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Retrospective study of mortality in Asiatic lions (*Panthera leo persica*) in the European breeding population between 2000 and 2014

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Abstract

The intention to import Asiatic lions (*Panthera leo persica*) from Sakkarbaug Zoo to the captive population managed under the European Endangered Species Program (EEP) emphasized how little is known about the health status of the EEP population. This study was designed to characterize mortality for this population through examination of the studbook and other records on 392 Asiatic lions living in the EEP between 2000 and 2014. 270 animals died during the period with 80% of them being under one year old. The mortality rate for under one year-olds was 54%, whilst the odds of survival of cubs within a litter increased if the dam had had litters previously. Survival to reproductive age was 44%. Post mortem reports were requested and the cause of death was obtained for 133 animals. Trauma inflicted by a conspecific and lack of care were common causes of death (26% and 22% respectively), and were also responsible for most of the neonatal mortalities. Congenital defects were responsible for 9% of deaths, although the true prevalence is likely underestimated. A common necropsy protocol for all Asiatic lion collections is needed to facilitate future studies. Low cub survival and a high rate of congenital defects might indicate inbreeding depression in the EEP and points to the need for new genetic material within this population.

Key words: Asiatic lion, *Panthera leo persica*, mortality review, infant mortality, congenital defects

Introduction

The Asiatic lion (*Panthera leo persica*) is slightly smaller than the African lion and can be differentiated by a prominent fold of skin that spans the length of the abdomen (O’Brien et al. 1987). The species is classified as endangered by the IUCN Red List and despite its historic range stretching from North Africa over Europe to eastern India, the Asiatic lion now only exists as a single free-living population in the Gir forest in India (Breitenmoser et al. 2008). Although this population recently increased to about 500 individuals, the presence of only one free-living population makes the species extremely vulnerable to catastrophic events (DeshGujarat 2015).

Asiatic lions went through two population bottlenecks in the past. After the first one 4,000 to 5,000 years ago, sport hunting and habitat encroachment reduced the population to only 20 individuals in the early 20th century (Driscoll et al. 2002). Today they are mainly threatened by human-carnivore conflict. There are occasional incidents of attacks on humans, and livestock makes up a significant part of a lion's biomass consumption (Breitenmoser et al.; Nowell and Jackson 1996; Banerjee et al. 2013).

Captive breeding programs for Asiatic lions currently exist in India and in Europe (Zingg 2007). Previous research on Asiatic lions in captivity has mainly been carried out at Sakkarbaug Zoo in India, which houses the largest captive population of Asiatic lions (Nowell and Jackson 1996). Sakkarbaug Zoo also takes in orphaned, sick and wounded lions from the wild, which are mated with captive individuals to maintain a healthy captive population (Gujarat State Lion Conservation Society 2011). Research on this population showed that reproduction starts earlier in captivity than in the wild. Both males and females start reproducing at about three years of age in captivity, compared to four years for females and five to eight years for males in the wild (Nowell and Jackson 1996). Both genders stop reproducing at about 15 years of age (Nowell and Jackson 1996). Longevity is not recorded for the free-living population and lies between 16 and 18 years in captivity, with 17 to 18 years for females and 16 years for males (Nowell and Jackson 1996). The mortality rate for lions under one year of age is estimated to be 33% in the wild and 36% at Sakkarbaug Zoo (Nowell and Jackson 1996). In the wild, infanticide can cause up to 60% of cub mortality (Breitenmoser et al.).

The European breeding program started in 1990 and has been managed as a European Endangered Species Program (EEP) since 1994 (Zingg 2007). From an original 12 founder animals there were 121 individuals living in 42 collections in December 2014 (Nielsen 2014). Both the free-living population and the population at Sakkarbaug Zoo have demonstrated high counts of morphologically abnormal sperm in the past, which has been recognized as a sign of inbreeding depression in African cheetahs (O'Brien et al. 1987; Wildt et al. 1987). Considering this, inbreeding depression is also probably a problem within the EEP, and the population would benefit from the introduction of new genetic material.

