

Recovery of the snow leopard in Sagarmatha (Mt. Everest) National Park: effects on main prey

Francesco Ferretti · Sandro Lovari · Isabelle Minder ·
Bernardo Pellizzi

Received: 17 October 2013 / Revised: 3 March 2014 / Accepted: 5 March 2014 / Published online: 16 March 2014
© Springer-Verlag Berlin Heidelberg 2014

Abstract Consequences of predation may be particularly heavy on small populations of herbivores, especially if they are threatened with extinction. Over the 2006–2010 period, we documented the effects of the spontaneous return of the endangered snow leopard on the population of the vulnerable Himalayan tahr. The study area was an area of central Himalaya where this cat disappeared *c.* 40 years before, because of persecution by man. Snow leopards occurred mainly in areas close to the core area of tahr distribution. Tahr was the staple (56.3 %) of snow leopards. After the arrival of this cat, tahr decreased by more than 2/3 from 2003 to 2010 (mainly through predation on kids). Subsequently, the density of snow leopards decreased by 60 % from 2007 to 2010. The main prey of snow leopards in Asia (bharal, marmots) were absent in our study area, forcing snow leopards to specialize on tahr. The restoration of a complete prey spectrum should be favoured through reintroductions, to conserve large carnivores and to reduce exploitation of small populations of herbivores, especially if threatened.

Keywords Predator–prey relationships · Small populations · Snow leopard · Himalayan tahr

Introduction

Predators can drive dramatic top-down processes, especially in manipulated ecosystems (e.g. following alteration of

predator/prey communities; Lovari et al. 2009a; Ripple and Beschta 2012). As a result, predation may drastically affect small populations of herbivores (e.g. Festa-Bianchet et al. 2006) with serious adverse impacts on the conservation status of both the predator and the prey, particularly where they are threatened with local extinction. In this short communication, we have analyzed the effects of the spontaneous return of the “endangered” snow leopard *Panthera uncia* on numbers of the “vulnerable” Himalayan tahr *Hemitragus jemlahicus* (<http://www.iucnredlist.org/>, February 2014), in the Sagarmatha National Park (SNP) in central Himalaya. In the 1960s, a breeding pair of snow leopards was recorded in SNP, when local hunters killed a female, two cubs and an adult male (Lovari et al. 2009a). After that, occasional presence and poaching events have been recorded (G. Ahlborn & R. Jackson, unpubl. data; Brower 1991), and by 2002–2003, at least one breeding pair of snow leopard was present in SNP (Ale and Boesi 2005).

The establishment of a breeding pair of snow leopards quickly affected the population structure of tahr, through selective predation on kids, especially in summer, resulting in the yearly removal of about 70–90 % of kids (Lovari et al. 2009a). We predicted that it would reduce the population of the main prey substantially (e.g. Lotka 1925; Volterra 1926) and, in turn, that the reduction of the main prey would affect numbers of the predator, unless they shifted their predation to alternative prey.

Methods

Study area

Our study was carried out in Sagarmatha National Park (SNP, 1,148 km², 27°20'N, 86°45'E). Our main study area lies

Communicated by C. Gortázar

F. Ferretti · S. Lovari · I. Minder · B. Pellizzi
Ev-K2-CNR, Via San Bernardino 145, 24126 Bergamo, Italy

F. Ferretti · S. Lovari (✉) · I. Minder · B. Pellizzi
Department of Life Sciences, University of Siena, Via P.A. Mattioli
4, 53100 Siena, Italy
e-mail: lovari@unisi.it

between the villages of Namche, Phortse and Gokyo Lake (3,440–4,750 m a.s.l.). Vegetation included mixed *Betula-Rhododendron-Abies* spp. forest (below 4,000 m); *Juniperus/Rhododendron* spp. (4,000–5,000 m); mosses, lichens, Alpine grasslands (beyond 5,000 m). In SNP, the community of wild large mammals has been altered by man (Lovari et al. 2005). Besides the Himalayan tahr and the relatively abundant musk deer *Moschus chrysogaster* (c. 300 individuals/1,000 km²; Aryal et al. 2010), only the rare Himalayan serow *Capricornis sumatraensis* is present (Lovari et al. 2005). Domestic yak *Bos grunniens* and their hybrids with zebu cattle *Bos indicus* (c. 2,000 individuals) also occur (cf. Lovari et al. 2013a). The common leopard *Panthera pardus* is the only other large predator living permanently in SNP (Brower 1991; Lovari et al. 2013a). The common leopard is confined below the upper tree line, whereas the snow leopard occurs mainly above it (Lovari et al. 2013a).

