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Sustainably Harvesting a Large Carnivore? Development of Eurasian Lynx Populations in Norway During 160 Years of Shifting Policy

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Abstract The management of large carnivores in multi-use landscapes is always controversial, and managers need to balance a wide range of competing interests. Hunter harvest is often used to limit population size and distribution but is proving to be both controversialand technically challenging. Eurasian lynx (*Lynx lynx*) are currently managed as a game species in Norway. We describe an adaptive management approach where quota setting is based on an annual census and chart the population development through the period 1996–2008, as management has become significantly more sophisticated and better informed by the increased availability of scientific data. During this period the population has been through a period of high quotas and population decline caused by fragmented management authority and overoptimistic estimates of lynx reproduction, followed by a period of recovery due to quota reductions. The modern management regime is placed in the context of shifting policy during the last 160 years, during which management goals have moved from extermination stimulated by bounties, through a short phase of protection, and now to quota-regulated harvest. Much management authority has also been delegated from central to local levels. We conclude that adaptive management has the potential to keep the population within some bounded limits, although there will inevitably be fluctuation.

Keywords Adaptive management · Eurasian lynx · Harvest · Large carnivore · Historical policy

Europe is home to more than 500 million people and consists of landscapes that have been extensively transformed by human land use for several thousand years. Despite this extreme anthropogenic impact, much of the continent's postpleistocene megafauna remains extant (Linnell and others 2001a), including five species of large carnivore (Eurasian lynx, *Lynx lynx*; Iberian lynx, *L. pardina*; brown bear, *Ursus arctos*; wolf, *Canis lupus*; wolverine, *Gulo gulo*). Although these species have survived, their distributions and densities have been constantly and dramatically impacted by humans, both directly through persecution and indirectly through human exploitation of forests and wild ungulates. In general, the last decades of the 19th century and first decades of the 20th century represented the nadir of Europe's large mammals and their forest habitats (Boitani 1995; Breitenmoser 1998; Linnell and others 2009). Since then, and especially in the last 30 years, there has been a dramatic reversal of fortune for many populations, as forest area has increased dramatically (Farrell and others 2000), wild ungulate populations have been restored to record levels in many areas (Milner and others 2006; Andersen and others 2004), and many large carnivore populations have expanded, through either natural expansion (Wabakken and others 2001; Valière and others 2003), reintroduction (Breitenmoser and others 2001), or both (Linnell and others 2009).

However, their return in many areas has been associated with conflicts, both material (Kaczensky 1999) and social

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(Skogen and Haaland 2001). These conflicts create difficult management situations that can result in controversy. For example, the use of hunting or lethal control is often applied as a conflict decreasing measure in many situations to keep carnivore populations within desired limits, to empower local people, or to maintain traditional livestock herding activities. However, this killing of carnivores is often controversial, as conservationists feel that too many are being killed, animal rights advocates feel it is often wrong to kill carnivores at all, and many rural interest groups (such as hunters and sheep farmers) feel that too few are being killed (Treves and Naughton-Treves 2005). The result of pressures exerted by these conflicting lobby groups can often be a high degree of political involvement in the technical field of wildlife management (Nie 2003; Sandström and others 2009). This can lead to a highly dynamic and fluid management situation where the actual consequences for the carnivore populations are uncertain. Globally there is very little experience with sustainably managing the harvest of large carnivores, as historical goals have almost always been to exterminate predators, either through direct policy, including the payment of incentives, or through passive neglect (Linnell and others 2001a). Therefore, all case studies of how populations have fared under different management regimes are valuable (e.g., Ross and others 1996; Yamazaki 1996; Creel and Creel 1997; Whitman and others 2004).

However, in order to gain perspective on present-day debates it is vital to view existing management situations within the context of their history (Mykrä and others 2005; Pohja-Mykrä and others 2005). It is also vital to initiate robust monitoring programs such that the effect of policy can be analyzed and to allow management to respond to undesired changes through adaptive management processes (Williams and others 1996).

In this paper we trace the historical development of official policy and population responses for Eurasian lynx in Norway. From 1845 until 1995 our only data to monitor population changes are derived from bounty payments and hunting statistics (Swenson and others 1995; Jedrzejewska and others 1996; Litvaitis and others 2006). From 1996 until the present we have access to annual census data that have been collected within the structured framework of a national monitoring program. Therefore our goal is to give a detailed description of the present-day status of lynx in Norway that is firmly embedded in the historical route it took to this situation.

Methods

Historical data on bounty payments and hunting statistics have been obtained from diverse databases within Statistics Norway (www.ssb.no). From 1846 until 1924 these were only available on the county level. However, from 1925 they are available on the municipality level. Details on the development of management policy have been obtained from a range of sources, including Olstad (1945), Myrberget (1967a, b, 1970), Søilen (1995), Rideng (1999), Søybe (2001), and the Internet pages of the Norwegian Directorate for Nature Management (www.dirnat.no) and the Ministry of the Environment (www.lovdata.no). There were often minor inconsistencies in numbers reported (e.g., animals killed in vehicle collisions were occasionally included in harvest statistics) and in the timing of when regulations came into effect (e.g., sometimes dates are given when a law was passed; other times, when it came into effect)—however, these minor errors should not influence overall conclusions.

