showed a pregnancy rate of 77% with a twinning rate of 14%.

Low twinning rate may be caused by a poor female condition which may result in low yearling productivity, increased age of first reproduction and reduced fertility (Musante et al. 2010).

Figure 3. Newborn twins with female (Photo: Prague ZOO archive)

1.4 Longevity

The maximum longevity of captive *Alces alces* has not been established yet. Weigl (2005) reported that record lifespan is 18.4 years in captivity. A lifespan of the wild elk has been recorded as 27 years as a maximum (Peterson 1974). However, according to Grzimek (2003), average longevity is 16 years in the wild. But still, because of these contradictory reports, the average of the longevity in Eurasian elk is classified as unknown.

1.5 Social behaviour

Eurasian elk are not a kind of social animals they are not marking or protecting their territory. They are mostly solitary and alert animals, except during the mating season, they keep distance around 100-200 hectares (Belova 2003; Andersen 2010).

Both sexes live separately in the wild, only females have a strong attachment with calves and remain with them up to the new parturition. Only during the mating season or during the cold winter, males and females may join and create social groups (Boyer 2004; Malmsten 2014). Outside the mating period, males and females are separated temporally, spatially and/or by habitat. Boyer (2004) has hypothesized that social behaviour of elk is because of the nutritional needs of each sex due to body size differences.

1.6 Feeding habitat

Eurasian elk is a herbivore which ranges especially in the boreal and temperate forestlands of the northern hemisphere. They are classified as browsers and switch between the winter and summer diet (Hofmann 1989). From early spring, elk select forbs and leaves which are easily digestible (Wam & Hjeljord 2010). During the winter elk switch to a diet with lower nutrient content and easier digestibility, which consist primarily of barks and twigs (Månsson et al. 2007; Wam & Hjeljord 2010). They become physiologically ready for the seasonal changes in their diet by reducing food intake during the fall. This reduced food intake is connected with reducing their metabolism and with changes in the rumen physiology (Regelin et al. 1985; Hofmann 1989). These changes depend on plant species composition, dry matter content, and digestibility (Cederlund & Nyström 1981).

1.6.1 Eurasian elk as a specialist herbivore

Eurasian elk are generally defined as specialists herbivores, which means that they consume mostly one or few plant species (Crawley 1983). However, Dearing et al. (2000) said that specialists also include herbivores consuming at least 60% of their diet from one plant genus. Regardless of the use of this definition, less than 1% of all mammalian herbivores are classified as specialists (Dearing et al. 2000; Shipley et al. 2009). For example, summer and winter diets of American moose (*Alces alces americanus*) in North America consist of 75-91% willow (*Salix* spp.). In contrast, in Sweden elk consume a more varied diet in which no single plant species comprise more than 60% of their diet. Shipley (2010) reported that elk consume during the winter around 60% of Scots pine (*Pinus sylvestris*) in Sweden. Therefore, how elk are classified according to the tree preferences depend on the location and extent where their diet is measured.

Eurasian elk are also known as specialist herbivores because of their problematic feeding in captivity. The typical diet for herbivore is composed by grain-based pellets supplemented with grass or alfalfa hay can cause enteritis, diarrhoea, and wasting in elk (Schwartz et al. 1985; Shochat et al. 1997). However, general herbivore diets are much higher in starch than a typical elk diet dominated mostly by browse because elk do not have enough enzymes for digesting starch (Schwartz et al. 1996). Shochat et al. (1997) reported that moose only prosper in captivity when a large amount of supplemental browse are allowed with herbivore pellets based on aspen. That is why other components of browse diet, such as tannins, salicin and lignin, may help to the digestive health of elk.

1.6.2 Browsing preferences

Eurasian elk browses, especially in young boreal forests. The highest densities are recorded in areas disturbed by forest fires and in mixed stands, forest harvesting, windfall, or insect outbreaks (Timmermann & Mcnicol 1988). These places provide plentiful deciduous shrubs and trees that represent the main food source for Eurasian elk. Elk can destroy a tree easily by twig browsing, stem breakage and leaf and bark stripping. Helle et al. (1987), Lavsund (1987) and Nygrén and Personen (1993) reported the relationship between the density of the elk population and the amount of damage, showing that one elk/km^2 means 10% critical damage on Scots pine and two elk/km^2 corresponds to 25% critical damage in Sweden. These damages may reduce growth or lower steam and timber quality (Lavsund 1987). Physical barriers around small, vulnerable trees or forests stand (Ward et al. 2000) and reducing elk abundance by increasing harvesting may prevent forest damage. Nevertheless, both methods are costly and may have unwanted economic and ecological side-effects (Kuijper 2011).

1.6.3 Seasonal changes in food intake

Eurasian elk are concentrate selectors that react to the cyclic seasonality of their environment. As concentrate selectors, they eat trees and shrubs (see Figure 4), based on the digestive system morphology and feeding habitats (Hofmann & Stewart 1972; Hofmann 1989). Due to their evolutionary morphophysiological adaptation, they select rich cell-content plant material with short food retention time. It is because of their comparatively small and simple ruminoreticulum, large salivary glands (Hofmann 1988) and low fibre digestion capability in the rumen (Hjeljord et al. 1982), but with a very large caeco-colic fermentation chamber (Hofmann & Nygren 1990). Their papillated rumen mucosa enlarges during the vegetative growth of plants when the cell contents from fruits and leaves are abundant. During the summer, papillated rumen reaches maximum size followed by a reduction of 30-50% during fall and winter (Hofmann & Nygren 1990). For example, summer rumen fill of moose in Alaska is about 30% higher than winter fill (White 1984). Hofmann and Nygren (1990) assumed that elk are adapted to changeable seasonal nutrition and their digestive system is focused on a strategy that maximizes growth and formation of fat deposition during the summer and fall.

Figure 4. Browsing of Eurasian elk (photo: Prague ZOO archive)

Eurasian elk avoid fibrous food when possible (Renecker & Hudson 1990) because fibrous food passes quite quickly through the elk forestomach, mostly undigested, representing part of “ruminal escape” (Van Soest 1982) to go through cellulolysis in the hindgut. Elk has a relative large reticule-omasal opening with numerous long papillae which makes easier passage of large fibre particles but averts unbroken leaves from passing.

Year-round, Eurasian elk consume willow (*Salix* spp.) and birch (*Betula* spp.) as staple foods in Scandinavia but also consume approximately 40 other plant species (Palo & Wallin 1996). Bilberry (*Vaccinium myrtillus*) in autumn and Scots pine (*Pinus sylvestris*) in winter are considered important foods (Cederlund et al. 1980; Palo & Wallin 1996). The digestibility of plants species varies seasonally because of the changes in chemical composition (Stolter 2008). Changes in the species composition of microorganisms in the rumen by food type, seasons, and their digestive capacity may be critical factors in food digestibility and utilization. Changes in nitrogen, phenols and fibre are the components that drastically change between plant species and within the season (Palo et al. 1985; Risenhoover 1989). Because of these facts, it is very important to understand their changes in the digestive process. Palo et al. (2012) studied two groups of Eurasian elks. Winter group had low nitrogen content in the digestive tract and high dry matter content and neutral detergent fibre. The summer group had a high level of nitrogen content and low dry matter content and neutral detergent fibre. These results indicate the seasonal changes in diet quality.

1.6.4 Changes in faeces consistency

Faeces are most easily recognizable and the most evident sign of each species (Liebenberg 2000). Especially mammal faeces have a social communication role (Gorman & Trowbridge 1989) and according to Camardella et al. (2000), several types of information can be obtained from them. From the faeces content we can obtain the most useful information such as diet composition, seasonal diet changes (Aragona & Setz 2001), health condition, and potential entero-parasites (Patton et al. 1986). Faeces consistency of Eurasian elk are changed seasonally. Also, size of the faeces varies among herbivores because of the differences in food intake during throughout the year. Especially during the spring and autumn, when different type of diet is consumed, faeces consistency is changed.

1.6.5 Diet composition

Wam and Hjeljord (2010) pointed out that Eurasian elk diet is very diverse during the summer but more uniform in the winter. During the summer, elk consume shrubs and herbs and nibble leaves of deciduous trees with a higher preference for birch, bilberry and rowan (Wam & Hjeljord 2010). During the winter, elk consume predominantly twigs, barks and needles of coniferous trees (Stolter et al. 2005).

There are few methods for analysing diets composition of Eurasian elk (Ortmann et al. 2006). The most applied non-invasive methods are micro histological analyses of faeces, surveying bite marks on vegetation and direct observation of foraging animals often called bite counts (Hubbard 1952).

