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Wild tigers conservation through anti-poaching management practices: Lessons from protected areas in Assam, India

Abstract

This research evaluates how three anti-poaching management levers—workforce capacity, patrolling effort, and deterrence policy—shape wild-tiger outcomes in Assam, India, a globally important biodiversity hotspot. Drawing on a decade of archival data from the Assam Forest Department covering four tiger reserves, we estimate reserve-level panel regressions that link (i) the number and remuneration of frontline staff, (ii) average kilometers patrolled, and (iii) recorded poacher arrests to trends in tiger abundance. Greater staffing and more intensive patrolling exhibit robust, positive associations with tiger population growth, whereas deterrence measures alone do not achieve statistical significance. The analysis also accounts for long-term disruptions from civil conflict in the Manas National Park, highlighting site-specific constraints on conservation effectiveness. Despite persistent understaffing and ranger wages that lag regional norms, Assam's tiger numbers have remained stable or increased—evidence that strategic investments in on-the-ground operations deliver outsized conservation returns. We conclude that strengthening ranger capacity, sustaining patrol intensity, and simultaneously improving prey availability and habitat quality are critical for durable tiger recovery in South Asia.

Keywords: tiger conservation, anti-poaching strategies, workforce capacity, patrolling, deterrence policy, protected areas

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Introduction

The Bengal tiger (*Panthera tigris tigris*, Linnaeus 1758) is a keystone species that plays a vital role as a top predator in maintaining ecosystem function and resilience.[1–3] The primary threat to wild tiger populations is poaching for the illegal wildlife trade, often exacerbated by habitat loss and fragmentation, which facilitates access for poachers.[4–7,2] Unlike many other forms of wildlife poaching, tiger poaching is driven by three main motivations: status and impunity, poverty (both economic and cultural), and human–tiger conflict.[8]

Tigers are poached for a wide range of body parts—including bones, skin, claws, whiskers, genitals, oils, teeth, and meat—which are in high demand across several Asian countries.[9–11] Approximately 95% of wild tiger populations consist of 120 individuals.[12] Given 120 individuals per population, Kenney et al.,[12] estimates poaching of five wild tigers per year can lead to extinction probability of less than 5%, and poaching of 10 wild tigers per year can lead to a rise in the extinction probability of 95%. For example, according to Ranthambhore Foundation, wild tigers in Ranthambhore Tiger Reserve were reduced from 44-46 wild tigers in 1991 to 15-20 wild tigers in 1992, leading to a 70-90% extinction probability in the population.

These forecasts have proven to be alarmingly prescient, as recent poaching incidents reported by Wong & Krishnasamy[11] underscore the ongoing crisis. Long-term poaching also reduces genetic diversity, increasing the risk of inbreeding by 0.34%, and accelerating population decline.[13] In addition, prey poaching compounds this threat by diminishing the food base required for tiger survival.[14,15]

Assam, India, recognized as a biodiversity hotspot, contains several tiger reserves and UNESCO-designated conservation areas.[16] However, wildlife poaching remains a significant challenge, in part due to Assam's porous international border with Myanmar and its state border with Nagaland, which facilitate opportunistic poaching activities.[17,18] Poached wildlife products are frequently trafficked to China,[10] and there is evidence of exchange between poachers and arms dealers across the Myanmar border.[18] To combat tiger extinction, the National Tiger Conservation Authority (NTCA) established tiger reserves, which are protected areas managed by the State Office of the Principal Chief Conservator of Forests (PCCF) and the Head of Forest Force (HoFF). These officials are responsible for overseeing all biodiversity conservation activities within the reserves, including anti-poaching operations, which are authorized and supported by the NTCA.[19]

In this study we used three different metrics which are grounded in empirical data to evaluate the effectiveness of anti-poaching management practices to help conserve wild tiger in Assam—workforce capacity, legal deterrence, and patrolling. Research shows that increasing well-paid, trained staff strengthens wildlife protection,[20] arrest data reliably reflects legal enforcement success,[21,22] and kilometers patrolled is a globally validated indicator of anti-poaching effort.[23,24] Together, these proxies form a robust framework for evaluating anti-poaching management effectiveness in Assam's Tiger Reserves.