Since 1996 lynx have been monitored using a common methodology based on unreplicated counts of family groups (*sensu* Knight and others 1995; Linnell and others 2007a, b). From 1996 to 2002 this monitoring was done more or less on an ad hoc basis by the individual counties. Results from the years 1996 and 1997 have been previously presented in unpublished reports (Kvam 1997). From 2002 and onward the work has been coordinated by the National Large Predator Monitoring Program based at the Norwegian Institute for Nature Research, with the State Nature Inspectorate responsible for verifying field observations. In early 2003 this monitoring program produced its first report of the national population status in 2002. However, the raw data from the pre-2002 period were reanalyzed along with the post 2002 data, such that data for all years are comparable. This reanalysis has led to some changes in the numbers presented by Kvam (1997) for 1996 and 1997, mainly in the direction of slightly lowering his estimates.

Records of lynx tracks with two or more individuals (assumed to be a family group outside the mating season) are collected by hunters, game wardens, and the public during the period from October 1st to the end of February. These observations are then verified by state-employed wildlife wardens from the State Nature Inspectorate and entered into a national monitoring database (ROVBASEN 3.0). Although the search effort varies between regions, experience has shown that local hunters put in a good deal of time to search for tracks, often in coordinated surveys. Furthermore, most of the counties with large lynx populations have adopted a system of index lines (>1900 transects, each 3 km long) that are examined for tracks on snow once per year, which provides a minimum search effort (Linnell and others 2007b; Odden and others 2008). This index line system is integrated into the National Large Carnivore Monitoring program, and all records of family groups are verified by state wardens. Studies have shown that almost all radio-collared lynx that are known to exist

within an area are detected (e.g., Odden and others 2001). Additional evidence of reproduction such as young of the year being shot, found dead, or killed in vehicle collisions between October 1st and April 30th are also included. Once all observations are available, a standardized set of distance rules derived from telemetry studies is applied to the observations (Linnell and others 2007a). These rules are based on maximal home range sizes and maximal distances traveled within known time periods (Linnell and others 2007a). Home range sizes and movement rates vary between study areas depending on prey availability (Linnell and others 2001a; Herfindal and others 2005a), requiring that different rules are applied in different parts of Norway. Presently three main "prey density" regions are recognized: (1) areas where semidomestic reindeer form the main prey, (2) areas with a relatively low density of roe deer, and (3) areas with a relatively high density of roe deer. The cutoff between high and low roe deer density is at a harvest density of 0.75 roe deer shot per year per 10 km^2. Two different sets of rules were developed for each region. For observations separated by more than a week, a fixed distance rule based on home range length is used. The program operates with a strict (long and, therefore, conservative) and a normal (shorter) distance rule. The strict rule is the mean of the lengths of 100% minimum convex polygon home ranges of adult female lynx. The normal rule is identical to that used in Swedish lynx monitoring (Östergren and Segerström 1998) and is the mean of the maximum home range lengths divided by the diameter of a circle of the same area. For observations that are closer in time a dynamic distance rule is used, which is based on the mean of the individual maximum day-to-day straight-line-movement distances. Details of the annual censuses are given by Brøseth and Odden (2008) and Odden and others 2008). For simplicity we only present results based on the normal distance rules.

There is no statistical estimate of the number of animals not detected, so that the result is a minimum count of the number of family groups which could be responsible for the total amount of observations. This minimum count of family groups can then be extrapolated to an approximation of total population size (Andrén and others 2002) based on factors developed from survival and reproductive rates for radio-collared lynx (Andrén and others 2006). Different extrapolation factors have been developed for the different prey type regions that take regional differences in demographic parameters into account. We present the monitoring data for Norway as a whole and for eight geographic regions that correspond to the management units that have been operational from winter 2004–2005 onward.

Norwegian hunting seasons extend from April 1st to March 31st. Most lynx are shot during the second half of the winter (February–March), while monitoring occurs in the period December–February. We attribute all hunting seasons and monitoring seasons to the year at the end of the winter; e.g., harvest statistics from the winter of 1994–1995 are referred to as 1995, and family groups resulting from birth in summer 1994 are attributed to the 1995 season when they were censused.

Results and Discussion

Policy Development

The history of lynx management (Table 1) can be divided into three broad periods: the bounty years, transition years, and the quota hunting years.

The Bounty Years (1846–1980)

Although wolves and bears were subjected to an official bounty that was paid by locally raised taxes from 1733 (Elgmork 2000), lynx were first covered by a state bounty from 1846. The "law on the extermination of carnivores and protection of other game" was passed in 1845 and introduced a state bounty for all large carnivores and a range of other avian and mammalian predators (Rideng 1999; Søybe 2001). As the title of the law makes clear, the official policy goal at that time was to exterminate the large carnivores because of their depredation on livestock and predation on wild ungulates. The state bounty stayed in place until 1980, with the exception of the years from 1930 to 1955. During that period many of the counties and municipalities continued paying it (Myrberget 1970) from local funds. Lynx were the last of the four large carnivores to have the state bounty removed. For comparison, bears had their state bounty removed in 1930, and even local bounties were banned in 1972, prior to their full protection in Norway in 1973 (Swenson and others 1995), the same year in which wolves were protected in all Norway and wolverines were protected in southern Norway (Landa and others 2000). In addition to the state bounty, a wide range of local bounties was also paid by the counties, municipalities, and local organizations for various periods. While information on these local bounties is poor, a survey from the mid 1960s indicates that the sum of local bounties was two to four times the state bounty (Myrberget 1967a). During that period lynx hunting was not attached to landowner rights in the manner of game species. Therefore, lynx could be hunted by everybody, anywhere, without the need to pay a hunting license, all year round except for the "Christmas protection" period (December 24–31). The only restrictions were on the use of poison, killing traps, and leg-hold traps imposed at various times during the mid 20th century (Table 1).