Data collection and analyses

Our study was conducted from May to November 2006 and from September 2007 to October 2010. The snow leopard diet was assessed through the monthly collection and analysis of scats ($N=76$) obtained walking along one fixed trail c. 140 km long (Lovari et al. 2013a). Scats were georeferenced and genotyped to assess distribution and minimum numbers of this large cat (Lovari et al. 2013a). We also recorded scrapes and hairballs (Lovari et al. 2013a). We also assessed, through repeated monthly counts from the same fixed trail used to collect leopard scats, the distribution and minimum numbers of tahr (Lovari et al. 2009a). We looked for tahr with 10×40 binoculars and a spotting scope 15×45 and their position was

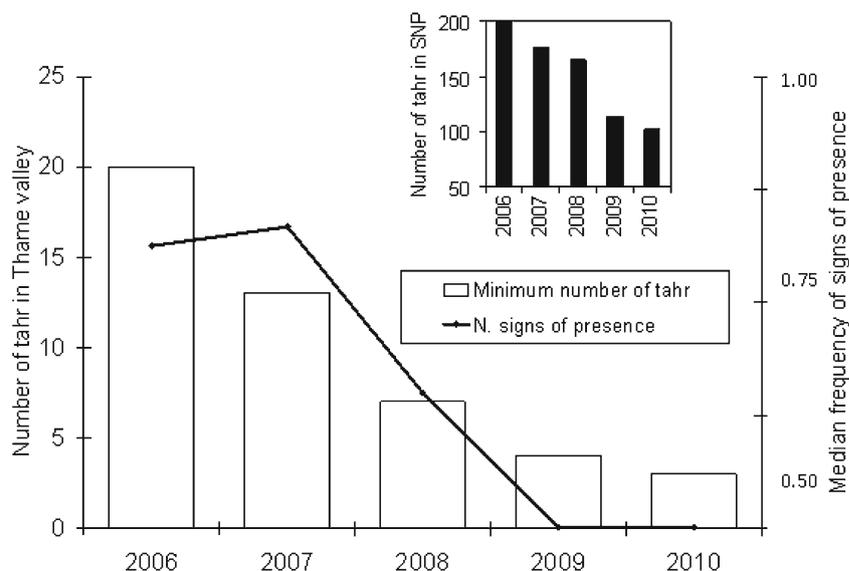
estimated by GPS. Lovari et al. (2009a; 2013a) provide details of the study area and the methods of diet/genetic analyses.

The percentage frequencies of occurrence of main prey (tahr, musk deer, livestock) were calculated (number of occurrences of each food/total number of scats×100) and compared between 2006–2008 and 2009–2010 through G tests (Sokal and Rohlf 1995). The core distribution area of sightings of Himalayan tahr (HTCA) was assessed by a 50 % kernel analysis of their locations (fixed kernel, Worton 1989; $N=544$ tahr sightings, 2006–2010). The effects of the distribution of tahr sightings on the distribution of snow leopards were evaluated through generalized linear models, with binomial errors (Crawley 2007). We compared the location of genotyped scats ($N=76$) in relation to their distance from the border of the HTCA with the location of 76 random points, placed on the fixed trail through the ArcView GIS 3.2 ESRI © software.

Results and discussion

The probability of the presence of snow leopard scats decreased significantly with the distance from the core area of tahr sightings ($\beta=-0.003$; $SE=0.000$; $z=-3.401$; $P<0.001$). Tahr was the staple of snow leopards (56.3 % frequency), followed by livestock (25 %) and musk deer (19 %). In the last decade, the minimum numbers of tahr decreased by more than 2/3 (2003: 300–350 individuals, Lovari et al. 2009b; 2006: 200 individuals, Lovari et al. 2009a; 2010: c. 100 ind.; Fig. 1). In turn, the numbers of uniquely genotyped snow leopards detected decreased from five individuals in 2007 (10.9 ind/1,000 km²) to two individuals in 2010 (4.3 ind/1,000 km²). In a part of our study area (SNP) where only genotyped scats of snow leopards were

Fig. 1 Number of signs of presence of the snow leopard and minimum number of tahr in Thame valley, over 5 years. *Inset:* Minimum number of tahr in Sagarmatha National Park



found (i.e. the Thame valley), the number of snow leopard signs declined to zero, together with a steady decrease (33–50 % per year) of tahr sightings in this area (Fig. 1).