1.6.5.1 Summer diet

Eurasian elk switch to summer diet during spring or early summer. During this time, birch (*Betula pendula*) is an important part of elk diet when the young shoots and leaves are eaten (Cederlund et al. 1980). The other one and non-negligible tree in elk diet is willow (*Salix* spp.). According to Markham (1971), willow produces bitter phenolic glycoside, salicylates, that can discourage feeding by some other herbivores (e.g. brushtail possums (*Trichosurus vulpecula*)). From the previous information, it is hard to say which plant species Eurasian elk prefer, nevertheless, the following studies are good examples.

The first study was conducted by Bjerga and Mysterud (1999) and was based on a summer diet of elk in Agder, Norway. Radio-collared animals were studied. Elk could choose from 35 different plant species including birch (*Betula pubescent*), bilberry (*Vaccinium myrtillus*), poplar (*Populus tremula*), willow (*Salix* spp.), juniper (*Juniperus communis*), bog asphodel (*Narthecium ossifragum*), etc. Bjerga and Mysterud (1999) found out that a birch (38.9%), bilberry (13.3%), and bog asphodel (10.8%) were the main plants eaten. Birch and bog asphodel were preferred more than bilberry and other plants species than expected on availability. However, bog asphodel is highly toxic and it has been reported that it can cause severe kidney damages in cattle (*Bos taurus*) and domestic sheep (*Ovis aries*) (FlâØyen et al. 1996). In Norwegian Veterinary Institute, elk were fed by bog asphodel and developed kidney damages similar to domestic ruminants. According to Provenza (1995), elk may not be able to detect toxic substances in big asphodel if the digestive system does not give negative feedback from toxins ingestion.

The second study was based on micro histological analyses of faeces. Elk could browse on trees and bush plants, including birch (*Betula* spp.), rowan (*Sorbus aucuparia* L), aspen (*Populus tremula* L), willow (*Salix* spp.), oak (*Quercus* spp.) and other deciduous tree species. In the micro histological analyses, browse species made up to 50% of all identified fragments per sample, ranging from 27% to 80%. Birch showed the highest preference compared to willow, aspen, oak and rowan. From these results, birch, willow and rowan made up 90% or more of the browse (Wam & Hjeljord 2010). The remaining contents of faeces were dominated by bilberry (*Vaccinium myrtillus*) 19.1%, grasses and grass-like plants (*Poaceae* and *Cyperaceae* spp.) 10.1%, and raspberry (*Rubus idaeus*) 9.1%. Wam and Hjeljord (2010) have been also pointed out that birch and then rowan were the two most frequently browsed plant species in field surveys.

1.6.5.2 Winter diet

At the beginning of winter, elk switch to a diet with lower nutrient content and easier digestibility, which consist primarily of barks and twigs (Månsson et al. 2007; Wam & Hjeljord 2010). Bergström and Hjeljord (1987) reported that Scots pine (*Pinus sylvestris*) is one of the most important winter food for elk in Scandinavia and at the same time is an important tree species for timber and pulp production. A common practice to reduce browsing pressure on commercially valuable trees is the use of supplementary feeding (Peek et al. 2002; Kalen & Bergquist 2004; Putman & Staines 2004). Supplementary feeding of elk during the winter is also used to reduce crop damages (Peek et al. 2002) and increase their survival. Feeding cervids during winter are a common practice in some parts of Europe including Hungary, Austria, Germany, Denmark, Sweden and Norway (Gill 1990).

Månsson (2007) reported that willow (*Salix* ssp.), rowan (*Sorbus aucuparia*), and aspen (*Populus tremula*) had a 14 times higher probability of being browsed than Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*), while silver birch (*Betula pendula*) and juniper (*Juniperus communis*) had 3.5 times higher probability browse than Scots pine and downy birch. Heikkilä and Härkönen (1993) mentioned that consumption of Scots pine increased as the availability of birch increased. Due to these results, we may deduce that tree preferences depend on plant species composition in certain areas.

1.6.6 Aquatic vegetation

Aquatic vegetation grows partially or completely in water. They require light and carbon dioxide for photosynthesis, water, and nutrients such as phosphorus and nitrogen, and oxygen for respiration. Plants with the leaves exposed above the water have a ready source of light, oxygen and carbon dioxide (Wersal & Madsen 2013). Aquatic vegetation is a nutritional resource with a high level of proteins and minerals, but low in fibre (Linn et al. 1975). Since, in view of the fact that fibrous cells of plants are quite hard for herbivores to digest (Van Soest 1994), aquatic vegetation provide suitable nutritional source for Eurasian elk.

Sodium importance is well known and is required for lactation, hair production, buffering of body fluids, growth, and the maintenance of appetite and body weight (Church et al. 1971; Smith et al. 1972). Elk start to consume aquatic plants in spring or during the early summer when leaves and twigs are particularly nutritious (Maclennan et al. 1977). The elk's winter diet of twigs is poor in sodium content and availability during a year may be limited to elk and should be added to a diet.

The most plausible explanation why the elk seek aquatic plants is because of its high level of sodium and/or other minerals (Jordan et al. 1973). On the ground of this hypothesis sodium is considered as a limiting factor to elk diet because it is a rare nutrient in northern ecosystems that do not receive oceanic salt impaction (Botkin et al. 1973; Jordan et al. 1973).

Belovsky's linear programming system

Herbivores have to make a compromise when selecting diets, a process which forms the principal of most models of diet selection for herbivores. Many innovations in optimal feeding models have been designed and tested with moose. One of the first foraging models for herbivores was Belovsky's linear programming system (Belovsky 1978) based on the trade-offs for moose in the USA. These Belovsky's foraging models depend on the consumption of deciduous leaves or aquatic plants by moose (Figure 5). Deciduous leaves are less fibrous and easier to digest than aquatic plants, but because most of the boreal forest are depauperate in sodium, forest plants have less sodium content than aquatic plants (Belovsky & Jordan 1981). Because of daily sodium requirements, moose need to eat a minimal amount of aquatic plants. Belovsky (1978) suggested that moose need to consume an adequate amount of deciduous plants or a large number of aquatic plants to meet their energy requirement. He also pointed out that elk must consume a mixture of terrestrial and aquatic plants within a close range of possibilities. Finally, as a browser, the species has limited rumen size which constraint the amount of food that the animal can consume. That means a narrow range of diet selection possibilities for the animals which will simultaneously supply adequate energy and minerals.

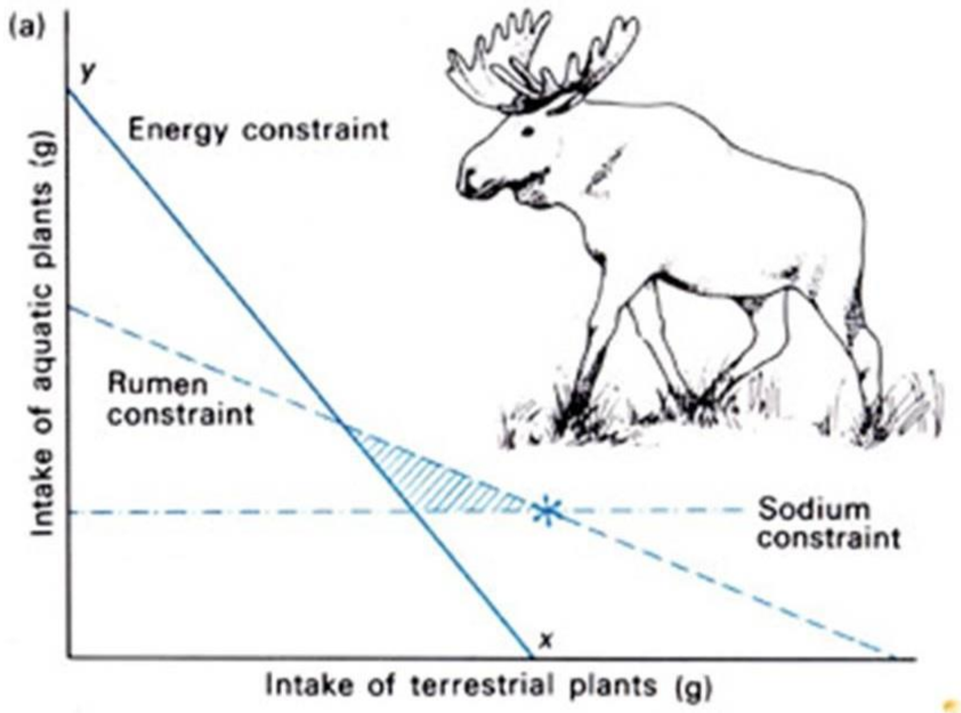

Figure 5. Optimal diet choice of Eurasian elk (Krebs & Davies 1993; p. 71)

1.6.7 Heat stress and thermoregulation

How elk are affected by temperature is hard to understand and it is important to know how climate may influence their population dynamics. Elk are well adapted to cold temperatures but are substantially less tolerant to high temperatures during both winter and summer (Giorgi et al. 2004). It may create a negative energy balance for elk especially during warm seasons, including late spring, summer and early autumn, when ambient temperature increases and their energy requirements are inhibited (Lenarz et al. 2009). This is associated with increased activity during the night (Dussault et al. 2004), reducing daily travel (Demarchi and Bunnell 1995; Broders et al. 2012) and increasing their seeking of thermal shelter during the daytime e.g. conifer stands or closed canopy (Renecker & Hudson 1986; Dussault et al. 2004). The high ambient temperature may also increase the susceptibility of elk to the prevalence of pathogens (Murray et al. 2006).

