SNOW LEOPARDS AND BLUE SHEEP IN NEPAL: DENSITIES AND PREDATOR: PREY RATIO

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I studied snow leopards (*Panthera uncia*) and blue sheep (*Pseudois nayaur*) in Manang District, Annapurna Conservation Area, Nepal, to estimate numbers and analyze predator–prey interactions. Five to seven adult leopards used the 105-km^2 study area, a density of 4.8 to 6.7 leopards/100 km^2. Density of blue sheep was 6.6–10.2 sheep/km^2, and biomass density was 304 kg/km^2. Estimated relative biomass consumed by snow leopards suggested that blue sheep were the most important prey; marmots (*Marmota himalayana*) also contributed significantly to the diet of snow leopards. Snow leopards in Manang were estimated to harvest 9–20% of total biomass and 11–24% of total number of blue sheep annually. Snow leopard: blue sheep ratio was 1:114–1:159 on a weight basis, which was considered sustainable given the importance of small mammals in the leopard's diet and the absence of other competing predators.

Key words: snow leopard, *Panthera uncia,* blue sheep, *Pseudois nayaur,* density, predator: prey ratio, harvest rate, livestock predation, Nepal

Snow leopards (*Panthera uncia*) are elusive and occupy precipitous terrain; as a result, there have been few ecological studies of this endangered species (Chundawat, 1992; Jackson and Ahlborn, 1988, 1989; Oli, 1991; Oli et al., 1993; Schaller et al., 1987, 1988). Few reliable estimates of their numbers are available, and many aspects of their ecology are still poorly understood. An understanding of interactions between mammalian predators and their prey may have significant management implications (Mills, 1990; Mills and Shenk, 1992), but we have little knowledge of the impact of predation by snow leopards on populations of prey.

In Nepal, the blue sheep (*Pseudois nayaur*) occurs sympatrically with the snow leopard (Jackson and Ahlborn, 1989; Oli, 1991; M. N. Sherpa and M. K. Oli, in litt.). Recent studies have shown that the blue sheep is the main prey of the snow leopard in many parts of the leopard's range (Chundawat, 1992; Oli et al., 1993; Schaller et al., 1987, 1988).

Predation on domestic livestock by snow leopards has brought the snow leopard into a conflict with local pastoralists, threatening the species' survival (Fox et al., 1991; Jackson, 1991; Oli et al., 1994; Schaller et al., 1987, in press). Improvements in husbandry practices have been suggested to reduce loss from predation and alleviate conflict, but, if livestock were an important food source, reduction or exclusion of livestock from the leopard's diet could have a detrimental effect on the leopard population (Fox et al., 1991; Oli et al., 1993, 1994). An analysis of the predator–prey relationship between snow leopards and blue sheep should provide insight into this dilemma. The present study examined the number and density of snow leopards and blue sheep in a Himalayan ecosystem in Nepal, aspects of interaction between these two species, and the importance of domestic livestock in the diet of snow leopards.

Materials and Methods

Study area.—This study was conducted in the upper Marsyangdi Valley of Manang District, within the Annapurna Conservation Area, Nepal (28°30'N–28°50'N, 83°50'E–84°55'E). The study area was in the rainshadow of the Annapurna Mountain Range, and the climate was dry and cold. Elevation ranged from 3,600 to 6,000 m.

The vegetation of the study area consisted of grassland interspersed with scrub. The snow leopard and red fox (*Vulpes vulpes*) were the only large mammalian predators, and blue sheep were the only wild ungulates found in the study area. Small mammals in the study area included the Himalayan marmot (*Marmota himalayana*), Royle's pika (*Ochotona roylei*), least weasel (*Mustela nivalis*), stone marten (*Martes foina*), and the Sikkim vole (*Alticola sikkimensis*), all of which are potential prey of snow leopards. The snow leopard was the only predator of adult blue sheep in Manang, with the red fox as the only potential mammalian competitor for young blue sheep. A detailed description of the study area was given by Oli (1991).

