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MORTALITY OF CAPTIVE BLACK-FOOTED FERRETS (*MUSTELA NIGRIPES*) AT SMITHSONIAN'S NATIONAL ZOOLOGICAL PARK, 1989–2004

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Abstract: Black-footed ferret (*Mustela nigripes*) mortality was investigated retrospectively based on the pathology records of 107 captive animals held at Smithsonian's National Zoological Park from 1989 to 2004. The majority of deaths in neonates were due to cannibalism (n = 42; 64.6%) and maternal trauma (n = 11; 16.9%); both of these causes of mortality decreased during the study period. Prior to 2001, juvenile mortality was most often caused by gastrointestinal disease (n = 11; 52.4%), including coccidiosis, salmonellosis, and clostridium infection. In 2001, improvements in husbandry, hygiene, and medical treatment led to decreases in juvenile mortality associated with gastrointestinal disease. The most common causes of death in adult ferrets were renal or neoplastic disease. The etiology of the high prevalence of renal disease in the last 4 yr of the study is unknown; it was not associated with increasing age or inbreeding. Improved hygiene and vigilant monitoring for signs of gastrointestinal and renal disease will continue to improve the success of the captive propagation of this species.

Key words: Black-footed ferret, coccidiosis, mortality, *Mustela nigripes*, neoplasia, renal disease.

INTRODUCTION

The black-footed ferret (*Mustela nigripes*) was once widely distributed in prairie habitats across much of western North America. The severe decline of the species is attributed to conversion of prairie habitat to agricultural lands and widespread attempts to eradicate prairie dogs (*Cynomys* spp.), which are the obligate prey item of the black-footed ferret.[14] The species was considered extinct in the 1970s, until a remnant population was discovered in Wyoming in 1981. After suffering a canine distemper virus epizootic, the surviving 18 individuals were captured and a captive propagation program was initiated in 1987 at the Sybille Wildlife Research and Conservation Education Unit near Laramie, Wyoming. The captive population was further divided in 1988 and additional collections were established at the National Zoological Park's (NZP) Center for Research and Conservation (CRC) in Front Royal, Virginia, and at the Henry Doorly Zoo in Omaha, Nebraska. There are currently seven institutions participating in the propagation program under the supervision of the United States Fish and Wildlife Service. Beginning in 1991, more than 5,000 black-footed ferrets have been born in captivity. Ferrets have been reintroduced at sites in six Western U.S. states and one site in Mexico.[3] The total estimated population is around 600 individuals, with the population in the wild slightly exceeding the captive population.

Of the original 18 captured animals, only 7 individuals reproduced and became the founders for the current population. Because of this extremely small number of founder animals, the genetic diversity of the present population is less than 90% of that present in the species prior to their decline in the wild.[17] This decrease in genetic diversity has lead to increased inbreeding and may lead to decreased fitness due to inbreeding depression, including immune system dysfunction and reduced reproductive success.[9] Probable genetic defects, including fused coccygeal vertebrae, xyphoid process malformations, and cryptorchidism are not uncommon in captive and wild black-footed ferrets.[2,3] Low sperm quality and high susceptibility to infectious diseases such as plague and canine distemper virus may also be due to inbreeding.[3,10] A high incidence of neoplastic disease among black-footed ferrets has also been recognized, and low genetic diversity was thought to be a possible etiologic factor, al-

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though a genetic association could not be found in one study.[5] Even though moderate inbreeding has occurred in captive and released black-footed ferret populations, the degree of genetic diversity remains within the goal of the American Zoo and Aquarium Species Survival Plan.[18]

Around 2001, several changes were made in the husbandry and care of the black-footed ferrets at the NZP, including less-intensive monitoring of neonates, improved hygiene, and new vaccine and anticoccidial treatment protocols. An increased number of adult ferrets were clinically noted to have signs of chronic renal disease since these management changes were instituted. This retrospective study analyzes the causes of mortality of the National Zoo's black-footed ferrets since the ferrets' arrival at the NZP in 1988.

In addition, these data were compared to the pre- and post-2001 management changes. The significance of these findings for the future management of this endangered species is discussed.

