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CAUSES OF MORTALITY IN REINTRODUCED EURASIAN LYNX IN SWITZERLAND

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ABSTRACT: Seventy-two lynx, found dead in the Swiss Alps and the Jura Mountains (Switzerland) from 1987–99, were evaluated to determine the cause of death. Seventy-two per cent (52/72) of all animals died because of noninfectious diseases or causes such as vehicular collision and poaching. Eighteen percent (13/72) died from infectious diseases, including some which could have been transferred to the lynx from domestic animals or other wild animals such as panleukopenia and sarcoptic mange. If only radio-tagged animals (included in a monitoring program) were taken into consideration, the percentage of mortality caused by infectious diseases rose to 40%, indicating that infections might be underestimated in randomly found mortality events. We hypothesize that even a few cases of infections in a small population like the lynx, which are additionally threatened by noninfectious causes, may threaten the long term survival of the population.

Key words: *Lynx lynx,* mortality, infectious disease, noninfectious mortality causes, reintroduced population.

INTRODUCTION

The Eurasian lynx (*Lynx lynx*) was eradicated in Switzerland and many other countries in central and western Europe at the end of the 19th century (Schauenberg, 1969; Eiberle, 1972). Due to improved habitat conditions and recovery of the prey base in the 20th century, lynx were reintroduced into the Alps of Switzerland, Austria, and Italy and into the adjacent Jura Mountains in Switzerland and Dinaric Mountains in Slovenia in the 1970s (Breitenmoser and Breitenmoser-Würsten, 1990). In Switzerland, two small distinct lynx populations developed after an expansion during the 1970s and 1980s (Breitenmoser, 1998). One population is located in the Swiss Alps extending slightly into France and Italy and one in the Jura Mountains of Switzerland and France. Each population was estimated to consist of approximately 50 adult resident individuals (Breitenmoser et al., 1998). After the first population growth phase, the expansion halted in spite of the fact that suitable habitat was still available, especially in the Alps (Breitenmoser, 1998). Mortality among juveniles and adults was estimated to be high in both populations (Haller, 1992; Breitenmoser et al., 1993; Breitenmoser et al., 1998), primarily due to human related causes, including vehicular collisions and poaching. The lynx is a protected species (Swiss Federal Law on the Hunting and Protection of Free Living Mammals and Birds (JSV), 1988) and the wildlife units of the Swiss cantons are obliged to report any lynx mortality.

The aims of this study were to provide qualitative information on lynx mortality in Switzerland and to evaluate the importance of different causes of mortality with regard to their effects on long-term population stability.

Published reports of similar investigations on wild feline populations are rare (Watson et al., 1981; Heidt et al., 1988; Roelke et al., 1993). Causes of mortality in free-ranging Eurasian lynx also rarely have been documented until now (Stahl and Vandel, 1999). It is known that lynx are affected by sarcoptic mange (Mörner, 1992), trichinellosis (Oksanen et al., 1998), rabies (Matjuschkin, 1978; Stahl and Van-

