

Is competition with livestock detrimental for native wild ungulates? A case study of chital (*Axis axis*) in Gir Forest, India

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Abstract: Livestock graze Indian forests to varying extents but their impact on wild native ungulates is rarely understood. Negative impacts of sympatric livestock on chital (*Axis axis*) demography and food availability were assessed and compared in the Gir Forest, India, at different spatio-temporal scales. No difference in average group size (mean \pm SE) (7.11 ± 0.8 indiv.) (short-term response), fawn to doe ratio (0.43 ± 0.03) (short- to medium-term response), chital density (44.8 ± 7.1 indiv. km^{-2}) (medium- to long-term response), and rate of population increase ($r = 0.07 \pm 0.014$) (long-term response) was found between areas sympatric and livestock-free at the larger spatial scale of Gir Forest. Instead, chital density was correlated with rainfall ($r = 0.92$). After controlling for confounding factors of rainfall, vegetation community, terrain and lion density, chital density was 62% higher for livestock-free compared with sympatric areas but other demographic parameters showed no statistical difference. Peak above-ground biomass was greater in livestock-free (3255 ± 209 kg ha^{-1}) compared to sympatric areas (1438 ± 152 kg ha^{-1}), but chital food was more abundant in moderately grazed areas compared to livestock-free areas. Overall, long-term livestock grazing has depressive effects on chital but in the short term habitat productivity and suitability overrides the depressive effects of sympatric livestock.

Key Words: above-ground biomass production, body condition, deer, density, distance sampling, group size, realized growth rate

INTRODUCTION

Livestock are sympatric with wild ungulates in most forest areas of India (Kothari *et al.* 1989) where they potentially compete for important resources. The interactions with livestock could be detrimental (Madhusudan 2004, Mishra *et al.* 2004), facilitative (Rannestad *et al.* 2006) or have no effect on wild ungulates (Berwick 1974, Khan 1995). Competition between domestic and wild ungulates has long been the focus of scientific investigation (Pickford & Reid 1948), yet recent reviews show a remarkable scarcity of information on the subject (Prins 2000, Putman 1996). One of the important reasons for the indecisive outcomes of such studies is due to the difficulty in demonstrating livestock as the only factor responsible for poor population performance of wild herbivores through depletion of shared resources. Ecological heterogeneity resulting from environmental stochasticity has a fundamental effect on herbivore

population dynamics especially in semi-arid landscapes (Owen-Smith 2002) and could potentially mask the competitive effects of livestock. Due to difficulties in designing and implementing perturbation experiments (Prins & Olf 1998, Schoener 1983, Young *et al.* 2005), rarely are data collected on a spatio-temporal scale to understand and control for the effects of the environmental stochasticity in studies involving competition. An alternative approach is to assess the population performance of a species of interest over ecologically comparable sites differing in terms of sympatric livestock. Such opportunities abound in protected areas of India where human settlements along with their livestock have been relocated in recent times (Kothari *et al.* 1989).

We use chital (*Axis axis*, Exelbern), an important forest ungulate in the subcontinent, as a model to study the effects of livestock on native ungulates in the Gir Forest of Gujarat, India. If sympatric livestock had a detrimental effect on chital then the following predictions that cover various time-scale responses should hold. In areas of sympatry with livestock we would expect chital

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to have: (1) Smaller group sizes – a population parameter that balances anti-predatory strategy (Beauchamp 2003, Bednekoff & Lima 2004) with immediate food-resource availability (Jarman 1974). (2) Poorer body condition – this is a short-term (seasonal) response to poor forage quality and quantity (Brochu *et al.* 1988, Clutton-Brock *et al.* 1997, Sinclair & Norton-Griffiths 1982). (3) Lower fawn to doe ratio – an annual response to reduced forage quantity and quality (Robbins 1993). (4) Lower density – chital density is a medium- to long-term response to range conditions incorporating processes of fecundity, mortality, immigration and emigration (Sinclair *et al.* 2006). (5) Poor population growth – the realized rate of increase r of a population is a long-term collective response of all individuals in a population to environmental influences (Caughley 1977). (6) Depleted food resources – above-ground herbaceous biomass, especially chital food resources, should be depleted in sympatric areas compared with livestock-free areas (Madhusudan 2004, Mishra *et al.* 2004). (7) Also, we would expect a negative correlation between chital and livestock abundance. Livestock density has reduced over the past 30 y following relocations of human settlements from the Gir Forest (Singh & Kamboj 1996). In this paper we test these hypotheses with field data collected between 2004 and 2006.