MATERIALS AND METHODS

Pathology records of all black-footed ferrets that died at the NZP from 1989 to 2004 were evaluated (n = 107). The most significant pathologic change, or cause of death, was determined from the pathology record and listed in categories and sorted by age. The cause of death was categorized into major groups, including cannibalism, stillborn fetus, trauma, sepsis, congenital defects, respiratory, circulatory, gastrointestinal, urinary, reproductive, neoplasia, and undetermined cause. Cannibalism was considered the cause of death if the kit's presence was confirmed by keeper staff, but the kit was later missing or a carcass was found partially consumed. A fetus was considered stillborn if pathologic exam revealed that the lungs had not been inflated. Trauma was diagnosed if the carcass was whole but showed signs of obvious trauma. The cause of death was defined as sepsis if signs of inflammation as well as cultures at the time of necropsy indicated systemic infection. Congenital defects were deemed the cause of mortality if they were severe enough to cause death and other signs of mortality were not present. Mortality associated with neoplastic processes was placed in the category neoplasia, regardless of organ system. The remaining cases were divided into organ systems in which lesions were present that were deemed responsible for the death of the animal: respiratory, circulatory, gastrointestinal, urinary, and reproductive. In some cases, the lesions discovered at necropsy were not adequate to explain the cause of death of the animal. The cause of death in these cases was considered to be undetermined.

The animals were divided into three age groups: neonates (0–30 days), juveniles (31 days–11 mo), and adults (>11 mo). Gross and histologic diagnoses were made by several pathologists during the time of the study. All cases with renal, neoplastic, or biliary changes were reviewed by one pathologist (TV).

To determine if renal disease or congenital defects were correlated with increased inbreeding, pedigree-based, individual inbreeding coefficients of ferrets with these diseases to ferrets that did not succumb to disease were compared. Because the diseased population was much smaller than the healthy population, variances among populations were not equal. In addition, inbreeding coefficients were constrained between 0 and 1, which violated the parametric assumption of normality. To avoid violations of parametric statistics, a randomization procedure to test the hypothesis that diseased populations had a greater inbreeding coefficient than healthy populations was used. The randomization procedure randomly reallocated the original observations into two groups, 10,000 times. During each reallocation, the difference between groups was calculated and standardized by the standard error (t) to produce a sampling distribution of t values. The t value calculated from the actual data was then compared to the distribution to determine the P value of the observed statistic. Twenty-six black-footed ferrets had diseases that were potentially genetic in origin. These were categorized into three diagnoses: renal disease as cause of death, renal disease as a secondary lesion, and congenital defects. Separate randomization tests were conducted on each category, and inbreeding coefficients were compared to those of healthy individuals that were born in the same time period as the diseased animals.

Difference in age at time of death between adult ferrets (>11 mo), as well as juvenile and adult ferrets (>31 days) that died before (1 January 1989–31 December 2000) and after 1 January 2001 (1 January 2001–31 December 2004) was evaluated with a Mann–Whitney U-test. The proportion of adults that died of renal failure before 2001 and after 2001 was compared with a two-tailed Fisher's exact test. Statistical analyses were performed with the Statistical Package for the Social Sciences software (Version 10.0, SPSS Inc., Chicago, Illinois 60606, USA). All test values were considered significant if $P < 0.05$.

RESULTS

Pathology records were examined from 107 black-footed ferrets, ranging from 0 days to 8 yr, 4

Table 1. Cause of death in black-footed ferrets (*Mustela nigripes*) (n = 107) at the National Zoological Park from 1989 to 2004.

Cause of death by disease category	Total black-footed ferrets (n = 107) n (%)	Neonates 0–30 days (n = 65) n (%)	Juveniles 30 days–11 mo (n = 21) n (%)	Adults >11 mo (n = 21) n (%)
Cannibalism	42 (39.3)	42 (64.6)	0 (0.0)	0 (0.0)
Stillborn	4 (3.7)	4 (6.2)	0 (0.0)	0 (0.0)
Trauma	13 (12.1)	11 (16.9)	2 (9.5)	0 (0.0)
Sepsis	3 (2.8)	2 (3.1)	1 (4.8)	0 (0.0)
Congenital	1 (0.9)	0 (0.0)	1 (4.8)	0 (0.0)
Respiratory	10 (9.3)	4 (6.2)	3 (14.3)	3 (14.3)
Circulatory	2 (1.9)	0 (0.0)	0 (0.0)	2 (9.5)
Gastrointestinal	14 (13.1)	1 (1.5)	11 (52.4)	2 (9.5)
Urinary	7 (6.5)	0 (0.0)	0 (0.0)	7 (33.3)
Reproductive	1 (0.9)	0 (0.0)	0 (0.0)	1 (4.8)
Neoplasia	6 (5.6)	0 (0.0)	0 (0.0)	6 (28.6)
Inanition	1 (0.9)	0 (0.0)	1 (4.8)	0 (0.0)
Not evident	3 (2.8)	1 (1.5)	2 (9.5)	0 (0.0)