The Zoological Society of London (ZSL) and Gujarat Forest Department (GFD) are collaborating to attempt an import of Asiatic lions from Sakkarbaug Zoo breeding facility to the EEP. As a result of this collaboration, it became apparent that little is known about the health status of the European population. This study aimed to improve our understanding by studying mortality occurring in the European population between 2000 and 2014. Conducting a mortality review can help to show trends in mortality for a captive population (Hope and Deem 2006) and may even point towards management strategies that could assist in preventing some diseases (Martínez et al. 2013).

The first objective of this study was to describe mortality occurring in the EEP, including information on mortality rates and ages at death. As part of the general data obtained on mortality, litter survival was investigated more closely. Generally, even if a dam starts her breeding record with low litter survival she is nonetheless bred from further. Anecdotal evidence points to survival improving with parity, and for other species it has been shown that parental experience has an influence on the survival of the young (Daunt et al. 2007; Meijer et al. 2011). The second objective was thus to look at litter survival with the hypothesis that the survival rate increases when a dam becomes multiparous. The last part of the study focused on the circumstances and causes of death in this population; thus the third objective was to identify the most common causes of death in the population as a whole and per age group and gender.

Methods

Data on all Asiatic lions living in the EEP (dead and alive) between 01.01.2000 and 31.12.2014 were collected from the Zoological Information Management System (ZIMS). These data included the date and location of birth, the date and location of death (if applicable), and the dam and sire of each animal. One collection had to be excluded from the analyses as it does not use ZIMS and did not supply any information for this study.

To allow statistical analysis, the animals were grouped into categories depending on the age at death. The "neonate" category included all animals less than one month of age, which correlates with the period before cubs start leaving their cubbing den. All deaths that occurred before animals reached reproductive age were grouped into "juvenile" (1-36 months). All animals of reproductive age (36-180 months) were classified as "adult", while all animals that reached post reproductive age were classified as "geriatric" (more than 180 months old).

Where applicable, the standard error of the mean was used to describe variation. A chi-square analysis (R version 3.2.1 (R Core Team 2015)) was used to determine if there was a difference in the number of males and females born during the study period. The mortality rate per year was calculated for the study population and a Cox proportional hazard model (R version 3.2.1 (R Core Team 2015), package "survival" (Therneau 2015)) was used to determine if there was a difference in survival between males and females. In order to determine if cub survival increased with the number of litters, a generalized linear mixed effects model was used (R version 3.2.1 (R Core Team 2015), package "lme4" (Bates et al. 2015)). For this analysis, dams with two litters or more were taken into account, and dams, sires and birth locations were included in the analyses as random effects. It has to be noted here that the exact number of cubs was unknown for at least four litters, as the litter was eaten by the dam before staff were able to see the cubs. It was assumed that these litters only contained one cub.

Data on the circumstances of death were obtained by contacting all past and present Asiatic lion holders within the EEP via the co-ordinator and collecting post mortem reports. If the original reports were not in English, a translation or summary in English was requested. If this was not possible the reports were translated by the first author. If the cause of death was not listed specifically it was ascertained by interpretation of the post mortem report wherever possible and in conjunction with the EEP Veterinary Advisor. As in other studies (Hope and Deem 2006;

Clancy et al. 2013), the reason for euthanasia was listed as the cause of death. Additional findings at post mortem were also noted. For collections that did not respond, the cause of death was obtained from ZIMS where possible. If “stillborn” was listed as the cause of death on ZIMS it was not included in the analyses, as some collections do not use this term to exclusively describe animals that are dead at birth.

Additionally, the causes of death were grouped into the following categories: “stillbirth” (dead at birth), “trauma” (death due to wounds inflicted by the dam or another conspecific), “degenerative” (degenerative, ‘wear and tear’ diseases), “congenital” (defects present at birth), “infectious” (infectious diseases), “lack of care” (cub abandoned or not cared for properly), “neoplasia” and “other” (all conditions that caused death in less than five cases). Unknown causes were grouped depending on the reason for this: “no report” (not received or of insufficient quality), “carcass eaten” (by dam or another conspecific) or “cause unclear” (due to carcass condition or lack of findings during post mortem examination).

