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REVIEW AND SYNTHESIS

PEOPLE AND NATURE BRITISH ECOLOGICAL SOCIETY

Recovery of tigers in India: Critical introspection and potential lessons

Yadvendradev Jhala[1] | Rajesh Gopal[2] | Vaibhav Mathur[3] | Prodipto Ghosh[4] | Himmat Singh Negi[5] | Sunita Narain[6] | Satya Prakash Yadav[3] | Amit Malik[3] | Rajendra Garawad[3] | Qamar Qureshi[1]

[1]Wildlife Institute of India, Dehradun, India; [2]Global Tiger Forum, New Delhi, India; [3]National Tiger Conservation Authority, Ministry of Environment Forest and Climate Change, Government of India, New Delhi, India; [4]The Energy and Resources Institute, India Habitat Center, New Delhi, India; [5]Madhya Pradesh Forest Department, Bhopal, India and [6]Center for Science and Environment, India Habitat Center, New Delhi, India

Correspondence
Yadvendradev Jhala
Email: jhalay@wii.gov.in

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Abstract

1. In a world where biodiversity is on the decline, examples of conservation success especially of large carnivores are of interest to policy makers and conservation practitioners. Herein, we elucidate the conservation actions that have been responsible for the recovery of tigers and their ecosystems in India; a feat many range countries are struggling to achieve.
2. Demand-driven poaching resulted in extinctions at two prestigious Tiger Reserves. India's Prime Minister constituted a Tiger Task Force that led to the formation of the National Tiger Conservation Authority, the Wildlife Crime Control Bureau, scientific monitoring of tiger populations and incentivized voluntary relocation of human settlements from tiger reserves. Tiger Conservation Plans, cognizant of constraints imposed by small reserves embedded in human land uses, aimed to create source populations within tiger reserves with corridor links between sources and to sink habitats. Metapopulation management enhanced occupancy and long-term viability of tiger populations. Tiger Protection Force and technology like MSTrIPES, E-eye and drones effectively reduced poaching. Community support was attempted through profit sharing, mitigating human–tiger conflict with a fast, fair and transparent compensation process and removal of problem tigers. Reintroduction and reinforcement of tigers and prey assisted natural recovery. Political will ensured resources.
3. Tigers were monitored using Spatially Explicit Capture–Recapture with camera traps and ecological covariates. In 2018–2019 from 381,000 km^2 of tiger habitat, 89,000 km^2 was occupied. Currently, 50 tiger reserves cover 72,750 km^2 and harbour 65% of India's ~3,000 tigers. Tiger reserves are managed with an annual investment of ~1,000 USD/km^2 with one staff per 6.5 km^2. Tiger reserves were regularly evaluated for Management Effectiveness. Tiger reserves were valued to have benefit flows between 76,900 and 292,300 US$ km^{-2}year^{-1}.

4. In the Anthropocene it is unlikely that tigers will survive without targeted conservation investments. Political commitment and resources can become available for conservation when people and tigers benefit simultaneously. Conscious balance by governments between development for rapid economic prosperity and long-term ecological security will ensure that wild tigers and their intact ecosystems will survive for future generations.

KEYWORDS
economic evaluation, global tiger population, incentivized voluntary village relocation, management effectiveness evaluation, reintroduction, tiger conservation plans, tiger reserves

1 | INTRODUCTION

At a time when global biodiversity faces one its worst crises due to human actions of habitat destruction, climate change, pollution and direct exploitation of species (Johnson et al., 2017), the lessons from any successful conservation program need to be widely shared so that its relevant features can be replicated elsewhere. The tiger *Panthera tigris*, an apex predator, that requires vast habitat to harbour viable populations, serves as an umbrella species for conserving Asia's forest systems. Tigers have declined globally due to direct hunting, prey depletion and habitat destruction (Wikramanayake et al., 2010). The continued illegal trade of tiger body parts and products driven by high demand in China and South East Asia threatens the species with extinction (Dinerstein et al., 2007). Taking cognizance of the dire situation facing wild tiger survival, world leaders and conservation practitioners met at St. Petersburg, Russia, in 2010 to discuss strategies for tiger recovery (Joshi et al., 2016). This event was a first in human history where country leaders met to discuss conservation of a species. The outcome was a Global Tiger Recovery Program, that outlined strategies that may be undertaken singly or jointly by range countries to increase tiger numbers from a global estimate of ~3,643 in the year 2010 to ~5,845 (Table S1 and data sources) by the year 2022 and to protect tiger habitats (Global Tiger Initiative, 2011). Without dwelling on the scientific merits of achieving such a target, and judging from the most recent status of tigers in range countries, global tiger numbers have increased to around 4,981 (4,232–5,781; Figure 1, Table S1). India leads amongst the few other countries (Bhutan, Nepal, Russia and Indonesia; Figure 1, Table S1) that have recovered wild tiger populations. Bangladesh has since corrected their baseline tiger population status using the