STUDY AREA

The Gir Forest is home to the last surviving population of the Asiatic lion (*Panthera leo persica*). It spreads over 1883 km² including 259 km² as a National Park which was created in 1978 by relocating all human settlements and livestock from within it (Singh & Kamboj 1996). The remaining part of the Gir Forest is a wildlife sanctuary, which is a multiple-use area with resident human and livestock populations but with wildlife especially lion conservation as the primary objective.

The Gir Forest experiences three distinct seasons, cold season (November–February), hot season (March–June) and rainy season (July–October). Average minimum and maximum temperature was 9 °C and 42 °C respectively (Singh & Kamboj 1996). The average annual precipitation for the past 20 y showed a gradient decreasing eastward. The precipitation in the western part of Gir sanctuary was 89 ± 2 cm y⁻¹; Central, National Park and adjacent areas was 80 ± 5 cm y⁻¹ and the eastern part of Gir sanctuary was 56 ± 2 cm y⁻¹ (Singh & Kamboj 1996). The rainfall gradient is well reflected in the vegetation communities (Qureshi & Shah 2004). The western part of the sanctuary supports relatively more diverse, productive and riparian plant communities dominated by teak (*Tectona grandis* L.) compared with the National Park and eastern part of the Gir sanctuary where

Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr. and thorn forest dominate (Qureshi & Shah 2004).

The Gir Forest is largely composed of dry deciduous vegetation, which is classified as 5A/C1b biogeographic subtype (Champion & Seth 1968). Wild ungulate species of Gir are chital, sambar (*Cervus unicolor*, Kerr), nilgai (*Boselaphus tragocamelus*, Pallas), four-horned antelope (*Tetracerus quadricornis*, Blainville), chinkara (*Gazella bennettii*, Sykes) and wild pig (*Sus scrofa*, Linnaeus). In Gir, chital constitute 91% in terms of density and 78% of the wild ungulate community biomass (Dave 2008). Chital contributes 44–50% to the lion's diet (Jhala *et al.* 2006). The other major food source for lions in Gir was livestock, contributing between 26–70% to the lion's diet (Chellam 1993, Jhala *et al.* 2006, Joslin 1973).

The study was conducted at two spatial scales; at the landscape scale we sampled the entire Gir Forest. At a local scale, we sampled two similar sites in the eastern part of the Gir Forest constituting two evacuated settlement sites (livestock free) and the grazing areas of five settlements (area sympatric with livestock). By estimating and comparing chital demographic parameters from these two sites we controlled for the confounding factors of topography, pastoral settlement site selection (as they tend to be located near perennial water), lion density and plant productivity resulting from the rainfall gradient (Allcock & Hik 2003, Coe *et al.* 1976, Harrington *et al.* 1995).

METHODS

Chital demographic characteristics at the landscape scale

We used distance sampling (Buckland *et al.* 1993, Burnham *et al.* 1980) on systematic line transects ($n = 44$ spatial and 82 temporal replicates; with 231 km of effort) spaced throughout the Gir Forest for estimating chital densities and group sizes between December 2006 and January 2006. The Gir Forest is divided into 37 forest blocks for administrative purposes. We systematically distributed line transects throughout the entire Gir Forest by demarcating one or two line transects in each forest block (Figure 1). Each 2–3-km transect was sampled two or three times during early morning hours (6h30–8h30) when ungulate activity was highest. Chital density was estimated using the program DISTANCE 5.0 (Thomas *et al.* 2010). Mean (MGS) and typical group sizes (TGS) of chital (Jarman 1974) were computed. Data on TGS were bootstrapped (Krebs 1989) 100 times to generate standard errors and we compared MGS and TGS between livestock-free and sympatric areas by means of a t -test (Zar 2005).