The prevalence of the different causes was calculated for the population as a whole and for each gender and age group, and the leading causes of death were identified. Fisher’s exact test was used to determine if the prevalence of causes of death was significantly different between male and female (R version 3.2.1 (R Core Team 2015)).

Results

General description:

270 dead animals and 122 live animals were included in this study from records referring to a total of 392 animals. Of these, 34% (132/392) were male (87 dead, 45 alive), 43% (172/392) female (97 dead, 75 alive) and 22% (88/392) were of undetermined gender (86 dead, 2 alive). 340 animals were born during the study period and for 252 of these the sex was known. Of these 43% (108/252) were male and 57% (144/252) were female, which represents a significant gender bias (p=0.02).

Figure 1

The average age at death was 2.39 ± 0.32 years (28.79 ± 3.91 months). 80% (215/270) of the animals that died during the study period did not reach one year of age (figure 1), and excluding these from the calculation increases the average age at death to 11.61 ± 0.77 years (139.41 ± 9.35 months). The oldest animal was a female that died when she was 19 years two months and 27 days old. So far no animal currently alive has reached this age. The Cox proportional hazard model showed that gender had no effect on survival (p=0.19) with the hazard ratio being 1.22 (95% CI: 0.91, 1.63).

Figure 2

The average yearly mortality rate during the study period was 17.5%. Over the years it fluctuated between 11.5% and 23.3% as shown in figure 2. Most of the deaths fell into the category “neonate”, with only about 10% of deaths in each of the other three categories (figure 3). Looking at the animals that could have reached reproductive age during the study period (born no later than 31.12.2011, n=313) showed that only 44% achieved this, and the mortality rate for animals under one year of age (including animals born before 31.12.2013, n=358) was 54%.

Figure 3

30 dams gave birth to two litters or more during the study period and 121 litters were included in the generalized linear mixed effect model. The results showed that the odds for cubs within a litter to reach one year of age increase significantly with the number of litters a dam had previously (OR=1.408, 95% CI: 1.19, 1.67)(p=0.00009).

Circumstances of death:

For ten of the 46 collections (22%) that hold or held Asiatic lions no death occurred within the study period. 50% (18/36) of the collections where deaths occurred supplied the requested data on the circumstances of death. This included data on 58% (158/270) of deaths. The information for whether death occurred spontaneously or due to euthanasia was available for 196 of the 270 deaths (73%). Of these 68% (133/196) were spontaneous and 32% (63/196) were due to euthanasia. In 48 cases, the reason for euthanasia was reported and was thus noted as the cause of death. In addition, the cause of death was obtained from ZIMS for seven animals. 32 reports did not include a cause of death and were recorded as "cause unclear" (eight cases) or as "carcass eaten" (24 cases). This resulted in a total of 133 known causes of death out of 270 deaths reported (49%).

The quality of these reports varied, ranging from a simple statement of the cause of death to a complete post mortem examination report. Furthermore, the extent of the conducted examinations differed. While animals dying at an older age received a full and detailed post mortem examination, cubs that died shortly after birth often received only a quick examination or none at all. Excluding the 24 cases where the carcass was eaten, a full post mortem examination would have been possible in 134 cases out of the 158 cases where a report was received. Information on comorbid findings was only received for 31% of these (42/134) and 32% (43/134) of the reports received only contained a simple statement of the cause of death.

Figure 4

Table 1

The causes of death per age category and in total are shown in figure 4 and table 1. The leading cause of death within this study population was "trauma" (26%), closely followed by "lack of care" (22%). The remaining cause categories are each responsible for 7-10% of the deaths (figure 4, table 2). The high incidence of "trauma" and "lack of care" in the whole study population is reflected in the "neonate" category, where 36% and 35% of deaths were caused by "lack of care" and "trauma" respectively. For juveniles the three most common causes of death are "trauma" (26%), "congenital" (30%) and "other" (30%). Apart from "other causes" the leading cause of death for adults is "degenerative" (figure 4, table 2). Only two causes of death were present in the "geriatric" age group, with "degenerative" (53%) making up a slightly higher percentage than "neoplasia" (47%).