Negative ambient temperatures may also affect elk population dynamics and have been observed in both species Eurasian elk in Scandinavia and moose in North America. It may result in short-term changes in muscle mass and fat reserves (Grøtan et al. 2009; Lenarz et al. 2009). Renecker and Hudson (1986) suggested that threshold for thermal stress in elk, are approximately 14 °C during summer and 5 °C during winter. According to Renecker and Hudson (1990), elk between 14 °C and 20 °C increase their respiration rates and decrease heat stress through evaporative cooling. These temperature thresholds and physiological responses, especially for summer, are relatively low and indicate heat-stress (Hudson & White 1985; Renecker & Hudson 1990). Consequently, we may assume that elk show some sort of thermoregulatory response to avoid the potential stressful effects of high temperatures.

1.6.8 Seasonal migration and home ranges

Migration behaviour and home ranges are a well-known phenomenon, however, there is still much knowledge lacking to understand how movement patterns are influenced by the surrounding environment and why the animals migrate (Bowlin et al.

2010). Where only partial migration occurs in some populations, there is poor knowledge of what determines who stay stationary and who become migratory.

Eurasian elk are large and highly mobile animals. They can move over large distances. Andersen (1991) showed that the migration routes and winter ranges of Eurasian elk are traditional. Calves follow their mothers to their winter ranges and it may take many generations to evolve a new, different route. Seasonal migrations have mainly been related to an adaptation to optimize food resources (Sinclair 1983) influenced by forage availability (Bergström & Hjeljord 1987), and snow conditions (Sandegren et al. 1985). Eurasian elk migrate often during the winter time when a nutritional value of plants is lower, but with higher browse availability when snow limits foraging. During the summer, elk migrate to places with a predominance of deciduous trees, herbs and shrubs (Månsson 2009). According to Histol and Hjeljord (1993), elk summer home range in a forest dominated by pine will stay relatively stable and are less likely to migrate.

The distance between the winter and summer habitats of migrant Eurasian elk varies considerably (Ballard et al. 1991; LeResche 1974) and has been reported to range from a few kilometres to several hundred kilometres (Pulliainen 1974; Kuznetsov 1987). Snow cover directly decreases the availability of food resources by burying (Sandegren et al. 1985), and depth of snow increases the cost of locomotion for foraging (Telfer & Kelsall 1984). Snow depth is affected by snow quality to which the animals sink into the snow and could be considered as an 'effective snow depth'. Effective snow depth affects the amount of energy needed for locomotion (Bunnell et al. 1990; LeResche 1974). From these assumptions might be both, snow quality and snow depth, important in habitat choice. Sweanor and Sandegren (1985) suggested that Eurasian elk migrate to areas with less snow for winter.

According to Nikula et al. (2004), during the summer Eurasian elk favour mature forests and non-pine dominated habitats, and avoid human settlements. On the contrary during the winter season, the Eurasian elk seek for more pine-dominated forests with shrubs and clear-cut field habitats, with less snow than the overall landscape (Ball et al. 2001). Within the home ranges, both sexes prefer non-pine dominated habitats more than mature forests. Within their home ranges, males and females use slightly different habitats during both seasons, suggesting spatially segregated habitat use by the individual sexes. The difference is more visible in winter when females tend to use less pine-dominated, young successional habitats than males (Nikula et al. 2004).

2 Aims of the thesis

The purpose of the thesis was to better understand the good practices in elk husbandry which may help to improve their performance in captivity.

<u>Hypotheses of the theses:</u>

H1: According to literature review we expected that seasonal changes in faeces consistency will be connected with changes in diet composition over a period of the year in captive Eurasian elk.

H2: Following the information reported by zoos, we expected that willow and birch will be the main preferred three species and they will have positive effects on Eurasian elk health.

H3: According to the feeding ecology of the species and common husbandry practices for other ruminants, we expected that number of tree species offered, use of premixes and quality of browse in winter will be practices positively affecting the breeding performance and longevity of captive Eurasian elk.

3 Methods

The structure of the thesis was composed according to the Methodical Manual for the Writing of Master's Theses of the Faculty of Tropical AgriSciences (FTA), Czech University of Life Sciences (CULS) Prague (FTA, 2018). References were cited according to the Citation Rules of the Faculty of Tropical AgriSciences, CULS Prague (FTA, 2014).

3.1 Literature review

The literature review came out from the analysis of scientific publications (especially from the scientific database ScienceDirect and Web of Science) dealing with this topic. The scientific articles were searched by following keywords: *Alces alces*, diet, aquatic plants, breeding, tree preferences, and others.

3.2 Study areas and subjects

Data were collected in captive Eurasian elk (*Alces alces*) herds in European Zoos, in 2016, through the questionnaires. The questionnaires were filled by the zoologists and zookeepers. From the completed data we made the data analyses focused mostly on the diet, a feeding strategy and breeding. Obtained data from the zoos were compared with the data from Species360 ZIMS (Zoological Information Management System) database.

From the European Zoos, we got information about 79 Eurasian elk. Questionnaires contained the following chapters with information about:

1. Animals – date of the birth of each individual; sex; average longevity; acclimatization problems; stress noticed by different subject (e.g. stress noticed by parasites, avoiding other animals or people) and stress noticed by changes in food intake.

2. Inside enclosure – number and size of the stables; floor material; separation area used for separation by sex or each individual.

3. Outside enclosure – use of the outside enclosure; kind of substrate of the surface; terrain; percentage of shade and additional shelter; presence and size

of pond or any other water body; aquatic vegetation; presence of trees and bushes; holder for branches; hay racks; automatic water supplier; information about fences height and material; visibility of outside enclosures.

4. Diet – length of use of the diet; quality of hay; possibility and time to graze; kind of vitamins and minerals supplements; changes in faeces.
5. Browse – feeding by branches, number of branches; type of feed during the winter (e.g. dried, frozen); kind of trees and their preferences depending on each individual; seasonally bark intake.
6. Breeding – experiences with breeding, month of parturition; success rate (e.g. birth of twins and percentage of their rearing); dam separation before parturition; dams' and calves' attachment to the birthplace; allonursing.
7. Antler cycle – separation of breeding male (e.g. feeding, rut season); breeding male housed with females; antler cycle (e.g. antler growing, velvet cleaning, antler shedding); male aggression toward the female; removing of antlers; consistency of faces during the rut.
8. Veterinary care – presence and king of intestinal endoparasites; treatment; the cause of the death (e.g. caused by endoparasites, neonatal weakness); self-caused injury.
9. Transportation – a type of vehicles used for the transport; use of anaesthetics; use of tranquillizers.

Questionnaires were sent to 48 zoological gardens in Europe from which 22 zoological gardens answered, including zoos in Germany, United Kingdom, France, Czech Republic, Switzerland, Denmark, Sweden, Finland and Russia.

