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Mortality in the Eurasian lynx population in Croatia during the 40 years

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ABSTRACT

The combination of intensive persecution, habitat loss and prey deficiency led to the extinction of Eurasian lynx (*Lynx lynx*) in the Dinaric Mountains at the beginning of the 20th century. In 1973, the population was re-established by reintroducing animals from the Slovakian Carpathian Mountains into Slovenia, from where the animals spread into Croatia and Bosnia and Herzegovina. Since the end of the 20th century the reintroduced population has been decreasing, leading us to investigate the principal causes of mortality. Understanding the causes of the declining lynx population in Croatia and elsewhere is important not only in its own right but also because few studies have examined how large carnivore populations have fared under different management regimes. After reintroduction, the first dead lynx was recorded in Croatia in 1978, and from that year until 2013 a total of 232 deaths were recorded. Annual mortality during this period averaged 6.4 deaths per year, ranging from 0 to 17. The number of dead lynxes found every year in the period before the legal protection (1978–1998) was significantly higher than the number of dead animals found in the period after the legal protection (1998–2013). The vast majority of deaths were human-related (92.7%), with only 2.1% not human-related; while the cause of the remaining 5.2% of deaths was undetermined. Shooting was the most dominant cause of death (73.7%), with significantly more males being killed by shooting than females, and significantly more animals shot before the legal protection. Between 1978 and 1998, the year when the lynx became legally protected in Croatia, 10 deaths due to poaching were recorded, accounting for 5% of all deaths in that period and an average of 0.48 poaching cases per year. During 1999–2013, 18 poaching deaths occurred, accounting for 60% of all deaths in that period and an average of 1.2 poaching cases per year. Our findings suggest that the synergy of human-induced mortality, concomitant reduction in genetic variation and possibly prey deficiency may be the principal factors behind the decline in the reintroduced lynx population in Croatia since the end of the 20th century.

1. Introduction

The combination of habitat loss, prey depletion and intensive persecution (Breitenmoser et al., 1998) led to the extinction of Eurasian lynx (*Lynx lynx*) from the Dinaric Mountains at the beginning of the 20th century. In 1973, Slovenian hunters organized the reintroduction of six animals from Slovakia into Slovenia in order to revive lynx trophy hunting. The newly established population encountered a favorable habitat and abundant prey, so the population rapidly expanded. By 1974, lynx had already appeared in Croatia and by 1980, they were observed in Bosnia and Herzegovina (Čop, 1987; Frković, 2001).

Lynx hunting began in Slovenia and Croatia in 1978 (Frković, 2001), and it continued in Croatia until 1998, even after the animal's legal status in Croatia changed in 1982 from game to protected species. From 1982 until 1998, annual hunting quotas were issued that limited total mortality to 7–14 animals per year (Frković, 1998). In 1998, the lynx was listed as a strictly protected species, and hunting quotas were no longer issued.

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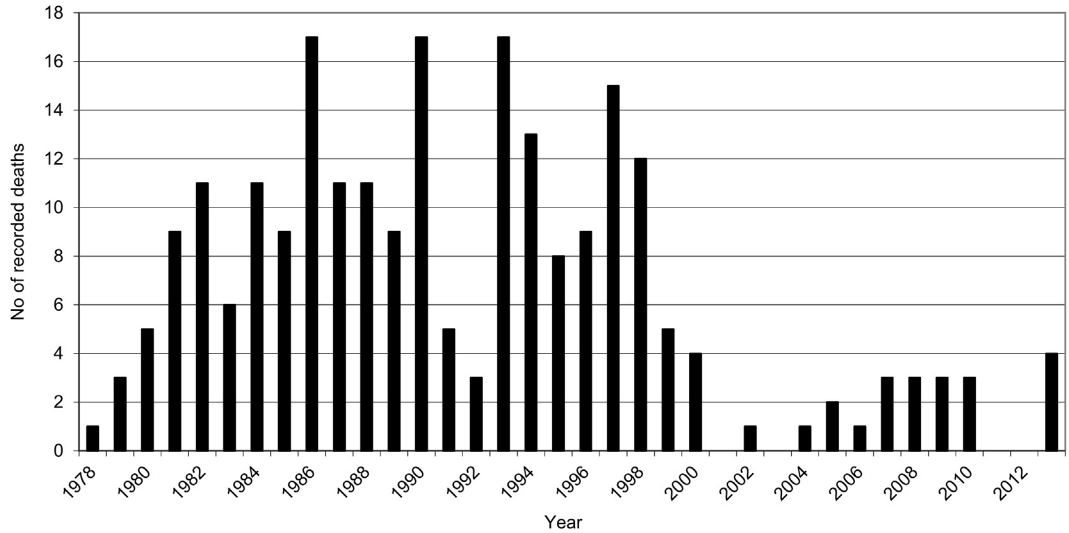