Density of snow leopards.—Three snow leopards (two females and one male) were captured, two by leg-snare traps and one by a "khor" (cage trap constructed using rocks and wooden planks). The captured leopards were weighed, measured, ear-tattooed, and fitted with motion-sensitive radiotransmitters mounted in collars (ca. 500 g, Telonics Inc., Mesa, AZ). I located the radiocollared snow leopards on foot and determined their positions using the standard methods of triangulation.

Footprints of each radiocollared snow leopard were reproduced by rubbing black ink on the pads of their feet and pressing them against a sheet of clean white paper. I searched the study area for fresh tracks from snow leopards and traced tracks of hind feet on a transparent plastic sheet following the methods of Panwar (1979). Date and location of tracks were noted, and an identification number was assigned to each.

Maximum length and width of each track and reproduced footprint were measured. Tracks of radiocollared snow leopards were distinguished from those of noncollared individuals. Once identified, tracks of radiocollared leopards did not require further analysis because the number of leopards responsible for these tracks was known. Therefore, I sorted tracks according to whether or not they could have been left by radiocollared snow leopards. Some fresh tracks were from the area that was known not to have been recently visited by the radiocollared leopards during at least the previous 2 days. Others were clearly different in size or shape from those of the three known leopards when tracings of tracks were overlaid or their measurements were compared. These two groups of tracks were considered left by noncollared leopards. A catalog was compiled of measurements of tracks from unidentified snow leopards.

Measurements of tracks from the same snow leopard can vary depending on the nature of the substrate; therefore, those whose dimensions were within certain margins were considered left by the same leopard. The number of leopards responsible for all unidentified tracks was estimated by using 1.0- and 1.5-cm error margins. Estimates of the minimum number of noncollared snow leopards corresponded to tracks whose measurements differed by ≥1.5 cm, and the maximum number included all tracks whose measurements differed by ≥1 cm. These estimates were then added to the number of radiocollared leopards to obtain the minimum and maximum numbers of snow leopards in the study area, respectively. Tracks of young were excluded from the analysis.

Relative biomass and number of prey consumed by snow leopards.—I assumed that the number of scats from snow leopards was related to the mass of prey consumed (Floyd et al., 1978) and that biomass of prey consumed by a snow leopard to produce one scat was similar to that of the cougar (*Felis concolor*—Ackerman et al., 1984), a felid similar in size to the snow leopard. The linear relationship = 1.98 + 0.035B (where B = body mass of prey in kg—Ackerman et al., 1984) was used to estimate the prey biomass consumed per scat produced. The resulting estimate was then used as a correction factor to convert frequency of occurrence (i.e., number or percentage of scats in which a prey species was present) to relative biomass, and relative number of prey consumed. Mass of species of prey <2 kg was not corrected for digestibility because the smaller the prey, the less likely it is to comprise a total scat (Ackerman et al., 1984).

The average mass of females (40 kg—Schafer, 1937; Schaller, 1977) was considered representative of the mass of blue sheep. Masses of several species of prey were derived from the literature (Himalayan marmot and Royle's pika—Feng et al., 1986; least weasel and stone marten—Kruska, 1990; Royle's vole—Niethammer, 1990; red fox—Naaktgeboren, 1990). An adult, male domestic yak may weigh ≤800 kg (Buchholtz and Sambraus, 1990), but there was no report of adult males being killed by snow leopards. Therefore, average mass of yak (subadult and juveniles) was estimated at 150 kg. Similarly, average masses of horses and oxen were estimated at 100 kg, and those of goats and sheep at 15 kg.

Data from Oli et al. (1993) on diet of snow leopards were used to calculate relative biomass and relative number of prey consumed following the methods of Ackerman et al. (1984). Correction factor was calculated as previously described. Relative biomass consumed was calculated by dividing the product of frequency of occurrence of each prey type and the correction factor by the sum of the same for all prey types. Relative number of prey consumed was calculated by dividing the product of relative biomass consumed and the estimated average body weight of each prey type by the sum of the same for all prey types (Ackerman et al., 1984). Both relative biomass and number consumed were then converted to percentages. The food requirement of the snow leopard was derived from the literature (Jackson and Ahlborn, 1984; Wemmer and Sunquist, 1988).