Workforce capacity is integral to wildlife management, providing protection to tigers, interfacing with local communities, and enabling habitat and population monitoring.[25–27] A study across Assam's protected areas (Dibru Saikhowa, Kaziranga, Nameri, and Orang) demonstrated a significant positive relationship between frontline staff numbers, their salaries, and the populations of rhinos and elephants—confirming that well-resourced human patrols are effective deterrents to poaching, particularly in regions where technological monitoring is limited.[20] India oversees 50 tiger reserves covering 72,750 km² and supporting approximately 65% of its wild tigers.[27] With around 60,000 frontline staff—the highest in South Asia—a survey of 1,783

rangers found average monthly salaries of USD 259.24.[25] Despite this, over 50% of sanctioned frontline positions remain vacant; many roles are filled by undertrained home guards and casual workers earning Rs 6,000–9,000/month without regular pay or benefits, which can undermine morale and conservation effectiveness.[28] To assess the impact of workforce capacity, we use frontline staff numbers and salaries as proxy variables associated with tiger population trends.

India's legal framework plays a crucial role in deterring wildlife crime. The Wildlife Protection Act (1972) and Sections 428/429 of the Indian Penal Code criminalize the killing, poisoning, or disabling of wildlife—especially Schedule I and II species like tigers—with penalties that include fines up to Rs 10,000 (~USD 126) and imprisonment between two and seven years.[29,30] Enforcement of these laws is essential: national data reveals more than 9,253 wildlife crime arrests in recent years.[22] Operations such as Kerala's Operation Shikkar (2015–2017) resulted in 72 arrests linked to ivory trafficking, effectively disrupting organized wildlife crime networks.[22] Notably, increased enforcement efforts in Maharashtra, including more frequent prosecutions, have been associated with a measurable reduction in poaching incidents.[21] By using the number of poachers arrested as a proxy for deterrence policy, this study aligns with existing literature highlighting that legal enforcement has a significant influence on poacher behavior.[31]

Patrolling is a frontline tactic in preventing tiger poaching. India's M-STRIPES (Monitoring System for Tigers – Intensive Protection and Ecological Status) integrates GPS- equipped mobile tools to monitor patrol routes, identify poaching hotspots, and track law enforcement efforts in real time.[24] The implementation of M-STRIPES beyond core reserves into buffer zones has strengthened coverage and reduced illegal activities.[32] Similarly, the SMART (Spatial Monitoring and Reporting Tool) system, widely adopted in Southeast Asia, has shown marked success: in Thailand's Western Forest Complex, tiger populations rose by 72% over 13 years following targeted, data-driven patrol deployments.[23] In Assam, frontline staff conduct daily foot patrols in pairs from anti- poaching camps, equipped with firearms, radios, compasses, and protective gear.[25,17] To assess the impact of patrolling on tiger populations, this study uses the average kilometers patrolled as a proxy for patrolling capacity.

The aim of this study is to evaluate the effectiveness of anti-poaching management strategies implemented by the Assam Forest Department. More specifically, we assess three key metrics: workforce capacity, deterrence policy, and patrolling capacity, and examine their associations with wild tiger populations. Workforce capacity is represented by the number of frontline staff and their salaries. Deterrence policy is proxied by the number of poachers arrested, while patrolling capacity is measured by the average kilometers patrolled. We hypothesize that variations in these management practices are significantly associated with tiger population trends. Using regression analysis based on data from the Assam Forest Department, we find workforce capacity plays a critical role in managing tiger population, while arresting poachers appeared not to be associated with tiger population density.

Study sites

Assam, located in northeastern India just south of the eastern Himalayas, lies along the fertile Brahmaputra and Barak River valleys. Recognized as a biodiversity hotspot, the region boasts a rich diversity of flora and fauna and is home to an extensive network of protected areas. Among these are Kaziranga, Manas, Nameri, and Orang National Parks, which hold special designations for the conservation of megafauna. These national parks are also officially designated as tiger reserves by the National Tiger Conservation Authority of India.[16,33] The size of these reserves varies significantly, ranging from 78.80 km² to 626 km². While each park supports a distinct assemblage of species, all are known to harbor populations of wild tigers. Table 1 provides an overview of the study sites and their conservation classifications, while Figure 1 illustrates the geographic locations of Assam's tiger reserves.

Table 1 Study sites in Assam, India

Protected area	Special designations	Size (sq. km)	Endangered megafauna
Kaziranga National Park	UNESCO World Heritage Site, Tiger Reserve	626	The Bengal tiger (Panthera tigris tigri)
Manas National Park	UNESCO World Heritage Site, Tiger Reserve, Biosphere Reserve	526	
Nameri National Park	Tiger Reserve	320	
Rajiv Gandhi Orang National Park	Tiger Reserve	78.8	

Methods

To determine the effectiveness of anti-poaching management practices, a unique dataset including frontline staff numbers per year, frontline staff salary per year, poachers arrested per year, average kilometer patrolled, and tiger census data from Manas, Kaziranga, Orang, and Nameri Tiger Reserves. The data were collected by Assam Forest Department between 1985 and 2020 and then integrated with the census data of endangered tigers in the four tiger reserves.

