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AN ANALYTICAL STUDY OF TIGER CONSERVATION AND ECOSYSTEM MANAGEMENT IN RANTHAMBORE NATIONAL PARK

Saurabh Kumar Singh[1], Dr. Pratima Vishwakarma[2]

Research Scholar, Department of Geography, ISBM University[1]

Research Guide, Department of Geography, ISBM University[2]

ABSTRACT

Ranthambore National Park (RNP) in Rajasthan, is the north-western apex of the global range of the Bengal tiger (Panthera tigris), and one of the most ecologically and politically important tiger reserves in India as a part of Project Tiger. The paper analytically discusses the results of tiger conservation and ecosystem management in RNP in the period 1973-2021. The goals were to assess the demographic recovery of tigers, as well as prey base dynamics, human-wildlife conflict and ecosystem service provision. The approach incorporates both secondary data analysis of camera-trap-based spatially explicit capture recapture (SECR) studies, line-transect prey density estimates, NTCA all-India tiger estimation cycles (2006-2018), Wildlife Institute of India (WII) demographic monitoring records and published economic valuation reports. It was hypothesized that the management driven by protection has led to significant population recovery, which is currently facing threats of long-term viability due to isolation, predation by livestock and habitat overpopulation. The results indicate an increase in the number of tigers since 25 (2005) to 48 (2013) and 55 in 2018, and prey biomass of 90 animals/km 2 and flow benefits of 8.3 billion per year. The research paper concludes that, although RNP is a Project Tiger success story, genetic isolation and saturation require corridor restoration, prey augmentation and conflict mitigation as priority management measures.

Keywords: *Panthera tigris[1], Ranthambore National Park[2], Project Tiger[3], ecosystem management[4], human-wildlife conflict[5].*

1. INTRODUCTION

Located at the intersection of the Aravalli and Vindhya hill ranges, in Sawai Madhopur district, Rajasthan, the Ranthambore National Park is in a unique ecological position being the north-western end of the modern range of the Bengal tiger in the Indian subcontinent. The park was first designated as the Sawai Madhopur Game Sanctuary in 1955 with an area of 282 km², but was upgraded to Project Tiger status in 197374 and made a national park in 1980, with Sawai Mansingh and Kailadevi Wildlife Sanctuaries later becoming part of the larger Ranthambore Tiger Reserve (RTR) RNP with its tropical dry deciduous and tropical thorn forests is bounded to the north by Banas river and south by Chambal, with three major lakes (Padam, Raj Bagh and Malik Talao) and the ancient Ranthambore Fort (Bagchi, Goyal and Sankar, 2003). Ranthambore conservation became ttested with a long-lasting symbolic status since the reserve became one of the nine original Project Tiger sites initiated on 1 April 1973 to stem the disastrous decrease in Panthera tigris in India (Jhala, Qureshi and Nayak, 2020). The tigers of Ranthambore have been through four recorded demographic cycles with an initial population of around 14 in early 1970s, growing to 40 individuals by the late 1980s, a steep crash to about 16 due to poaching in 2006 and a recovery to about 40 in 2016 (Sadhu et al., 2017). In 2018, the All-India Tiger Estimation estimated at about 55 tigers in RTR, as compared to 2,967 in all of India, with photographic identifications of 97 individual tigers in RTR in 2006 to 2014 by WII (Sadhu et al., 2017; Jhala, Qureshi and N

The conservation problem in RNP is unique as the population has now become small, semi-arid, and fenced by the highly populated rural agriculture sector and nearly completely separated by other source populations in central India (Reddy et al., 2012; Yumnam et al., 2014). Genetic analysis supports the view that Ranthambore tigers constitute a separate northwestern population with low allelic diversity, which has bottleneck signatures and high risk of inbreeding (Yumnam et al., 2014; Khan et al., 2021). Simultaneously, human activities in the area, including more than 300 villages in a 5-km radius and large livestock numbers create ongoing human-tiger conflict (Reddy et al., 2012; Singh et al., 2015). It is against this background that the current analytical paper is a review of and statistical synthesis of field-based evidence data on tiger population, prey density, dietary structure, patterns of conflict, demographic vital rates and ecosystem service values of RNP until 2021. It is hoped that the analysis will help reveal whether the protection-and-monitoring paradigm has yielded ecologically sound recovery, or whether structural limits now demand an ecological shift to landscape-scale, corridor-based management approaches that ensure long-term metapopulation sustainability of one of the most-studied Indian tiger reserves.