Table 1 Development of regulations governing lynx management in Norway 1846–2004

Year	Regulations	Bounty	Hunting season	Consequences	Period
1846	"Law on extermination of carnivores and protection of other game" comes into effect	State bounty introduced	All year	Lynx hunting open to all, without need for landowners permission. Shooting, poison, leg-hold traps, live-capture traps, and killing traps allowed	Bounty years
1863		State bounty increased			
1899	Introduction of first hunting law			Hunting rights for all game transferred to landowner; does not apply to large carnivores, which remain open for everybody	
1900		State bounty increased			
1932	Revision of hunting law	State bounty removed; left to counties		Use of poison limited to special permission	
				Use of leg-hold traps banned except on bait/kills	
1951	New hunting law		All year except 24–31 December	Confirms that lynx hunting is (i) open to all, (ii) no need to pay hunting license, and (iii) no need to have landowner's permission	
1956		State bounty reinstated			
1960				Total ban on use of leg-hold and killing traps	
1971				Total ban on poison	
1972				Ban on use of motorized vehicles in hunting	
1976	CITES Appendix II				
1979	Bern Convention signed; lynx in Appendix III without reservations				
1980		State bounty removed			Transition years
1982	New hunting law		22 August to 14 April	Landowner given hunting rights	
1983	Hunting law revised			Possible to issue out-of-season permits to control depredating individuals	
1986	Bern Convention ratified		1 November to 15 April		
1989			1 February to 31 March		
1990				Ban on live-capture box traps	
1992	1st parliamentary white paper, "On the Management of Bears, Wolverines, Wolves and Lynx in Norway"			Complete protection in south Norway	
				Responsibility for census and quotas given to counties	
				Introduction of compensation for lynx-killed livestock	
1993	Convention on biological diversity signed New regulations			Counties delegated authorities to set hunting quotas	
1994	Revised regulations			Quota regulated hunting opened in 6 counties	Quota hunting
				Counties encouraged to set female subquotas	
1995				Quota hunting extended to total of 8 counties	
1996				Quota hunting extended to 11 counties	

Table 1 contiued

Year	Regulations	Bounty	Hunting season	Consequences	Period
1997	2nd parliamentary white paper, "On Large Carnivore Management," revised regulations			Quota hunting extended to 12 counties Specified that lynx were to be excluded from certain areas Live-capture box traps allowed again Trial with local management committees in 2 counties	
2000	Revised regulations			Permit to issue permits to kill depredating individuals can now be given by counties	
2002	Revised regulations		1 February to 30 April		
2004	3rd parliamentary white paper, "Large Carnivores in Norwegian Nature"			8 management zones created, with national population goals. Lynx quotas and depredation permits to be set by politically appointed committees in each zone	
2005	Revised regulations		1 February to 31 March		

The Transition Years (1980–1994)

These years saw a huge number of changes in lynx management. Soon after the state bounty was removed in 1980 a new hunting law came into effect (1982, with the first revisions already in 1983) which effectively transformed lynx from being unprotected to being a game species. The new law also included the major philosophical shift from all species being huntable unless protected to all species being protected unless specifically opening a hunting season. Lynx hunting was attached to landowner rights such that a landowner's permission was needed to hunt, and state hunting licenses needed to be purchased, although there were no limits on the numbers of lynx that could be killed. The 1983 revision of the law was also the first legal text to formally declare that national objectives were to maintain viable populations of all species, including lynx, although the goal of maintaining lynx populations (rather than exterminating as before) had been informally operational within the wildlife management system since at least the 1960s (Myrberget 1970). During the transition years hunting season length was reduced three times, from 9 down to 2 months, and the use of live-capture box traps was banned. Then in February 1992 a hunter in southeastern Norway shot an entire family group (adult female and two kittens). Although perfectly legal, the action received a great deal of media attention, which in turn led to a public outcry (Rideng 1999). Because there was little information on the status of lynx in Norway at that time, the Ministry of the Environment responded to public opinion by temporarily protecting lynx throughout southern Norway (Rideng 1999).

At the same time, parliament was for the first time debating a white paper on the topic of large carnivore management (Ministry of the Environment 1992). The white paper provided the first political statement outlining the twin management goals of conserving carnivores while limiting damage to livestock interests that are still at the core of present-day policy ("The government will ensure the survival of viable populations of bears, wolverines, wolves and lynx in Norway. At the same time the damage caused by large carnivores will be limited as much as possible"). This was the first time lynx had been included under the same umbrella as wolves, bears, and wolverines [their management was already governed by a management plan from 1987 (Vaag and others 1987)], creating what is known today as the "big four" large carnivores. State-paid compensation for livestock killed by lynx was introduced for the first time in 1994 (Fig. 3a). Responsibility for population censuses and setting quotas where populations could support harvest was delegated down to the 18 Norwegian counties. There was no coordinated or standardized attempt to census the populations or coordinate harvest during this period.

Table 2 Development of the number of reported tracks, lynx family groups, and extrapolated total lynx population size for the period 1996–2008 in Norway

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Tracks reported			185	259	186	221	161	115	139	103	91	152	191	201	261
Family groups			69	82	68	76	61	55	56	46	44	56	65	74	76
Population goal (family groups)	"Sustainable population"			"Same level as in 1996/1997"								65 family groups			
Extrapolated population size			410	486	403	448	366	327	332	272	259	329	385	439	452
Hunting quota	47	54	103	146	155	139	140	123	116	85	50	51	48	74	96
Units with female subquota								8/18	7/18	7/18	7/18	7/18	5/8	5/8	7/8
Number shot	41	50	85	95	117	91	95	81	92	62	35	44	40	58	90
Harvest (% of population)			21	20	29	20	26	25	28	23	14	13	10	13	20

The Early Quota Hunting Years (1994–2004)