The nutritional pinch period in Gir is just prior to the onset of the rainy season. During this period (last week

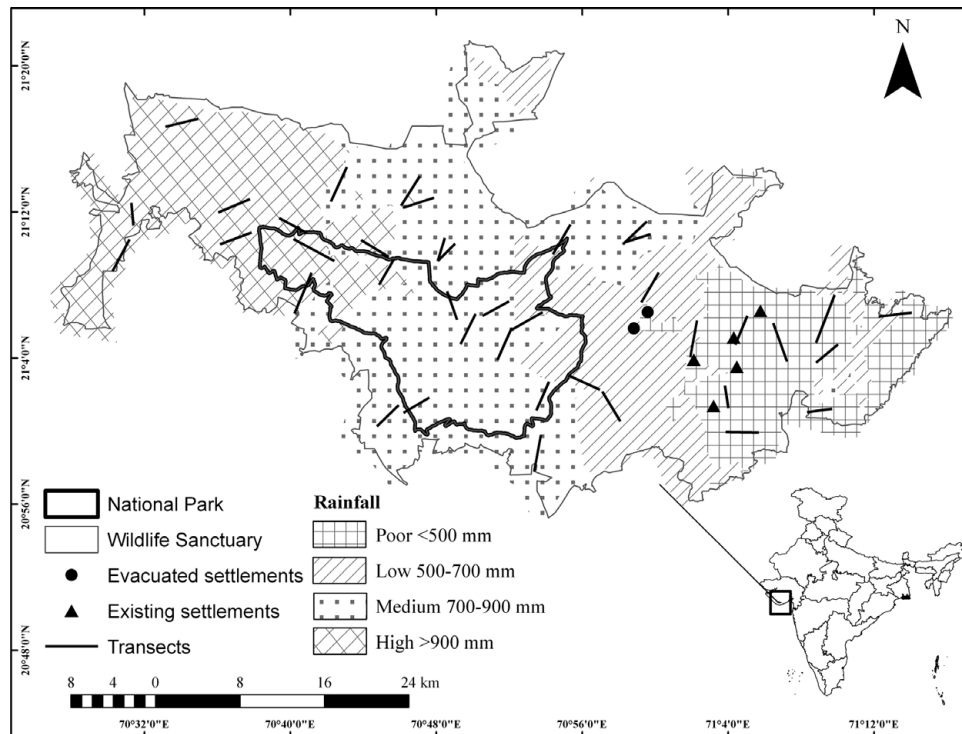


Figure 1. Location of foot transects and intensive study area around the evacuated and existing pastoral settlements on a precipitation gradient map of the Gir Forest. Map inset shows the location of Gir within the State of Gujarat, India.

of May and first week of June 2006) we systematically sampled throughout the Gir Forest and scored a minimum of three chital in each group encountered ($n = 730$ chital) for body condition. The index consisted of scoring different regions of the chital's body, i.e. the rump, thigh, pelvic girdle, pectoral girdle and ribs (Riney 1960). We used multi-response permutation procedure (MRPP, Berry & Mielke 1983) in BLOSSOM software (Cade & Richards 2005) to simultaneously compare the five body-condition scores of chital obtained from livestock-free areas and areas sympatric with livestock. We computed the fawn to doe ratios (Caughley 1977, Skalski *et al.* 2005) of chital considering sampling with replacement scheme and compared them between livestock-free and sympatric areas using Fisher's Exact test (Zar 2005). Chital density, mean group size and typical group size were compared between areas that were sympatric and livestock-free by independent-sample *t*-tests (Zar 2005).