Some variables were transformed to make them relative to a national park or tiger reserve, as stated below.

a) Average kilometer patrolled per year*:* The purpose of patrolling is to help curb wildlife poaching and illegal farming/logging, and to collect information on wildlife habitat and populations.[34] In Assam National Parks, patrolling is done by the frontline staff twice a day–day and night. Even though there are various types of patrolling (boat, jeep, elephant, and foot), we focused on foot patrolling in our analysis regarding the regression models. The average KM patrolled per year was not normalized for the national park/tiger reserve and log-transformed because we were interested in the km patrolled rather than its proportion of the size of the tiger reserve.

b) Tiger population density. We calculated population density for endangered tigers using the ratio of tiger population numbers to the tiger reserve's core tiger habitat (sq. km) and log-transformed using natural logarithm.

c) Frontline staff numbers per year. In our analysis, the frontline staff included mainly the positions of Forest Guard, Game Watcher, Forester I and II, and Ranger Officer I and II job positions. We calculated the frontline staff number using the ratio of the frontline staff to the area (sq. km) of the national park and log transformation using natural logarithms. We did this to normalize the frontline staff numbers in the national park.

d) Frontline staff salary per year. The salary was the same for all frontline staff each year. Thus, we needed to transform the variable. First, we took the mid-range of the frontline staff income. Second, we convert this income from Rupees to USD using the observed year currency exchange rate. Then, we multiplied the mid-range income in USD by the number of frontline staff in each national park per year to reach the frontline staff salary so that frontline staff salary is proportional to frontline staff numbers. Lastly, we log- transformed frontline staff salaries using natural logarithms to normalize the data.

e) Poachers arrested per year*:* India has various legal framework to protect wildlife and punish the criminals. Animal Laws under Indian Penal Code of 1860 and the Wildlife Protection Act of 1972 deals with penalties regarding hunting of endangered species. There are fines and prison time associated with the Indian Penal Code and Wildlife Protection Act. Both authorize the Assam Forest Department to apprehend poachers. The number of poachers arrested per year was not normalized for the national park/tiger reserve and log-transformed because the number of poachers arrested per year for each national park/tiger reserve was generally zero with little variation.

f) Year: The 'year' variable was added as the control. The data is from 1985 to 2020.