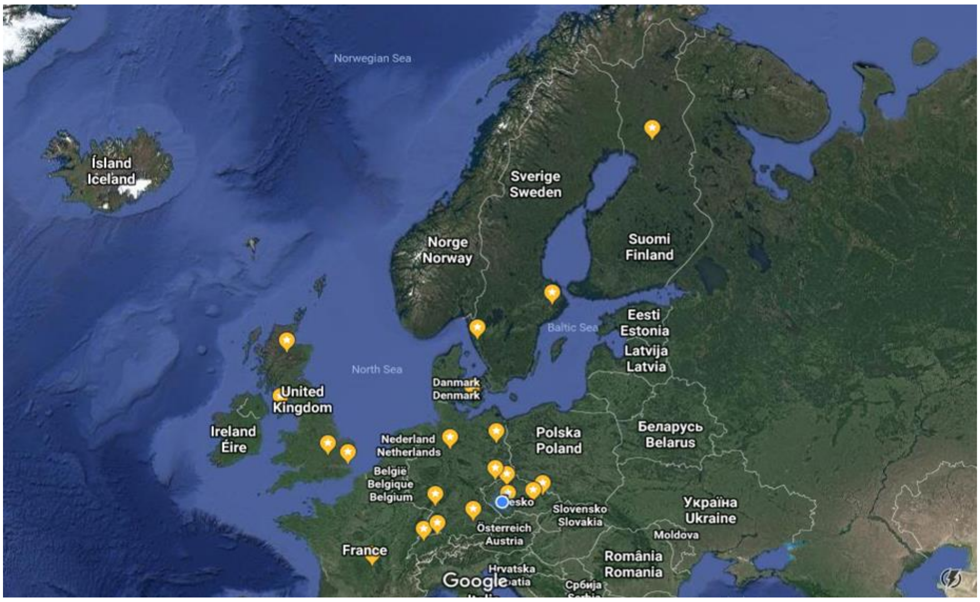

Figure 6. European Zoos distribution (www.google.cz/maps)

3.2.1 Germany

Hellabrunn Zoo

Hellabrunn Zoo is located in the southern part of Germany in München. The herd consisted of 7 Eurasian elk in a total; four females, one male and two calves are kept in one outside enclosure with approximately 0.5 hectares of a total pasture area with grass substrate.

Tierpark Berlin

Tierpark is located in the east part of Berlin, in Germany. In a total, three Eurasian elk are bred there with one male, one female and two calves - twins. Outside enclosure of total area 0.7 hectares with grass substrate may be divided into two enclosures with five stables used for separation.

Wisentgehege Springe

Zoological garden is situated in the northern part of Germany, close to Springe and Hannover. In total, six Eurasian elk are bred in the zoo with one male, two females and two calves. Animals are kept in outside enclosures with 5 hectares of a total area with no inside enclosure. Outside enclosures can be spread into 3 smaller enclosures for separation (e.g. rut season).

Zoological Stadtgarten Karlsruhe

Karlsruhe Zoo is situated in the south-west of Germany in Karlsruhe. The herd of the Eurasian elk consisted of 3 animals in a total with one male and two females. A total area of the outside enclosure is 1.9 hectares with forest surface and is divided into two outside enclosures where animals are kept separately by sex.

3.2.2 France

Animal Park Auvergne

Animal park is situated in the southern part of France in Ardes. The herd of Eurasian elk consisted of three animals in a total with one male, one female and one calf. Animals are bred in two outside enclosures on a total area of 0.3 hectares. Substrate of outside enclosures is grass and soil substrate with predominance of soil. Outside enclosure contained also two stables used for separation by sex.

3.2.3 Denmark

Knuthenborg SafariPark

Safari Park is located in the southeast part of Denmark in Bandholm. In a total, three bulls are bred there. A total area of the outside enclosure is 5.1 hectares with grass and marshy surface and the road in the middle. This safari park does not have any experiences with breeding of Eurasian elk.

3.2.4 Switzerland

Stiftung Wildnispark Zürich

Wildpark is situated in the north part of Switzerland in Zürich. The herd of Eurasian elk consisted of six animals in a total with one male and five females. Outside enclosure is 2.6 hectares large with 5 stables.

Tierenpark Bern

Zoo is located in the northwest part of Switzerland in Bern. Only one bull is bred there on total area 0.31 hectares of outside enclosure with grass surface.

3.2.5 United Kingdom

Curraghs Wildlife Park

Park is located on the west side of the United Kingdom on Isle of Man island near to Ballaugh. Only one bull is bred there on a total area of 0.5 hectares with hard stand substrate.

RZSS Highland Wildlife Park

Zoo is situated in the northern part of the United Kingdom in Scotland, near Kingussie. In total, five animals are bred there with two males, two females and one calf. Animals are kept on a grass substrate in four outside enclosures with 7.1 hectares of total area.

Wildwood Trust

Wildwood Trust is situated in the southeast part of the United Kingdom in Herne Bay. Only one female is bred there on a total area of 0.25 hectares with forest floor. They do not have any experiences with breeding of Eurasian elk.

ZSL Whipsnade Zoo

Zoo is located in the south of the United Kingdom in Whipsnade. Two Eurasian elk are bred there with one male and one female on a total area of 0.8 hectares.

3.2.6 Sweden

Skansen Zoo

Zoo is located in the southeast part of Sweden in Stockholm. The herd consisted of four Eurasian elk in total; two females and two calves are kept in outside enclosure with approximately 0.42 hectares of a total area with grass and sand substrate.

Slottsskogens djurpark

Zoo is located in the southwest part of Sweden in Göteborg. In a total, one male and two females are bred there. A total area of outside enclosure is 0.74 hectares. Animals are kept on grassy and mountain surface.

3.2.7 Finland

Ranua Wildlife park

Zoo is situated in the northern part of Finland close to Ranua. The herd consisted of eight Eurasian elk in a total. Four males and four females are kept in three outside enclosures with approximately 1.7 hectares of a total pasture area on natural ground surface.

3.2.8 Czech Republic

Prague Zoo

Zoo is located in the middle of the Czechia in Prague. In a total, five animals are bred there. Three females, one male and one calf are reared in two grassy outside enclosures with a total area of 0.27 hectares. Enclosures included three stables usually used for breeding, etc.

Prague Zoo – Dobřejov

In a total, three animals are bred there; one male and two females. Animals are kept in the two outside enclosures with natural grass substrate. Size of the enclosure was 2.23 hectares.

Brno Zoo

Zoo is situated in the southeast part of the Czech Republic in Brno. Four animals are bred in this zoo. One male and three females are kept in two outside enclosures of a total area 0.66 hectares.

Hluboká Zoo

Zoo is situated in the southern part of the Czech Republic in Hluboká nad Vltavou. One male, two females and two calves (twins) are bred in outside enclosure with soil substrate area of a total size 0.19 hectares.

Olomouc Zoo

Zoo is located in the east part of the Czech Republic in Olomouc. Two females are bred in outside enclosure of a total area 0.14 hectares. Substrate of the surface is mainly marsh with grass.

Podkrušnohorský Zoopark Chomutov

Zoo is situated in the northwest part of the Czech Republic in Chomutov. In a total, one male, one female and one calf are bred there on grassy outside enclosure of a total area 0.66 hectares.

3.2.9 Russia

Municipal Autonomous institution of culture Zoo "Python"

Zoo is located in the southeast part of Russia in Komsomolsk area. Two Eurasian elk (subspecies *Alces alces cameloides*) are bred there with one male and one female on soil and bark substrate area.

3.3 Data processing

Data extracted from the questionnaires

1. Reported feeding practices

For hay quality three groups were used according to the protein content as follows: alfalfa hay (the highest protein content), second cut + mountain hay and as the last one was established the first cut. The quality of winter browse was divided into 3 categories according to the quality: fresh, frozen, dried. The length of grazing period was measured from 1 month up to twelve months, as maximum. The number of tree species offered were counted from 1 species up to 6+ different species, where 6+ included more than 6 tree species. The tree preferences were ranked from 0 to 1, where 1 was taken as the highest preference and 0 was taken as the lowest preference. For the use of premixes, daily feeding, browsing *ad libitum*, use of naked branches in winter and changes in faeces consistency we used a binary coding: 0 (no) and 1 (yes).

2. Reported breeding performances of the animals

The breeding periodicity was estimated into two categories. The first category was for animals breeding every year and the second category for animals breeding every second year. The birth rate, twinning rate and survival rate of twins were estimated into three categories, according to success rate: 0-24%, 25-74% and 75-100%.

Breeding performances calculated from ZIMS

The twinning rate (for last 30 and 5 years) and breeding success (for last 30 and 5 years) were statistically analysed for all animals liveing in zoological gardens. The period of 5 years was chosen because most zoos used the same diet during this period. The period of 30 years was used to have a long-term comparison. For the average longevity (in 1+ and in 6+ months) were used only animals born and dead in the same zoo. From the average longevity in 1+ and 6+ months were excluded animals living less than one/six months, because of the frequent neonatal mortality. The rate of survival to weaning age was established at six months. In the wild, calves are weaned approximately at the age of five months with an average weight of 94 kg (Malmsten 2014) and are able to survive without mother.

