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Short communication

# A conservation success story in the otherwise dire megafauna extinction crisis: The Asiatic lion (*Panthera leo persica*) of Gir forest

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## ABSTRACT

Carnivores in Asia and throughout the world face high risk of extinction due to factors such as continued habitat loss and hunting. However, the Asiatic lion of Gir forest, India presents a conservation success story whose history may help to guide the recovery and conservation of other imperiled predators. Protection of core and satellite habitats and the relocation of pastoral communities and their livestock triggered forest recovery and coincident increases in native prey populations. Wild ungulate populations increased by 10-fold between 1970 and 2010, supporting an increase in the lion population from 180 animals in 1974 to 411 animals in 2010. Coincident with this increase, lions shifted their predation preferences from a diet composed of 75% livestock to one composed of just 25% livestock. This example demonstrates the value of native prey populations to sustain imperiled carnivore species, and the use of protected areas and livestock exclusion to maintain healthy prey populations.

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## 1. Introduction

Biodiversity conservation in Asia faces major challenges. Continued threats from habitat conversion and hunting place tropical Asia at the top of the world's most threatened regions (Sodhi et al., 2010). Within these imperiled habitats, large carnivores and other megafauna face high risk of extinction (Morrison et al., 2007), and these threatened species require immediate conservation intervention to ensure their continued survival. What rare conservation success stories exist must serve as examples to study and follow in order to protect other imperiled species facing similar threats.

The Asiatic lion (*Panthera leo persica*) persists as one remaining population in and around Gir forest in the southwest part of Saurashtra region in the state of Gujarat, India. Although classified as endangered (Breitenmoser et al., 2008), the Asiatic lion has displayed a remarkable recovery in the past century, coming from the brink of extinction with an estimated population of just a few dozen individuals at the beginning of the 20th century to a population of over 400 individuals today (Singh, 2007). The management history of this species may reveal valuable lessons to guide conservation efforts for other carnivores in tropical Asia and worldwide.

In this paper, we examined population changes of Asiatic lions in relation to availability of native prey and domestic livestock and to the management of lion habitat in the Gir forest. We predicted that lion population size would be positively related to the abundance of native prey species and consequently to the protection of lion habitat in the Gir forest. This study reveals the importance of managing healthy prey populations in order to sustain threatened top predators.