Growth rate and abundance of chital in relation to livestock abundance at the landscape scale

Several researchers have reported ungulate densities of Gir (Berwick 1974, Goyal *et al.* 2004, Joslin 1973, Khan *et al.* 1996). Simultaneously, a good record has been kept by the protected-area management on the number of human families and livestock resettled in the past 30 y (Singh & Kamboj 1996). We used this

information to compute the realized rate of increase for chital by regressing natural logarithm-transformed density estimates against time (Caughley 1977) for the entire Gir Forest and separately for the livestock-free (National Park) and sympatric (Sanctuary) areas of the Gir Forest. We computed the Pearson's correlation coefficient (Zar 2005) between chital abundance and livestock (cattle and buffalo) abundance over a temporal scale of 30 y ($n = 5$ population estimates).

Chital demography at the local scale

At these two ecologically similar sites in the eastern part of Gir Forest, we collected data on chital group sizes, fawn to doe ratio ($n = 45$ and 52 for livestock-free and sympatric area, respectively), body condition ($n = 124$ and 160 for livestock-free and sympatric area, respectively), and density ($n = 32$ and 36 for livestock-free and sympatric area, respectively) by line transects ($n = 68$ spatial replicates, Buckland *et al.* 1993). The data were analysed to compare chital demographic parameters between livestock-free and sympatric areas of the Gir Forest.

Livestock density

The livestock in the Gir Forest are herded into thorn corrals at each settlement every night as an anti-predatory

strategy against lions and leopards. Livestock numbers were estimated for each settlement in the intensive study area by total counts when they were confined in the corrals.

Pastoralists take their stock out into the forest every morning to graze and return to the settlement before sundown. We accompanied livestock on their grazing circuits ($n = 50$) with a hand-held GPS unit (Garmin™ 72) to determine the route and distance they travel. We buffered each settlement with the average linear distance moved by the livestock to determine the area of impact by livestock (Riginos & Hoffman 2003). Density of livestock was computed as the total number divided by their foraging area.

Herbaceous biomass at a local scale

We set up 10×10 -m ungulate-proof exclosures with chain-link fencing close to settlement sites (high-intensity livestock grazing $n = 3$ within 500 m of settlement), far from settlement sites (low-intensity livestock grazing $n = 3$, 500–1500 m from settlements), and in livestock-free areas ($n = 4$). We sampled peak above-ground biomass (AGB) just prior to the next growing season (May 2006) by clipping five paired quadrats of 1 m^2 inside and outside each exclosure (Beebe *et al.* 2002). Clipped herbaceous biomass was sorted to species and was classified as palatable and unpalatable based on chital and livestock food habits (Dave 2008) and oven dried at 60°C to constant dry weight. We analysed the herbaceous biomass data with two-way ANOVA (Zar 2005) with main effects as: (1) Livestock grazing intensity category having three treatments (close to settlement, far from settlements, and livestock-free areas) and (2) Exclosures having two treatments i.e. inside (ungrazed) and outside (grazed).

RESULTS

Effect of sympatric livestock on chital demography: comparisons at the landscape scale

Mean group size (MGS \pm SE) of chital ($n = 296$ groups) was 7.11 ± 0.8 while typical group size (TGS \pm SE) was 18.5 ± 1.7 for the entire Gir Forest. Mean group sizes were similar between livestock-free (6.73 ± 0.96) and sympatric areas (7.30 ± 1.0 ; t -test: $t = 0.99$, $P = 0.34$). Typical group size of chital in livestock-free areas was smaller (10.0 ± 2.0) compared with typical groups observed in areas sympatric with livestock (21.4 ± 3.78 , t -test, $t = 18.9$, $P < 0.001$).