3.4 Data analysis

The data were statistically evaluated using the IBM SPSS Statistics 22 program (StatSoft, Inc., 2013). For all calculations significance level α = 0.05 was established. All calculated numerical values were rounded off to three decimal places. All numbers counted per cent were rounded off to two decimal places.

Data were statistically analysed for the normality. Shapiro-Wilk normality test was used because of the low number of samples (n>50).

Table 1. Shapiro-Wilk normality test for continuous variables

Independents		df	p-value
Length of grazing period	W=0.945	22	0.250
Number of tree species offered	W=0.932	21	0.152
Dependents			
Twinning rate (30 years)	W=0.897	19	0.043*
Twinning rate (5 years)	W=0.618	19	<0.001***
Breeding success (30 years)	W=0.896	19	0.042*
Breeding success (5 years)	W=0.805	19	<0.001***
Average longevity	W=0.707	16	<0.001***
Average longevity (1+ month)	W=0.918	16	0.154
Average longevity (6+ months)	W=0.927	16	0.217
Rate of survival to weaning	W=0.921	16	0.175

***, ** and * indicate significance at 0.001, 0.01 and 0.05 levels, respectively.

According to the characteristics of the variables (normal vs not normal distribution; categorical vs continuous), we applied the appropriate statistical tests for each analysis required. For the data which did not show normal distribution, following non-parametric tests were used: Kruskal-Wallis test, Mann Whiney U test, Spearman's correlation. For the data normally distributed Pearson correlation, One-way ANOVA and Student t-test were used. Pearson's chi-square test was used for the analyses between two categorical variables.

4 Results

4.1 Information reported by zoological gardens

4.1.1 Feeding practices and digestive effects

Feeding of Eurasian elk was influenced by the season, where two types of diet, summer and winter, were used. Most zoos (70%; n=20) switched between the winter and summer diet, and the rest of zoos (30%; n=20) did not change the diet through the year. Ten zoos (50%; n=20) switched to summer diet from March to April, and twelve zoos (60%; n=20) switched to winter diet from September to November. Due to the seasonal changes in diet composition, there were observed changes in faeces consistency (29.41%; n=17). However, seven zoos (41.18%; n=17) did not recorded seasonal changes in faeces consistency, when the different type of diet was fed. Nevertheless, the faeces consistency changed depending on the season, there were no significant factors affecting the faeces consistency (see Table 2). Thus, the first hypothesis of this thesis was rejected because it was not proved that changes in faeces consistency were connected with seasonal changes in diet composition over a period of the year.

Table 2. Factors affecting changes in faeces consistency, as reported in Eurasian elk by 22 European zoos

Independent	Test		df	p-value
Hay quality	Chi-square	$X^2 = 1.534$	3	0.632
Use of premixes	Chi-square	$X^2 = 0.055$	1	0.814
Daily feeding	Chi-square	$X^2 = 2.338$	1	0.126
Browsing *ad libitum*	Chi-square	$X^2 = 1.040$	1	0.308
Use of naked branches in winter	Chi-square	$X^2 = 0.421$	1	0.516
Quality of browse in winter	Chi-square	$X^2 = 1.644$	2	0.440
Length of grazing period	One-way ANOVA	F = 0.895	9	0.564
Number of tree species offered	One-way ANOVA	F = 1.079	6	0.427
Seasonal changes in diet composition	Chi-square	$X^2 = 0.762$	1	0.394

In the most zoos, elk could graze from early spring until the end of autumn. Elk could graze from January, at the earliest, but in the most zoos, elk could graze from April/May (45.45%; n=22). There were also some exceptions in four zoos where elk could graze all year-round. In elk diet, were also very important mineral and salt licking stones and vitamins addition which could provide them some part of the missing minerals and vitamins and should be available *ad libitum* for year-round. Seventeen zoos (77.27%; n=22) provided mineral supplements and salt licks. Mostly were used licks for deer or cattle.

The basic component of diet was consisted of fresh browse with or without leaves and hay, as an Alfalfa hay or mountain hay, both presented *ad libitum*. The basic diet was completed by adding browser pellets for elk or deer (e.g. Mazuri, Biostan, Lundi). Feeding dose was followed by adding root vegetable usually sliced into rounds. The most often used vegetable were carrot, parsley and/or beetroot. The dose of vegetable was generally up to four kilos with average two kilos per day per animal. In some zoos (18.18%; n=22) was added fruits as apples into the diet. The number of fruits was up to half a kilo per day per animal. Feeding doses for males and females did not differ too much. The amount of feed was generally influenced by direct factors, including weight, rut season, diseases and indirect factors as a season and temperature.

4.1.2 Browsing

The branches were main and one of the most important supplementary feed in captive elk diet. Elk were fed by branches usually daily in the zoos (81.82%; n=22) and mostly *ad libitum* or from three to five branches per animal. Branches were usually spread on the meadow or were hanged on the trees.

Animals could choose from the different kind of tree branches. The zookeepers offered to the animals at least one tree species up to eight different tree species (see Figure 7). Most often elk could choose from five to six different trees species (50%; n=22), including the basic as a willow (*Salix* spp.), oak (*Quercus* spp.), birch (*Betula* spp.), maple (*Acer* spp.), aspen (*Populus tremula*), pine (*Pinus silvestris*) and other species e.g. hornbeam (*Carpinus* spp.), hazel (*Corylus* spp.), ash (*Fraxinus* spp.), etc.

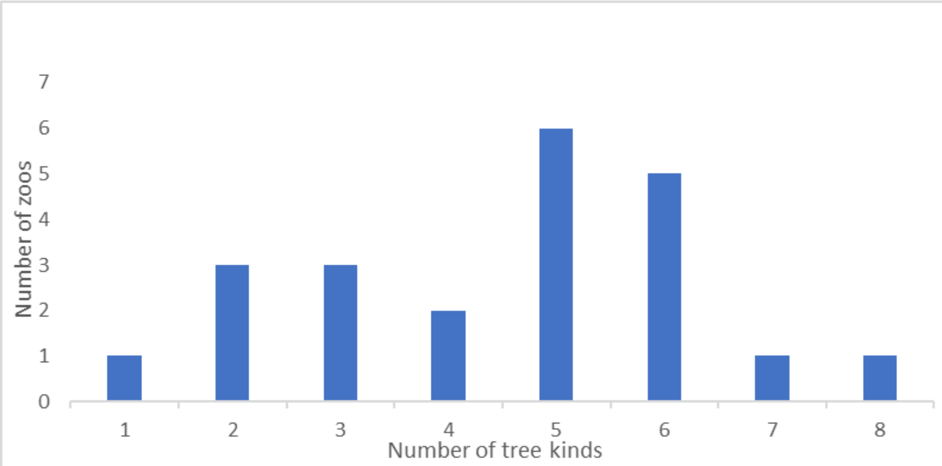

Figure 7. Number of tree species offered

4.1.2.1 Tree preferences

From the collected data we got overall information about tree preferences. Willow, oak, birch, maple, aspen and pine were the main tree species used in zoos. Eurasian elk preferred the trees species in the following order: willow 0.97, oak 0.69, birch 0.67, pine 0.64, maple 0.61 and aspen 0.58. All these main offered tree species were ranked relatively high, the lower preferences had species which were offered according to availability e.g. bilberry, hazel and hornbeam. From the previous order, it is obvious that oak, birch, pine and maple have a same possibility to be browsed by captive Eurasian elk. However, we could not accept the second hypothesis, because we did not prove that willow and birch were the main preferred tree species and whether they have a positive effect on elk health.

It was not proved that offering willow, birch and aspen affected the following dependent factors: changes in faeces consistency, reported breeding periodicity, reported birth rate, reported twinning rate, reported survival rate of twins, calculated twinning rate (30 years), calculated twinning rate (5 years), calculated breeding success (30 years), calculated breeding success (5 years), calculated average longevity, calculated average longevity (1+ month), calculated average longevity (6+ months), calculated rate of survival to weaning.

However, it was found out that oak significantly affected changes in faeces consistency (Chi-square test: $X^2 = 4.747$, df = 2, p = 0.029, N = 22). In eleven zoos were not observed changes in faeces consistency, if oak was not offered. In five zoos were recorded changes in faeces consistency, when oak was offered.