Fig. 1. Annual lynx mortality in Croatia based on data from a national monitoring program, 1978–2013.

Evidence suggests that after reintroduction, the lynx population enjoyed rapid population growth and range expansion until the late 1980s, after which it probably stabilized until the late 1990s. Then, according to field studies, the population began to decrease at the end of the 20th century (von Arx et al., 2004; Gomerčić et al., 2009, 2010; Sindičić et al., 2010a), a hypothesis corroborated by molecular genetic analysis indicating low effective population size, considerable inbreeding and low genetic diversity (Sindičić et al., 2013).

Several factors may be contributing to this decrease, which threatens population survival. These factors may include habitat fragmentation, prey base depletion, poaching and traffic-related mortality, as well as a possible reduction in the fitness of individual animals due to loss of genetic diversity (Sindičić et al., 2013). Indeed, Eurasian lynx live at low densities in large habitats and have low reproductive and population growth rates, making them potentially vulnerable to numerous factors affecting population dynamics. Understanding the causes of the declining lynx population in Croatia and elsewhere is important not only in its own right but also because few studies have examined how large carnivore populations have fared under different management regimes (Linnell et al., 2010).

Therefore the present study investigated the primary drivers of mortality in the Eurasian lynx population in Croatia during the 40 years since its reintroduction, and it assessed the importance of these drivers for long-term population stability. The results provide much-needed insights into factors associated with long-term mortality in a reintroduced population of large carnivores.

2. Material and methods

Data on mortality of the lynx population in Croatia were collected through a national monitoring program. This includes data on harvest since the reintroduction until the total legal protection, chance observations and mortality of radio collared lynx. Until 2002 a total of 8 lynxes were monitored trough radio-telemetry. The national database included information on cause, date and location of deaths, as well as on the sex and estimated age of the dead animal (categorized as yearling or >1 year old). Since the lynx was declared a strictly protected species in 1998 whenever possible carcasses were collected and examined at the Faculty of Veterinary Medicine, University of Zagreb. A total of 11 necropsies were conducted according to a standard veterinary protocol. When poaching was suspected, as well as in most forensic cases, the entire animal was radiographed to detect fragments of bullets or lead pellets. In several cases, retrieving the body was impossible. We confirmed these cases to be deaths when we had a photograph, tissue from the dead animal body, a destroyed radio collar in the case of a missing radio-tracked animal or a poaching tip from a reliable person or eyewitness.

A Mann–Whitney *U*-test was done to compare the number of dead lynxes found every year between the period before the legal protection (1978–1998) and the period after the legal protection (1998–2013). Chi-square tests were used to test the significance of differences between causes of mortality among sex classes; causes of mortality among age classes; causes of mortality between the period before the legal protection (1978–1998) and the period after the legal protection (1998–2013). The significance of differences between numbers of dead individuals of different age classes in each month was also tested using a Chi-square test.