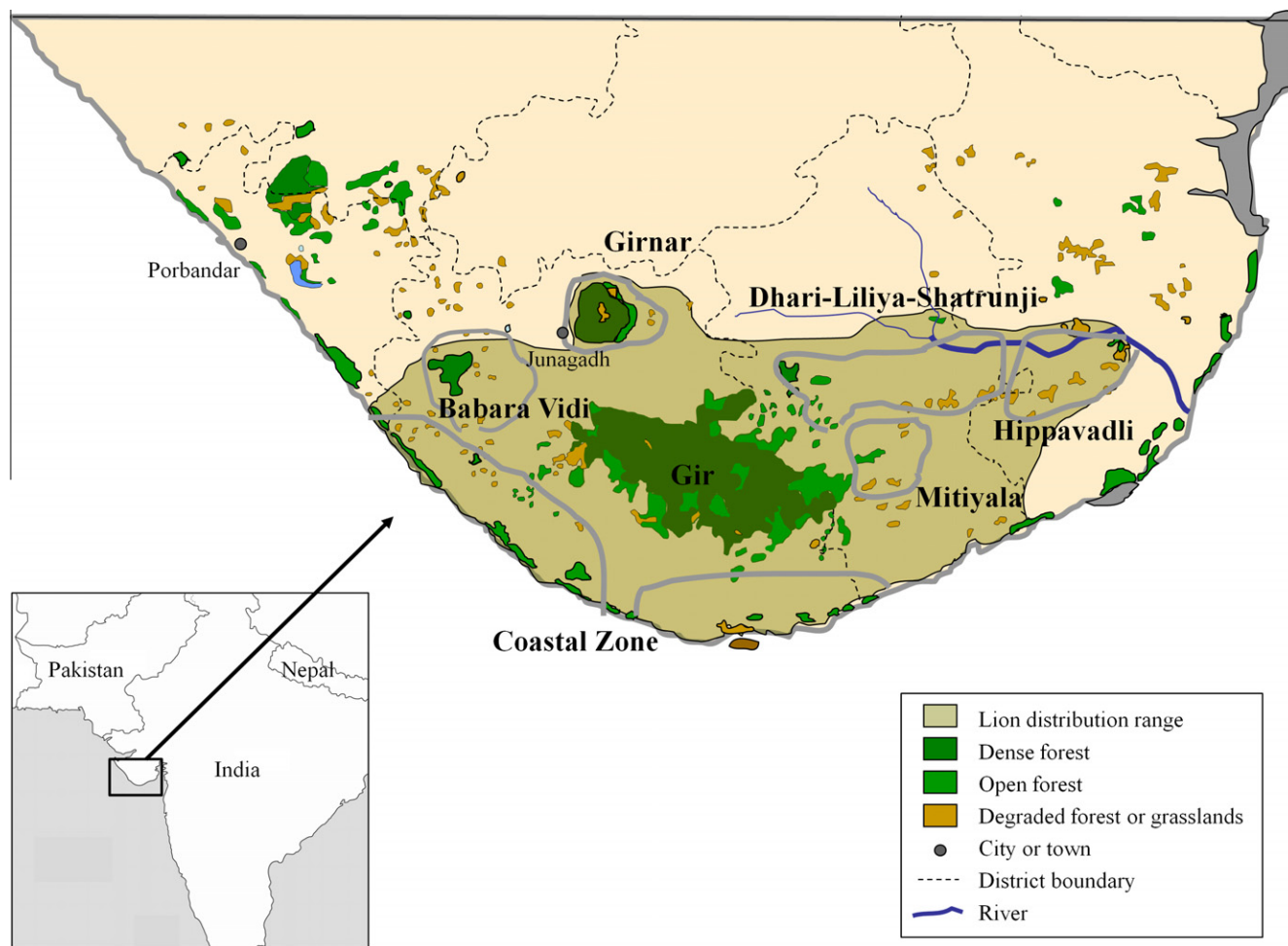
## 2. Materials and methods

## 2.1. Study region

Asiatic lions occupy remnant forest habitats in the state of Gujarat, India. Two hill systems in this region, Gir and Girnar, comprise Gujarat's largest tracts of dry deciduous forest, thorny forest, and savanna, which provide valuable habitat for a diverse flora and fauna that includes several endangered species (Fig. 1; Singh and Kamboj, 1996). These habitats also support the highest concentration of top carnivores in India, with over 600 lions and leopards (*Panthera pardus*; Singh, 2007; Anon., 2010). Native ungulates include the chital or spotted deer (*Axis axis*), sambar (*Cervus unicolor*), blue bull (*Boselaphus tragocanelos*), chinkara (*Gazella gazelle*), four-horned antelope (*Tetracerus quadricornis*), blackbuck (*Antelope cervicarpa*), and wild boar (*Sus scrofa*). Of these, the chital, sambar, blue bull, and wild boar comprise the main wild prey items for lions in Gir (Joslin, 1973). Additionally, lions frequently hunt

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**Fig. 1.** Location of lion populations in the core Gir forest and surrounding satellite habitats including Babara Vidi, Girnar, Dhari-Liliya-Shatrunji, Hippavadli, Mitiyala, and Coastal Zone.

livestock, primarily buffaloes and cows, in the forest and surrounding settlements (Anon., 1975).