Body condition of chital in livestock-free areas was significantly better (MRPP, test statistic = -14.0 , $P < 0.001$). Chital density \hat{D} (\pm SE) in the Gir Forest was estimated at 44.8 ± 7.1 individuals km^{-2} . Chital density

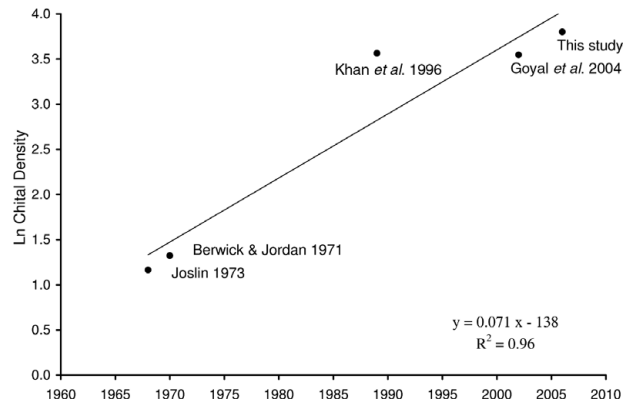


Figure 2. The natural logarithm of chital density plotted against years (1969 and 2006) for computing the realized rate of increase for chital (Axis axis) in the Gir Forest.

in areas sympatric with livestock was 47.0 ± 9.3 indiv. km^{-2} and was similar to livestock-free areas (33.2 ± 6.6 chital km^{-2} , t -test, $t = 1.39$, $P = 0.17$). Chital densities were correlated with average rainfall with marginal statistical significance due to small sample size of four rainfall zones (Pearson's correlation coefficient, $r = 0.923$, $P = 0.077$). The fawn to doe ratio for chital in Gir was 0.43 ± 0.03 . The fawn to doe ratio did not differ between areas sympatric with livestock (0.42 ± 0.043) and livestock-free areas (0.44 ± 0.036 , Fisher's exact test, $P = 0.554$).

Growth rate and abundance of chital in relation to livestock abundance at landscape scale

The realized rate of increase ($r \pm$ SE) for chital was 0.071 ± 0.014 ($P \leq 0.001$, $R^2 = 0.9$) in the Gir Forest, with initial population density of 3.2 indiv. km^{-2} (1968–1971, Joslin 1973) that increased to 44.8 indiv. km^{-2} in 2006 (present study) (Figure 2). The realized rate of increase for chital population did not differ between areas sympatric with livestock (0.069 ± 0.008 , $P = 0.003$, $R^2 = 0.97$) and livestock-free areas (0.055 ± 0.008 , $P = 0.02$, $R^2 = 0.95$; t -test, $t = 1.33$, $P = 0.22$). On a temporal scale chital densities were found to increase as livestock densities decreased (Pearson's correlation coefficient $r = -0.93$, $P = 0.022$).

Livestock density, composition and grazing impact zone at local scale

Official livestock population for the Gir Forest was reported to be 11 000 (Pathak *et al.* 2002). Our seasonal total counts of eight pastoral settlements yielded an estimate of 533 ± 86.9 cattle and 1747 ± 234 buffalo. On average livestock travelled a total distance (mean \pm SE) of $5.8 \pm$

Table 1. Comparison of density (mean \pm SE), mean group size (MGS) and typical group size (TGS) of chital (*Axis axis*) in two ecologically similar sites differing in presence of sympatric livestock in the eastern part of Gir Sanctuary.

Chital (<i>Axis axis</i>)	Livestock present	Livestock absent	Statistical test	Test statistic	P value
Density (km^{-2})	55.8 \pm 9.6	89.5 \pm 12.9	<i>t</i> test	2.61	0.037
Fawn to doe ratio	0.44 \pm 0.036	0.49 \pm 0.058	Fisher's exact test		0.54
Mean group size	5.92 \pm 0.87	5.95 \pm 0.82	<i>t</i> test	0.03	0.98
Typical group size	11.9 \pm 0.36	10.6 \pm 0.28	<i>t</i> test	2.84	0.006

0.22 km during their daily grazing circuit in the cold season and were observed to have an average (\pm SE) daily linear displacement of 1.9 ± 0.12 km from settlements. Some impact zones of two or more pastoral sites overlapped i.e. these areas were used by livestock from more than one settlements. Therefore, a common buffer of 1.9 km was created on the cluster of settlement locations to generate a polygon ($9.8 \pm 1.1 \text{ km}^2$) to compute livestock density and their overall impact zone. The average livestock density for our study area was $31.4 \text{ livestock km}^{-2}$ for the cold season of 2005–2006.