Density and biomass of blue sheep.—Blue sheep were censused in spring (13 April–9 May 1990), autumn (10–25 September 1990), and winter (2 January–28 February 1991), but only data for spring were used in analyses because only the census in spring systematically covered the entire study area.

I scanned mountain slopes with 10 by 50× binoculars. Once located, blue sheep were observed with a variable-magnification (15–60×) spotting-scope mounted on a tripod. Because all slopes could not be censused during a single day, some slopes were surveyed on >1 day, which increased the possibility of over-counting sheep. Therefore, two estimates of density were employed. The maximum number of sheep was taken as the sum of sheep counted during all census trips (both single- and multiple-day counts). The minimum number was determined by subtracting the number of sheep suspected to be counted more than once from the maximum number. When multiple counts were necessary for a slope, the highest count from 1 day's census was the minimum. To minimize repeated counts, I noted distinguishing features (e.g., broken horn tips) of one or more individuals in a herd whenever possible; however, it was often difficult to identify the sheep individually. Age and sex composition also could sometimes be used to distinguish between herds observed in two adjacent areas of the same slope within 1–2 h of each other. Error of duplicate counts was minimized, but the possibility of missing some sheep or counting them more than once could not be eliminated.

When possible, I classified the sheep as trophy-age male (≥7 years old), medium-age male (4–6 years old), young male (2–3 years old), yearling male or female (1–2 years old), adult female (≥2 years old), and young-of-the-year (<1 year old—Wegge, 1979). Data on herd composition were used only when observations allowed all members of a herd to be classified. Otherwise, only the total number of individuals was noted.

Number, age, and sex composition in spring were used to estimate biomass of blue sheep. The corrected number of blue sheep belonging to each sex and age class was obtained by multiplying average of estimated maximum and minimum number in the study area by the percentage composition of sheep in that category. The corrected number of sheep in each sex and age class was then multiplied by the average mass of the sheep in that class to obtain biomass of sheep belonging to that category. The total biomass of blue sheep was calculated by summing biomass of sheep belonging to all sex and age classes.

Results and Discussion

Densities of snow leopard and blue sheep.—In addition to the three radiocollared snow leopards (two females and one male), two to four other adult leopards used the study area. Thus, the estimated population size was five to seven adult leopards, a density of 4.8 to 6.7 leopards/100 km^2. Tracks of a noncollared leopard always were associated with tracks of one or two young, suggesting that three of the adults were females.

Density of snow leopards recorded in this study is similar to the density of five to 10 adult leopards/100 km^2 reported by Jackson and Ahlborn (1989), using radiotracking and leopard spoors from Langu Gorge, Nepal. Other estimates of density of snow leopards are available (0.8 leopards/100 km^2—Annenkov, 1990; 0.7/100 km^2—Mallon, 1984; 1.5–6.6/100 km^2—M. N. Sherpa and M. K. Oli, in litt.; 1.2/100 km^2—Schaller, 1977; 0.4–0.5/100 km^2—Schaller et al., 1987; 1/100 km^2—Schaller et al., 1988); however, none of these surveys used standard methods for estimating number of leopards, and these densities may not be comparable. Nonetheless, Manang seems to support one of the densest populations of snow leopards reported so far.

It was not possible to individually identify tracks of two snow leopards with certainty, although a similar technique was reported to be rigorous for individual identification of mountain lions (*Felis concolor*—Smallwood and Fitzhugh, 1993). However, radiocollaring of a significant proportion of the population of snow leopards allowed me to monitor movements of the collared leopards, and I could reliably assign any new track either to the collared leopards or to a noncollared leopard. This certainty, as well as the margin allowed for variation in measurements of tracks due to substrate type or conditions, should have minimized such error.