3. Results

The first recorded death of a lynx in Croatia since reintroduction was in 1978 by shooting. Over the period from 1978 to 2013, 232 deaths were recorded. Of these, 110 (47.4%) were females, while 88 (37.9%) were males and the remaining 34 (14.7%) were of undetermined sex. Most of these animals were older than 1 year ($n = 155$, 66.8%), with the minority younger than 1 year ($n = 68$, 29.3%) and nine of undetermined age (3.9%).

Annual mortality averaged 6.4 lynx per year, ranging from 0 to 17 per year (Fig. 1). Of the 232 dead lynx over the entire 36-year study period, the vast majority (202) occurred between 1978 and 1998, when the last yearly hunting quota was issued. During this 20-year period, annual mortality averaged 9.6 per year and was significantly greater than that recorded in 1998–2013 ($p < 0.01$). Between 1998 and 2013, recorded mortality was quite sparse, with only 30 deaths in 15 years; annual mortality averaged 2.0 per year and ranged from 0 to 5 per year. A drop in mortality in the 1991–1995 period is probably due to the Homeland War in Croatia, because during that time mortality could not be properly monitored.

Analysis of the geographic distribution of recorded lynx deaths in Croatia (Fig. 2) suggests that population range expanded until the late 1980s, after which it remained stable during the 1990s, and then contracted starting around the year 2000. The core lynx habitat

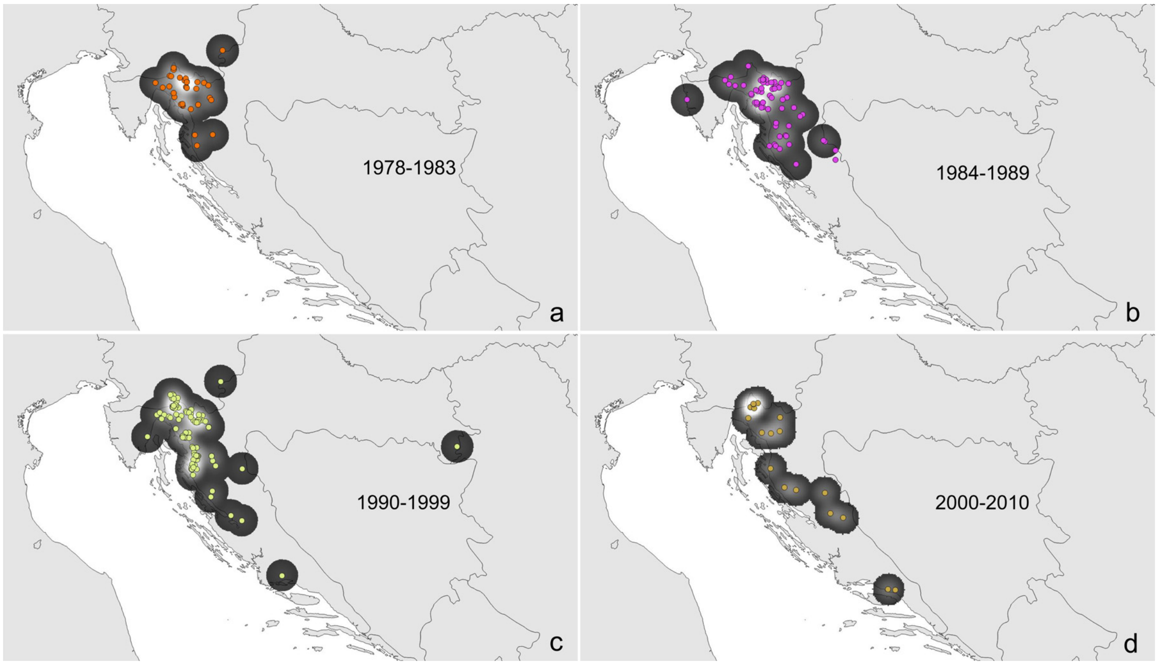

Fig. 2. Geographic distribution of reported lynx deaths in Croatia during different periods: (a) 1978–1983, (b) 1984–1989, (c) 1990–1999, (d) 2000–2010.