In the second half of the 20th century, as the Asiatic lion was on the verge of extinction, several conservation actions were taken to protect lion habitat. The Gir Wildlife Sanctuary became the first protected area in Gujarat in 1965. The Sanctuary was subsequently expanded to cover peripheral forests, and the core area was declared the Gir National Park in 1975 with enhanced protection levels. Adjoining lion habitat in the Amreli district was declared the Pania Sanctuary in 1989, and surrounding community lands were declared protected forests to serve as a buffer zone to the Gir forest. Following these initial actions, lion numbers steadily increased and animals started dispersing into satellite forest patches in the districts of Junagadh, Amreli, and Bhavnagar (Fig. 1; Singh and Kamboj, 1996). Management followed the dispersal of lions to protect reclaimed habitats surrounding Gir, and additional sanctuaries were created in Mitiyala in 2002 and in Girnar in 2007. Thus, five protected areas currently exist to protect the Asiatic lion: Gir Sanctuary, Gir National Park, Pania Sanctuary, Mitiyala Sanctuary, and Girnar Sanctuary. The first three protected areas form the Gir Conservation Area ( $20^{\circ}57'–21^{\circ}20'N$ ,  $70^{\circ}27'–71^{\circ}13'E$ ), a 1452 km<sup>2</sup> forest block that represents the core habitat of the Asiatic lion (Singh, 2007). The other two sanctuaries, Mitiyala and Girnar, protect satellite areas within dispersal distance of the Gir Conservation Area. An additional sanctuary is currently being established in the nearby Barda forest to serve as an alternative home for Gir lions.

Following designation of protected areas, resident indigenous pastoral communities, “Maldharis”, were relocated outside the Gir forest. Prior to this resettlement, the Gir forest was heavily degraded and used by livestock, which competed with and restricted the population sizes of native ungulates (Berwick, 1974; Anon., 1975). During the Gir Lion Sanctuary Project, which started in 1972, over two thirds of the Maldhari families and their livestock were relocated outside the Gir forest (Anon., 1975; Singh and Kamboj, 1996). Various studies reveal tremendous habitat recovery and increases in wild ungulate populations following the Maldhari resettlement during the last four decades (Singh and Kamboj, 1996). A full history of the management of the Gir Conservation Area and surrounding habitats is provided in Singh and Kamboj (1996).

## 2.2. Methods and data

Published scientific studies and official monitoring data from Gujarat Forest Department provided past and current population estimates of lions and prey species analyzed in this paper. Since 1968, the Forest Department has conducted wildlife censuses every 5 years in the Gir forest, most recently in April 2010 (Anon., 2010). Visual surveys were used to identify the minimum number of lions in Gir forest and surrounding habitats. Live bait stations were used to attract lions during visual surveys through 1995, but subsequent surveys were conducted without the use of bait. All visual surveys were conducted in the different lion populations

simultaneously during the summer, when the number of water holes is reduced, allowing for more efficient population surveying. Wild ungulate population sizes were estimated by road counting and strip counting by the Forest Department but do not include error estimates. Resident livestock numbers were registered for all settlements within the sanctuary boundary, and livestock kills by lions within and outside the sanctuary were reported to secure compensation. These census data and the population changes of lions and their prey observed during the last four decades provide trends of population status, predation patterns, and dispersal of lions.

To examine the relationship between lion and prey abundance, we used Spearman's rank correlation test with a positive association as our alternative hypothesis. All statistical analysis was performed in the statistical program R Version 2.11.1 (R Development Core Team, 2010).

### 3. Results and discussion

#### 3.1. Population changes of native prey species and livestock

Following Maldhari resettlement, native prey populations in Gir forest increased (Table 1). Immediately prior to resettlement, Joslin (1973) estimated a total of 5600 wild ungulates in 1969–1970, and Berwick (1974) estimated a similarly low population of 6400 individuals in 1970–1971. In 1974, the Forest Department estimated the wild ungulate population to be 9650 individuals. This population grew consistently in subsequent surveys, reaching 31,490 in 1990 and 64,850 in 2010 (consisting of 52,490 spotted deer, 4440 wild boar, 4000 sambar, 2890 blue bull, 740 chinkara, and 290 four-horned antelope). Thus, in the past four decades, the population of wild ungulates increased by over ten times. Average annual population growth rates peaked in the two decades following Maldhari resettlement at 11.0% in the 1970s and 10.0% in the 1980s, and subsequently declined to 7.4% in the 1990s and 2.1% in the 2000s.