2. LITERATURE REVIEW

A 40-year long research initiative into the ecology of predators, prey, demography, genetics and human-dimension questions has created scientific literature on Ranthambore that has yielded one of the richest tiger landscapes in the world. Early studies by Bagchi, Goyal and Sankar (2003) estimated prey abundance using eight line-transects in November 2000-April 2001 and found an overall prey density of 96.65 animals/km 2 and sambar and chital were most preferred by tigers, whereas nilgai and chinkara were shunned (Bagchi, Goyal and The conceptual framework of prey-selection analysis in the Indian tiger landscapes had already been laid down by Karanth and Sunquist (1995) who found that a preference of large prey was a consistent attribute of the P. tigris foraging ecology. Karanth et al. (2004) built on this by a mechanistic model that related the density of carnivores with the biomass of prey at eleven Indian sites, including RNP, and concluded that the reserve was capable of supporting tiger densities of 710/100 km2 when the ungulates biomass was high. Sadhu et al. (2017) predominate the demographic aspect of the study through radio-telemetry, camera-trap and direct observation of 97 individually identified tigers, which were studied in a spatially explicit capture recapture (SECR) model in the years 2006-2014, estimating density at 5.68 (2012), 7.56 (In parallel with an evaluation of the ungulates encounter rates and population structure based on the vehicle road transects, Lahkar et al. (2015) revealed that the populations of sambar and nilgai were dominated by chital and had skewed adult sex ratios. In a study of human-tiger conflict in pastoral villages adjacent to RTR during 2005-2011, Singh et al. (2015) systematically and categorised the conflict, finding 113 incidences, 88.5% of which were livestock depredation, and 11.5% of which were human.

Genetic research has re-sited Ranthambore in the national tiger conservation policy. Reddy et al. (2012) reported the tiger population structure using non-invasive genetic sampling to record the population between RTR, Kuno-Palpur, Madhav, Bandhavgarh and Pench and formed isolation indices that formed the basis of further landscape planning. Yumnam et al. (2014) combined landscape genetics with permeability modelling to determine priority corridors between RTR and central Indian populations, and Khan et al. (2021) experimented that Ranthambore tigers harbour approximately twice the inbreeding load of central and southern Indian populations, which might cause imminent demographic risk. A managerial post-mortem of the Sariska local extinction and Kailadevi degradation had been provided by Reddy (2008) who had found the patrolling, intelligence and political will to be weak and directly applicable to RNP. The ecosystem services flows of RTR were quantified by Verma et al. (2017) and Reddy et al. (2012) with a ₹8.3 billion/year value to cover the protection of its gene pool, water supply, and carbon sequestration. The longitudinal backbone of this study is the serial all-India estimates by NTCA (Jhala et al., 2008, 2015; Jhala, Qureshi and Nayak, 2020) which place Ranthambore in the national patterns, and the classical phytosociology of WWF-India and Champion and Seth (1968) which gives the vegetation Collectively, this literature has made Ranthambore a small, remote, well-fenced yet ecologically saturated reserve with its future relying on landscape connectivity and proactive genetic control.

3. OBJECTIVES

1. To analytically evaluate the demographic trajectory of the tiger population in Ranthambore National Park between 1973 and 2021 using published census, camera-trap and demographic data.
2. To assess the status of prey availability, human–tiger conflict and ecosystem service flows that determine the long-term effectiveness of conservation and ecosystem management in the reserve.