Reported birth rate (Chi-square test: $X^2 = 6.073$, df = 2, p = 0.048, N = 18) was significantly affected by oak consumption. Reported survival rate of twins was marginally affected by oak consumption (Chi-square: $X^2 = 5.200$, df = 2, p = 0.074 N = 18). How oak consumption affected the birth rate and survival rate of twins see in Table 3.

Table 3. Contingency tables showing the interactions between the use of oak tree branches and birth rate and survival rate of twins in Eurasian elk, as reported by 18 European zoos.

	Birth rate			**Survival rate of twins**		
	0-24%	25-74%	75-100%	0-24%	25-74%	75-100%
Offered	4	3	2	4	3	2
Not offered	1	8	0	0	6	3

Calculated breeding success over the last 5 years (2012 – 2016) was positively marginally affected by offering Scots pine (Mann-Whitney U test: U = 64.000, p = 0.086; offered: 0.365 ± 0.353, not offered: 0.121 ± 0.165).

4.1.3 Breeding

86.36% zoos had experiences with the breeding of the species. Three zoos did not have experiences with breeding of Eurasian elk (13.64%; n=22). In most cases (83.3%; n=18) females bred every year and in three zoological gardens females bred every other year (17.7%; n=18). As shown in Table 4, there was no significant level affecting reported breeding periodicity in captive Eurasian elk.

Table 4. Factors affecting breeding periodicity in Eurasian elk, as reported by 22 European zoos.

Independent	Test		df	p-value
Hay quality	Chi-square	$X^2 = 2.356$	3	0.509
Use of premixes	Chi-square	$X^2 = 0.781$	1	0.377
Daily feeding	Chi-square	$X^2 = 0.257$	1	0.612
Browsing *ad libitum*	Chi-square	$X^2 = 0.660$	1	0.416
Use of naked branches in winter	Chi-square	$X^2 = 0.055$	1	0.814
Quality of browse in winter	Chi-square	$X^2 = 0.240$	2	0.887
Length of grazing period	One-way ANOVA	F = 0.444	9	0.876
Number of tree species offered	One-way ANOVA	F = 0.480	5	0.785

During the observation were not observed any cases of allonursing. In five zoos (27.8%; n=17), keepers separated dam before giving the birth. From collected data, we got information about specific attachment to the place, where dams gave a birth and where calves were born. It was observed that 73.3% (n=15) of dams had a specific attachment to the birthplace and only 26.7% (n=15) of born calves had a specific attachment to the birthplace.

We got information about breeding success from nineteen zoos in total. The birth rate was measured per cent from 0% to 100% as a maximum rate. In most zoos (57. 89%; n=19) were average of birth rate from 50% to 99%. Two zoos had a birth rate equal to 100%. Three zoos had birth rate relatively low, from 1% to 24%.

As shown in Table 5, we found out the marginal significance level between the use of premixes and reported birth rate in Eurasian elk. In ten zoos (n=17) was observed relatively higher birth rate (25-74%), while using of premixes.

Table 5. Factors affecting the reported birth rate in Eurasian elk by 22 European zoos.

Independent	Test		Df	p-value
Hay quality	Chi-square	$X^2 = 8.745$	6	0.188
Use of premixes	Chi-square	$X^2 = 5.302$	2	0.071†
Daily feeding	Chi-square	$X^2 = 0.748$	2	0.688
Browsing *ad libitum*	Chi-square	$X^2 = 0.066$	2	0.967
Use of naked branches in winter	Chi-square	$X^2 = 4.406$	2	0.110
Quality of browse in winter	Chi-square	$X^2 = 4.353$	4	0.360
Length of grazing period	One-way ANOVA	F = 1.778	9	0.215
Number of tree species offered	One-way ANOVA	F = 0.274	5	0.918

† indicates marginal significance at 0.1 level

Twinning rate was relatively high in all responding zoos. In 66.67% cases (n=18) were a twinning rate between 25% and 74%. Two zoos had twinning rate higher (11.11%; n=18), between 75% and 99%. 16.67% (n=18) zoos had twinning rate lower, between 1% and 24%. Only one zoo (5.56%; n=18) did not have any case of twins' birth.

By the statistical analysis, we found out that the use of premixes affected reported twinning rate (see Table 6). In eleven zoos (n=17) was observed higher twinning rate (25-74%), while using of premixes. In two zoos was recorded twinning rate from 75% to 100%, when premixes were included into the diet.

Table 6. Factors affecting the reported twinning rate in Eurasian elk by 22 European zoos.

Independent	Test		Df	p-value
Hay quality	Chi-square	$X^2 = 4.308$	6	0.635
Use of premixes	Chi-square	$X^2 = 6.679$	2	0.035*
Daily feeding	Chi-square	$X^2 = 2.089$	2	0.352
Browsing *ad libitum*	Chi-square	$X^2 = 0.258$	2	0.879
Use of naked branches in winter	Chi-square	$X^2 = 0.554$	2	0.758
Quality of browse in winter	Chi-square	$X^2 = 4.275$	4	0.370
Length of grazing period	One-way ANOVA	F = 0.512	9	0.831
Number of tree species offered	One-way ANOVA	F = 0.284	5	0.913

* indicates significance at ≤0.05 level

The reported survival rate of twins was between 25% and 74% (47.37%; n=19) in most cases. Five zoos (26.32%; n=19) had a significantly higher survival rate of twins equal to 100%, means that both calves were reared successfully. Three zoos (15.79%; n=19) had the survival rate of twins equal to 0%, means that one calf or both calves died during the rearing.

Reported survival rate of twins was marginally affected by daily feeding. In fourteen zoos was recorded (n=18) positive effect between daily feeding and survival rate of twins. In ten zoos was survival rate of twins from 25% - 100%, when animals were fed daily (see Table 7).

We found out positive effect between the reported survival rate of twins and the use of premixes. In twelve zoos (n=17) was observed reported survival rate of twins from 25% to 100%, while using of premixes. In two zoos were not used premixes and reported survival rate of twins decreased (0-24%).

Table 7. Factors affecting reported survival rate of twins in Eurasian elk by 22 European zoos.

Independent	Test		df	p-value
Hay quality	Chi-square	$X^2 = 10.019$	6	0.124
Use of premixes	Chi-square	$X^2 = 4.958$	2	0.084†
Daily feeding	Chi-square	$X^2 = 5.143$	2	0.076†
Browsing *ad libitum*	Chi-square	$X^2 = 1.264$	2	0.532
Use of naked branches in winter	Chi-square	$X^2 = 2.049$	2	0.359
Quality of browse in winter	Chi-square	$X^2 = 5.242$	4	0.263
Length of grazing period	One-way ANOVA	$F = 2.519$	9	0.104
Number of tree species offered	One-way ANOVA	$F = 2.370$	5	0.102

† indicates marginal significance at 0.1 level

4.2 Information obtained from ZIMS

The following results were based on the data obtained from the Species360 Zoological Information Management System database and compared with the data obtained from the zoological gardens in European zoos about feeding practices.

The calculated twinning rate for last 30 years was not affected by the hay quality, use of premixes, daily feeding, browsing *ad libitum*, use of naked branches in winter, quality of browse in winter, length of grazing period and by number of tree species offered (see Table 8).

Table 8. Factors affecting the twinning rate in Eurasian elk in 22 European zoos. Twinning rate was calculated from data extracted from ZIMS for the last 30 years (1986-2016).

Independent	Test		df	p-value
Hay quality	Kruskal-Wallis	H = 4.101	3	0.251
Use of premixes	Mann-Whitney U Test	U = 11.500	1	0.348
Daily feeding	Mann-Whitney U Test	U = 19.000	1	0.946
Browsing *ad libitum*	Mann-Whitney U Test	U = 16.000	1	0.705
Use of naked branches in winter	Mann-Whitney U Test	U = 31.000	1	0.395
Quality of browse in winter	Kruskal-Wallis	H = 0.708	2	0.702
Length of grazing period	Spearman's correlation	$\rho = 0.128$		0.603
Number of tree species offered	Spearman's correlation	$\rho = 0.043$		0.862

The calculated twinning rate for the last 5 years was positively affected by browsing provided *ad libitum* (see Table 9). The rest of the independent variables did not affect the calculated twinning rate for last 5 years.

Table 9. Factors affecting the twinning rate in Eurasian elk in 22 European zoos. Twinning rate was calculated from data extracted from ZIMS for the last 5 years (2012-2016).