In contrast, populations of domestic buffalo and cattle declined following resettlement, largely due to direct removal of resident livestock from the Gir Conservation Area. The population of 24,250 resident animals in the 1970s declined to 12,500 in the mid-1980s. The recovery of wild ungulate populations following decreases in livestock herds was observed in other situations in India, and was attributed to a release from resource competition (Khan et al., 1996; Madhusudan, 2004). However, livestock numbers in Gir forest increased to 16,570 animals in 2005 and 23,440 animals in 2010, and an additional 94,600 cows and buffaloes currently occupy the peripheral villages surrounding Gir and sometimes enter Gir forest during the monsoon season. The large livestock populations within and surrounding the Gir Conservation

Area compete for the limited resources within Gir forest and may thereby restrict the population of native ungulate species.

Based on these population sizes, we calculated the standing biomass of prey, a useful figure that governs the carrying capacity of predators including lions. For the 25,300 domestic animals and 6400 wild ungulates that occupied Gir forest prior to the Gir Lion Sanctuary Project, Berwick (1974) estimated the standing biomass to be 7.69 million kg (7.21 million kg for livestock and 0.48 million kg for wild ungulates). Using the same average masses per animal, we estimated today's standing biomass of 23,440 domestic ungulates and 60,410 wild ungulates (excluding wild boar) to be 10.64 million kg (6.82 million kg for livestock and 3.82 million kg for wild ungulates), an increase of 38.4% from four decades ago. In the same time period, the proportion of wild ungulates in total standing herbivore biomass increased from 6.3% to 35.9%. Although the population size of wild ungulates is now three times that of resident livestock, the standing biomass of livestock continues to exceed that of wild ungulates due to larger livestock body sizes. The continued presence of livestock may restrict the population growth of wild ungulates, and consequently, of Asiatic lions in Gir forest.

#### 3.2. Population changes of lions and other predators

Following the considerable increases in wild ungulate populations, the lion population has steadily increased in Gir, more than doubling from a low of 180 individuals in 1974 to today's level of 411 animals (consisting of 97 adult males, 162 adult females, 75 sub-adults, and 77 cubs; see Table 1). Besides lions, the other major predators in Gir forest, leopards and hyenas, also more than doubled in population size in the past four decades (Table 1). Previously, lions were largely confined to the Gir forest and its immediate surroundings, but in the 1980s lions began to disperse to satellite areas in Girnar, Mitiyala, and Babara Vidi (Fig. 1). As of 2010, approximately 105 lions (35 males, 35 females, 19 sub-adults, and 16 cubs) existed outside the Gir forest, representing a full quarter of the entire lion population. The increase in satellite lion populations may represent the saturation of the lion population in the Gir forest and subsequent dispersal by sub-adults compelled to search for new territories outside their natal pride (Khan, 1995; Singh, 2007). Over the past two decades, these satellite areas became established, self-sustaining populations as evidenced by the presence of cubs since 1995. Use of habitat outside the Gir forest is largely restricted to forest pockets and corridors that link to the Gir forest, but lions occasionally enter surrounding villages at night to hunt livestock (Singh, 2007).

#### 3.3. Prey–predator abundance and biomass ratios

As both lion and wild prey populations have increased in the Gir forest, the ratio of prey to predator, an important indicator for assessing carrying capacity of predators, has also increased. The wild prey–lion ratio increased fourfold from 54 in 1979 to 212 in 2010. When compared to other protected areas in India that support lion or tiger populations, the prey–predator ratio is high in the Gir forest, despite Gir's exceptionally high density of predators.