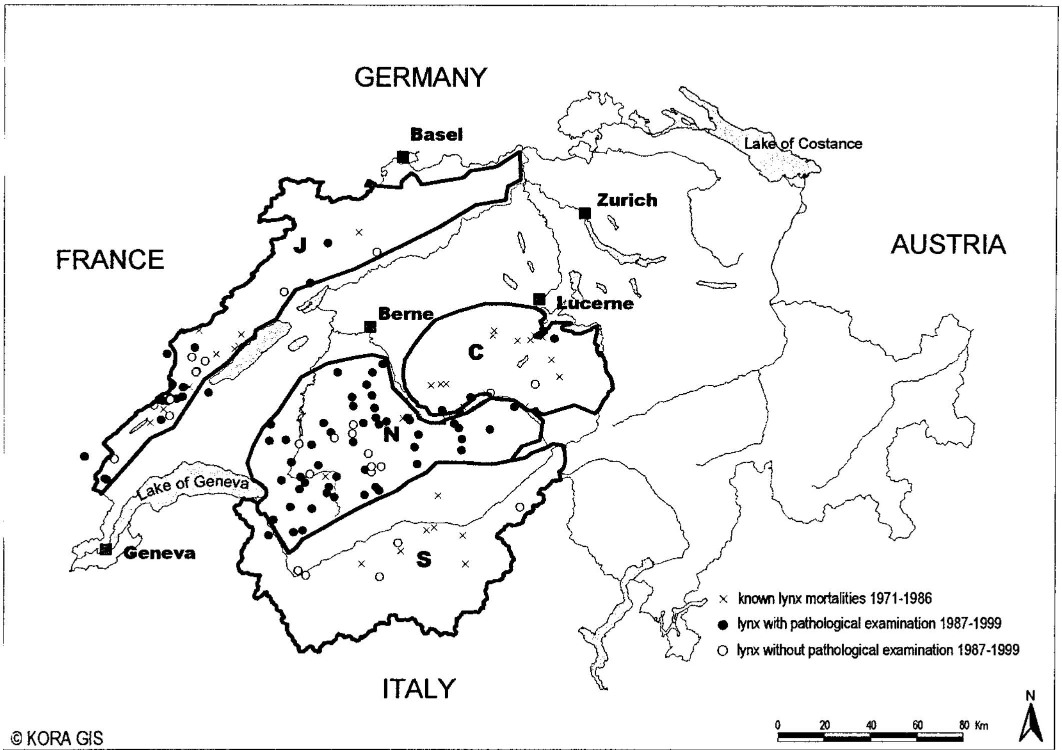

FIGURE 1. Distribution of dead lynx found in the Alps and the Jura Mountains of Switzerland. Areas surrounded by bold lines are the Jura Mountains (J), Central Alps (C), Northwestern Alps (N), and Southwestern Alps (S). Major rivers and lakes are shown. Animal locations outside Switzerland are from individuals trapped and radio-collared in Switzerland that dispersed into France.

del, 1999), and panleukopenia (Stahl and Vandel, 1999), but little is known about the relative importance of these mortality factors in the population as a whole.

MATERIALS AND METHODS

Since 1983, lynx have been followed by means of radiotelemetry in different study areas in the Alps (Haller, 1992; Breitenmoser and Haller, 1993; Breitenmoser et al., 1998) and the Jura Mountains (Breitenmoser et al., 1993). Since 1987, lynx carcasses which were found in connection with the radiotelemetry program and those reported to the state game wardens were sent to the Institute of Animal Pathology (IAP), University of Bern, for postmortem examination. On four animals the necropsy was performed in other institutes (Institute Galli Valerio, Lausanne, Switzerland; Laboratoire Vétérinaire Départemental, Lons-le-Saunier, France) and only part of the material was sent to the IAP. For our study, material (whole carcasses or parts of the body) from 72 lynx examined between 1987 and 1999 was available. Eight animals were found still alive, but had to be euthanized because of severe debilitation using 400 mg kg^{-1} pentobarbital intraperitonaly (Vetanarcol®, Veterinaria AG, Zurich, Switzerland). We differentiated between the populations in the Alps and the one in the Jura Mountains, with the Alpine population further subdivided into central, northwestern, and southwestern subpopulations (Fig. 1). Three age groups were distinguished: juveniles (animals less than 10 mo of age), subadults (females <2 yr, males <3 yr), and adults (females >2 yr, males >3 yr). If unknown, the age was estimated by means of cementum-annuli method (Jensen and Nielson, 1968). All whole carcasses were measured and weighed, and a complete necropsy was performed. Ectoparasites were identified on the basis of typical morphologic characteristics (Rommel et al., 2000). Fecal samples of 58 lynx were examined for protozoan and helminthic parasites using $ZnCL_2$/NaCl and NaCl floatation methods and Baermann method (Rommel et al., 2000). Examination for *Trichinella* sp. using the digestion method (OIE Manual, 1996) on diaphragm muscle was started in April 1998.

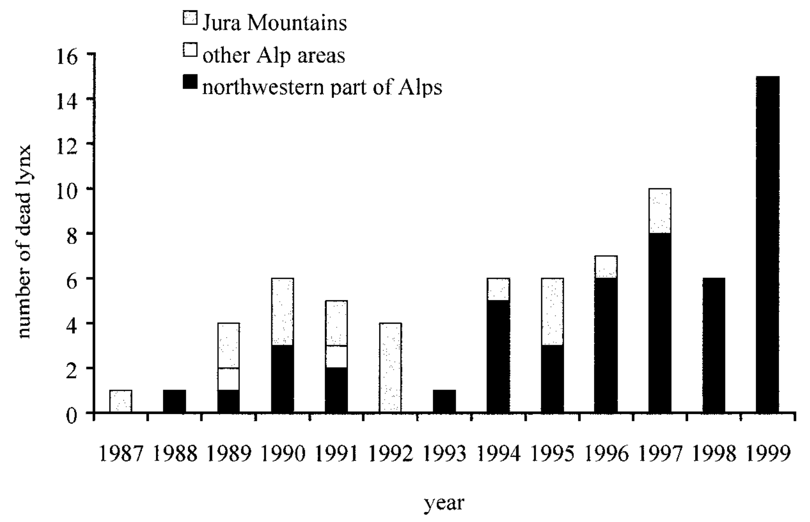

FIGURE 2. Number of lynx in Switzerland examined per year and area.