Following the acceptance of the white paper in 1992, lynx in southern Norway remained fully protected for the 1992–1993 hunting season. By winter 1994 the counties began to open for quota-regulated lynx hunting. The number of counties with quota-regulated hunting rapidly increased from 6 in 1994 to 12 in 1997. In 1997, parliament debated a second white paper on large carnivore management, which upheld the same principles as the first but included more precise goals for large carnivore populations (Ministry of the Environment 1997). These goals called for lynx populations to be kept at roughly the 1996–1997 levels. However, the white paper also called for the exclusion of lynx from areas where the livestock conflict potential was too high: mainly in western Norway and some coastal areas and islands of northern Norway. These areas were subject to the same harvest regulations as the rest of Norway with the exception that there were no quota limits on the number of lynx that could be killed. In addition, in two of the counties with the largest lynx populations there was to be a trial system where the quota-setting responsibility would be transferred from each county governor's Department of Environmental Affairs to local committees, composed of politicians and interest-group representatives (Guldvik and Arnesen 2001). In the counties with quota limits on lynx harvest there was a trend to introduce regulations and practices designed to prevent potential overharvest. Female subquotas were introduced such that the entire hunt in a county would stop if a certain number of females were killed even before the whole quota was filled (Table 2). In addition, quotas were often assigned to specific subregions within a county in an effort to focus harvest on regions where conflict with livestock was greatest. Finally, a number of counties began to issue the quota in two stages, holding back a part of the quota for some days or weeks. The idea was to reduce the chances of the total quota being exceeded.

Recent Developments (2005–Present)

In December 2003 the government presented to parliament the third white paper on large carnivore management in 11 years (Ministry of the Environment 2003). After much debate a modified version was accepted by a large parliamentary majority in May 2004, with the changes in management coming into effect in early 2005. From the point of view of lynx there were two significant changes. First, management was moved from the 18 counties to 8 regional units (Fig. 1), where a committee composed of elected representatives from the county assemblies assumed responsibility for setting quotas (Sandström and others 2009). These units correspond either to some large counties or to an aggregation of two or more smaller counties. This was an attempt to decentralize management to a biologically meaningful scale and increase public acceptance for

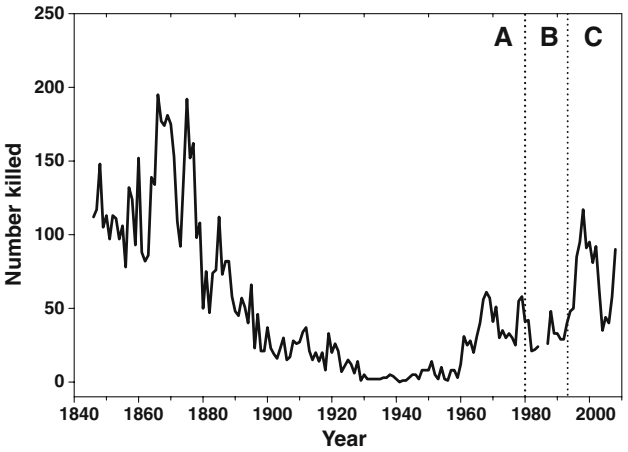

Fig. 1 Numbers of lynx shot in Norway from 1846 to 2008. Period A, the time when state bounties were operational; Period B, the timeafter state bounty was removed but before limits were placed on harvest; Period C, the time during which a quota has limited annual harvests

management decisions through the empowerment of elected representatives as outlined in the white paper of 2003. Second, national population goals for each region were set by central government, such that the regional committees have clear frames within which they can operate. Each committee will be able to call on technical expertise from one of the county management authorities within their region, and will only have power to set quotas once their region has reached its population goals. The regional committees also have been required to develop large carnivore management plans for their region.

Patterns of Conflict

Lynx are associated with three major conflicts in Norway. First, domestic sheep are grazed in forests and mountains throughout Norway during summer. Most flocks are free-grazed, without fencing, supervision, or guarding. The result is widespread depredation on livestock (Odden and others 2002; Zimmermann and others 2010). Losses of sheep are basically related to the size of the lynx population (Herfindal and others 2005b) and the number of sheep compensated annually has fluctuated between 6000 and almost 10,000 since 1994 (Fig. 3a). These very high depredation rates are supported by ecological studies of lynx (Odden and others 2002) and telemetry studies of sheep mortality rates. Second, semidomestic reindeer are grazed by the Sami ethnic group in central and northern Norway. Reindeer are also highly vulnerable to depredation by lynx, although the exact numbers and factors influencing losses are still debated (Sunde and others 2000). Annual compensation figures lie between 2300 and 3300 reindeer. Third, roe deer hunters perceive lynx as being a major competitor for their shared quarry (Nilsen and others 2009). It is reasonable to suspect that both of the latter conflicts are also related to the size of the lynx population. Therefore, lynx management is regarded by politicians, managers, and the public as a process of balancing the need to maintain viable lynx populations with the need to minimize conflicts with sheep herders, reindeer herders, and hunters.