Prey–predator biomass ratios are also high in Gir. The standing biomass density of prey in Gir forest is high at around 7631 kg km<sup>-2</sup>, comparable to seven important lion habitats in Africa with a mean herbivore biomass (excluding elephant) of 4853 kg km<sup>-2</sup> in lean season and 13,297 kg km<sup>-2</sup> in good season (Celesia et al., 2010). In Gir forest, total standing biomass of predators (306 lions, 200–210 leopards, and 150 hyenas) has been estimated at 45,900 kg. After comparing to the total prey biomass of 11.09 million kg, the prey–predator biomass ratio in Gir forest is 242, a value higher than in three African lion reserves (Nairobi National Park: 94; Ngorongoro: 108; Manyara: 174) but lower than in Serengeti

**Table 1**

Population sizes of lions, leopards, hyenas, and wild prey species in and around Gir forest. The lion population reports the minimum population size and is further divided between the Gir forest population and populations in satellite areas. The leopard population reports the total population in both Gir and Girnar hill areas; the Gir forest leopard population in 2010 was 200–210 individuals.

Year	Lions			Leopards	Hyenas	Wild ungulates
	Total	Gir	Satellite areas			
1974	180	180	0	142	63	9640
1979	205	205	0	161	84	14,960
1984	239	235	4	201	192	16,910
1990	284	267	17	212	97	31,490
1995	304	265	39	268	137	38,220
2000	327	271	56	NA	NA	53,600
2005	359	291	68	NA	NA	51,330
2010	411	306	105	310	150	64,850



National Park (260–301; Schaller, 1972; Singh, 2007). However, one major difference in the Gir forest is that prey biomass includes a substantial proportion of livestock: the biomass of domestic livestock ( $4600 \text{ kg km}^{-2}$ ) greatly exceeds that of wild ungulates ( $2931 \text{ kg km}^{-2}$ ). Although the presence of resident livestock forms a substantial portion of the total herbivore biomass, observed predation rates on livestock are much lower than on wild ungulates, possibly because livestock are guarded by owners (discussed below).

During the last four decades, the Gir lion population increased by 70.0% following a 38.4% increase in ungulate biomass. This suggests a positive relationship between lion density and ungulates biomass, similar to that observed in Africa (Celestia et al., 2010). Our Spearman's rank correlation analysis confirmed the relationship between predator and prey, revealing a strong correlation between lion and prey populations ( $\rho = 0.9762$ ,  $p < 0.001$ ). This illustrates the importance of managing healthy prey populations in order to sustain threatened top predators. A similar relationship between prey and predator abundance was observed for tiger populations in India (Karanth et al., 2004).

#### 3.4. Predation pattern and selection of native and non-native prey

Following changes in both predator and prey communities, Asiatic lions shifted their predation patterns. Before Maldhari resettlement, analysis of lion scats collected in 1969–70 by Joslin (1973) showed that 75% of the lion's diet comprised livestock, primarily buffaloes and cattle. In the two decades following resettlement, the predation pattern gradually shifted towards wild ungulates following increases in wild ungulate populations and decreases in livestock populations. Studies in the 1980s reported that between 52% and 64.8% of scats contained traces of wild prey (Sinha, 1987; Chellam, 1993). More recently, Dharaiya et al. (1998) reported that livestock comprised just one third of the lion's diet, and a further decrease to 25% was reported by a recent study (Kumar, in press).