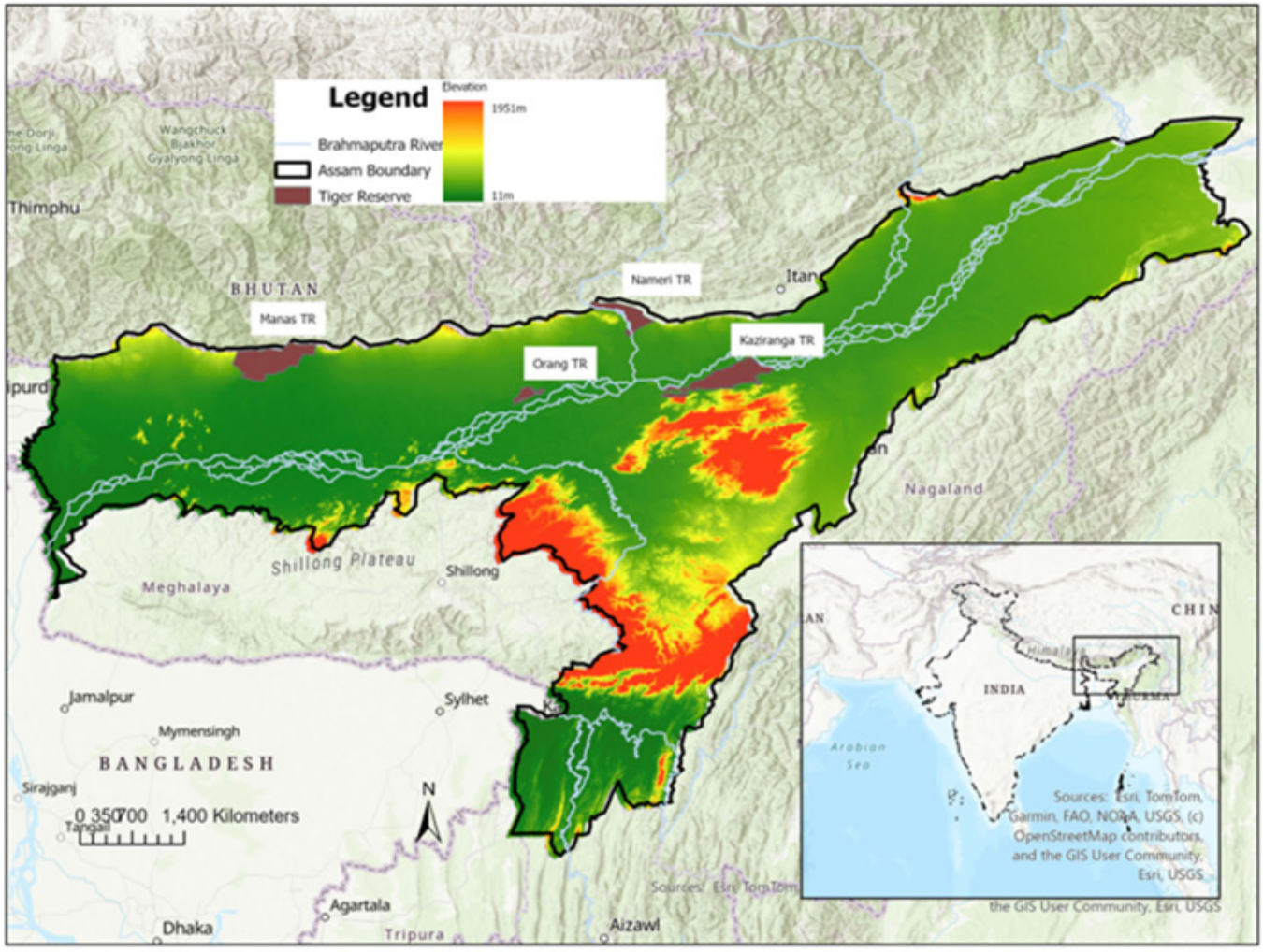

Figure 1 Map of study sites.

Results

Based on statistical modeling, workforce capacity, patrolling capacity, and year are predictive of endangered tiger populations. The relationships of interest were analyzed by OLS regression method in R.[35] It should be noted that outliers were not excluded from capturing the changes or variations of species population size that could be driven by changes in the environment and market demands. We performed group mean imputation for missing data of tiger population density.[36] The tiger model was tested for multicollinearity using the variance inflation factor (VIF) criterion of four (4). Lastly, we conducted the Breusch-Pagan Test for heteroscedasticity, and there was no evidence it in this model.

Both frontline staff numbers, frontline salary, and average kilometer patrolled were predictive of endangered tiger populations ($p < 0.001$). Year was predictive of endangered tiger populations ($p < 0.01$). However, the deterrence policy (e.g. poachers arrested) was not predictive of endangered tiger populations. Table 2 provides the descriptives of all the variables and Table 3 provides the regression analysis.

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Table 2 Descriptive summary

Variable	Number of observations	Mean	SD	Max	Min
Average Kilometer Patrolled	144	8.458	2.933	10	0
Frontline Staff Number	144	-0.279	0.181	0.075	-0.62
Frontline Staff Salary	144	-5.612	0.533	-4.611	-6.397
Poachers Arrested	144	13.109	20.136	113.00	0.000
Tiger Population	144	-1.084	0.438	-0.366	-2.028

Table 3 Regression analysis outcomes between tiger conservation management practices and tiger population size

Endangered species	Variables		Regression model (Coefficient (standard deviation))
Tiger population	Workforce capacity	Frontline staff	3.086***(0.166)
		Frontline salary	0.745***(0.055)
	Deterrence-based policy	Poachers arrested	-0.002(0.001)
	Patrolling	Average kilometer patrolled	-0.032***(0.007)
	Control	Year	0.005**(0.002)
	Observations		144
	Adjusted R2		0.739
	Note: * = p<0.05, ** p<0.01, ***=p<0.001		

Discussion

Workforce capacity plays a foundational role in wildlife management and the protection of endangered species.[37] Our analysis found a positive correlation between workforce capacity—measured by the number of frontline staff and their average salaries—and wild tiger populations. In Assam, frontline personnel are responsible for patrolling tiger habitats, monitoring populations, mitigating human–tiger conflicts, and combating poaching, all of which contribute to the persistence and recovery of wild tigers.[19,33] While Jhala et al.,[27] reported that more than 50% of frontline staff positions in tiger reserves remain vacant, these staffing shortfalls do not appear to have adversely affected tiger populations in Assam.