Figure 5

Table 2

The causes of death for each gender are shown in figure 5 and table 2. “Trauma” (27%) is the leading cause of death for males, and for females “lack of care” (20%), closely followed by “trauma” (19%), is the leading cause of death. For the individuals of unknown sex “stillbirth” (23%) and “lack of care” (27%) are common causes of death while “trauma” (41%) is the leading cause of death. Excluding the individuals with undetermined gender from the analyses showed that there was no significant difference in the causes of death between genders (p=0.5).

Trauma: 34 cubs were killed through trauma. In 23 cases the individual responsible for the trauma was known. In 70% (16/23) of these cases trauma was inflicted by the dam, and sires were responsible for 9% (2/23). In one case trauma occurred as late as 137 days after birth, where a female cub was killed by her sire.

Congenital defects: In a total of eleven cases (9%), congenital defects were the cause of death during the study period. In most cases (musculo-) skeletal abnormalities were the reason for euthanasia. One cub was euthanized due to multiple distal limb developmental abnormalities, and three other cubs were euthanized because of severe scoliosis or other malformations of the vertebral column. In two cases the congenital defects were neurological, and in one case the cause of death was renal dysplasia. Two cubs of the same litter died of syringomyelia, and a cub in another collection was born with a cleft palate. The most severe congenital defects were observed in a cub that was born with an incomplete closure of the abdominal wall and skin, a missing tail, sacrum and anus, and severe scoliosis.

Infectious: This category included five cases of pneumonia, all of which occurred in neonates. There was one case of cowpox and four cases of bacterial infection, with one of these being systemic. In one case an *Escherichia coli* infection resulted in acute hemorrhagic nephritis and kidney failure, and in another a leg abscess caused by *Streptococcus canis* led to euthanasia. For one case included in "infectious" there were no further details available.

Neoplasia: Different types of neoplasm were the cause of death during the study period, but the majority were carcinomas (four cases) and haemangiosarcomas (three cases). Of the nine cases overall, seven occurred in the oldest age group "geriatric", and one occurred in the age group "adult" (a 14 year old female). The youngest animal affected by neoplasia was a two year old male that died of a haemangiosarcoma.

Degenerative: Renal failure was the cause of death in six of the 13 cases included in the "degenerative" category. It was responsible for 10% and 13% of the deaths of adult and geriatric animals respectively (three cases each). The youngest individual affected by this was a ten year old female that was euthanized. In two cases death was the result of an age-related heart condition, and in two cases degeneration of the central nervous system (CNS) was the cause of death. In nine of the 13 cases the animal was euthanized (information unknown for one animal).

Other causes: The category "other causes" included many different causes of death: A twelve year old female was killed by the male sharing her enclosure, and the male was subsequently euthanized. Two animals were euthanized after sustaining injuries: an eight year old male developed back paralysis, and a two month old cub suffered a fractured leg. In two cases accidents resulted in death: A two year old female drowned in the wet moat of the enclosure, and a nine year old female died of injuries sustained from an electrical fence. Additionally, two animals in the same collection died after suffering from Vitamin A deficiency, and there were two cases of herniation of the cerebellar vermis in one year old littermates. Lastly, there was one case each of degenerative myelopathy, gastrointestinal ulceration and encephalitis.

Additional relevant findings noted at post mortem: Only 46 reports received included other findings at post mortem. Apart from the cases described under "congenital", there were two cases of scoliosis and two cases of other musculoskeletal defects present as secondary findings. Two cubs from the same litter presented with patent ductus arteriosus (PDA), but clinical significance was not established and in an additional case in another collection PDA was suspected.