Changes in Numbers Shot

Using harvest statistics to detect changes in population size requires some caution. In the early years there was undoubtedly some forgery, for example, with arctic fox skins being handed in as lynx (Søybe 2001). However, the high monetary value of the bounty led to improved control on the side of the state and strong motivation on the part of the hunter to report the kill, implying that records are likely to be reasonably complete and accurate. At least up until 1992 there was also little motivation for poaching, as

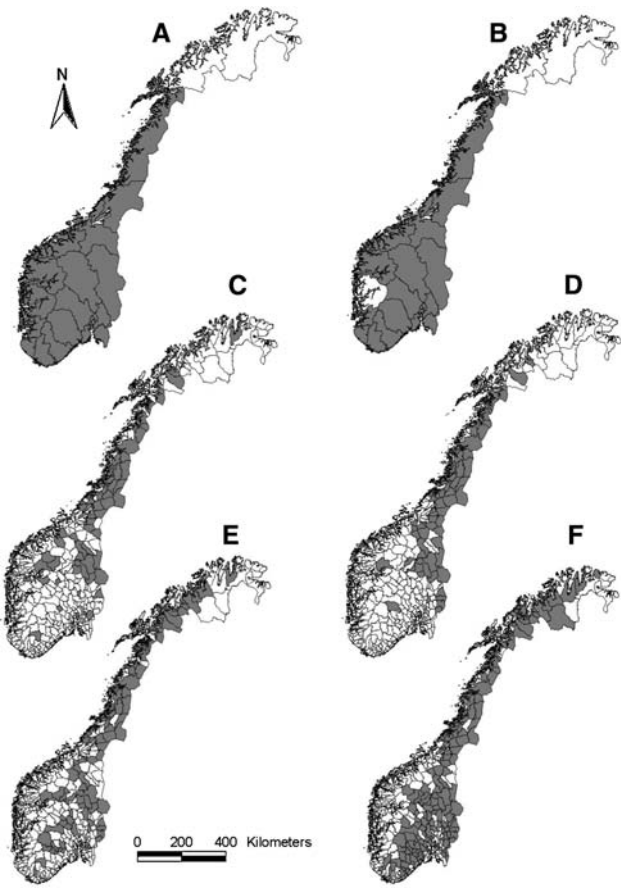

Fig. 2 The changing distribution of lynx in Norway from 1846 to 2008 as indexed by administrative units where at least one lynx was shot in the given periods. **a**, **b** Data are available only on the level of the county. **c**–**f** Data are on the municipality level. The years included in are **a** 1846–1885 (early years of bounty harvest), **b** 1886–1925 (period of rapid decline), **c** 1926–1965 (the low-population phase), **d** 1966–1980 (period of slight recovery; bounty still in place), **e** 1981–1993 (postbounty period), and **f** 1994–present (quota regulated harvest)

hunting was effectively not limited by quotas. Therefore, we believe that for the period from 1846 to 1992 the public records provide an accurate record of the numbers of lynx being killed each year, and that the harvest statistics and bounty payments provide a general picture of the distribution and relative size of the lynx population (Swenson and others 1995; Jedrzejewska and others 1996; Litvaitis and others 2006). An exception may be the period from 1930 to 1955, when the state bounty was removed. It was assumed by central management agencies that the counties and municipalities would take over the bounty payments, although it is not known to what extent they did this. This may have reduced both the motivation to hunt and the accuracy with which the kills were reported. Also, during the years of the Second World War when Norway was occupied (1941–1945), hunting weapons were confiscated, and even after the war ammunition was in short supply and

rationed. From 1992 onward the harvest data are less useful as a direct index of population size, as the harvest was usually limited by the size of the quota. Furthermore, the increasing conflict with farmers and hunters, and the limits on permissible harvest, presumably led to an increase in poaching. Poaching is presently a common cause of death among radio-collared lynx (Andrén and others 2006).

Bearing these limitations in mind, the hunting statistics indicate that for the first 30 years after the bounty was introduced, there was no detectable change in population distribution or size (Figs. 1, 2), although the annual bag varied substantially. However, following 1880 the population went into a steep decline, reaching its nadir in the 1930s and 1940s. For the reasons discussed above, the hunting statistics during this period may not be directly comparable with the previous and subsequent periods, creating an impression that the reduction was greater than it appears. However, contemporary accounts confirm the fact that lynx were very rare during this period—being found mainly in the central Norwegian county of Nord-Trøndelag, with a few individuals surviving in southern Norway (Olstad 1945; Myrberget 1970).

Beginning in 1960 the population appeared to increase again, first in density and then in distribution (Figs. 1, 2). The numbers shot each year remained fairly stable up until protection in 1992. There has been much speculation about the reasons for this increase, with various authors attributing it to improved prey availability as roe deer populations increased (Andersen and others 2004), a decline in the interest in lynx hunting, as the older generation of hunters died away, and of immigration from the lynx population in Sweden, which had increased following protection (Myrberget 1961, 1970). Once quota hunting started in 1994 there was a dramatic increase in the numbers being shot and the geographic distribution of these kills. This peaked in 1998, with a harvest of 117 animals. This was the highest number killed in a single year since 1877. After this peak the harvest declined again; by 2004 it had returned to levels typical of the 1960–1990 period. From 2005 and beyond there has been a substantial recovery in the size of the population.

Therefore, based on the indications provided by harvest numbers, Norwegian lynx populations seem to have undergone a fall (from 1890 to 1930), a rise (1960–1997), a new fall (1997–2004), and a new recovery (2005–2008). While many anecdotes and independent data (such as depredation rates on sheep) indicate that there was a real increase in the early to mid 1990s, there was a dramatic increase in hunter interest in lynx hunting following the controversy of protection and the introduction of quota limitations. Once limits were placed on the harvest, many more people wanted to take part than in the previous years when there were no limits. Our own observations indicate that the interest in lynx hunting is enormous. Large hunting