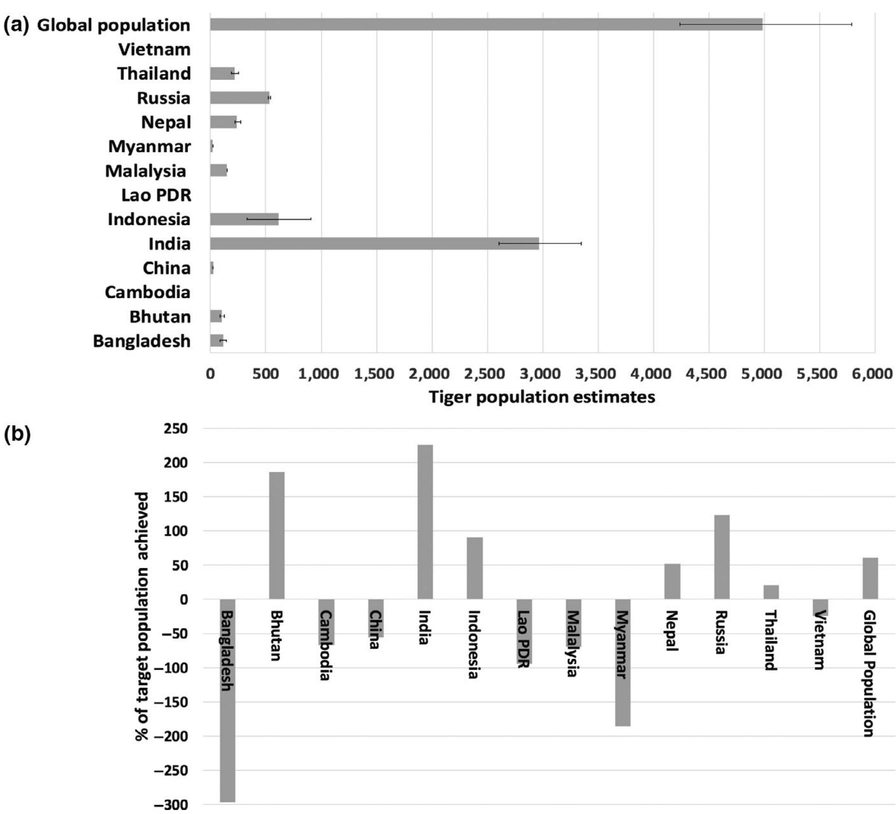

FIGURE 1 (a) Recent estimates of tiger numbers in range countries (see Table S1 and data sources); (b) Progress towards achieving the targeted tiger population number by range countries as depicted in the Global Tiger Recovery Plan. India and Bhutan have overachieved their targets while Nepal and Russia have made progress. Bangladesh has registered severe deficit due to an incorrect population baseline in 2010

modern scientific approach of spatially explicit capture–mark–recapture using camera traps (Borchers & Efford, 2008) to 106 (83–130) (Dey et al., 2015).

Herein, we provide a brief historical perspective, major conservation challenges, and highlight science-based policy and management strategies that have turned the tide for wild tiger conservation in India. Lastly, we outline the future actions required for conserving tigers and their ecosystems in India and elsewhere.