Table 1
Causes of death for all 232 lynx deaths recorded in Croatia for the period 1978–2013.

	1974-1998			1999-2013			Total	
	Female	Male	Unknown	Female	Male	Unknown		
Human	Shooting	81	67	8	2	5	8	171
induced	Traffic accidents	9	4	5	2		2	22
	Trapping	7	1			1		9
	Various	3	4	4		2		13
Natural causes		1			2	2		5
Undetermined		2	1	5		1	3	12
Total		103	77	22	6	11	13	232

was the Gorski kotar and Lika regions, and throughout the 36-year study period most deaths were recorded in this area. No mortality was recorded in the continental region of the country, except for one case in 1994 on the border with Serbia. Mortality records suggest expansion southeast along the Dinaric Mountains towards Bosnia and Herzegovina, with the southernmost documented death occurring near town Split in 1993. Two cases reported in 2009 and 2010 near town Omiš, even farther south, were attributed to poaching by reliable sources but could not be documented with material evidence.

Of all 232 recorded cases, 215 (92.7%) were caused by humans, including 171 due to shooting, 18 (7.8%,) due to road traffic, 9 (3.9%) due to trapping, four (1.7%) due to trains, two lynx were poisoned and one died due to a land mine (Table 1). Another 10 animals (4.2%) were killed in various ways after a close encounter with humans, including being killed with an axe or beaten to death with a rock, wooden stick or metal pole. In one case, a man followed lynx tracks in the snow, saw the animal enter a hole between some rocks and sealed the hole with a concrete.

Five of all recorded mortality cases (2.1%) did not have causes related to humans. One rabid animal was shot due to strange behavior, one animal drowned in the sea on the west coast of Istria and three animals were severely cachectic. Detailed forensic analysis of the cachectic animals was impossible because of autolytic progression. The cause of death could not be determined in 12 cases (5.2%).

Shooting was the most dominant cause of death both in the period before the legal protection (1978–1998) and in the period after the legal protection (1999–2013), with more individuals being shot in the first period than in the second one ($p < 0.01$). There was no significant difference between periods, for the other causes of death.

Of all 232 recorded deaths, 28 (12.1%) were attributed to poaching, including 10 before legal protection in 1998. Most of these ten poaching cases before 1998 occurred in the first years after the quota system was introduced and corresponded to animals shot after the quota had been reached. During the period 1999–2013, after total legal protection had been implemented, 18 of the 30 recorded deaths (60%) were due to poaching. We were unable to retrieve the carcass in nine of these poaching cases: we were informed about one case by a hiker who reported seeing a dead lynx, but we found only lynx hair at the location of the sighting; we found a destroyed radio collar of a radio-tracked animal in another case; we obtained photographs of the shot animals in two cases; and we were told by confidential informants about five poached animals, but were unable to collect any physical evidence.

The most dominant cause of death among 110 female lynx was shooting ($n = 83$, 75.5%) while 11 (10%) died due to the traffic accidents, and 7 (6.4%) died after being caught in trap. A total of 72 (81.8%) males died due to shooting, 4 (4.5%) due to the traffic and 2 (2.3%) were trapped. Significantly more males were killed by shooting than females ($p < 0.05$) while there was no significant difference

Table 2
Number of dead individuals in each month.