Response of chital demography and herbaceous biomass to livestock at the local scale

When we controlled for the effect of rainfall and pastoral site location, typical group size and density were significantly higher in the livestock-free area compared with the area sympatric with livestock (Table 1). However, fawn to doe ratio, mean group size and body condition did not differ between areas sympatric and free from livestock (Table 1).

Peak above-ground biomass of herbaceous vegetation increased as livestock grazing intensity decreased ($1438 \pm 152 \text{ kg ha}^{-1}$ in areas sympatric with livestock to $3260 \pm 209 \text{ kg ha}^{-1}$ in areas devoid of livestock) (Figure 3). However, chital food production in moderately grazed areas ($877 \pm 92 \text{ kg ha}^{-1}$) was more than in areas devoid of livestock ($539 \pm 167 \text{ kg ha}^{-1}$) after short-term (1 y) grazing exclusion (Figure 3).

DISCUSSION

Effect of livestock on chital at the landscape scale

Most of our predictions in support of the hypothesis that livestock detrimentally affect chital did not hold at the landscape scale. We believe that two factors were primarily responsible for non-conformity to our predictions at the landscape scale. These factors were: (1) response of chital to a precipitation gradient, as chital density was found to be correlated with rainfall and increased from east to west by a factor of 0.6; and (2) the livestock-free habitat comprising the National Park is more hilly and not the prime habitat for chital (Khan 1995), good chital habitat is found in the eastern and

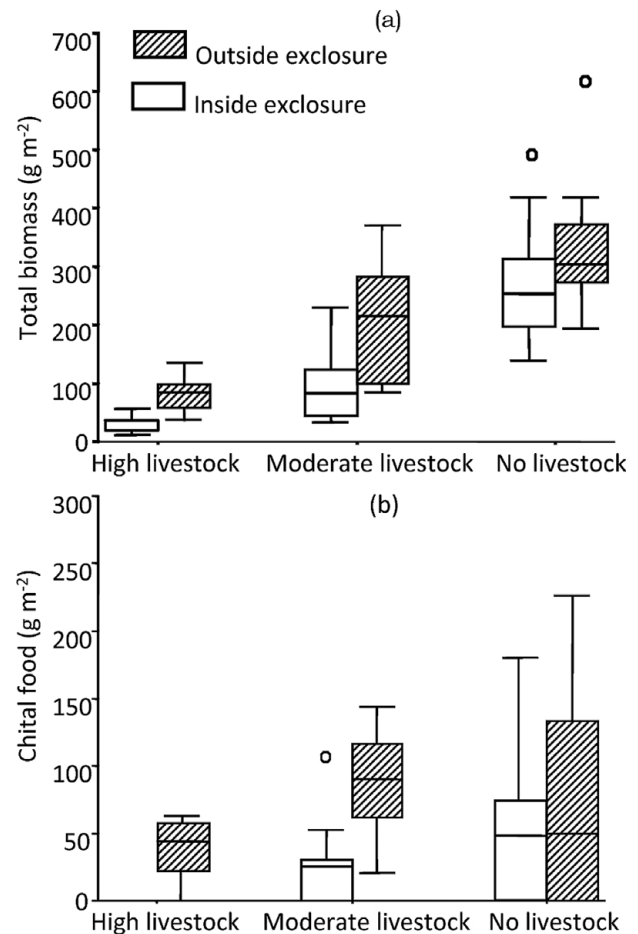


Figure 3. Above-ground herbaceous biomass (AGB) sampled during the month of May 2005 and 2006 at different livestock grazing intensity in the Gir Forest. The box-and-whisker plots represent the interquartile range of total herbaceous above-ground biomass (a) and herbaceous chital food biomass (b); boxes are limited by the 25th and 75th percentile, the midlines in boxes are the median values, the whiskers are mild outliers, while the severe outlier values are shown as circles.

western parts of the Sanctuary which were also used by livestock.