The estimated number of blue sheep ranged from 697 to 1,071. The density of blue sheep ranged from 6.6 to 10.2 sheep/km^2, and total estimated biomass was 31,868 or 304 kg/km^2 (Table 1). The method used to estimate the number of blue sheep excluded repeated counts, but did not take into account sheep that were missed during the census. Therefore, the actual number of sheep is likely to be closer to the maximum estimate.

The density estimates for blue sheep were similar to those of 10.0 sheep/km^2 reported by P. Wegge and M. K. Oli (in litt.) for a part of the study area, suggesting that the population has remained relatively stable over the past 3 years. Densities recorded in Manang are considerably higher than those reported for elsewhere in the species' range (Jackson and Ahlborn, 1989; Schaller, 1977; Schaller et al., 1988; P. Wegge, in litt.; Wilson, 1981), but similar to those reported for Nar-Phu Valley, northeast of the study area (M. N. Sherpa and M. K. Oli, in litt.).

TABLE 1.—*Average mass, sex and age composition (spring 1990), and estimated biomass of blue sheep in Manang, Nepal.*

Sex/age class	Average mass (kg)	Percent composition of sheep	Observed number	Corrected number[b]	Estimated biomass[c]
Trophy male	57[a]	14.0	63	125	7,125
Medium male	51[a]	9.4	42	83	4,233
Young male	40	10.0	45	89	3,560
Adult female	40[a]	35.7	160	316	12,640
Yearling	25[a]	12.0	54	106	2,650
Young-of-the-year	10	18.8	84	166	1,660

[a] Calculated from data from P. Wegge (in litt.).
[b] ([Maximum estimated number + minimum estimated number]/2) × percent composition.
[c] Average mass × corrected number.

Harvest rate and predator : prey ratio.—Jackson and Ahlborn (1984) estimated the food requirements of adult snow leopards to be 1.3–2.0 kg/day. They calculated that 600–900 kg of meat is required to support an adult snow leopard for 1 year, a figure that takes into account the increased energy expenditure of a wild snow leopard (ca. 25%) and the inedible portion of its prey (ca. 35%).

Based on this food requirement, five to seven adult snow leopards in the study area would need 3,000–4,500 and 4,200–6,300 kg of prey/year, respectively. The estimated annual harvest rate of the ungulate biomass by snow leopards, therefore, would be 9–14% and 13–20% for the minimum and maximum number of snow leopards, respectively. Assuming that an adult snow leopard requires 20–30 sheep annually (Jackson and Ahlborn, 1984), the estimated five to seven snow leopards would need to

TABLE 2.—*Frequency of occurrence (percentage in parentheses), relative biomass, and relative number of prey consumed by snow leopards in Manang, Nepal.*

Prey item	Frequency of occurrence[a]	Estimated mass[b] (kg)	Correction factor[c]	Relative biomass consumed[d]	Relative number consumed[d]
Wild					
Blue sheep	110 (51.64)	40.00	3.38	49.74	9.20
Marmot	44 (20.66)	5.30	2.17	12.75	17.80
Royle's pika	34 (15.96)	0.20	0.20	0.91	33.65
Royle's vole	16 (7.51)	0.10	0.10	0.21	15.84
Least weasel	10 (4.69)	0.10	0.10	0.14	9.89
Marten	8 (3.76)	1.30	1.30	1.39	7.93
Bird	3 (1.41)	1.00	1.00	0.40	2.97
Red fox	2 (0.94)	7.00	2.23	0.60	0.63
Domestic					
Yak	29 (13.62)	150.00	7.23	28.06	1.38
Horse	6 (2.82)	100.00	5.48	4.40	0.33
Sheep and goat	2 (0.94)	15.00	2.51	0.67	0.33
Ox	1 (0.47)	100.00	5.48	0.73	0.05

[a] Data from Oli et al. (1993).
[b] Estimated live weight (kg).
[c] 1.98 + 0.035B (Ackerman et al., 1984).
[d] Defined in text.

kill 100–210 blue sheep annually, which is 11–24% of the average (of maximum and minimum) estimated number of blue sheep in Manang. Without the biomass contribution of small mammals and livestock, the estimated 31,868 kg of ungulate biomass (Table 1) gives a predator:prey ratio of 1:114–1:159 on a weight basis, assuming that the number of snow leopards is five to seven and the average live weight of an adult snow leopard is 40 kg.