mo. The records included 65 neonates, 21 juveniles, and 21 adults. The primary cause of death was recorded for 105 of these ferrets (98.1%). The causes of death, presented by age group and disease category, are listed in Table 1.

There were no animals in the study that died between 10 wk and 10 mo. The mean age of black-footed ferrets >1 mo at the time of death from 1989 to 2000 (n = 24) was 645 days (1 yr, 9 mo, 10 days) + SE 201 days and from 2001 to 2004 (n = 18) was 1,169 days (3 yr, 2 mo, 14 days) + SE 239 days, which was found to be statistically significant ($P < 0.03$). However, a significant increase in age at death in adult ferrets was not found. The average age at the time of death for adults was 1,483 days (4 yr, 23 days) + SE 320 days between 1989 and 2000 (n = 10); and 1,872 days (5 yr, 1 mo, 17 days) + SE 170 days from 2001 to 2004 (n = 11) ($P > 0.05$).

Carcasses were not submitted for 42 cases (39.2% of all ferrets). All of these cases were neonatal animals, and a diagnosis of cannibalism was assumed. These records were included for completeness. Forty-one of the examined ferrets were males, 22 were females, and 44 were of unknown gender. Of those 44, 42 were the neonatal cases without submission of a carcass, 1 specimen was autolyzed so sex could not be determined, and gender was not recorded for 1 animal.

Among the 66 neonates, 42 were presumed or observed to have died of maternal cannibalism, 11 died of maternal trauma, and 4 were stillborn. Furthermore, four neonates died of respiratory disease (three with aspiration pneumonia within 4 days of birth, and one with lung atelectasis at 26 days); two died of *Escherichia coli* sepsis; and one ferret died with gastrointestinal disease (acute ulcerative enteritis). The cause of death in the final neonate could not be determined due to advanced autolysis.

The most common cause of death among juvenile ferrets was gastrointestinal disease, found in 11 of 21 juveniles (52.4%). Seven of those cases were determined to be caused by coccidiosis, two of which also had concurrent *Salmonella enterica* ser. newport infection. The gastrointestinal disease in 2 of the 11 juvenile ferrets was attributed to *Clostridium perfringens* infection based on culture, and an additional animal had similar findings at necropsy, although the agent was not isolated. One juvenile died of gastric bloat caused by foreign body ingestion. Respiratory disease caused the death of three juvenile ferrets, one of aspiration pneumonia and two with asphyxia due to impaction of a food item in the oropharynx and proximal esophagus. Among the remaining seven juveniles, two died of trauma (one with cranial trauma likely caused by the mother, and the second animal was caught in cage furniture); one of sepsis (suppurative enteritis, hepatitis, and pneumonia due to *Enterococcus* sp. which was isolated from heart blood); one of congenital hydrocephalus; and one of inanition of undetermined cause. The cause of death in two juvenile ferrets was undetermined.

The most common cause of mortality in adult ferrets was renal disease (7/21; 33.3%) of varying histologic characteristics (Table 2). All cases of renal disease as the cause of death occurred between 2002 and 2004; therefore there was a significant increase in the number of cases of renal disease that occurred before 2001 compared to those after 2001

Table 2. Kidney lesions seen at necropsy in adult black-footed ferrets (*Mustela nigripes*) with renal disease as primary cause of death (n = 7).