Independent	Test		Df	p-value
Hay quality	Kruskal-Wallis	H = 3.144	3	0.370
Use of premixes	Mann-Whitney U Test	U = 17.000	1	0.871
Daily feeding	Mann-Whitney U Test	U = 12.500	1	0.279
Browsing *ad libitum*	Mann-Whitney U Test	U = 22.000	1	0.080†
Use of naked branches in winter	Mann-Whitney U Test	U = 13.500	1	0.143
Quality of browse in winter	Kruskal-Wallis	H = 0.802	2	0.567
Length of grazing period	Spearman's correlation	$\rho = 0.304$		0.205
Number of tree species offered	Spearman's correlation	$\rho = -0.008$		0.975

† indicates marginal significance at 0.1 level

As shown in Table 10, the calculated breeding rate for last 30 years was not affected by any independent variables.

Table 10. Factors affecting breeding rate in Eurasian elk in 22 European zoos. Breeding rate was calculated from data extracted from ZIMS for the last 30 years (1986-2016).

Independent	Test		df	p-value
Hay quality	Kruskal-Wallis	H = 1.487	3	0.685
Use of premixes	Mann-Whitney U Test	U = 11.500	1	0.348
Daily feeding	Mann-Whitney U Test	U = 11.500	1	0.281
Browsing *ad libitum*	Mann-Whitney U Test	U = 19.000	1	0.344
Use of naked branches in winter	Mann-Whitney U Test	U = 33.000	1	0.275
Quality of browse in winter	Kruskal-Wallis	H = 0.450	2	0.799
Length of grazing period	Spearman's correlation	ρ = 0.207		0.396
Number of tree species offered	Spearman's correlation	ρ = 0.026		0.916

As shown in Table 11, calculated average longevity was not affected by any independent variables. Calculated longevity was 1.8 year.

Table 11. Factors affecting calculated breeding rate in Eurasian elk in 22 European zoos. Breeding rate was calculated from data extracted from ZIMS for the last 5 years (2012-2016).

Independent	Test		df	p-value
Hay quality	Kruskal-Wallis	H = 1.533	3	0.675
Use of premixes	Mann-Whitney U Test	U = 19.500	1	0.825
Daily feeding	Mann-Whitney U Test	U = 8.500	1	0.128
Browsing *ad libitum*	Mann-Whitney U Test	U = 21.500	1	0.151
Use of naked branches in winter	Mann-Whitney U Test	U = 14.000	1	0.212
Quality of browse in winter	Kruskal-Wallis	H = 0.287	2	0.866
Length of grazing period	Spearman's correlation	ρ = 0.477		0.309
Number of tree species offered	Spearman's correlation	ρ = 0.146		0.552

The calculated longevity of calves surviving more than one month was not affected by any independent variables, as shown in Table 12. Calculated longevity 1+ month was 3.2 years.

Table 12. Factors affecting the calculated longevity of Eurasian elk in 22 European zoos. Only animals born and died in the same zoo were included in the analyses.

Independent	Test		df	p-value
Hay quality	Kruskal-Wallis	H = 2.504	3	0.475
Use of premixes	Mann-Whitney U Test	U = 18.00	1	1.000
Daily feeding	Mann-Whitney U Test	U = 19.500	1	1.000
Browsing *ad libitum*	Mann-Whitney U Test	U = 14. 500	1	0.925
Use of naked branches in winter	Mann-Whitney U Test	U = 20.000	1	0.627
Quality of browse in winter	Kruskal-Wallis	H = 1.558	2	0.459
Length of grazing period	Spearman's correlation	ρ = −0.113		0.678
Number of tree species offered	Spearman's correlation	ρ = −0.079		0.771

The calculated longevity of calves surviving more than one month was not affected by any independent variables, as shown in Table 13. Calculated longevity 1+ month was 3.2 years.

Table 13. Factors affecting the calculated longevity of Eurasian elk calves surviving 1+ month in 22 European zoos.

Independent	Test		df	p-value
Hay quality	One-way ANOVA	F = 0.525	3	0.674
Use of premixes	Student's t-test	t = −0.178	13	0.862
Daily feeding	Student's t-test	t = 0.411	14	0.688
Browsing *ad libitum*	Student's t-test	t = −0.553	9	0.607
Use of naked branches in winter	Student's t-test	t = 1.378	14	0.190
Quality of browse in winter	One-way ANOVA	F = 1.871	2	0.193
Length of grazing period	Pearson correlation	r = 0.018		0.946
Number of tree species offered	Pearson correlation	r = −0.168		0.533

We did not find any factors affecting the calculated longevity of calves surviving more than six months (see Table 14). Calculated longevity 6+ months was 4.1 years.

Table 14. Factors affecting the calculated longevity of Eurasian elk calves surviving 6+ months in European zoos.

Independent	Test		Df	p-value
Hay quality	One-way ANOVA	F = 0.657	3	0.595
Use of premixes	Student's t-test	t = −0.743	13	0.471
Daily feeding	Student's t-test	t = 0.650	14	0.526
Browsing *ad libitum*	Student's t-test	t = 0.487	9	0.638
Use of naked branches in winter	Student's t-test	t = 0.772	14	0.453
Quality of browse in winter	One-way ANOVA	F = 1.032	2	0.384
Length of grazing period	Pearson correlation	r = 0.05		0.855
Number of tree species offered	Pearson correlation	r = −0.141		0.603

As shown in Table 15, calculated weaning age was not affected by any independent factors. Calculated percentage of calves surviving up to the weaning age was 36.59%.

Table 15. Factors affecting the calculated percentage of Eurasian elk calves surviving up to the weaning age in 22 European zoos.

Independent	Test		df	p-value
Hay quality	One-way ANOVA	F = 0.599	3	0.629
Use of premixes	Student's t-test	t = 0.096	13	0.925
Daily feeding	Student's t-test	t = −0.600	14	0.558
Browsing *ad libitum*	Student's t-test	t = 0.223	9	0.828
Use of naked branches in winter	Student's t-test	t = 1.136	14	0.275
Quality of browse in winter	One-way ANOVA	F = 0.081	2	0.923
Length of grazing period	Pearson correlation	r = 0.039		0.885
Number of tree species offered	Pearson correlation	r = −0.135		0.617

Even though, the use of premixes affected several factors, such as the reported twinning rate, reported survival rate of twins and reported birth rate, number of tree species offered and quality of winter browse did not affected any breeding performances factors. For that reason, the third hypothesis of this thesis was rejected.

5 Discussion

Husbandry and breeding of Eurasian elk is difficult in captivity, especially because of their complicated feeding ecology (Shochat et al. 1997; Schwartz et al. 1985). Shochat et al. (1997) reported that moose only prosper in captivity when a large amount of supplemental browse are allowed with herbivore pellets based on aspen. The aim of my thesis was to find out if it is possible to improve the keeping and breeding of Eurasian elk in zoos, and if so, how the performance and welfare of the captive population may be improved. That is necessary because there is a lack of studies focusing on management of captive Eurasian elk. On the other hand, there are a good amount of studies focusing on free-ranging Eurasian elk or American moose, which can provide relevant information about the nutritional needs of the species in captivity. For these reasons, our results are in most cases compared with those available for free-ranging elk.

5.1 Summary

In following chapters, we will discuss the most important questions. At first, we will focus on feeding practices and digestive effects. This chapter include changes in diet composition, factors affecting faeces consistency and use of premixes. The second chapter is focused on browsing and we will discuss the most important tree species offered and their positive or negative effects. The third and last chapter is focused on breeding performance and factors which influence the breeding performance. The last chapter includes data obtained from ZIMS.

This research was focused mainly on feeding practices and on breeding performances affected by these feeding practices. The diet composition and feeding doses will be analyse in future studies.

5.2 Information reported by zoological gardens

5.2.1 Feeding practices and digestive effects

As we found out, most zoological gardens switch the diets between summer and winter. This fact is very important because this is the situation that free-ranging elks face in nature. Zookeepers mostly provide higher amount of pellets during the winter but, it is seems to be contradictory, because free-ranging elk reduce the food intake at this time (Hofmann, 1989). According to Wam and Hjeljord (2010), elk switch to the summer diet from early spring, which is the same period as most zoological gardens do. However, zoo keepers switch to winter diet quite earlier, compared with free-ranging elk (Månsson et al. 2007). In some zoos, winter diet is provided as early as from September. Diet in this autumn period should be something in-between of summer and winter diet, when elk is gradually reducing the metabolism and food intake (Hofmann 1989), leading to changes in the rumen physiology (Regelin et al. 1985). Unfortunately, we did not get enough information about the length of the period of transition between summer and winter diet to allow statistical analyses; however, we may suspect that too drastic changes among diets may lead to digestive disorders and reduced performance.