2 | HISTORICAL, RELIGIOUS AND CULTURAL PERSPECTIVE

Wildlife and tigers have been an integral part of Indian history, culture and religions. The most ancient records of tigers are found in the cave paintings of central India dated between 100,000 and 30,000 BP (Badam & Sathe, 1991). The seals and artefacts recovered from the civilizations of the Indus Valley depict tigers with the most ancient deity *Shiva* as *Pashupatinath* or the lord of animals (~5,000 YBP; Fairservis, 1983). The first Protected Areas in the world were declared in India by the Buddhist king Ashoka as *Abhaya Aranya* or 'forests without fear' around 250 BCE (Rangarajan, 2005). Several wild animals and plants, especially tigers are revered in religions that evolved within the Indian sub-continent (Hinduism, Jainism and Buddhism). These Eastern religions' doctrine of humans as *custodians* of nature that contrasts with the Abrahamic religious beliefs that promote humans to have *dominion* over nature (White, 1967). This philosophical mindset along with the concept of *Ahimsa* endows the society with a high level of tolerance towards all life forms that extends event to predators like tigers. This mindset is still the primary factor responsible for coexistence between high-density human populations and wildlife in India. However, this attitude is also responsible for sustaining a large population of feral livestock, dogs, and cats which are becoming a major problem for wildlife conservation. It was only after the colonial occupation of India that systematic removal of wildlife, including that of tigers, was undertaken by the Government through bounties and state sponsored actions (Rangarajan, 2005).

Modern conservation era began much after India's independence in the early 1970s, with the enactment of the Wildlife (Protection) Act (1972) (WPA, 1972). At the behest of J. C. Daniel and renowned ornithologist Salim Ali from the Bombay Natural History Society, the then Prime Minister of India, Indira Gandhi, took personal interest in tiger conservation and with assistance from the then World Wildlife Fund launched Project Tiger in 1973 as a central Government sponsored scheme in nine Protected Areas of India. The lion was subsequently replaced by the tiger as the national animal of India. India's tiger population was down to around 1,800 at the commencement of Project Tiger from a pre-colonial estimate of about 40,000 tigers (Panwar, 1982). The initial success of Project Tiger evaluated by the pugmark census technique put the figure to around 3,500 tigers by 1990s. This success brought in complacency in protection since legal hunting was banned in India and domestic market for tiger trophies was almost extinguished. However, during this period due to rapid economic growth in China and South East Asia (Milanovic, 2011), demand for tiger body parts for traditional medicine increased substantially. Owing to this increased demand, and after depletion of local tiger populations in China and SE Asia to unprofitable illegal harvest levels, tiger populations in India became the target for poachers. While India basked in the glory of Project Tiger (Panwar, 1982), tiger populations in India were steadily being decimated by demand driven poaching. In 1994–1995, tigers in the famous Ranthambore Tiger Reserve were reduced to a handful by poachers, but it was only after the local extinction of tigers at Sariska Tiger Reserve in 2005 and associated media coverage, that then Prime Minister, Dr. Manmohan Singh appointed a Tiger Task Force to address the tiger conservation crisis in India.

3 | TIGER CONSERVATION POLICY

The Tiger Task Force took cognizance of problems that plagued tiger conservation in India, some of that are universal across the range of the tiger, while others were unique to India. Tiger Task Force suggested implementable remedies through policy and management interventions (Narain et al., 2005). After a thorough research, the Tiger Task Force pinpointed major problems as systematic institutional failure, failure in protection due to alienation of poor local communities, misreporting of tiger numbers (Karanth et al., 2003), need for inviolate space for conservation, isolation of small Protected Areas and need for habitat connectivity—a landscape approach to tiger conservation planning, amongst others. The major recommendations of the Tiger Task Force were a paradigm shift for (tiger) conservation from being an *exclusion* model that alienated local communities to an *inclusive* one, where the local community became satisfied partners in conservation efforts. These recommendations led to the amendment of the Wildlife (Protection) Act of 1972 in 2006 (WPA, 1972 amendment 2006) by the Indian Parliament. The National Tiger Conservation Authority (NTCA) and the Wildlife Crime Control Bureau were created as statutory bodies. This transformed Project Tiger from a mere Central Government funding scheme to one of reciprocal commitments between the Center (NTCA), States (Chief Wildlife Wardens) and Tiger Reserves (Field Directors of tiger reserves). This relationship was operationalized by a legally binding memorandum of understanding between the three parties.