Discussion

Mortality:

Most noticeable in this study was the very young average age at death of 2.4 years, with the mortality rate of animals under one year of age being 54%, and only 44% of animals reaching reproductive age. A study on the free-living population in Gujarat showed that 51% of young cubs survived to adult stage (Banerjee and Jhala 2012). However, it is difficult to compare these numbers. Observing cubs under one month of age proved difficult in the wild, and infanticide due to territorial takeovers by an adult male was a substantial cause of cub mortality (Banerjee and Jhala 2012). Cubs under one month of age account for most of the mortalities in this study and infanticide by an adult male was only reported in two cases.

For Sakkarbaug Zoo the mortality for under one year-olds is given at 36% (Nowell and Jackson 1996), which is comparable to the under one-year mortality rate of Amur leopards in the EEP, which is given at 39% (Blomqvist 2008). If the measurements at Sakkarbaug Zoo include all animals born, then mortality in the EEP is noticeably higher. A possible cause for the higher rate of 54% in the EEP may be inbreeding depression. When comparing inbred individuals of certain species to non-inbred individuals, juvenile mortality was shown to be higher amongst inbred individuals (Ralls and Ballou 1982; Ralls and Ballou 1982; Ralls et al. 1988; Wielebnowski 1996). Sakkarbaug Zoo regularly breeds its captive animals with animals that have been brought in from the wild for rehabilitation (Gujarat State Lion Conservation Society 2011). This way fresh genetic material is constantly added to their captive population, which is currently not the case in the EEP.

In various species parental experience also plays a role in breeding success and juvenile survival (e.g. Daunt et al. 2007; Meijer et al. 2011). Amongst primiparous lionesses, infanticide is not uncommon and does not mean that the lioness will repeat this behavior with her next litter (AZA Lion Species Survival Plan 2012). Experience may also play a role in low cub survival rates, such as provision of insufficient care or abandonment of cubs. Based on the assumption that cub survival will increase with experience, many captive collections further breed from dams despite previous low cub survival. This study showed that this assumption was correct for the EEP population of Asiatic lions, where the odds for survival to one year of age increase with the number of litters of a dam.

Causes of death:

The fact that "lack of care" and "trauma" are the only causes that are each responsible for over 20% of deaths matches the high neonatal mortality rate observed in the study population. 36% of neonatal mortality is due to trauma, which is mostly inflicted by the dam. In the wild, infanticide is the cause of up to 60% of cub mortality (Breitenmoser et al.). A study by Banerjee and Jhala (2012) found that territorial takeovers by males that resulted in infanticide were the main cause for cub mortality. The rate of infanticide in the EEP may be higher than 36%, as some of the carcasses that were eaten may have been killed first, but this study points towards a lower infanticide rate in the EEP compared to the wild. This is probably due to the fact that unrelated males are mainly responsible for infanticide in the wild, whereas the dam is responsible in captivity. It is, however, difficult to establish if there is a difference between the EEP and the free-living population where trauma inflicted by the dam is concerned.

Unsurprisingly, degenerative diseases and neoplasia were mainly a concern for old animals. The unusual case of a two year old male dying from a haemangiosarcoma will not be discussed here as it is published as a case report (Vercammen et al. 2015). Renal failure caused 5% of the deaths with a known cause in the whole study population and 13% of the deaths in the geriatric age class. This is not unusual, as various kidney diseases are known to affect old felids, both domestic and wild (Newkirk et al. 2011) and a retrospective study on wild felids in German collections found renal lesions in 87% of the animals included in the study (Junginger et al. 2015).

Both causes of death summarized under “infectious” and “other” are a possible cause of concern, but with these occurring only in a few cases they do not represent a significant problem. Cases such as Vitamin A deficiency and accidents resulting in deaths are issues that need to be addressed by the affected collection but do not affect the breeding population as a whole.

9% of the known causes of death were due to congenital defects. However, even congenital defects that do not result in death can be of concern for the health and welfare of an animal. Some of these defects may be hereditary in Asiatic lions. Scoliosis was present in at least six individuals from the study population and is known to be hereditary in humans (Shangguan et al. 2008). PDA is hereditary in some dog breeds (Buchanan and Patterson 2003) and although it has not been established as the cause of death in any animal of the study population, it might play a role in cubs dying of problems associated with inappropriate maternal care. In the United States, 3% of humans are born with birth defects (defined as “conditions that […] have a serious, adverse effect on health, development, or functional ability” (Centers for Disease Control and Prevention)) and this study points towards the percentage in Asiatic lions being higher.