Date of death	Age at death	Sex	Histopathological renal findings	Final diagnosis
8/2/2002 euthanized	5 yr, 2 mo, 7 days	male	acute tubular degeneration, acute tubulointerstitial nephritis, tubular regeneration, focal hemorrhagic necrosis, medullar mineralization	acute tubular degeneration
10/15/2002 euthanized	4 yr, 6 mo, 6 days	male	chronic marked interstitial nephritis, glomerular amyloidosis, moderate medullar mineralization	chronic tubulointerstitial nephritis, glomerular and duodenal amyloidosis
10/22/2002 died	3 yr, 4 mo, 13 days	male	membranoproliferative glomerulonephropathy, moderate tubular ectasia, moderate interstitial fibrosis	glomerulopathy and tubular ectasia with systemic amyloidosis
12/3/2002 euthanized	5 yr, 8 mo, 14 days	female	marked membranoproliferative glomerulonephropathy	glomerulopathy (8 days postvaccination)
2/18/2003 died	3 yr, 10 mo, 21 days	male	glomerular amyloidosis, nephrosis	systemic amyloidosis secondary to chronic dental disease
10/21/2003 died	6 yr, 4 mo, 18 days	male	moderate interstitial fibrosis, mild interstitial nephritis, mineralization, cyst	chronic nephrosclerosis
1/29/2004 euthanized	2 yr, 7 mo, 22 days	female	membranous glomerulonephropathy; tubular ectasia; tubular proteinosis	glomerulopathy, possible vaccine-induced (2 wk postvaccination) or autoimmune-mediated

(P = 0.004). Six ferrets (28.6%) died because of neoplastic disease, all of which had multiple concurrent neoplastic processes (Table 3). Three adults died of respiratory disease, caused by aspiration of a food item and asphyxia in one animal with severe chronic renal disease; lipid pneumonia in a second ferret; and bacterial pneumonia and sepsis caused by *E. coli* in the third animal. Two cases of circulatory disease were also reported, including one ferret with dilated cardiomyopathy and a second with acute circulatory shock after anesthesia and vaccination. Two adults died of gastrointestinal disease, one with acute necrohemorrhagic gastroenteritis caused by *Clostridium sordellii*, and a second 11-mo-old animal with coccidiosis. A single case of reproductive disease was seen in an adult female

Table 3. Neoplastic lesions seen at necropsy in adult black-footed ferrets (*Mustela nigripes*) with neoplasia as primary cause of death (n = 6).

Date of death	Age at death	Sex	Neoplasia
11/28/1997	6 yr, 5 mo, 20 days	male	interstitial cell tumor, right testis with metastasis; (cryptorchidism of left testis); apocrine adenoma, skin
2/25/1999	7 yr, 9 mo, 13 days	female	basal cell carcinoma, perineum with metastasis; biliary cyst adenocarcinoma with metastasis
12/9/1999	7 yr, 7 mo	male	basosebaceous carcinoma, perineum with metastasis; biliary cystadenoma, liver
3/23/2001	6 yr, 10 mo, 14 days	male	squamous cell carcinoma, palate; adenoma, preputial gland; interstitial cell tumor, testis
7/22/2003	5 yr, 2 mo	male	lymphosarcoma, small intestine; cystadenoma, liver
9/22/2004	8 yr, 4 mo, 1 day	female	metastatic adenocarcinoma, lymph node; cystadenoma, thyroid; apocrine adenoma, skin; biliary adenoma, liver

Table 4. Mean and standard error of pedigree-based, individual inbreeding coefficients of black-footed ferrets thought to have genetic disease and their healthy contemporaries. The *t* statistic refers to the standardized difference between the two groups (healthy and diseased).

Animals grouped by disease process	Mean inbreeding coefficient	SE inbreeding coefficient	*n*	*t*	*P*
Renal lesion, primary	0.106	0.004	7	2.33	0.22
Healthy contemporaries	0.108	<0.001	1,637		
Renal lesion, secondary	0.050	0.01	11	3.05	0.06
Healthy contemporaries	0.094	<0.001	2,721		
Congenital defects	0.075	0.017	8	2.53	0.15
Healthy contemporaries	0.103	<0.001	3,656		

that died of dystocia. At necropsy, uterine perforation was confirmed and believed to have occurred iatrogenically during artificial insemination.

When compared to healthy individuals of the same cohort, no significant difference in inbreeding coefficients among individuals were found in animals that died with renal lesions ($P = 0.22$), individuals with secondary renal lesions ($P = 0.06$), and individuals with congenital defects ($P = 0.15$) (Table 4).