A landscape approach to management planning; with provisions for an inviolate core zone that houses a viable tiger source population, a buffer zone that may be a sink habitat, with permitted multiple uses and habitat corridors that connect tiger populations within a landscape, was mandated for all tiger reserves (Gopal et al., 2007). For making core areas free of human settlements and use (inviolate), a monetary package of INR one million (USD 13,300; a small fortune by Indian standards) was offered per adult in a family by Project Tiger as a package for incentivized voluntary relocation. A major lacuna that was identified by the Tiger Task Force was the mechanism and associated procedural delays of fund transfer from the central Government (Project Tiger) to the tiger reserves. To address this, a local repository of funds for each tiger reserve was created in the form of a Tiger Conservation Foundation. Profits emanating from tourism activities based on tigers were to be shared with buffer zone communities by the park management as well as by the tourism industry. A monitoring protocol for tigers, associated fauna and their habitat, that was scientifically robust yet practical for large scale surveys was designed, tested and recommended to be implemented every four years across India and every year for all tiger reserves (Narain et al., 2005).

4 | CONSERVATION MANAGEMENT

4.1 | Tiger reserves: Core, buffer and corridors

Currently, tigers occupy around 89,000 km^2 in India while forest area (potential habitat) within tigers' range is around 381,000 km^2 (Jhala et al., 2020). Thus, tigers were clearly limited by direct persecution and quality of their habitat (prey depletion). Of the total population of around 3,000 tigers in India 65% were within tiger reserves (Jhala et al., 2020). Although habitat was the least limiting factor yet, species like tigers can only thrive in legally protected human-free space. Such space in the form of core areas of tiger reserves is the most difficult requirement to secure in a densely populated, rapidly growing country like India. India has striven to increase areas gazetted as tiger reserves (Table S2). The current 50 tiger reserves cumulatively protect an area of 72,810 km^2 of which, 40,145 km^2 is *inviolate* core. The average size of tiger reserves was 1,456 km^2 but varied between 492 (Orang TR) and 5,907 km^2 (Amrabad and Nagarjunsagar Srisailam tiger reserves combined as they are adjacent). Core areas across 50 tiger reserves averaged at 803 km^2 and varied between 79 and 4,762 km^2 (Table S2). The principle was to establish source populations (in core areas of tiger reserve) within larger sink habitats (buffer zones of tiger reserves and forested habitats across the landscape) that would have low-density tiger occupancy. A demographically viable tiger population requires a minimum of ~20 breeding females which translates to a population of between 75 and 100 tigers (Bisht et al., 2019; Chapron et al., 2008; Gopal et al., 2007). In India, due to the possibility of achieving high ungulate density, an average breeding tigress could successfully rear cubs within a territory of 40–50 km^2. In some high prey density areas territories as small as 10–20 km^2 have been recorded for breeding tigresses (Y. Jhala & Q. Qureshi, unpubl. data; Sharma et al., 2010). A core area of 800–1,000 km^2 of a tiger reserve is the minimum required size to establish a source population. Many tiger reserves (42%) had core areas that could not potentially sustain 20 breeding females. Such tiger populations would remain viable only if they remained connected through habitat corridors as a metapopulation of two or more tiger reserves (Hanski et al., 1996). Tiger occupancy probability (Ψ) from across India was estimated through replicate ground surveys at every ~15 km^2 of forest patch and modelled using habitat, prey and human footprint indices. Habitat resistance to tiger movement was estimated as $1 - \Psi$ and corridors of least resistance between tiger reserves (protected areas) modelled using circuit theory in CIRCUITSCAPE (McRae et al., 2013). In central India, tiger movement across these corridors using non-invasive genetic sampling from 169 individual tigers was validated (Yumnam et al., 2014). All major habitat corridors connecting tiger populations within each landscape were modelled, mapped (Qureshi et al., 2014; Figure 2.) and made an integral part of the legally mandated Tiger Conservation Plan that contained site-specific prescriptions for management of core, buffer and corridor habitats. Such an NTCA-approved plan was made an essential requirement for each tiger reserve to receive funding support from the centrally sponsored scheme of Project Tiger as part of the tripartite memorandum of understanding. Habitat corridors traverse multiple land cover and land uses, many of which, were not under legal protection. The NTCA, through the legal power of a statutory body, has ensured that any land use change in a tiger corridor that is likely to have a barrier effect, requires approval from the National Board of Wildlife, and if approved, is usually implemented with appropriate mitigation. Linear infrastructure projects of national importance like roadways, railways, canals and pipelines often conflict with corridors and are usually cleared with mitigation measures of animal passage ways (Clevenger & Huijser, 2011).