Limitations:

The limitations of this study mainly concern the analyses of the causes of death. For only 49% of the lions that died during the study period the cause of death was established. Although an unknown cause of death was mainly due to lack of reporting by the collections, it would not have been possible to know the cause of death for all animals. In 15% of the received reports determination of the cause of death was not possible because the carcass had been eaten. Even the known causes of death cannot be viewed with absolute certainty. Many collections only provided a simple statement of the cause of death and it could not be verified by a post mortem report. Cases recorded as “stillbirth” have to be considered with caution, as the exact definition of what classifies as a stillbirth at the different collections is not clear.

The extent of post mortem examinations conducted differed greatly, which is reflected by the fact that a lot of deceased cubs are of undetermined sex. Conditions present might have gone unnoticed due to an inadequate post mortem exam. For example a thorough cardiac exam is necessary in order to recognize PDA, but is only carried out in a few cases. In general, the prevalence of congenital defects such as PDA and scoliosis might be underestimated. As mentioned above, many cubs do not receive a full post mortem examination, so if a congenital defect was not the cause of death or the reason for euthanasia it likely went unnoticed.

Nonetheless, a higher compliance rate would have allowed for a more detailed analysis in some areas of this study. Although data analysis showed that the odds for cub survival to one year of age increased with the number of litters a dam had, it was not possible to look into the reasons for this. If the cause of death had been established for more cubs, it might have been possible to examine whether the increasing odds for survival correlate with a decrease in incidences of “lack of care” and “trauma”. Comparison between cub mortality in the wild and in the EEP was also limited, as the cause of death was unknown for many cubs. Although it will never be possible to establish the cause of death for each individual, a higher compliance rate could have enabled a more significant comparison.

Implications for the future:

For many large mammals living in captive collections the management of geriatric problems is becoming increasingly important. This is an issue mainly concerning the individual and not the population as a whole, and research on geriatric problems in Asiatic lions has been scarce so far. As in domestic cats, renal disease is a concern in older animals. Dietary adjustments play an important part in managing chronic renal failure (CRF) in domestic cats. There is evidence that diets specifically designed for CRF management might increase survival time (Elliott et al. 2000) as well as manage the clinical signs of uremia (Rubin 1997; Elliott 2006). Protein restricted feeds are used to reduce disturbances in mineral, electrolyte and vitamin balance (Rubin 1997; Elliott 2006), and diets for dogs and cats with CRF typically have a high fat content as this represents a non-protein energy source (Elliott 2006). Research on captive cheetahs showed that the protein to fat ratio was lower for whole rabbit carcass diets than for meat-only diets (Depauw et al. 2012).

Whole carcass feeds might thus be an option for managing renal disease in Asiatic lions, but further research is needed to validate the effects in lions.

Further research is also needed to answer questions raised during this study. Comparing the free-living, EEP and Sakkarbaug Zoo populations is currently difficult, as not all necessary information is available. Knowing if there is a difference in infant mortality in the EEP compared to the other two populations could show if inbreeding might be affecting the Asiatic lions in Europe. Not only does the infant mortality rate itself require further investigation, but the reasons for cub mortality are also difficult to compare. Especially trauma inflicted by the dam needs to be explored in more detail, as it is unclear how the rate observed in the EEP compares to the other populations. Furthermore, the reasons for a dam killing or abandoning her cubs need to be considered. A mortality review for red foxes showed, that maternal culling of unhealthy cubs in order to improve the survival chances of healthy siblings likely played a role in trauma induced neonatal death (Acton et al. 2000). Knowing which cases of dams killing or abandoning their cubs are due to selective culling and which are due to stress or a lack of experience might point towards beneficial management actions.