Many studies have explained the regulatory role of food resources in maintaining equilibrium density of ungulates (Dublin *et al.* 1990, Sinclair 1977, Skogland 1980). Productivity of semi-arid regions is primarily dictated by annual rainfall (Allcock & Hik 2003, Harrington *et al.* 1995). Ungulate populations in such regions are mainly regulated through food resource availability dictated by

rainfall patterns (Illius & O'Connor 2000, Mandujano & Naranjo 2010). Chital in the semi-arid landscape of Gir likely conform to this pattern. Due to these overriding effects of habitat productivity and habitat suitability on chital, negative competitive effects of livestock on chital were likely masked (Bugmann & Weisberg 2003).

Effect of livestock on chital at the local scale

When we controlled for this masking effect of confounding factors by selecting two sites with similar rainfall and pastoral site selection factors, differing only in the presence of sympatric livestock, evidence was found in support of our competition hypothesis (Table 1). Chital density was significantly higher in livestock-free areas compared with areas with livestock. Short- to medium-term responses of average group size, body condition, and fawn to doe ratio were similar between the two sites (Table 1). The annual rainfall during 2005–2006 was exceptionally good, and we believe that these short-term response parameters were influenced by this higher food availability which reduced average competitive interactions between chital and livestock. The long-term response of depressed chital density had a substantial size effect with chital density being 60% higher in livestock free-area.

Long-term effect of livestock removal on chital at the landscape scale

Chital population of the Gir Forest was found to increase at the realized rate of 0.07 ± 0.014 . Most ungulate populations have a potential r_{max} between 0.16 and 0.22 (Owen-Smith 2006). The realized rate of increase (r) for chital for the past 34 y was much lower than the potential r_{max} . This could be either due to intra- and inter-specific competition for limited resources or high rate of predation. Gir has a high density of large carnivores, with about 18 lions and 15 leopards per 100 km² (Singh & Kamboj 1996). We failed to detect differences in the realized growth rate of chital between livestock-free areas and areas sympatric with livestock. When the central part of the Gir Forest was gazetted as a National Park, all the resident livestock herders from the National Park area were relocated outside or on the periphery of the Gir Forest. However, during the past 34 y livestock densities have also been reduced in the sanctuary part of the Gir Forest by voluntarily relocating pastoral families and their livestock outside of Gir Forest as a management practice (Pathak *et al.* 2002). Therefore, even though livestock were sympatric with chital in the sanctuary area their densities have been declining over the past 34 y. This, combined with better

chital habitat found in the sanctuary area could be the probable reason that chital continued to increase at a similar rate between sympatric and livestock-free areas. The continued increase in the chital population in the Gir Forest for the past 34 y cannot be solely attributed to removal and reduction of livestock from the Gir Forest. As a result of a cyclone in 1983, many trees in the Gir Forest were uprooted; several of these still survive lying prostrate with their foliage within browsing reach of ungulates. This opening up of the canopy and increase in browse availability has likely increased the ungulate-carrying capacity of Gir. Besides, illegal hunting of wild ungulates has been almost eliminated in the Gir Forest by better management, protection measures, stringent law and increased awareness (Pathak *et al.* 2002). With a lack of past detailed information on competition with livestock, increase in forage availability, or illegal harvest rates, it is not possible to attribute the continued increase of chital to any one of these factors. It is also possible that all of the three factors may be contributing to the observed rate of increase in chital density.

A better insight is provided into the long-term effect of livestock removal by the high negative correlation ($r = -0.93$, $P = 0.022$) obtained between livestock and chital numbers in the Gir Forest. Although correlation analysis cannot be ascribed as cause and effect (Draper & Smith 1981), this result lends additional support to the competition hypothesis.