4.2 | Operationalizing inclusiveness of communities

Forests and even many Protected Areas in India are inhabited by people who depend on forest resources to a large extent to eke out a living (Wani & Kothari, 2007). With increasing human population such a lifestyle is unsustainable and forests continue to degrade due to overuse. Communities living within Protected Ares are unable to readily access many basic modern amenities like hospitals, school and higher education, and markets for purchase and selling their produce. Their livelihoods are threatened by depredation of livestock by large carnivores and crops raided by wild ungulates. Therefore, when such communities are offered a genuine alternative, they are generally willing to resettle outside of the forest. Unfortunately, during the initial years of Project Tiger, forest dwellers from within tiger reserves were evicted forcibly and without just compensation or handholding with alternative/new livelihoods (Wani & Kothari, 2007). These bitter experiences combined with strict restrictions on resource use and extraction from within tiger reserves by managers had alienated communities living within and on the edges of reserves. These disgruntled evictees readily assisted or themselves indulged in poaching tigers. In the experience of several of us, without the assistance of local communities, it is difficult to poach tigers.

The reforms that changed the relationship between communities and tiger reserves were:

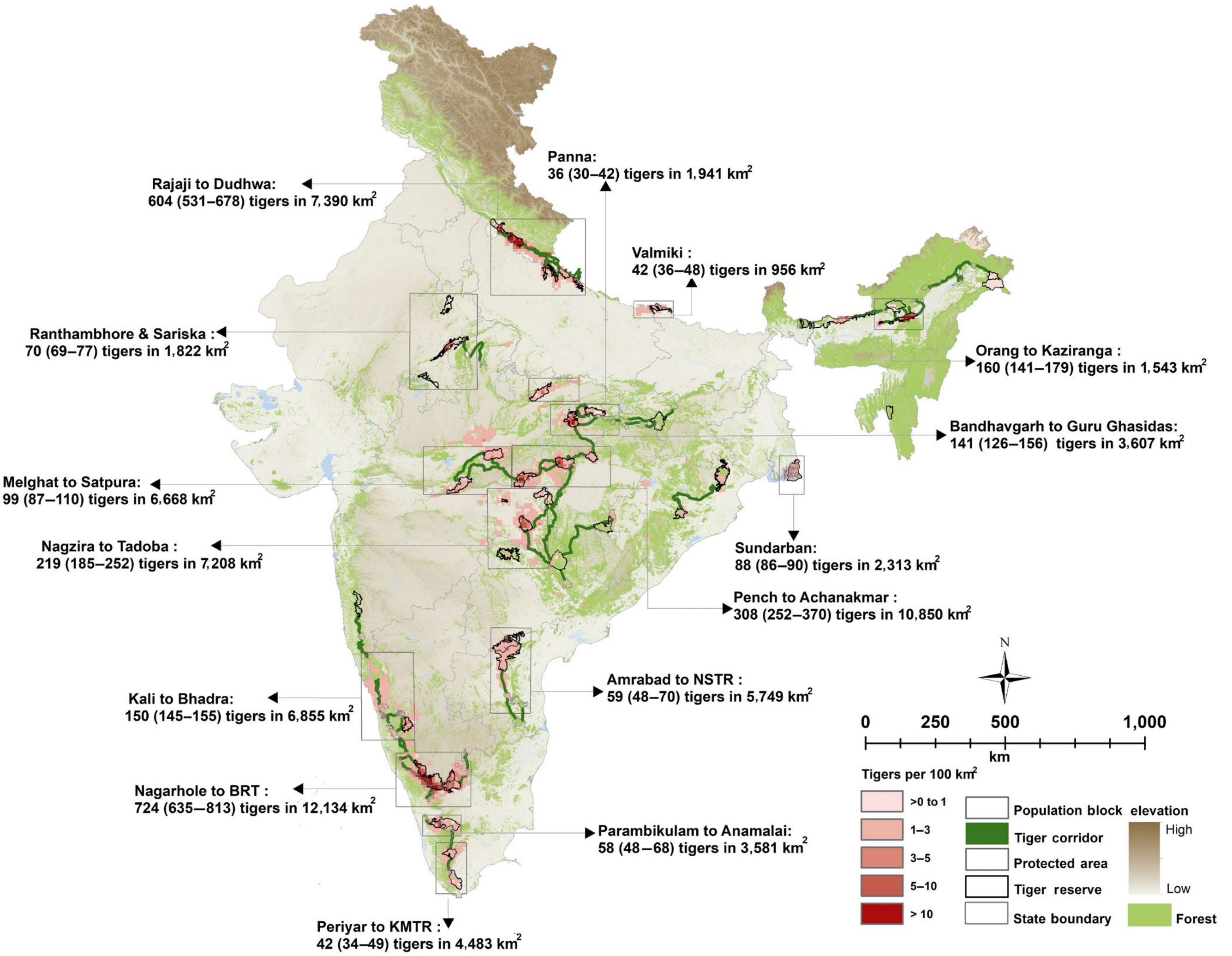

FIGURE 2 Tiger populations and density across occupied forests overlaid with habitat corridors connecting tiger reserves within each landscape (source: Jhala et al., 2020; Qureshi et al., 2014)

1. Incentivized voluntary relocation; In 2006 the Indian Parliament enacted the 'Forest Rights Act' (FRA, 2006) which made eviction of forest dwellers from Protected Areas illegal and the rights of communities to dwell and use forests as well as Protected Areas were legally recognized. However, if forest dwellers were to voluntarily relocate, there were no laws preventing them from doing so. The Wildlife Protection Act, 2006 amendment, made a provision for Project Tiger to incentivize relocation with a monetary package of INR one million per adult in the family to relocate from within the core areas of tiger reserves after the settling of their legal rights. This was an offer few forest dwellers could spurn, and many forest villages voluntary agreed to relocate outside the core. Project Tiger has since spent an average of 12.88 (*SE* 1.7) million