In 25 cases of suspected bacterial infections routine bacteriologic examinations were carried out according to established diagnostic techniques (Quinn et al., 1994).

In 30 cases macroscopically altered tissues were fixed in 4% buffered formalin, paraffin embedded, cut to 5 μm slices, and stained with hematoxilin and eosin. Seven animals, which originated from areas where rabies was considered endemic at the time, were tested for rabies with a direct immunofluorescent antibody test (Dean and Abelseth, 1973). In two cases an immunohistochemical analysis for feline parvovirus and feline coronavirus was performed according to published protocols (Tammer et al., 1995).

Examined lynx were classified according to their monitoring status (radio-tagged and found by means of telemetry or found by chance), the population or subpopulation, the year of death, age, sex, and the cause of mortality.

Significance of differences between distribution of age and sex classes and between the infectious and non-infectious causes of death were tested using a Chi-square test. All statistical analyses were calculated using SYSTAT program (version 8.0, SPSS Inc. Chicago, Illinois, USA). The level of significance was set at $P < 0.05$.

RESULTS

Origin, age, and sex data

Submitted lynx originated from the populations in the Alps ($n = 53$) and the Jura Mountains ($n = 19$) (Fig. 1). From the Jura Mountains, 11 of 19 carcasses date from the years 1989–92. Since then, findings were sporadic and ceased for the past 2 yr. The number of carcasses submitted from the northwestern Alps since 1994 greatly increased (Figs. 1, 2). In the late 1980s, carcasses were only occasionally reported from this part of the Alps. Except for three cases, all lynx from the Alpine population originated from the northwestern part of the Swiss Alps (Cantons of Bern, Fribourg, and Vaud). One carcass was found in the Canton of Uri (central part) and two others in the Canton of Valais (southwestern part). Compared to findings before 1989 (Fig. 1) submissions from these Alpine regions decreased sharply. This development correlates with the current size and distribution of the population as to date the main part of the alpine lynx population is located in the northwestern part of the Swiss Alps (Breitenmoser et al., 1998).

Twenty-nine (40%) of the 72 lynx examined were juvenile, 14 of 72 (19%) subadult, and 26 of 72 (36%) adult. In three animals the age could not be determined because the carcass was not complete. In all age classes the sex ratio was balanced (females/males): juveniles: 17 of 12, subadults: 8 of 6, adults: 13 of 13 ($\chi^2 < 3.84$, $P > 0.05$).

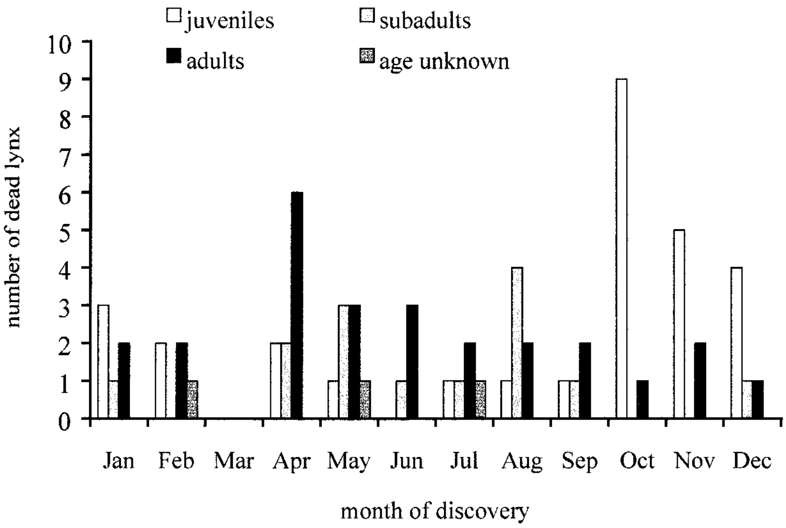

FIGURE 3. Number of lynx examined per month and age class in Switzerland.