There are some indications of a parallel decline in musk deer numbers, although this decline might have been determined by the decrease of Himalayan tahr, in turn increasing predation on musk deer by either leopard species. In 2010, we found no latrines of this deer in the Sjangboche mixed conifer-rhododendron forest (in SNP c. 3,800 m a.s.l.), walking the same transects (in total, a 6-km long and 10-m wide strip) which yielded 18 latrines in 1994 (Buffa et al. 1998). Lovari (1992) reported that dung piles and footprints of musk deer were frequent, i.e. $n > 25$, over an area of at least 8–10 km² (c. 2,700–4,000 m a.s.l.), in a survey covering the whole park territory, in the autumn 1989. The same observer counted only three latrines in autumn 2010, in the same area.

Throughout our study, the frequency of occurrence of tahr in the scats of the snow leopard declined substantially (30 % decrease in 2009–2010, with respect to its previous percentage in scats), but the statistical significance of the decline was only weak (G test, $G = 2.858$, $df = 1$, $P = 0.09$). No significant increase of either the proportion of musk deer or that of livestock in diet was found ($P > 0.05$) in 2009–2010 with respect to 2006–2008, even if the proportion of musk deer increased by 70 % in 2009–2010, with respect to its previous proportion in 2006–2008.

Small populations of wild Caprinae are sensitive to stochastic predation events which can easily drive them to local near-extinction (Festa-Bianchet et al. 2006) and, presumably, to local extinction. Our results suggest that, after the return of snow leopards, minimum numbers of Himalayan tahr plummeted by 60–70 % between 2002/2003 and 2010. Within that period, minimum numbers of snow leopards decreased from 2007 (5 ind.) to 2010 (2 ind.). This is consistent with the small number of leopards having a very large impact on their primary prey and then declining as a result of reduced food availability.

One could expect that the snow leopard might have switched its predation from this large goat to musk deer and livestock, compensating for its decrease with increased predation on other diet components. This expectation was not met. There was some indication of an increased reliance on musk deer (but not livestock), and a coincident decrease in musk deer, although the elusive habits of this small, nocturnal and forest-dwelling ruminant prevented the collection of adequate quantitative data.

One may have expected the snow leopard to use the forest more frequently than before, to increase predation on musk deer. However, behavioural interference is widespread in carnivores, with the killing of the smaller species by the larger one (Palomares and Caro 1999; Donadio and Buskirk 2006). The presence of the larger common leopard in forest may therefore have discouraged the snow leopard from using this

habitat, limiting the extent to which they were able to switch from tahr to musk deer, leading to the decrease of the snow leopard as numbers of their primary prey declined (Lovari et al. 2013a, b).

The main prey of the snow leopard elsewhere in Asia (e.g. bharal *Pseudois nayaur*; ibex *Capra sibirica*; *Marmota* spp.; Lovari et al. 2013b) were absent from our study area, limiting the potential for prey switching by these cats. The substantial decrease of tahr (Fig. 1) and the presence of the potentially competing common leopard in the forest (up to 76 % diet overlap, in winter, Lovari et al. 2013a) may make it difficult for snow leopards to persist long-term in SNP. This risk could be exacerbated if a further reduction of tahr resulted in an increase of livestock depredation (Meriggi and Lovari 1996), thus increasing the risk of retaliatory killing.

Our results suggest that the persistence or restoration of complete assemblies of prey species should be favoured through direct conservation measures (e.g. reintroductions of bharal to SNP, Lovari et al. 2009a; Aryal et al. 2013). These actions will (1) enhance the opportunities of persistence for large carnivores, (2) reduce the probability of livestock depredation, and (3) reduce the negative effects of predation on small populations of threatened herbivore taxa.