DISCUSSION

Significant trends among age groups were demonstrated in this retrospective study of black-footed ferrets at the NZP. The overwhelming majority of neonatal deaths was attributed to cannibalism ($n = 42$; 64.6%) or trauma by the mother ($n = 11$; 16.9%). Cannibalism was seen mostly in very young kits during the first few days of life, the average age at death of these individuals being 2.1 days, with a range of 0–14 days. Cannibalism is fairly common in nondomestic carnivores; it has been reported in black-footed ferrets during the first few days of life[16] and is likely caused by inexperienced mothers, stress, abnormal or dead offspring, and/or inadequate surroundings. Three of the four cases of stillbirth were from one litter at the time of a Caesarian section performed on the dam. It is possible that some of the cases of suspected cannibalism were due to mothers eating stillborn or otherwise abnormal neonates, as carcasses were not available for evaluation. The cases of maternal trauma leading to death, for which the carcass was recovered for necropsy, were on average 26.6 days old, with a range of 14–30 days. All cases of cannibalism and maternal trauma occurred before 2001.

Several husbandry changes were initiated during the study period that may explain the lack of neonatal mortality observed after 2001. These include less-invasive initial monitoring of neonates, improved hygiene, and change of nest box construction and cleaning routine. In the first several breeding seasons, the mothers were monitored intensely with video cameras within the nest boxes, and direct daily observation of the nest box was performed by keepers lifting the lids. This allowed for excellent collection of information, especially regarding cannibalism deaths, but also likely disturbed the mothers and may have been a contributing factor to the higher numbers of cannibalism and maternal trauma cases seen. By 2000, the birth of kits was confirmed by keepers listening for sounds only. Nest boxes were not checked until day 5, and not cleaned until day 10. Substrate was also changed from pine shavings to cellulose-based bedding, and wooden nest boxes were replaced with plastic containers, which were lighter and easier to clean. Keepers were able to switch out the plastic boxes and disturb the mother and kits for less than a minute compared to cleaning the wooden nest boxes for 5–10 min each, while the animals were inside.

The most common cause of death in juvenile ferrets was related to the gastrointestinal tract, causing mortality in 52.4% of the animals in this age group ($n = 11$). Infectious causes predominated and included *C. perfringens*, *S. newport*, and coccidial infections. Some animals were diagnosed with several of these diseases concurrently. The age range of the ferrets that died with gastrointestinal disease was 41–75 days with a mean age of 60.2 days, which lies within the period when the kits begin to eat solid food. Gastrointestinal disease is a well-known cause of morbidity and mortality in captive black-footed ferrets with *Eimeria ictidea*, *E. furonis*, and *Cryptospordium* spp. often as primary agents,[15] especially when animals become stressed, such as after handling, during hospitalization, and at the time of weaning.[16] As observed for neonatal cannibalism and maternal trauma, all gastrointestinal-related juvenile deaths occurred before 2001.

Several husbandry changes initiated at this time likely contributed to the decrease in fatal cases of infectious gastrointestinal disease, including the transition from wooden to plastic dens and more careful monitoring for symptomatic animals. Furthermore, in the fall of 2000, one of the authors (MB) began to use the antiprotozoal diclazuril (Vecoxan, Janssen Pharmaceutica Ltd., Halfway House, 1685, Republic of South Africa) in an off-label manner for the treatment and control of coccidiosis, in addition to trimethoprim–sulfadiazine (Tribrissen®, Schering-Plough Animal Health Corp., Union, New Jersey 07083, USA) and sulfadimethoxine (Albon®, Pfizer Animal Health, Exton, Pennsylvania 19341, USA), which are used widely in black-footed ferrets. In the authors' experience, diclazuril was found to be safe and have excellent efficacy for clinical coccidiosis cases as well as for prophylactic use. The drug was used intermittently and reserved for severe or refractory clinical cases. The time during which this drug was used more frequently in the NZP population of black-footed ferrets coincides with the last cases of fatal coccidiosis that occurred in July 2001. Furthermore, after the multiple deaths and suspected clinical cases related to enteric *C. perfringens* infection in weanlings in 1991, smaller, more frequent feedings were offered to prevent overfeeding.[11] Additionally, one of the authors (MB) initiated the use of a long-acting single dose of penicillin during anesthetic procedures, which subjectively appeared to decrease the number of clinical cases, and mortalities due to *C. perfringens* have not occurred since that time. It is furthermore interesting to note that *Cryptosporidium* spp. did not cause death in any of the animals in this population and was only seen in the intestine of one juvenile ferret at the time of necropsy but did not appear to contribute to its death.