Fifteen of the 72 examined lynx were found because they were radio-tagged. In the radio-tagged group all animals except one were subadults or adults, because juveniles were not radio-tagged.

Most of the juveniles were found from October to December with 9 of 29 (31%) found in October (Fig. 3). Four of these juveniles were orphans because their mothers had died due to vehicular collisions or poaching during the fall hunting season. Adults showed a slight peak in April (6/26). For subadult mortality, there was no distinct seasonal pattern.

Infectious diseases were determined as the actual cause of death in 13 of 72 (19%) investigated animals (Table 1). Five animals were juvenile, three subadult, and five adult, therefore the prevalence of infectious causes of mortality was similar in all age classes; 17% (5/29) in juveniles, 21% (3/14) in subadults, and 19% (5/26) in adults. Among the radio-tagged lynx, significantly more animals died because of infectious diseases (6/15) than in the group of lynx found by chance (7/57); ($\chi^2 < 5.83$, $P = 0.02$).

Among these 13 cases of infectious cause of mortality parasitic diseases were the most frequent (7/13) followed by bacterial diseases (5/13). One viral infection was diagnosed (Table 1). In 1999, five cases of severe infestation with mites were diagnosed in the northwestern part of the Alps. In two animals *Notoedres cati,* in two others *Sarcoptes scabiei,* and in one case a simultaneous infestation with both mites was diagnosed (M.-P. Ryser-Degiorgis, pers. comm.). All of these animals had a severe proliferative dermatitis with crust formation mainly on the head, trunk, and extremities and were cachectic. Two juveniles died because of an endoparasitosis with *Toxocara* sp. Both animals were cachectic with a catarrhal enteritis and a severe infestation with *Toxocara* sp. In one of these animals the endoparasitosis led to small intestinal obstruction.

Five lynx died because of bacterial infections. A purulent bronchopneumonia was diagnosed in four animals. Beta-hemolytic streptococci were isolated in two cases, *Streptococcus canis* and *Pasteurella* sp. in one case, and in one case no specific pathogenic bacteria could be isolated due to postmortem overgrowth of enteric flora. In two animals bronchopneumonia was associated with pyothorax and purulent peri- and epicarditis. One animal had an additional ascending urinary tract infection with hemolytic *Eschericia coli* leading to a purulent cystitis and pyelonephritis. One

TABLE 1. Causes of mortality in free-ranging lynx in Switzerland. Distinguished are infectious and noninfectious diseases for different age groups. The number of radio-tagged animals are given in parentheses.

	Swiss Alps					Jura Mountains					
	Juveniles	Subadults	Adults	Age unknown	Total	Juveniles	Subadults	Adults	Age unknown	Total	Total
Infectious diseases	5	2 (2)	4 (1)	—	11 (3)	1	1 (1)	2 (2)	—	4 (3)	15 (6)
Parasitic	2	1 (1)	3 (1)	—	6 (2)	1	—	—	—	1	7 (2)
Bacterial	2	1 (1)	—	—	3 (1)	—	—	2 (2)	—	2	5 (3)
Viral	—	—	—	—	—	—	1 (1)	—	—	1 (1)	1 (1)
Unknown	1	—	1	—	2	—	—	—	—	—	2
Noninfectious diseases	17	6	12	—	35	3	5	6	1	15	50 (8)
Traffic accident	1	3	2	—	6	1	4	3	1	9	15
Illegal killing	3	1	—	—	4	—	—	2 (2)	—	2 (2)	6 (2)
Starvation	4 (1)	—	—	—	4 (1)	—	—	—	—	—	4 (1)
Obstipation	1	—	1	—	2	—	—	—	—	—	2
Legally shot	—	—	3 (1)	—	3 (1)	—	—	—	—	—	3 (1)
Miscellaneous[a]	—	2	3 (2)	—	5 (2)	1	—	—	—	1	6 (2)
Unknown	8	—	3	—	11	1	1	1	—	3	14 (2)
Unknown cause	3	—	2 (1)	2	7 (1)	—	—	—	—	—	7 (1)

[a] Two subadults from the Swiss Alps were killed in a trap or were drowned. One adult lynx fell down a steep rock, one was killed in an intraspecific fight, and one radio-tagged animal died during anesthesia. One juvenile animal originating from the Jura Mountains was killed by a dog attack.

lynx had developed a purulent alveolar-periostitis from a broken canine tooth with subsequent septicemia and acute necrotizing lesions in most organs. Beta-hemolytic streptococci were isolated from liver, spleen, lymph nodes, kidney, and lung.