4. METHODOLOGY

The research design is analytical and a secondary data research design based on systematic synthesis of peer-reviewed research on the ecology of Ranthambore National Park, government technical reports and published valuation studies of the park between 1973 and 2021. The sample frame consists of (a) all four All-India Tiger Estimation cycles published by the National Tiger Conservation Authority and Wildlife Institute of India (Jhala et al., 2008, 2015; Jhala, Qureshi & Nayak, 2020); (b) primary peer-reviewed studies on Ranthambore's tiger demography, prey ecology, food habits, genetic structure and human–tiger conflict (Bagchi, Goyal & Sankar, 2003; Karanth et al., 2004; Reddy et al., 2012; Yumnam et al., 2014; Singh et al., 2015; Sadhu et al., 2017; Khan et al., 2021); and (c) the Indian Institute of Forest Management economic valuation reports (Reddy et al., 2012; Verma et al., 2017). Analysis tools are (i) descriptive statistical re-tabulation of population, density and prey parameters, (ii) trend analysis of the tiger numbers using the census cycles, (iii) proportional analysis of prey selection using scat data with the biomass correction technique developed by Ackerman et al. (1984) applied by Bagchi, Goyal and Sankar (2003) and (iv) comparative ratio analysis The density estimates were based on the reports of spatially explicit capture recapture (SECR) in peer-reviewed literature on prey densities based on line-transect distance sampling; biomass estimates based on standard species body-mass estimates by Karanth and Sunquist (1995). To remove transcription error, all the numerical data were checked against the original published source and cross-validated by at least two independent citations. The analysis timeframe is limited to 1973-2021 to conform to the post-Project Tiger management regime, and to avoid post-2021 census cycles. The design has limitations such as using aggregated census data, year-to-year change in the effort in conducting the surveys and data on the micro level patrol is not available; these are addressed by triangulation of NTCA, WII, and academic sources. The ethical aspects are restricted to the attribution and integrity of data because no new field sampling was made.

5. RESULTS

Table 1: Tiger Population Trend in Ranthambore Tiger Reserve (1972–2018)

Year	Estimated Tigers	Source / Census Cycle
Early 1970s	~14	Project Tiger baseline (Sadhu et al., 2017)
Late 1980s	~40	NTCA records (Sadhu et al., 2017)
2005	25	NTCA records (Reddy et al., 2012)
2006	~16	All-India Tiger Estimation (Jhala et al., 2008)
2013	48	NTCA cycle (Jhala et al., 2015)
2014	~62 (regional N from SECR)	Sadhu et al. (2017)
2018	~55	All-India Tiger Estimation (Jhala, Qureshi & Nayak, 2020)

Source: Compiled from Sadhu et al. (2017); Jhala et al. (2008, 2015); Jhala, Qureshi & Nayak (2020); Reddy et al. (2012).

Table 1 shows that there is a non-linear demographic recovery of the tiger track. The 1972 stable of 14 tigers had risen to around 40 towards the end of the 1980s, but then fell to 16 by 2006 due to reported poaching incidences, and then rose to 48 by 2013 and a rough estimate of 55 by 2018. The average annual growth in 2006-2018 is about 11 percent, signifying an effective protection-based recovery. The recovery however, levels off at the ecological carrying capacity of the reserve (Sadhu et al., 2017).

Table 2: Prey Density Estimates for Ranthambore National Park (Bagchi et al. Study, 2000–2001)

Prey Species	**Density (animals/km²)**	**Rank**
Chital (*Axis axis*)	~50	1
Common langur (*Semnopithecus entellus*)	~24	2
Sambar (*Rusa unicolor*)	~10	3
Nilgai (*Boselaphus tragocamelus*)	~6	4
Wild pig (*Sus scrofa*)	~5	5
Chinkara (*Gazella bennettii*)	<2	6
Total prey density	**96.65**	–

Source: Bagchi, Goyal & Sankar (2003).

Table 2 indicates that Ranthambore sustains an extremely high prey density of 96.65 animals/km² which is far beyond the 50/km² threshold that is deemed to support viable tiger populations (Karanth et al., 2004). Chital is the backbone of the prey base (in terms of demographics), and sambar, the energetically favored prey of tigers, is found at lower densities but sufficient. The mid-sized ungulates diversity is in line with the dry deciduous forest type and supports the conclusion that there is a strong bottom-up support of predator persistence (Bagchi, Goyal & Sankar, 2003).

Table 3: Prey Composition in Tiger Diet from Scat Analysis (n = 109 scats)

Prey Item	**Relative Biomass in Diet (%)**
Sambar	47
Chital	31
Nilgai	5–7
Domestic livestock	10–12
Chinkara	<1
Other (langur, wild pig)	~4

Source: Bagchi, Goyal & Sankar (2003).