The most common cause of mortality among adult ferrets in this study was renal disease (33.3%), with all cases occurring since 2002. Renal histopathology was reviewed by one pathologist (TV) and both glomerular and tubular disease was found in acute and chronic forms, with a wide range of renal lesions and no evident common etiology, with dilatation, vacuolization of tubular epithelium, cyst formation, disorganization, and proteinosis being most commonly reported. This was also true to a lesser degree for the renal pathology findings in 11 additional ferrets in the study that died of various other primary causes, including gastrointestinal, respiratory, cardiovascular, and neoplastic disease, but had renal changes at the time of death.

Explanation for the increase in prevalence of renal disease since 2001 in this population could include various changes in husbandry and medical treatment in the past years. Also, many of the ferrets with renal disease were older ferrets, suggesting that the disease may be age-related and due to ferrets attaining an older age in recent years. The mean age at death increased in adults that died after 2001, although the difference was not found to be significant. An alternative reason for the high prevalence of renal disease may be that black-footed ferrets, like other carnivores, have a predisposition to kidney disease, possibly compounded by their genetic homogeneity. However, animals with renal disease did not have higher inbreeding coefficients than their healthy contemporaries, suggesting that the disease did not have measurable genetic causes associated with inbreeding depression. Finally, the introduction of new medications and vaccines used in these animals to treat and prevent serious gastrointestinal and infectious diseases may be lowering the incidence of disease in juveniles but causing renal disease in adults. In toxicology studies of diclazuril, side effects in multiple lab animal species, including carnivore species, have been limited to mild, reversible hepatocellular changes; renal changes have not been reported (Niemegeers et al., unpublished data; Verstraeten et al., unpublished data).[12] The histopathologic findings in our study did not support acute toxic tubular changes, as would be expected with iatrogenic toxicity.

Two animals in the study population had been vaccinated 8 and 14 days before death with both a killed rabies vaccine (Imrab® 3, Merial, Inc., Athens, Georgia 30601, USA) and a recombinant canarypox-vectored canine distemper virus vaccine (Purevax™, Merial, Inc., Athens, Georgia 30601, USA). Both had similar renal changes that may be suggestive of vaccine-induced disease, including membranous or membranoproliferative glomerulopathy, possibly caused by antigen–antibody deposition within the glomerular capillaries.[4] Similar findings have been anecdotally reported in individuals at other black-footed ferret breeding facilities. The number of cases in this study is not large enough to make conclusions about possible vaccine-induced disease, especially because other individuals in the study had similar changes but had not been recently vaccinated. Further studies are needed to address this concern and make recommendations for vaccination of captive and wild black-footed ferrets.

A high prevalence of neoplastic disease has been previously reported in a study of 227 adult (>1 yr) captive black-footed ferrets from 1986–1996 from

seven institutions, including NZP-CRC.[5] In that retrospective study, the overall prevalence of neoplasia was 55.4%, with neoplasia reported as the cause of death in 33.7% of adult animals. In the present study, 6 of 21 (28.6%) adult ferrets were diagnosed with neoplastic disease at necropsy. All six animals had more than one type of neoplastic disease; multiple neoplasias in individual animals were also reported to have occurred in half of the black-footed ferrets in the previous study.[5] A further common finding between these two studies is the correlation between advanced age and occurrence of neoplastic disease. All five ferrets with neoplasia in our study population were older than 5 yr, which is past the average reproductive age of black-footed ferrets[13,16] and likely beyond the average life span of wild ferrets, as ferrets over 4 yr are rarely seen in the wild.[8] Therefore, this group of neoplastic diseases is unlikely to significantly impact the species at a population level. The prevalence of neoplastic disease in the NZP black-footed ferret population was lower than that previously reported, although the incidence of neoplasia in this study remains higher than that reported for dogs and domestic ferrets.[5,7] The high prevalence of neoplasia among black-footed ferrets in the previous study was thought to be due to either genetic homogeneity, environmental exposure to toxins, or infectious agents of the black-footed ferret population, although a direct correlation of inheritance or geographic clustering was not apparent.