One radio-tagged subadult female from the Jura Mountains showed a severe, diffuse, acute fibrino-necrotizing gastroenteritis. Immunohistochemically, antibodies directed against feline parvovirus antigen reacted positive in small intestinal epithelial cells.

Overall, 74% of all analyzed animals (43/58) had parasites. In 67% (39/58) endoparasites in the gastrointestinal tract, the lung, or the skeletal muscles and in 16% (9/58) ectoparasites were diagnosed. Among the endoparasites, *Toxocara* sp. was most frequently found (23/58). Additionally, *Taenia* sp. (3/58), *Trichuris* sp. (5/58), *Capillaria* sp. (5/58), *Uncinaria* sp. (1/58), *Nematodirus* sp. (1/58), *Toxascaris leonina* (1/58), ascarids which could not further be identified (3/58), and coccidia (7/58) were diagnosed. In five cases (9%) infection with *Aelurostrongylus abstrusus* was found. In only one animal this resulted in a multifocal, mild, granulomatous pneumonia which was interpreted as an incidental finding.

Six of 20 lynx (30%) tested for *Trichinella* sp. were positive. All these animals were subadults or adults.

Ectoparasites included *Notoedres cati* (3), *Sarcoptes scabiei* (3) mentioned above, as well as *Otodectes cynotis* (1), and unidentified fleas (7), and ticks (4).

None of the seven lynx tested for rabies was positive.

Non-infectious diseases

Noninfectious causes of mortality were determined in 52/72 lynx (72%) and are summarized in Table 1. Except in 1999, these were the most common causes of mortality (Fig. 4). Noninfectious causes of mortality were diagnosed in 72% (21/29) of juvenile, 78% (11/14) of subadult, and 69% (18/26) of adult lynx.

Seventy-seven per cent (44/57) of all non radio-tagged subadult and adult ani-

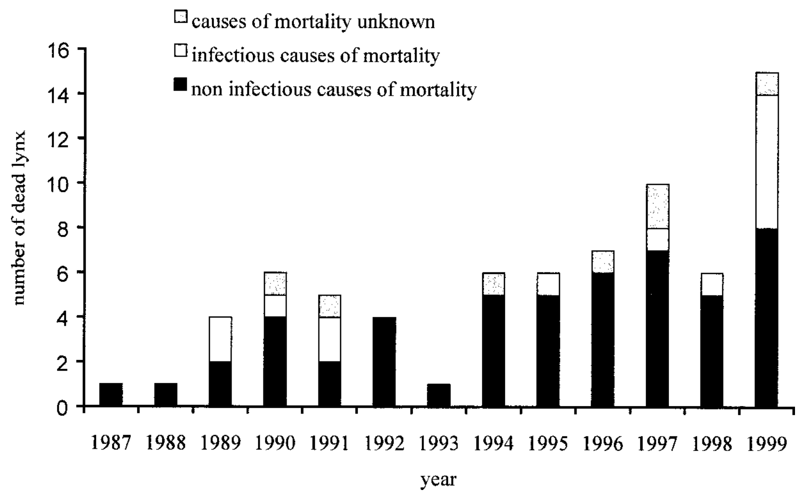

FIGURE 4. Distribution of causes of mortality of lynx in Switzerland 1987–99.

mals died of non-infectious causes. Forty-eight per cent (21/44) of these were human-caused, most frequently vehicular collisions (15/44; 34%). Four lynx (9%) were poached. Three adults of this group were legally shot by state game wardens because they were mainly preying upon domestic sheep. In three cachectic juveniles starvation was considered the final cause of death as no other signs of underlying disease were found. All these animals were known to be orphans and appeared in human settlements searching for food.

In contrast, fewer radio-tagged animals died due to non-infectious causes (8/15; 53%). None of these died because of a vehicular collision. Two were poached (Table 1).

In seven animals the cause of death remained undetermined. One adult died from an acute necrotizing pancreatitis with fibrinous and plasmacellular serositis. Neither other lesions nor antigens of feline coronavirus were detected. In one juvenile severe metastatic calcification in lung, kidney, and vessels in all organs concomitantly with a mild membranous glomerulonephritis was present. However the etiology of these lesions could not be determined. In five cases no diagnosis was achieved because of severe postmortem autolysis or incompleteness of submitted carcasses.