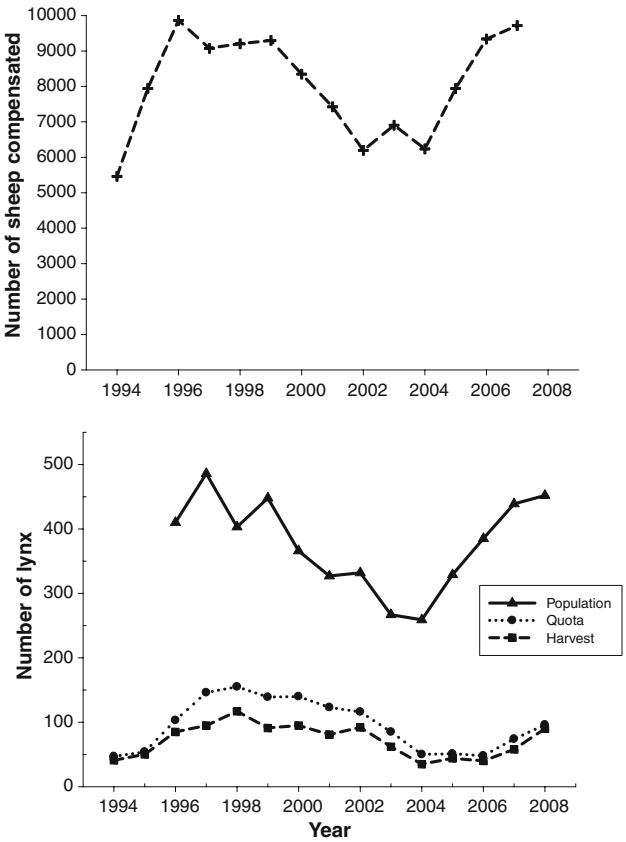

Fig. 3 Development of numbers of sheep compensated following lynx depredation, lynx harvest, lynx quota, and lynx population size in the period 1994–2008

teams, of up to 100 people, spend weeks prior to the opening of the hunting season searching for, and following, lynx tracks. In many counties quotas are filled in a matter of days if snow conditions are favorable. This occasionally leads to overfilling of quotas, as there are inevitable delays between the reporting of a kill and other hunters updating themselves as to whether the quota was still open. Likewise, the steepness of the decline in numbers shot during the 2003–2004 probably overestimates the real magnitude of decline in population size. Rather it reflects a response by management to correct the sharp decline revealed by monitoring data (see below) and reducing the quota accordingly.

Monitoring-Based Population Development

When viewed at the national level the monitoring data show a very clear pattern of a fluctuating population (Fig. 3). From a peak in 1997 the population declined constantly until 2004. The overall decline for this period, estimated from regression lines, was 43% until 2004 (slope = –25.2, $R^2 = 0.8$, $P = 0.01$). However there is a good deal of variation between regions (Fig. 4). Within 4 years of the introduction