USD per year for resettling people from core areas of tiger reserves to create inviolate space for tigers and their ecosystems (Figure S1). This monetary package from Project Tiger could be combined (and often is) with State funds and other packages offered to poorer sections of the society to provide land for agriculture, housing, electricity, water and basic amenities. Often the tiger reserve managers work with NGO's that specialize in handholding resettled communities, training them to engage with new livelihood options (Bharadwaj & Bharadwaj, 2020).
2. Sharing of revenues generated from tiger reserve gate receipts with communities residing in the buffer zone. The Tiger Task Force recommended that revenues generated from the tiger reserve by the Government as well as by the tourist industry should be shared with communities residing in the buffer zone. The prior practice was that all gate receipts were deposited with the State treasury and unavailable to the tiger reserve for its management. To circumvent this limitation Tiger Conservation Foundations were created for tiger reserves. Gate receipts, donations, funds for antipoaching activities (secret funds) could now be deposited with the tiger conservation foundation that were administered by a local committee with the Field Director of the tiger reserve as member secretary and representatives of local communities as committee members. Currently tiger conservation foundations are functional in 46 tiger reserves out of the 50 tiger reserves,

with the past five-year average annual income of each tiger conservation foundation amounting to 287,000 (*SE* 75,000) USD. Of this, on an average 40% of revenues generated by the tiger conservation foundations were to be used for buffer zone community welfare activities. Another 40% were used by the tiger reserve for enhancing protection. Tiger conservation foundations of all tiger reserves were not equally resourceful as some world-renowned tiger reserves attracted more funds (e.g. Ranthambore Tiger Reserve averages at 2.5 million USD income per year) compared to other tiger reserves. At the discretion of the State Chief Wildlife Warden and the tiger conservation foundation committees the surplus funds from better-resourced tiger conservation foundations could be used for activities in the buffer zones of other tiger reserves within the State. These additional resources directly emanating from tiger reserves to communities provide the required incentives to support the conservation initiatives and convert hostile neighbours into supporters.