Our statistical analysis did not detect if there are some factors affecting the faeces consistency; and unfortunately, there have been no study based on the changes in faeces consistency and factors affecting these changes (see Table 2). In most zoological gardens, changes in faeces consistency were observed both during spring and autumn. This period is, of course, the same as the diet composition was changed. However, no clear interaction between changes in diet and changes in faeces consistency was detected. Changes in faeces consistency were also detected in males during the rut season, which takes place simultaneously as the switch to winter diet (Chapman et al. 1975; Hoffmann et al. 2008). Milner et al. (2013) reported that 75% of free-ranging elk in Norway, had at least one type of gastrointestinal parasite. From the previous sentences, we can assume, that changes in faeces consistency could be caused by different factors, rut season and diet composition. However, it is evident that both factors are in mutual relationship, especially in males. But unfortunately, we did not find out, whether the changes in faeces consistency are really affected by seasonal changes in diet composition or by other factors such as rut season. Because of that, the first hypothesis of this thesis was rejected. However, these changes were recorded in a quarter of responded zoological gardens. For that reason, more studies focusing on the changes in faeces consistency and the factors affecting it are still necessary to make clear conclusions, so that, we can better understand the feeding practices in captive Eurasian elk.

The last chapter in this research was focused on breeding management where use of premixes showed positive effects on breeding performances. The premixes include mostly vitamins and minerals mainly in a form of licking stones. There is a lack of information about the use of premixes in captive Eurasian elk diet, however, there are several studies focused on American moose or free-ranging Eurasian elk. Tankersley and Gasaway (1983) reported that the use of licks typically occurs during the spring and summer in temperate ecosystems, with females using licks earlier than males. This fact is supported by the study made by Stepanova et al. (2017) with moose (*Alces alces* L.) in Russia. They found out that use of minerals licks occurring especially during the summer. They observed that monthly visiting of licks was as follows: June - 43.3%, July - 49.2%, August - 5.8%, September - 1.7% and October - 0%. The sex ratio of using the licks was as follows: males - 47.6% (n=10), females - 52.4% (n=11). It was also reported that licks can provide supplemental elements and buffering compounds (Ayotte et al. 2006). Especially sodium demands, increase approximately by 40% during early lactation and the sodium needs are necessary (Staaland et al. 1980). Botkin et al. (1973) and Jordan et al. (1973) considered sodium as a limiting factor to elk diet. In the wild, elk maily obtain minerals from aquatic vegetation, which is a nutritional resource with a high level of proteins and minerals, but low in fibre (Linn et al. 1975). On the ground of the research done by Jordan et al. (1973), elk seek aquatic plants because of its high level of sodium and/or other minerals. In the zoos, and in case elk have pond, any of them had aquatic vegetation. Especially, elk's winter diet of twigs is poor in sodium content and thus, the premixes are essential replacing the pond as mineral source. Not only for that reason, we may assume that mineral and vitamins premixes should be included in the captive Eurasian elk diet and should be provided when needed or, preferably, *ad libitum*.

5.2.2 Browsing and tree preferences

Eurasian elk is well-known as a specialist herbivore (Crawley 1983) and require enough browse all year-round. In our study, elk were offered with six basic kinds of tree species (willow, oak, maple, aspen, birch and pine, in order of preference). However, zoo keepers provided them also other tree species and shrubs, depending on availability.

Willow was the most preferred tree species in zoological gardens. After willow, elk preferred oak, pine and aspen, while birch was just mid-ranked. Because of that, the second hypothesis of this thesis was not accepted. Even though willow showed the highest preference and was consumed more than other tree species, birch was consumed as well as pine or oak. Nevertheless, Bjerga and Mysterud (1999) reported that birch is the main tree species eaten by free-ranging elk. This was also supported by Wam and Hjeljord (2010), who found that birch showed the highest preference compared to willow, aspen and oak. More surprisingly is the fact that oak consumption seems to have a negative effect on birth rate and twinning rate, and marginal significance on the survival rate of twins. Unfortunately, there is low information about use of oak by wild animals. However, oak was reported by zookeepers as the second most preferred tree species consumed in zoos, so these negative effects could be just due to the low sample size. One reasonable explanation why oak is used in zoos is because of its effects on faeces consistency. In some zoos, oaks are not offered much frequently, but in a nutritional way is used as a treatment to stop digestive disorders such as diarrhoea, when detected (Barbora Dobiášová – personal communication). It has been previously reported that oak can be offered in a form of fresh branches or as an oak bark, if possible (Homolka 1998). Due to the previous results, oak consumption and its effects on health are very interesting and could be a topic for further research.

Scots pine was well preferred tree species such as birch or maple. Shipley (2010) and Smeets (2014) reported that elk consume around 60% of Scots pine during the winter in Sweden. The second study found out that Scots pine and birch had similar probability of being browsed by free-ranging elk. In our study, Scots pine was found to have a possitive effect on breeding success and thus it can be recommended to include this species in the diet of captive elk.

5.2.3 Breeding

We already discussed the effects of premixes on Eurasian elk performance (see 5.1.2 Feeding practices and digestive effects). From the previous chapter follows that use of premixes has positive health effect on breeding performance.

The reported twinning rate in captive Eurasian elk was relatively high (38.5%), compared with study made by Testa and Adams (1998), where the twinning rate in free-ranging elk was approximately 23%. Although the reported twinning rate was relatively high compared with other cervids (e.g. white-tailed deer, where the twinning rate is 21%) (Roseberry & Klimstra 1970), in research done by Jones et al. (2017) was twinning rate in free-ranging moose only 14%. According to Boer (1992), variation in twinning rate has been attributed to differences in body condition of elk and may be caused by a poor female condition which may result in low yearling productivity, increased age of first reproduction and reduced fertility (Musante et al. 2010)

In our study was reported survival rate of twins estimated on 49.50%. Unfortunately, there is a lack of information based on this topic. However, Sivertsen et al. (2012) reported survival rate of free-ranging Eurasian elk calves between 20-40%. Even though, the twinning rate and survival rate of twins of captive elk are higher than in a free-ranging elk, survival rate of twins in captivity is very low. This fact may be caused by winter diet composition where, winter diet of captive elk mostly contains more browser pellets than summer diet. Consequently, the most credible explanation why the survival rate of twins is low is that, during the winter elk is reducing the food intake which is closely connected with changes in rumen physiology and thus low survival rate may be caused by overfeeding in winter season. Nevertheless, the comparison between captive and free-ranging Eurasian elk are difficult, because free-ranging elk is the predominant prey of wolves in Scandinavia (Sand et al. 2005). For that reason, the comparison of survival rate of twins cannot be exact.

5.3 Information obtained from ZIMS

From the Zoological Information Management System, we got information about calculated breeding rate, twinning rate, average longevity and about surviving up to weaning age. Unfortunately, majority of the results were not affected by hay quality, use of premixes, daily feeding, use of naked branches in winter, quality of browse in winter, length of grazing period and by number of tree species offered. However, calculated twinning rate for last 30 years was affected by browsing *ad libitum*. Eurasian elk are classified as browsers and spend majority of time by browsing (Hofmann 1989). Even though, the number of the tree species offered did not affect any factors, browsing ad libitum showed as a good practice and should be allow in captive Eurasian elk breeding management.

Maximum longevity of captive Eurasian elk was established at 1.8 years. Unfortunately, the longevity is very low because of the frequent death of calves immediately after birth. Weigl (2005) reported record longevity in captive Eurasian elk at 18.4 years. However, maximum longevity of captive Eurasian elk has not been specified yet. For comparison, average longevity in free-ranging Eurasian elk was established at 16 years (Grzimek 2003).

6 Conclusions

This research highlighted some feeding practices which could improve the breeding and performance in captive Eurasian elk.

On the ground of our results, we can recommend the use of premixes, which showed positive effects on breeding. Next interesting practise is to allow browse ad libitum, and providing certain preferred species such as willow, birch and pine. However, not all trees species showed as a suitable browse for elk and its consumption is unrecommended or should be limited, as it is the case for oak.

Further research must focus on the diet composition and other husbandry practices which may influence a healthy digestive tract. Moreover, the small sample size analysed (23 institutions) may explain why few practices were found to be significant in this study, and thus, it is advisable to make some effort to collect information from all the 48 zoological gardens in European countries breeding Eurasian elk.

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