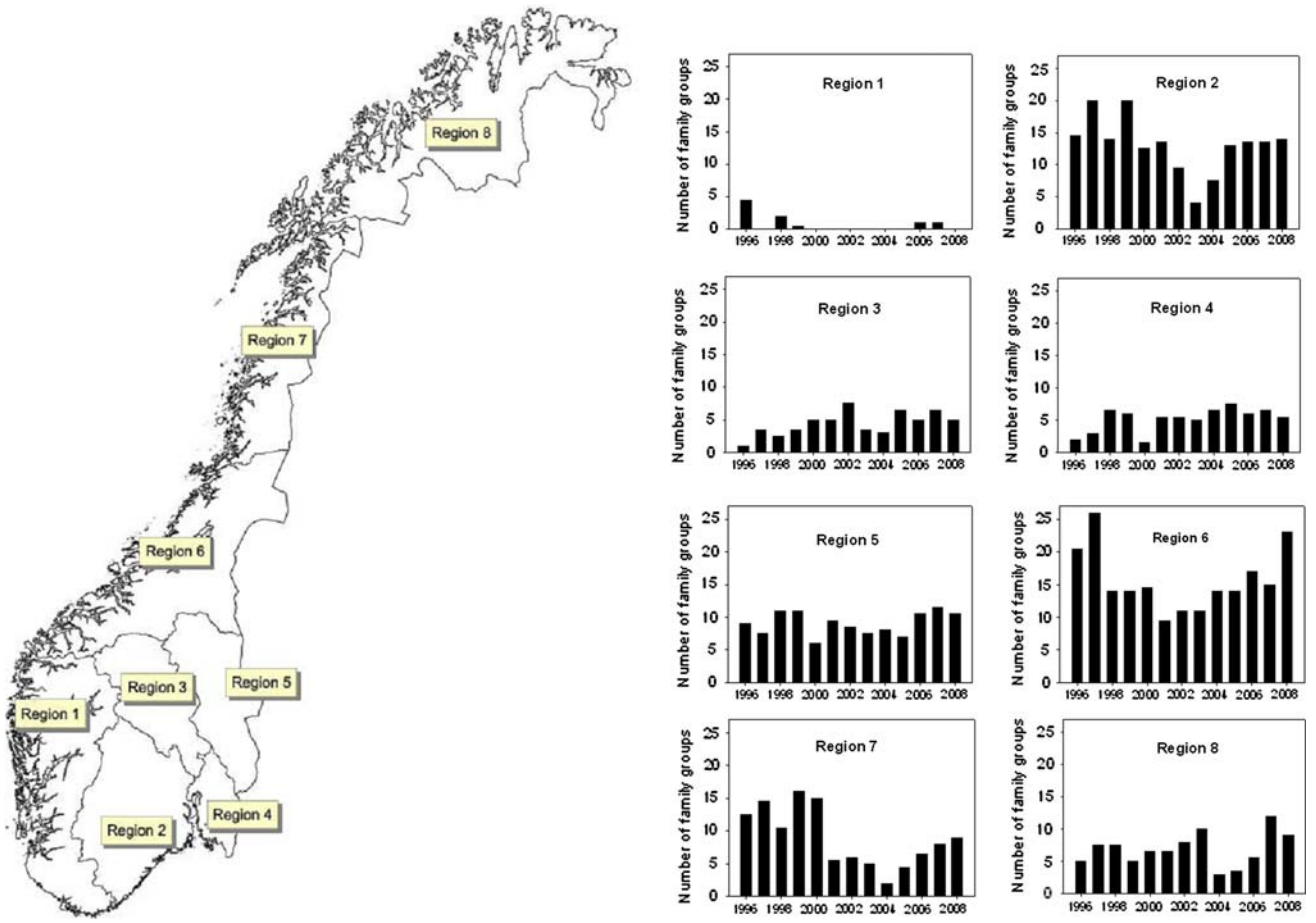

Fig. 4 The eight large carnivore management regions which have become operational in Norway since 2004, with regional goals for the numbers of annual reproductions (post 2004), and histograms of regional lynx population development 1996–2008 (expressed as number of family groups)

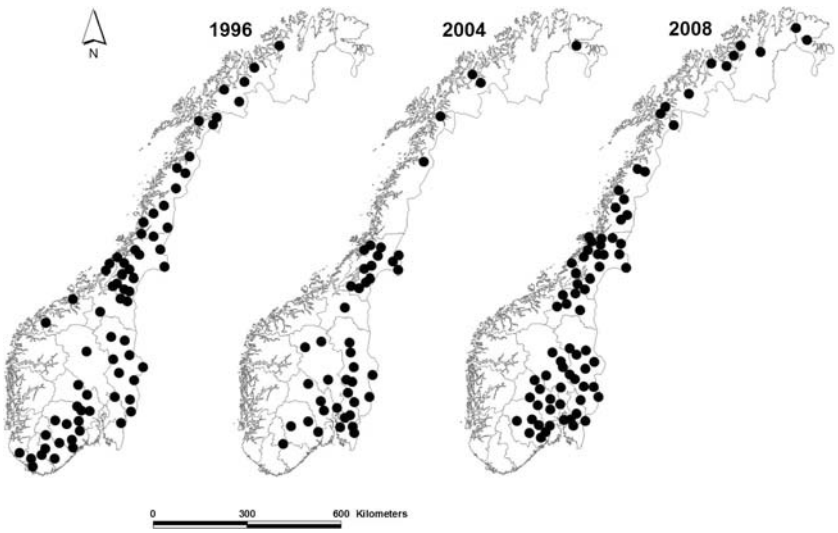

Fig. 5 Distribution of lynx family groups in 1996, 2005, and 2008

of quota hunting, lynx had been exterminated from south-western Norway (Region 1; Figs. 4, 5), and by 2004 severe declines were apparent in southern Norway (Region 2) and the two central Norwegian regions (Regions 6 and 7; Fig. 4), while the populations maintained relatively constant levels in the other four regions (Fig. 4). Despite these reductions in

distribution, lynx remained well distributed in the southeastern (Regions 4 and 5) and central (Region 3) areas, although the thin distribution in the north (Region 8) gives grounds for concern (Figs. 4, 5). In many ways the 2005 population distribution closely resembles the distribution during the 1960s and 1970s (Fig. 2). The expansion northward and southwestward that characterized the 1996 distribution had effectively been reversed, or at least greatly reduced (Fig. 5). The data from 2005 to 2008 indicate that the population has recovered again, exceeding the national goals in many regions. There has been no new colonization of southwestern Norway (Region 1), which is also not intended in the new management plan (Ministry of the Environment 2003).

Given the historical development of policy, it seems somewhat surprising that the population should decline so rapidly in a period (1997–2004) when there was an unprecedented degree of limitation on hunting activity (method restrictions, season length, quota limitation), on the one hand, and an abundance of good monitoring data (see above) and biological and demographic data on lynx (e.g., Andrén and others 2006; Herfindal and others 2005a), on the other hand. Possible explanations lie in three causes: (1) fragmented management authority, (2) lack of specific regional population goals, and (3) time lags in management responses. The survival data collected on radio-collared lynx during this period allow us to exclude the possibility of other processes such as disease; by far the vast majority of lynx die from direct human causes (Andrén and others 2006).

The 1997 white paper set a goal of maintaining the lynx population close to the levels they were at in 1997. However, there was also a desire to reduce lynx populations in the southwestern counties, because of potential conflicts with sheep farming, and in the central counties, which had relatively dense lynx populations and high conflicts with semidomestic reindeer herding (Ministry of the Environment 1997). As planned, the hunting virtually exterminated lynx from the west and southwest and severely reduced lynx in central Norway. However, the dramatic decrease in Telemark and Nordland counties was not planned. Clearly if the national population was to be kept stable while reducing local populations, there should have been a balancing increase in some areas. However, no other counties allowed any increase in their lynx population such that the overall effect was a national decrease. Therefore, the fragmentation of management authority at the county level led to a lack of holistic planning until the national monitoring program was first able to produce an updated national survey for the entire period 1996–2002, in 2003. This summary led to instructions being issued from the central Directorate for Nature Management to the counties recommending a dramatic reduction in quota and harvest for the 2004 hunting season (Table 2; Fig. 3).

Time lags in management's response to population change are a well-known problem in harvest management of game species [e.g., Solberg and others (1999) for moose, *Alces alces*, harvest]. Psychology plays an important part in the willingness of managers to react to monitoring data. There is a tendency to believe that "there are hidden animals not counted" when data indicate a reduction in population size, thus causing high harvests to continue even when a population has begun to decline (Swenson and Sandegren 1996). This problem is made worse when operating with minimum count data (like the family group counts), as there is no statistical estimate of uncertainty regarding the number of family groups not found. Furthermore, during the late 1990s there was a constant conflict among researchers, managers, and hunters over population estimation, with hunters, and some managers, dramatically overestimating lynx population size (Skogen 2003). Local political pressure from livestock and hunting interests may have also played a role in hindering the counties from reacting sooner to perceived declines. These factors combined would have tended to make local managers slow to reduce quotas in response to indications of population decline.