Notably, the average salary of frontline staff in Assam is approximately $163.52 USD per month (INR 14,000), which is significantly lower than the South Asian regional average of $259.24 USD per month (WWF, 2018). These findings suggest that although Assam's Forest Department is operating under constrained workforce capacity, it continues to support tiger population growth.

In contrast, our analysis revealed that deterrence-based strategies—particularly the arrest of poachers—were not statistically significant in influencing tiger populations. Deterrence theory is grounded in the assumption that poaching is largely opportunistic and can be curbed through punitive measures.[38] However, in Assam, where the illegal market for wildlife products remains strong and the likelihood of prosecution is low, fear-based enforcement strategies appear to have limited impact. This suggests that arresting poachers alone may be insufficient as a conservation tool in regions where structural and legal enforcement limitations persist.

Foot patrols are widely recognized as a vital component of wildlife conservation[34] and are instrumental in identifying poaching hotspots.[39,38] However, our analysis identified a negative correlation between patrol efforts—measured in kilometers patrolled—and tiger population levels. Assam's tiger reserves vary in size from 78.80 km² to 626 km²,[16] which directly affects how patrol duties are distributed across anti-poaching camps. Larger reserves generally require more extensive patrols, yet the number of frontline staff per camp may not scale proportionately. One likely explanation for this negative relationship is the impact of civil unrest in Manas Tiger Reserve. From the mid-1980s to 2003, civil unrest resulted in a near-total collapse of conservation management, including the suspension of patrol activities and the abandonment of the reserve by forest staff.[40] During this period, poaching led to the local extinction of rhinos and a sharp decline in tiger numbers, with estimates showing a drop from 125 to just 12 individuals. Given that Manas previously supported the highest wild tiger populations in Assam, the unrest likely had a cascading effect on tiger populations across the region.

The findings from this study offer several implications for wildlife managers and policymakers. First, there is a clear need to hire more qualified and professionally trained frontline staff for tiger reserves. A persistent challenge in many reserves is the shortage of personnel who possess both ecological knowledge and the skills necessary for effective patrol and monitoring.[41] While locally recruited staff bring valuable knowledge of terrain, weather, and wildlife behavior,[42] they may lack the capacity to conduct systematic data collection or enforce conservation protocols.[41,42]

Interviews with frontline staff in Assam also revealed significant gaps in equipment and infrastructure, including the need for night-vision goggles, binoculars, durable footwear, modern firearms, thermal imaging devices, advanced communication systems, and unmanned aerial vehicles (Mr. Najrul Islam of Wildlife Trust of India (local NGO), Ranger Officer Barin Boro in Manas National Park; and Division Field Officer Pradipta Baruah in Orang National Park, personal communications, August 2021). Supplying such essential resources would likely improve patrol efficiency and overall conservation outcomes. Skilled, well-equipped personnel are more likely to contribute effectively to wildlife research, protection, and habitat management.

Beyond staff and enforcement, improving prey availability and managing tiger habitats are also critical to successful conservation outcomes.[43–46] Without sufficient prey, a growing tiger population may increase the frequency of human–tiger conflicts, particularly in communities near reserve boundaries. Such conflicts often result in human casualties and livestock loss, disproportionately affecting economically vulnerable populations.[44,47,48] Other ecological challenges within Assam's reserves include limited natural habitat

succession, frequent flooding, invasive species proliferation, and wetland eutrophication,[49] all of which may undermine tiger recovery and must be addressed in tandem.

A key limitation of this study lies in the limited sample size used in our regression analysis, a consequence of irregular tiger census collection over the years. To mitigate this, we used conditional mean imputation for missing data points, enabling a more consistent analytical framework while acknowledging methodological limitations. Despite these constraints, our study provides an empirical foundation—based on archival data from the Assam Forest Department— for assessing the relationship between anti-poaching management practices and the conservation outcomes for endangered megafauna.[50–55]

Conclusion

To our knowledge, this study is the first to empirically examine wild tiger conservation through the lens of anti-poaching management practices—specifically workforce capacity, deterrence policy, and patrolling capacity. Our findings suggest that workforce capacity and patrolling effort are significantly associated with tiger population outcomes, while deterrence-based enforcement (e.g., arresting poachers) does not show a statistically significant effect. Based on these results, we recommend that wildlife managers and policymakers consider increasing the number of frontline staff, improving their salaries, and expanding patrolling coverage (measured in kilometers patrolled) to enhance conservation outcomes. While these strategies are important for sustaining and growing wild tiger populations, they should be complemented by broader efforts to maintain a sufficient prey base and ensure effective habitat management, both of which are critical to long-term tiger conservation success.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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