Another important aspect raised by this study is the prevalence of congenital defects. Especially those congenital defects that might be hereditary require investigation. Before being able to establish heritability, the actual prevalence of birth defects, not only of those leading to death, needs to be established. A first step in learning more about congenital defects would be to implement a common necropsy protocol in the EEP. As mentioned, cubs often only receive a superficial necropsy leading to conditions possibly going unnoticed. A common protocol could include examinations needed to establish if a congenital defect known to affect the EEP is present. For example, a thorough cardiac exam at each necropsy could show if PDA is a problem with a significant impact or not. If it is discovered that congenital defects such as scoliosis or PDA are hereditary, decisions may be taken to not breed from parents that have produced offspring with these conditions in the past. The lack of a common necropsy protocol has already limited other mortality studies (e.g. Maia and Gouveia 2002; Yss et al. 2012), and the implementation of such a protocol may reveal additional diseases within the population not discovered during this study.

Both congenital defects and high infant mortality are possibly due to inbreeding depression. Establishing this will however be a slow process, but the risk alone should justify the addition of new genetic material to the EEP. If inbreeding depression is an issue in the EEP, this might be a precautionary measure to avoid an increase in cub mortality rates and prevalence of congenital defects. Artificial insemination (AI) using sperm from free-living Asiatic lions or from those at Sakkarbaug Zoo would be a theoretical option, but as AI on lions has so far not resulted in live offspring (Goeritz et al. 2012), this is not yet a viable option. The best option available at the moment would be for ZSL and GFD to continue with their attempt to import Asiatic lions from Sakkarbaug Zoo to the EEP.

Conclusions

1. The high neonate mortality was the most noticeable result of this study. Low cub survival rates might be a sign of inbreeding depression, but more comparable research is needed to establish this.

2. Investigation into litter survival in relation to parity of the dam showed that anecdotal evidence of cub survival increasing with litters is supported by data collected here for Asiatic lions in the EEP.

3. A common necropsy protocol for all Asiatic lions in the EEP would enable a more detailed investigation into several areas, including the prevalence of congenital defects. A more detailed necropsy might also reveal underlying reasons for dams abandoning or killing their cubs, which are the main causes of death for young animals.

Overall this study pointed to some areas that require further investigation, but some issues identified might be solved if new genetic material were to be added to the European population of Asiatic lions.

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Table 1. Known causes of death per age category

	Neonate	Juvenile	Adult	Geriatric	Total
Stillbirth	12 (15%)	-	-	-	12 (9%)
Lack of care	29 (36%)	-	-	-	29 (22%)
Trauma	28 (35%)	6 (26%)	-	-	34 (26%)
Congenital	4 (5%)	7 (30%)	-	-	12 (9%)
Infectious	7 (9%)	2 (9%)	2 (14%)	-	11 (8%)
Neoplasia	-	1 (4%)	1 (7%)	7 (47%)	9 (7%)
Degenerative	-	-	5 (36%)	8 (53%)	13 (10%)
Other cause	1 (1%)	7 (30%)	6 (43%)	-	13 (10%)
Total	81	23	14	15	133

Table 2. Known causes of death per gender

	Male	Female	Undetermined
Stillbirth	3 (6%)	4 (7%)	5 (23%)
Lack of care	11 (21%)	12 (20%)	6 (27%)
Trauma	4 (27%)	11 (19%)	9 (41%)
Congenital	6 (12%)	4 (7%)	1 (5%)
Infectious	6 (12%)	5 (8%)	-
Neoplasia	2 (4%)	7 (12%)	-
Degenerative	7 (13%)	6 (10%)	-
Other cause	3 (6%)	10 (17%)	1 (5%)
Total	52	59	22

Figure 1. Number of animals living in the EEP population between 1990 and 2015. Figure supplied by the EEP coordinator.