My estimated predator : prey ratio in Manang is within the range estimated by Schaller (1972) for African savanna ecosystems (1:94–1:301) and also is comparable to the estimate of Emmons (1987) for the large felids of Cocha Cashu, Peru. This ratio is slightly higher (i.e., less prey biomass per kg of predator) than that for tigers (*Panthera tigris*) in the Royal Chitwan National Park, Nepal (Sunquist, 1981). Similarly, the estimated harvest rate of 9–20% by biomass and 11–24% by number is slightly higher than the harvest rate reported for tigers in Chitwan (Sunquist, 1981), Serengeti predators (Schaller, 1972), or large felids of Cocha Cashu, Peru (Emmons, 1987). However, given the absence of competing predators, importance of other prey types, and a good recruitment rate for blue sheep (Oli, 1991), predator:prey ratio and harvest rate may be considered sustainable.

Relative importance of prey and livestock predation.—Snow leopards in Manang ate seven wild and five domestic species of mammals, as well as one unidentified mammal and birds (Oli et al., 1993). I infer from the estimated relative biomass consumed that blue sheep contributed the bulk of biomass consumed by snow leopards, but marmots also contributed significantly (Table 2) except in winter, when marmots hibernated and were, thus, not available (Oli et al., 1993). Wild and domestic prey contributed 66 and 34% of the biomass of the diet of snow leopards, respectively.

The estimated contribution of domestic prey, particularly yaks, to biomass in the snow leopard's diet probably is over-represented. Because of small holdings, day-to-day husbandry, and the importance of livestock to the local community, herdsmen recovered the carcasses of missing animals, often within hours. Even when a leopard kills a yak of 300 kg, it usually could consume only a small portion before herdsmen located the kill. Therefore, the actual contribution of domestic yaks to the biomass of the diet of the snow leopard may be much smaller than suggested. The over-representation of biomass of yaks consumed by the leopards is apparently caused by the large body weight of the yaks; the estimated relative number of prey consumed (Table 2) should better represent the contribution of yaks to the diet of snow leopards. This adjustment would further increase the importance of blue sheep to snow leopards as a staple source of food.

Marmots are reported to be as important as, or more important than, blue sheep in the summer diet of snow leopards in the Taxkorgan Reserve, China (Schaller et al., 1987), and they also contributed substantially to the leopard's diet in Manang (Oli et al., 1993; Table 2). Considering the significance of small mammals, particularly marmots, to the snow leopard's diet, the lack of competing predators, and the fact that some of the leopards may have had only a part of their home range within the study area, the population of blue sheep at Manang apparently is adequate to support the present population of snow leopards of five to seven, and possibly more, adult leopards.

Predation on livestock by snow leopards is widespread and has brought the leopards into direct conflict with local pastoralists (Fox et al., 1988, 1991; Mallon, 1984; Oli et al., 1994; Schaller et al., 1987, 1988, in press; M. N. Sherpa and M. K. Oli, in litt.). The leopards are considered vermin and are persecuted by local herders. Retaliatory killing of the leopards and a negative public attitude towards them are the greatest threats to the population in Manang (Oli, in press; Oli et al., 1994).

The population of blue sheep, the snow leopard's staple prey in Manang, is relatively stable (Oli, 1991; present study), and the present study has shown that the population of blue sheep is adequate to support the estimated number of leopards. Snow leopards in Manang kill domestic livestock because livestock are abundant and easily killed, not because they are an important food source. It, therefore, may be concluded that reduction or exclusion of livestock from the diet of snow leopards would be unlikely to affect the population of snow leopards in Manang and elsewhere where wild ungulate prey will support them.

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