Acknowledgments We are grateful to NAST and especially to A. Da Polenza and the personnel of Ev-K2-CNR for backing our project; to S.B. Ale, K. Thapa, several students and especially to B.B. ‘Lalu’ Gurung for help in the field work; to Lhakpa Sonam Sherpa and to Pema Sherpa, their families and their staffs for the lodging and friendship; to an anonymous associate editor for revising our draft. Our work was financially supported by Project SHARE (Ev-K2-CNR, Italy) and the Italian Ministry of Foreign Affairs. We are grateful to N. Mucci and E. Randi for the genetic analyses of scat samples. F. F. conducted some data analyses and wrote the first draft; S. L. planned and supervised this study, from data analyses to writing; I. M. and B. P. carried out diet analyses and participated in writing drafts.

References

- Ale SB, Boesi R (2005) Snow leopard sightings on the top of the world. *CAT News* 43:19–20
- Aryal A, Raubenheimer D, Subedi S, Kattel B (2010) Spatial habitat overlap and habitat preference of Himalayan musk deer (*Moschus chrysogaster*) in Sagarmatha (Mt. Everest) National Park, Nepal. *Curr Res J Biol Sci* 2:217–225
- Aryal A, Brunton D, Raubenheimer D (2013) Habitat assessment for the translocation of blue sheep to maintain a viable snow leopard population in the Mt Everest region, Nepal. *Zool Ecol* 23:66–82
- Brower B (1991) *Sherpa of Khumbu: people, livestock and landscape*. Oxford University Press, London
- Buffa G, Ferrari C, Lovari S (1998) The upper subalpine vegetation of Sagarmatha National Park (Khumbu Himal area, Nepal) and its relationships with Himalayan tahr, musk deer and domestic yak. An outline. In: Baudo R, Tartari G, Munawar M (eds) *Top of the world environmental research: Mount Everest–Himalayan ecosystem*. Backhuys, Leiden, pp 167–175
- Crawley M (2007) *The R book*. Wiley, Chichester

- Donadio E, Buskirk SW (2006) Diet, morphology and interspecific killing in Carnivora. *Am Nat* 167:524–536
- Festa-Bianchet M, Coulson T, Gaillard JM, Hogg JT, Pelletier F (2006) Stochastic predation events and population persistence in bighorn sheep. *Proc R Soc Lond B* 273:1537–1543
- Lotka AJ (1925) *Elements of physical biology*. Williams and Wilkins, Baltimore
- Lovari S (1992) Observations on the Himalayan tahr and other ungulates of the Sagarmatha National Park, Khumbu Himal, Nepal. *Oecol Mont* 1:51–52
- Lovari S, Ale S, Boesi R (2005) Notes on the large mammal community of Sagarmatha National Park. *Proceedings of the First International Karakorum Conference, Islamabad*: 225–230
- Lovari S, Boesi R, Minder I, Mucci N, Randi E, Dematteis A, Ale SB (2009a) Restoring a keystone predator may endanger a prey species in a human-altered ecosystem: the return of the snow leopard to Sagarmatha National Park. *Anim Conserv* 12:559–570
- Lovari S, Pellizzi B, Boesi R, Fusani L (2009b) Mating dominance amongst male Himalayan tahr: blonds do better. *Behav Process* 81:20–25
- Lovari S, Minder I, Ferretti F, Mucci N, Randi E, Pellizzi B (2013a) Common and snow leopards share prey, but not habitats: competition avoidance by large predators? *J Zool* 291:127–135
- Lovari S, Ventimiglia M, Minder I (2013b) Food habits of two leopard species, competition, climate change and upper treeline: a way to the decrease of an endangered species? *Ethol Ecol Evol* 25:305–318
- Meriggi A, Lovari S (1996) A review of wolf predation in Southern Europe—does the wolf prefer wild prey to livestock? *J Appl Ecol* 33:1561–1571
- Palomares F, Caro TM (1999) Interspecific killing among mammalian carnivores. *Am Nat* 153:492–508
- Ripple WJ, Beschta RL (2012) Trophic cascades in Yellowstone: the first 15 years after wolf reintroduction. *Biol Conserv* 145:205–213
- Sokal RR, Rohlf FJ (1995) *Biometry*. Freeman and Company, New York
- Volterra V (1926) Fluctuations in the abundance of a species considered naturally. *Nature* 118:558–560
- Worton BJ (1989) Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164–168