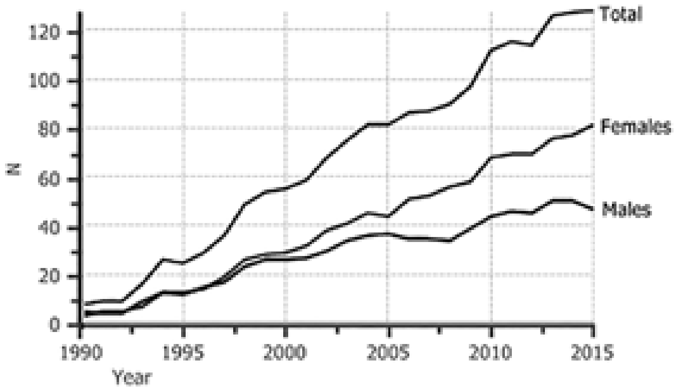

Figure 2. Number of cubs born per year. Graph includes all animals born during the study period (n = 340).

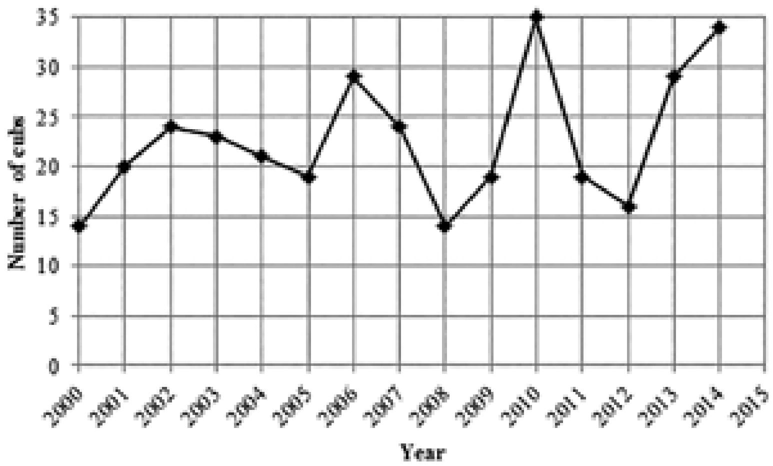

Figure 3. Number of animals that reached the respective age. Graph only includes animals that died during the study period (n = 270).

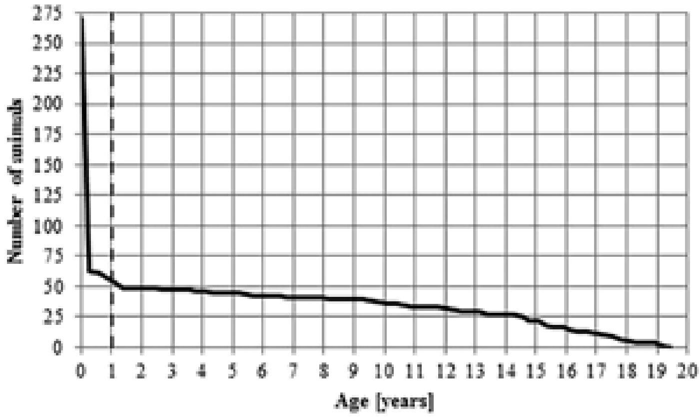

Figure 4. Yearly mortality rate between 2000 and 2014.

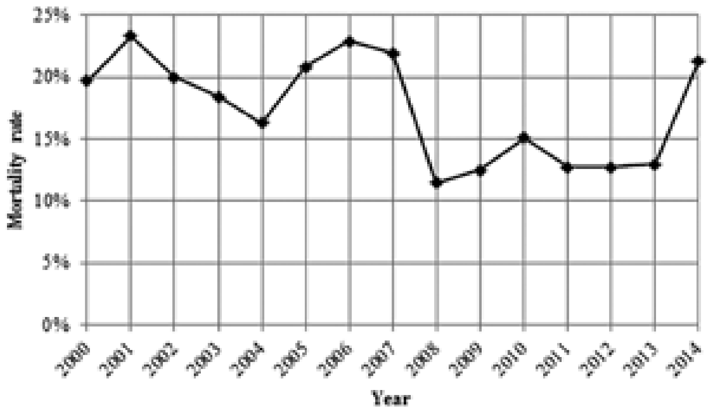

Figure 5. Number of animals that died due to trauma at the respective age. Only including animals that were under 15 days old (n = 28).