Month	Total	Younger than one year	Older than one year
January	35	11	24
February	39	10	29
March	11	2	8
April	11	3	8
May	7	0	4
June	12	3	8
July	7	3	4
August	10	4	6
September	18	4	14
October	25	11	14
November	27	10	17
December	25	6	19
Unknown	5	1	

between any other cause of death among females and males. Shooting was also the most dominant cause of death among animals younger than one year (54.4%) and older than one year (78.1%), with traffic and trapping as the second and third most frequent cause of death among both age classes. There was no significant difference between any causes of death among animals of different age classes. Most of the deaths occurred in the winter period from October until February, with the highest percentage in January (15.5%) and February (16.8%) and the lowest in May–June period (3.0%). The same pattern was observed for both age classes, with highest percentage of deaths occurring in January and February (Table 2). There was no significant difference between numbers of dead individuals of different age classes in each month. Out of 8 radio-collared lynxes, one female (12.5%) died after being hit by a car on a highway and one male (12.5%) was illegally killed (destroyed radio collar was found).

4. Discussion

Understanding the causes of carnivore mortality is crucial for gaining insight into population dynamics and the evolutionary forces acting upon them (Bischof et al., 2009; Nilsen et al., 2012). The vast majority of lynx deaths (92.7%) recorded in Croatia during the period 1978–2013 were due to humans, similar to what has been observed in several carnivore populations geographically overlapping with human populations (Schmidt-Posthaus et al., 2002; Andrèn et al., 2006; Breitenmoser-Würsten et al., 2007; Bischof et al., 2009). While it is difficult to assess how such high human-induced mortality may influence population dynamics, it seems unlikely to be sustainable (Rodriguez and Delibes, 2004).

Potočnik et al. (2009) estimated that the Dinaric lynx population size peaked in 1990–1995, with an average of 110 individuals. For that period average annual mortality was 11 lynx per year in Croatia and 6.2 in Slovenia (Kos et al., 2005) (there is no published data for Bosnia and Herzegovina). Summing these two rates to get 17.2 animals per year and assuming a population of 110 animals (Potočnik et al., 2009), we obtain a mortality rate of approximately 15.6%. This is close to the maximum harvest rate of 17% proposed as sustainable in lynx populations (Andersen et al., 2003; Henriksen et al., 2005; Andrèn et al., 2006). We speculate that this level of human-induced mortality, acting in synergy with a concomitant reduction in genetic variability (Sindičić et al., 2013) and perhaps also prey deficiency (Sindičić et al., 2010b), caused the reintroduced lynx population in Croatia to decline. Consistent with this suggestion, Potočnik et al. (2009) have concluded that changes in the survival rates of subadult and adult individuals and prey availability significantly affected lynx population growth in the Dinarics after reintroduction.

Our data on poaching provide some insight into how both legal treatment, and public perception, of the reintroduced lynx have affected its population dynamics. From 1978 to 1998, 10 poaching cases were reported, all of which were animals shot outside of the quota, mostly in the first years after the quota system was introduced. This likely reflects the adjustment period for hunters to come to terms with the limited number of kills permitted. Although the lynx lost its trophy value for hunters when it was listed in 1998 as a strictly protected species, it took on a reputation of economic pest because it was suspected of preying on game species (Potočnik et al., 2009). This usually leads to an increase in illegal hunting (Breitenmoser et al., 2001; Červeny et al., 2002), and indeed lynx poaching in Croatia increased from 0.48 recorded cases per year ($N = 10$, 5% of recorded mortality) in 1978–1998 to 1.2 recorded cases per year ($N = 18$, 60% of recorded mortality) in 1999–2013. Poaching poses a similar threat to lynx populations elsewhere in Europe (von Arx et al., 2004): it accounts for 71% of all known lynx mortality in Poland (Jędrzejewski et al., 1996); for 46% of all adult lynx mortality in Norway (Andrèn et al., 2006) while illegal killings were responsible for up to 55% of known loses in the Jura Mountains (Breitenmoser-Würsten et al., 2007). The evidence makes clear that legal safeguards of the lynx are often ineffective for lack of appropriate enforcement measures and awareness campaigns (Rodriguez and Delibes, 2004).