Another factor which has to be considered is the delay in being able to compile and analyze data. At present it has not been possible to estimate the size of the lynx population in the same year that the data are needed for quota setting: this is because the monitoring program depends heavily on observations made during the first weeks of hunting. The result is that managers have potentially only had access to the previous year's estimate (from before the hunting season) to set this year's quota.

Finally, there is the issue of the time it takes results from scientific research to enter the management system. The use of standardized distance rules only emerged from 2001 to 2002, and these were based on research conducted during the period from 1992 to the present. Earlier estimates of lynx population growth rates had led to the belief that lynx could tolerate harvest rates well over 20%. More recent analysis of data collected from telemetry indicates that 17% may be a maximum (Andersen and others 2003; Henriksen and others 2005; Andrén and others 2006), although this number relies heavily on the number of adult females in the harvest. The dramatic increase in harvest from 1995 to 1997 clearly exceeded the level of sustainability (Table 2), with harvests regularly exceeding 20% of the estimated population size. It was first in 2004 that the harvest dropped to <17% of the population. This revised estimate also fails to include poaching—which studies have shown to be a major cause of mortality (Andrén and others 2006). In some regions it is actually surprising that the population has survived as well as it has in the face of the heavy mortality from harvest and other causes of mortality. It appears that sharing a border with Sweden, where lynx are more abundant and subject to

far lower harvest rates, has buffered the Norwegian lynx population through immigration. One example is the region of Akershus-Østfold, which has a stable population despite an average 35% hunting rate from 2000 to 2003 (Andrén and others 2006). Also, the starting point was overly optimistic, as the estimates made by Kvam (1997) have since been revised downward, given the increased availability of telemetry data from a wider range of study sites (Linnell and others 2007a) and a more strict interpretation of the veracity of observations.

Overall, it is possible to explain the period of overharvest of Norwegian lynx through a combination of fragmented management without access to centrally produced monitoring data, time lags in both the reaction to monitoring data and the inclusion of scientific results in management, and an overoptimistic starting point with respect to both population status and population growth rates. The main critique that can be raised with the benefit of hindsight is that the responsible authorities failed to exercise the precautionary principle, i.e., erring on the side of caution (with respect to the potential impact on the lynx population) when faced with uncertainty.

However, there can be few excuses for the future. A national monitoring program is now in place such that all decision-making bodies have access to standardized and up-to-date estimates of population status. Furthermore, regulations require that these decision-making bodies use these estimates as their foundation for decision making. Good scientific data on lynx demographics exist so that we now have a more realistic idea of potential population growth rates and therefore of quota sizes that are likely to be sustained. The need to include nonharvest mortality like poaching and vehicle collisions is realized, such that it is now clear that the whole potential rate of increase is not available for hunters. Regional population goals are now in place such that each region's decision-making body has to relate to its own population's status and goals. Furthermore, we have just had a practical demonstration that overharvest can dramatically reduce a population in 7–9 years despite having intensive regulations of hunter effort. Fortunately, there was still a widely distributed population of lynx throughout Norway, and there is a long border with Sweden that lynx can immigrate from, which permitted rapid recovery. The reduction in harvest intensity in the period 2005–2008 has resulted in an increase in the lynx population again to such an extent that in 2008 it exceeded the stated management goals in many regions.

Conclusions

This summary shows the manner in which human management policy has been the dominant factor in shaping the size of a large carnivore population in human landscapes (Swenson and others 1995; Jedrzejewska and others 1996). It also shows how difficult it can be to sustainably manage the harvest of a large carnivore species, even when harvest controls and monitoring data are available. The decline in lynx during the early monitoring period has been used by some environmentalists to call for a ban on lynx hunting. However, the subsequent increase shows that adaptive management does work, and that management agencies were able to reverse the undesired decline, albeit after a significant delay. Despite the difficulties in achieving sustainability of lynx harvest, we believe that in the current high-conflict context of Norwegian large carnivore management, allowing hunting has at least some conflict reduction benefits within both the livestock depredation conflict (Herfindal and others 2005b) and the wider social conflict (Skogen 2003). Viewed as a whole, the current Scandinavian population is so large [currently 1800–2000 animals (Linnell and Brøseth 2004; Liberg and Andrén 2004)] that the current risk of extinction must be considered to be quite low. This gives management some room for error in the short term, as they gain experience at managing lynx harvests. All in all, this is a unique historical experiment, as extermination policies have given way to a quest for sustainability. Adaptive management provides a potentially functional tool, although there are clear challenges. The delegation of some management authority to the eight regions is another unique part of the experiment which attempts to balance science with political and social acceptance. Given uncertainties in population estimation and variation in reproductive rates between year and regions (Andersen and others 2003), and the political nature of the decision-making process, it is unlikely that it will be possible ever to achieve a perfectly stable population size. Rather, we must learn to expect constant fluctuations, with the subsequent challenge being to keep these within acceptable limits. The long-term future of the management system could be enhanced by addressing some of the depredation conflicts in a proactive manner through mitigation, rather than depending heavily on harvest. There will also be a need to respond to future changes in environmental conditions that could influence lynx demographics (e.g., climate- or harvest-induced changes in prey populations) or our ability to census or harvest lynx (e.g., climate change could reduce snow cover and therefore the possibility of collecting track observations).

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