This study examined the primary cause of death for each animal. However, several incidental findings were also apparent and noteworthy. A high prevalence of biliary and liver cysts was reported. They were present in eight of the adults (38.1%), all of which were >5 yr, and five of which died of neoplastic disease unrelated to the liver pathologies. Lair et al.[5] previously reported a high prevalence of biliary cysts and proposed a correlation between biliary cysts and neoplasia of the biliary tree. Our study supports such a theory, since we also observed a high prevalence of biliary cysts as well as four cases of simultaneous biliary neoplasia (three cystadenomas, one biliary cyst adenocarcinoma).

Few signs of obvious congenital abnormalities, suggestive of inbreeding, were found. Two neonates, 14 days and 30 days, had bilateral cataracts; a 28-day male and 42-day male had hydronephrosis; and there was one case of fatal hydrocephalus in a 28-day male. A 7-yr, 9-mo female was found to have agenesis of the left kidney; and a 6-yr, 5-mo male was cryptorchid and developed interstitial cell carcinoma of the descended testes. Furthermore, one of the necropsied animals had a history of uterine agenesis, but the reproductive tract had been removed surgically 2 yr before death. With the exception of the animal with hydrocephalus, the possible congenital lesions were incidental findings at the time of necropsy and were not determined to be the cause of death, although changes such as cataracts and hydronephrosis could decrease chances of survival. Unilateral renal agenesis was observed in one of the seven founder animals and cryptorchidism has been observed in several animals to date.[2,3] A genetic link has not been proven for any of these congenital changes in the black-footed ferret population, although cryptorchidism, hydrocephalus, and neonatal cataracts have been seen in other wild animals with known low heterogeneity.[9] Overall prevalence of possible congenital abnormalities from all submitted black-footed ferret carcasses (n = 65) in the present study was 12.3%. In a study conducted during 1998 to 2000 on a similarly inbred carnivore species, the Florida panther (*Felis concolor coryi*), it was found that 11% of the animals necropsied had congenital atrial septal defects, and 45% of all examined male panthers were cryptorchid.[1] The overall incidence of congenital defects in a population is generally considered to be at or below 1%, but is dependent on the evolutionary history of the population.[6] Although the incidence of congenital defects appears high in this population of black-footed ferrets, we did not find significantly greater inbreeding coefficients in animals displaying congenital defects.

There are several limitations to the present study. The population represents only ferrets that died at the NZP facility, even though many had previously spent varying amounts of time at other black-footed ferret breeding institutions. These data are furthermore confounded by the fact that this was not a closed population of animals. Multiple young adult ferrets were moved to different facilities for breeding, and several older ferrets with poor breeding histories were brought to the CRC for intensive reproductive management, which may have increased the number of older, less healthy ferrets in the NZP population. Furthermore, one of the captive propagation program's major goals has been, and continues to be, the reintroduction of black-footed ferrets into the wild, so many of the younger, healthy adults that had spent time at NZP had either moved to other institutions or had been released into the wild, and were thus not represented in our study. Drawing conclusions from retrospective studies must be done cautiously, especially in regard to population dynamics and trends.

CONCLUSIONS

This retrospective study examines the overall mortality of the captive black-footed ferret at the NZP since initiation of the propagation program in 1989. The drastic decrease in genetic diversity of this highly endangered species as well as the intensive management of the captive and reintroduced populations make information concerning pathologic trends and causes of death valuable. The high, but decreasing, incidence of gastrointestinal disease in juvenile ferrets is encouraging and is likely due to improved husbandry, hygiene, and medical management. The etiology of the high prevalence of renal disease in the study remains unknown, but does not appear to be related to age or inbreeding. Because of the advanced, postreproductive age of many of the individuals with renal and neoplastic lesions, it is unlikely that these diseases will affect the wild black-footed ferret population's overall survival. However, knowledge of the likelihood of these diseases may help to improve captive management practices. Older ferrets should be carefully monitored for early signs of renal and neoplastic disease in captivity. Further investigation of possible vaccine-related renal changes is warranted.

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