Key to controlling lynx poaching may lie in encouraging the public to accept the lynx as a predator, rather than pest, in the modern landscape (Andersen et al., 2004; Kleiven et al., 2004). Poachers are unlikely to be motivated by the desire to reduce perceived economic losses due to lynx: since 2000, lynx in Croatia have caused less than one livestock death per year, and the small lynx population is unlikely to affect game animal stocks significantly (Sindičić et al., 2010b). Rather, poachers may be motivated by the general negative perception of lynx: in a survey of 168 hunters in Croatia in 2008, 42.5% thought the lynx population was large enough, 10% thought it was too large and 15% thought that lynx cause unacceptable levels of damage to livestock (Sindičić et al., 2010b). This mindset about the role of lynx as vicious pests should be addressed in awareness campaigns targeted at hunters and related constituencies.

Although our results provide one of the few national-level assessments of mortality in a reintroduced carnivore population and the first such assessment for lynx in Croatia, the data should be interpreted with caution. Overall lynx mortality is likely to have been higher during the study period due to unreported or unobserved deaths. Previous studies confirmed the distribution of causes of mortality clearly differed between the radio-tagged animals and animals found by chance with radio-tagged animals more accurately presenting the actual situation in the wild (Schmidt-Posthaus et al., 2002). Most of our data comes from the national monitoring program during the period when lynx was legally hunted and after that from chanced observations, with only 8 radio-tagged animals. So for sure mortality due to poaching is underestimated due to difficulties in detection, as are natural deaths, such as those due to infectious disease and kitten mortality, since carcasses are rarely found. Indeed, in reintroduced Swiss population diseases are one of the most important mortality factors and up to 40% of radio-tagged animals died due to infections (Schmidt-Posthaus et al., 2002; Breitenmoser-Würsten et al., 2007). Also, disease was found to be the major cause of mortality (38.5%) in radio-tagged Iberian lynxes, especially in the Doñana population (López et al., 2014). Throughout the past decade, infectious diseases were one of the most important threats to Iberian lynx (Millán et al., 2009; Meli et al., 2010), and high levels of inbreeding in the Doñana Iberian lynx population may have led to immunosuppression that contributed to such disease (Palomares et al., 2012). The Dinaric lynx population also shows considerable inbreeding and low genetic diversity (Sindičić et al., 2013), suggesting that it may be particularly susceptible to disease. In this study we found no evidence of infectious diseases, although a low number of carcasses were examined. Also we cannot exclude the presence of such disease in three severely cachectic animals, which could not be analyzed in detail due to progressive autolysis. Starvation has been observed in juvenile Eurasian lynx, usually orphans still too young to hunt by themselves (Stahl and Vandel, 1999; Schmidt-Posthaus et al., 2002; Ryser-Degiorgis et al., 2005) and indeed two of three severely cachectic animals in our study were less than one year old.

Risks of mortality caused by infectious diseases should be thoroughly investigated in future work. Also research show that radio tagged animals represent better the actual situation (Schmidt-Posthaus et al., 2002; Breitenmoser-Würsten et al., 2007) so the number of animals monitored with radio telemetry in the Dinaric population should be increased in order to gain better insight into factors threatening population survival.

5. Conclusions

The present study suggests that the lynx population reintroduced into Croatia has been declining for the past 15 years, primarily due to human activity. The high hunting pressure together with poaching caused the population to decline. Ironically, full legal protection of the species in 1998 led to a significant increase in poaching, highlighting the need for public education and sensitization campaigns to dispel the perception of lynx as pests threatening farmers' livestock or hunters' game animals. The insights from the present work may help guide future efforts to reintroduce lynx into the Dinaric Mountains, which may be the only way to ensure lynx survival in the region. Also it is necessary to further improve the quality of mortality monitoring, as high percentage of animals hunted before the legal protection probably masque the significance of other mortality causes, primarily poaching and infectious disease. The combination of radio-telemetry studies and veterinary investigations including detailed necropsies should provide the most reliable insight (Ryser-Degiorgis, 2009).

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