Table 3 shows sambar has the greatest proportion of tiger prey (47 percent) by relative biomass, which is followed by chital (31 percent), and supports an indication of a preference towards medium-to-large ungulates. The contribution of livestock in the country of 1012% is statistically significant and points to a structural conflict node in RNP. The prey preferences of tigers have been strongly positively selected (Manly, 2003) in sambar, chital and negatively selected in nilgai and chinkara, indicating the prey choice is influenced by the rate of encounter and the efficiency of handling the prey and not pure abundance (Bagchi, Goyal & Sankar, 2003).

Table 4: Tiger Density Estimates from Spatial Capture–Recapture (SECR), 2012–2014

Year	Trap Effort (nights)	Individuals (M+F)	Density (tigers/100 km²)	95% CI
2012	60	30	5.68	3.74–8.64
2013	76	40	7.56	5.47–10.44
2014	182	39	7.22	5.27–9.88

Source: Sadhu et al. (2017).

Table 4 presents estimate of densities based on spatially explicit capture recapture analyses, which are statistically stronger than previous pugmark-marking-based analyses. Between 2012 and 2014, density increased, and the 95-percent confidence intervals of density overlap, demonstrating relative stabilization. These important values make Ranthambore one of the denser reserves in dry deciduous India (Sadhu et al., 2017). The 27 percent growth over three years is an indication of intra-reserve recruitment at a fast pace but is also almost saturated.

Table 5: Pattern of Human–Tiger Conflict in RTR Buffer, 2005–2011 (n = 113 incidents)

Conflict Category	% of Total Incidents
Livestock attacks	88.5
– Cows	31.6
– Bulls	21.1
– Calves	16.7
– Buffaloes	19.3
– Goats	11.4
Attacks on humans	11.5 (4 fatal, 9 non-lethal)

Source: Singh et al. (2015).

As shown in table 5, 88.5 percent of all conflicts recorded are related to livestock depredation, with majority of them being in the interior of the villages (53.4 percent) and the agricultural fields (44.5 percent). The percentage of cattle (cows + bulls + calves) kills is 69.4% which is unprotected nocturnal grazing. The case-fatality ratio was 30.7, with four out of 13 attacks on humans lethal. Conflict is statistically concentrated around the park boundary (5 km buffer) meaning that prey saturation within the core causes dispersing tigers to be pushed out of the core (Singh et al., 2015).

Table 6: Annual Ecosystem Service Flow Benefits from Ranthambore Tiger Reserve

Ecosystem Service	Annual Value (INR)
Gene-pool protection	₹7.11 billion
Habitat & refuge for wildlife	₹182 million
Water provisioning	₹115 million
Carbon sequestration	₹69 million
Nutrient cycling	₹34 million
Total flow benefits	**₹8.3 billion (~₹0.56 lakh/ha)**

Source: Reddy et al. (2012); Verma et al. (2017).

Table 6 measures the economic value of the ecosystem services of RTR. Gene-pool protection with ₹7.11 billion constitutes 85.7 percent of the total flow benefits as these are rare in the world ecosystems anchored by large carnivores. The economic case of conservation has been statistically proven as the ratio of benefits to the management and cost of RTR was estimated as more than 1:600. The total 8.3 billion yearly flow equals about 0.56 lakh/hectare/year, which is similar to other Project Tiger flagship reserves (Reddy et al., 2012; Verma et al., 2017).

6. DISCUSSION

The analytical synthesis used in this paper, which aligns with the first objective, has established that there has been a statistically significant demographic recovery in the tiger population of Ranthambore between 1972 and 2018 but this recovery is structurally limited. The trend in Table 1 indicates three different stages establishment (1973-1990), poaching-induced collapse (1990-2006) and protection-induced recovery (2006-2018) as the population-level has stabilized at about 55 individuals. Although this is a 244 per cent increase compared to the 2006 low, the SECR-based density estimates of 5.68 to 7.22 tigers/100 km^2 reported by Sadhu et al. (2017) shows that the reserve is nearing its ecological carrying capacity, which is generally agreed to be between 50 and 70 breeding adults under present core That is why the number of sub-adult tigers dispersing into the buffer and into the landscapes dominated by humans is becoming more and more frequent, a trend that is the major driving force behind conflict numbers reported in Table 5 (Singh et al., 2015). As far as the second objective is concerned, the information on the prey ecology in Tables 2 and 3 supports the recovery narrative. Aggregate prey density of 96.65 animals/km 2 that Bagchi, Goyal and Sankar (2003) recorded is one of the highest densities of the aggregate prey of tigers in India, and is comparable to Kanha and Nagarhole, and a hundred times higher than Panna or Bandhavgarh in similar decades (Karanth et al., 2004). The bottom-up energetic foundation of tiger population is justified as sambar and chital make up 78 percent of dietary biomass. The contribution of livestock to diet of 1012% is however structurally important: it directly translates into the 88.5% livestock-loss factor of human tiger conflict in Table 5, indicating close correspondence between dietary opportunism and socio-economic conflict (Singh et al., 2015).