DISCUSSION

Veterinary evaluation generally has been recommended for monitoring of reintroduced populations (IUCN, 1998). Postmortem examinations of mortalities should be an integral part of any monitoring program. Information about the distribution, significance, and trends of mortality causes is valuable for any management program, particularly in cases of small, endangered populations.

In this study 18/26 resident adults died of non-infectious causes. All of these animals were still of reproductive age, and it is unknown whether the population is able to compensate for these losses. If the turnover is too high and if the total number of animals is small, the population may not be able to survive in the long term (Lacy, 1992, 1997; Franklin and Frankham, 1998). In contrast to juvenile mortality, mortality rates among adults should remain low in a stable population of long-living, solitary animals. A high rate of adult mortality could threaten the long-term survival of the two populations in Switzerland. Our results correspond with the findings of Stahl and Vandel (1999) who also found a high mortality rate among adult and subadult lynx in France. These authors also determined that mortality among adults and subadults was more frequently human-related than in juveniles. This is in contrast to our study, where the distribution of causes of mortality among the age classes was balanced. However, because poaching in subadults and adults (juveniles were not radio-tagged) is relatively higher in radio-tagged animals than in animals found by chance, we hypothesize that poaching has a much more important role in the overall mortality of lynx in Switzerland than was apparent in this study.

In our study, the distribution of causes of mortality clearly differed between the radio-tagged animals and the animals found by chance. We assume that radio-tagged animals represent better the actual situation in the wild because all of these lynx were found independent of the cause of death. Among the animals found by chance, road kills were most likely to be reported. In contrast, infectious diseases as well as illegal killings were likely to be under-represented in the overall group of animals sent in for examination. Based upon our data from radio-tagged animals, 40% died due to infections.

In small populations continuously threatened by non-infectious causes like vehicular collisions and poaching, even few cases of fatal infectious diseases could severely affect the population. Wild lynx are susceptible to diseases common in domestic cats or red foxes (*Vulpis vulpis*). Foxes and domestic cats are casual prey of lynx (Jobin et al., 2001), hence disease transmission is possible. In our study we diagnosed one animal with panleukopenia and five animals with *Notoedres cati* and/or *Sarcoptes scabiei* infestations. All cases of mange were diagnosed in 1999. Sarcoptic mange has been endemic in red fox populations in southern Switzerland and only recently has developed to epidemic foci north of the Alps (Wandeler et al., 1985; C. Fischer, pers. comm.), potentially increasing the risk of transmission to lynx.

Infectious diseases have seldom been described to cause population decline in free-ranging large carnivores (Murray et al., 1999). These declines are mainly reported to correlate with larger sympatric populations of domestic or other free-ranging carnivores (Kat et al., 1995; Roelke-Parker et al., 1996; Ballard and Krausman, 1997). Viral diseases like rabies and canine distemper played the major role. Most of the affected species (Weiler et al., 1995; Ballard and Krausmann, 1997; Alexander and Appel, 1994; Kat et al., 1995; Holzman et al., 1992; Roelke-Parker et al., 1996) were group-living animals. In contrast, lynx are solitary (Breitenmoser et al., 1993), and therefore an epidemic is less likely. Nevertheless, the five mange cases in 1999 demonstrate that in the Swiss population infectious diseases may suddenly become important and consequently, veterinary screening should continue. In this study one case of panleukopenia was diagnosed in 1989. Since then, no other cases of viral infections were detected; however, because no serologic surveys were performed, the epidemiologic situation of viral infections of lynx in Switzerland is unclear.

Finally, effects of disease may be aggravated when combined with other factors, such as malnutrition, stress, or inbreeding (O'Brien et al., 1985; Ullrey, 1993; Lloyd, 1995). This was described in cheetah and black-footed ferret populations (O'Brien and Evermann, 1988), but the importance of this interaction in free-ranging animals is unclear. As the lynx populations in Switzerland are still isolated and have developed out of a few animals released in the early 1970s, we suspect that genetic diversity in the Swiss lynx populations is small. Further investigations of the genetic structure of these populations are in progress (G. Obexer-Ruff, unpubl. data).

To summarize, our results provide important data about distribution of wild lynx populations in Switzerland and the main factors threatening their survival. We also showed that systematic postmortem investigation of endangered species, as the Eurasian lynx, is indeed a valuable part of a wildlife-monitoring program.

ACKNOWLEDGMENTS

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