Livestock kills by lions may also be studied using depredation records. Despite increasing lion populations, predation on livestock has become increasingly rare within the sanctuary due to increases in wild ungulate abundance and decreases in livestock abundance. The proportion of livestock kills within the sanctuary declined consistently from about 75% in early 1970s to 49.8% in early 1980s, 24.5% in mid 1990s, and to only 15.4% in the past 5 years (Joslin, 1973; Sinha, 1987; Singh and Kamboj, 1996). Today, very few livestock kills occur within the sanctuary, and instead most occur in peripheral villages. In and around the Gir forest, depredation records indicate that lions killed on average 1675 livestock annually between 1986 and 2001 and 2023 individuals annually between 2005 and 2009 (an additional 696 individuals were killed annually in satellite areas between 2005 and 2009; Singh, 2007). Despite increases in absolute number of livestock killed by lions, the proportion of total livestock killed per year within protected area boundaries has decreased from just 3% in the 1970s to just 1.12% at present (264 animals per year). As Polisar et al. (2003) reported from South America, the frequency of livestock depredation may be inversely related to the availability of native prey. Protecting native prey species and excluding livestock from the forest will help to minimize lion depredation on livestock (Polisar et al., 2003).

We estimated the total dietary requirement of lions based on previous studies. Schaller (1972) estimated the daily food requirement for the African lion at 7 kg for males and 5 kg for females, while Chavan (1993) estimated the annual food consumption by Gir lions to be 3600 kg for males, 2500 kg for females, and 750 kg for cubs. In the Sakkarbuag Zoo, Junagadh, average daily food requirement was 7.4 kg for males, 5.9 kg for females, 3–4 kg for sub-adults, and 1.5 kg for cubs. Based on these numbers, the total population of 411 lions in the Gir forest and satellite areas would require 660,000 kg, or 984,000 kg of prey biomass if 33% of bio-

mass is discarded and not consumed as observed in previous studies. Domestic animals may constitute up to 238,000 kg of the total required prey biomass, but may not be freely available to predators because they are monitored and protected by owners and hence the rate of predation of domestic animals is lower compared to that of wild ungulates.

#### 3.5. Habitat changes and impact on prey and predators

Following Maldhari resettlement, the forest recovered from previous disturbance to become denser. Many suggest that this habitat change would favor tigers to the detriment of lions, and past management plans prescribed but did not implement the removal of trees to facilitate grass growth. However, this forest structural change may actually benefit lions, as the carnivores spend the majority of their time in thick forest habitat (Jhala et al., 2009).

Changing regional climate may also explain changes in forest structure in Gir. Throughout the twentieth century, droughts were frequent. However, during the last two decades, average rainfall has increased, possibly due to increased western monsoon in India. Continued rain may cause native thorn forest and savannas to be replaced by broad leaved forests. Thus, both the relocation of pastoral communities and increased rainfall in recent years may explain the recovery of the Gir forest.

## 4. Conclusions

Following the creation of several protected areas and the resettlement of pastoral communities and their livestock outside protected lion habitat, wild ungulate populations in Gir forest increased by 10-fold. This impressive growth in prey base appears to explain the coincident increase in lion numbers, which more than doubled in the same time period. This explanation is supported by the proportional decrease in lion predation on livestock, which previously comprised 75% of the lion's diet but today comprises just 25%. Thus, the managing of healthy populations of native prey species appears to be a major factor that enabled the recovery of the Asiatic lion, and should be emphasized when protecting top predators elsewhere. Similar recoveries of wild ungulate and tiger populations were observed following the creation of protected areas and exclusion of livestock in Nepal (Wegge et al., 2009).

Despite impressive recoveries of wild ungulates, recent increases in livestock populations in the Gir Conservation Area may limit the potential recovery of wild prey species and consequently the Asiatic lion. The removal and permanent exclusion of non-native ungulates from the entire lion range would enable the continued growth and recovery of native herbivores and their top predators, including the Asiatic lion.

Another key aspect in the conservation of the Asiatic lion was their dispersal and the subsequent protection of surrounding satellite populations. Approximately one fourth of Asiatic lions are located in protected satellite populations outside the Gir Conservation Area, and subsist primarily on wild prey species. The protection of these satellite habitats and the maintenance of corridors linking them to the core population in the Gir Conservation Area has allowed for the continued growth of this endangered species (Banerjee et al., 2010; Venkataraman, 2010). The creation and expansion of these protected areas has succeeded in protecting the lion's habitat, its prey species, and consequently, the lion itself.

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