The story of conservation is rewritten with genetic discoveries. Protection has been achieved but isolation has not. Reddy et al. (2012) and Yumnam et al. (2014) report that RTR is genetically isolated to the populations of central Indians, and there is limited gene flow along the Kuno-PalpurMadhav corridor. Recent re-examination of the DNA by Khan et al. (2021) indicates that Ranthambore tigers bear an average of two times more inbreeding load than central and southern populations and there have been reported cases of the presence of deleterious alleles. The F-statistic indicates that the population is no longer in zero and this suggests that statistically there is a departure of Ranthambore as an isolated genetic island and this requires active intervention within a metapopulation structure. This makes the ecological success of the last four decades a risky genetic position of the following four. Table 6 in the economic case is also educative to the management. The ₹8.3 billion per annum flow benefit estimated by Reddy et al. (2012) and re-estimated by Verma et al. (2017) indicates that the public-finance justification of conservation is preponderantly good with benefit-cost ratios two to three orders of magnitude higher than unity. This leads to the fulfillment of the second objective of proving that the management of the ecosystems surrounding the tigers is not a cost, but a capital good, which finances the relocation of the village, compensates livestock and replenishes the corridors with quantifiable returns. However, the seemingly successful economic results conceal distributional inequalities: villagers (who bear 88.5% of the losses of livestock) do not share the gene-pool or carbon-sequestration values, creating endemic local resistance to conservation.

Combining both of the objectives, one comes to three policy implications. To begin with, the population is already recovering but is already saturated thus any increase in demographics will be achieved by restoring and supplementing the corral not by evolving the intra-reserve (Sadhu et al., 2017; Yumnam et al., 2014). Second, the diet density coupling in Tables 2 and 3 statistically supports prey augmentation in the buffer area especially through sambar restocking (Bagchi, Goyal & Sankar, 2003). Third, conflict-reduction investments (better livestock corrals, ex-gratia disbursement and night-time vigilance) must be invested in in a manner that explicitly quantifies the ecosystem-service flows in Table 6, internalizing the cost where the benefit is received (Singh et al., 2015; Reddy et al., 2012). The Sariska re-introduction experience (Reddy, 2008) serves as a warning model that in the absence of genetic and social management, protection is inadequate. The experience of Ranthambore, then, is a graduated lesson to the larger Project Tiger architecture in India as it goes through the phase of demographic recovery to landscape-scale, metapopulation-linked management.

7. CONCLUSION

One of the most analytically documented and ecologically significant tiger reserves in India, with almost 50 years of Project Tiger intervention, is the Ranthambore National Park. The data collected in this work proves that Tiger population improved to about 55 individuals in 2018 after being at the level of 16 in 2006, which was made possible through an extremely high density of prey of 96.65 animals/km 2 and sambar-and-chital-based diet. However, the same evidence confirms that the reserve is now functioning at saturation level, that human-tiger conflict in the buffer is institutionally institutionalized with 88.5% of the incidents having a livestock basis and genetic isolation is a plausible long-term threat despite an estimated ecosystem service value of ₹8.3 billion every year. The new management of ecosystems in the future should thus revolve around ceasing intra-reserve protection towards landscape-scale restoration of corridors, scientifically informed supplementation, prey enrichment and equitable financing of conflict mitigation. Ranthambore shows that success in conservation of the demographic register can be accompanied by structural weakness in the genetic and social registers, and how successfully the management authorities respond to these overlapping constraints, the reserve will be moving in the next phase of the reserve after 2021.

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