Effect of livestock removal and different grazing intensity on herbaceous vegetation

The impact of livestock on the herbaceous community is through biomass removal (Fleischner 1994) and trampling (Cumming & Cumming 2003, Hobbs & Searle 2005). Exclosure studies showed that grazing by ungulates (wild and domestic) reduced above-ground biomass substantially. Wild ungulates accounted for removal of $14.4\% \pm 6.9\%$ of the standing above-ground biomass, whereas both livestock and wild ungulates removed $54.4\% \pm 5.0\%$ of the standing above-ground biomass. Considering utilization by wild ungulates to be similar between livestock-free areas and areas sympatric with livestock, removal by livestock was estimated at 40.0% of the standing AGB. Livestock grazing was bound to reduce AGB and our result shows the obvious; however, does this reduction in AGB translate to reduced forage availability for chital? We find that chital food biomass is significantly reduced in the proximity of settlement sites – an area of high livestock impact. But moderately grazed areas by livestock still had good quantities of chital food available at the worst time of the year, i.e. the hot season prior to rainy season (Figure 3). When this moderately used area by livestock was protected

from grazing, chital food biomass equalled or exceeded that produced in livestock-free areas – a response that is suggestive of a highly resilient system even with short-term protection from grazing. Considering the absence of any large native coarse feeder in Gir cattle and buffalo are likely fulfilling an important ecological role by grazing on coarse perennial grasses and facilitating forage availability to chital (Gwyne & Bell 1968, McNaughton 1979). Wild ungulate grazing did not compensate for the removal of livestock as AGB was substantially higher in livestock-free areas. This suggests that wild ungulates did not negatively impact livestock food resources (Young *et al.* 2005). Over 80% of the AGB in livestock-free areas was composed of perennial coarse grasses, which are not the preferred food of chital (Dave 2008), while in moderately grazed areas by livestock 43% of AGB was composed of chital food plants, which is indicative of facilitation by livestock. Typical group size of chital was observed to be larger in areas sympatric with livestock both at the larger landscape scale and local scale of the Gir Forest, suggestive of higher food availability for chital caused as a result of possible facilitation by livestock. Overall, our data suggest that habitat productivity and suitability were more important for chital demographic response in comparison to competition with livestock.

Livestock form a substantial part of the lion's diet (Chellam 1993, Jhala *et al.* 2006, Joslin 1973). Lion densities and pride sizes were observed to be larger in areas sympatric with livestock (Jhala *et al.* 2006). Considering these ecological roles of livestock in the Gir Forest, it may be relevant to consider management strategies that maintain low livestock densities instead of strategies that aim at total removal. However, we caution that though our data and experimental design of vegetation exclosures targeted the pinch period of the year, our work was done in years of relatively good rainfall. It is likely that in years of poor rainfall, competition between chital and livestock can become severe and could deplete chital food with serious consequences. Also, our study targeted chital, an intermediate feeder (Hofmann 1985) with the ability to be extremely selective due to morphological adaptation of mouth parts in comparison to other wild ungulates. It is possible that competition with livestock may be an important limiting factor for other wild ungulates that have similar diets to livestock (Madhusudan 2004, Mishra *et al.* 2004).

In conclusion, our data support the competition hypothesis with livestock depressing chital densities – a long-term response to competition. In the short term, we either found no effect of sympatric livestock or an indication of grazing facilitation. Our study highlights that interactions between native wild ungulates and livestock are complex and varied under different ecological conditions. Interactions between chital and livestock are likely driven through a dynamic mechanism

of forage production and their density wherein, when forage production is low and density of livestock is high, competition is likely to be a much stronger force than facilitation (Hobbs *et al.* 1996). To mimic the livestock density of moderately grazed areas wherein our results suggest minimal negative impacts on chital food plants we recommend that livestock densities in Gir be reduced by half of the current stocking densities. Large ungulates (livestock) have significantly greater trampling impacts (Hobbs & Searle 2005) therefore we recommend that pastoral sites be rotated at an interval of a 3–4 y period so as to have minimal long-term trampling effects on the vegetation as observed by our exclosure studies in close proximity to pastoral settlements (where chital food plants were greatly reduced but were extremely resilient). Such management strategies would minimize the detrimental effect of livestock on wild ungulates and still be able to harness the positive role that livestock are likely to play.

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