4.3 | Improving protection

The Wildlife (Protection) Act 1972 is a very powerful legislation. It provides for penalties of 3–7 years of imprisonment and/or fine of INR 5,000 to 200,000 for the poaching of tigers. Winning over local communities does help in reducing poaching. However, given the fact of international market demand for tiger body parts, the incentive for poaching of tigers remains. Therefore, enforcement of law through patrols on the ground, use of modern technology that helps in apprehension of poachers, recording evidence that would stand the scrutiny of the legal process and result in conviction, are all equally important. The systemic failure referred to by the Tiger Task Force related to the Protection Agenda as well. Several vacancies (over 50%) of sanctioned posts of frontline staff of tiger reserves remained unfilled for years, guards were over-aged and physically unfit, and there were no mechanisms to ensure that guards actually patrolled their beats. To address these lacunas:

(a) Retired army personnel were engaged to form a Tiger Protection Force for a few tiger reserves. Equipped with arms and trained in their disciplined use, the Tiger Protection Force brought back the professional respect law enforcement had lost in the recent years. Vacancies were filled on priority within tiger reserves, with a current vacancy of 28.3%, the average ratio is of one management staff for every 6.5 km^2 area of a tiger reserve. The tripartite memorandum of understanding between NTCA, State Government and tiger reserves enabled NTCA to play a role in selecting and appointing the best suited officers from the Indian Forest Service to serve as Field Directors of tiger reserves.
(b) Appropriate training of frontline staff in crime investigation, collection of evidence, maintenance of custody and developing a (secret) network of informants for intelligence gathering were undertaken.
(c) Use of technology such as the E-eye, a sensor-based system of thermal, and visual cameras deployed along some sensitive borders of high-profile tiger reserves relayed real-time surveillance to tiger reserve managers and acted as major deterrent for poachers. In some tiger reserves surveillance was also done with drones. A pattern extraction and comparison software (ExtractCompare; Hiby et al., 2009) is used to develop and maintain a photo-database of about 100,500 camera trap tiger photos of about 8,000 individual tigers from the region (India, Nepal, and Bangladesh) at the Wildlife Institute of India (WII) since 2008. Tiger skins seized by law enforcement agencies from the illegal market are matched with camera trap images using ExtractCompare to identify poaching hotspots and trade routes.
(d) A mobile phone GPS-based patrolling application MSTrIPES (Monitoring System for Tigers Intensive Protection and Ecological Status), was developed and implemented across all tiger reserves. This application ensured that guards actually patrolled with the required spatial coverage and were incentivized with appropriate recognition for their efforts. The MSTrIPES allowed for optimization of patrols in space by identifying vulnerable areas through analysis of information collected by patrols and ecological evaluation.
(e) The effective implementation of law enforcement and inter-agency coordination within India and abroad orchestrated by the Wildlife Crime Control Bureau led to the deciphering of the illegal wildlife trade nexus. Arrests and convictions of major players in this nexus (http://wccb.gov.in/Content/Convicts.aspx) led to the break-down of the illegal trade in parts and products of tigers and further reduced poaching.

4.4 | Mitigating conflict

Ideally, it would be best not to mix humans and wildlife (especially large carnivores like tigers) through zoning (Linnell et al., 2012). However, in densely populated countries like India availability of sufficient exclusive space to maintain viable populations of large carnivores is difficult and coexistence becomes an essential strategy for effective conservation (Woodroffe et al., 2005, 2014). The only exclusive space available for the global population of Asiatic lions is a 250 km^2 Gir-National Park, that is of insufficient size to hold a viable lion population. Around 500 lions coexist with humans in >10,000 km^2 of Saurashtra's agro-pastoral–industrial landscape (Jhala et al., 2019).

Conflict is inevitable when humans and wildlife mix; crop raiding by wild ungulates, predation on livestock, attacks on humans and human deaths by large carnivores are major concerns which need to be effectively managed to prevent retaliation (Jhala et al., 2019). Although most States in Indian pay compensation for crop, livestock and human losses to wildlife, these were not free from corruption nor fair in relation to market prices of crops and livestock (Banerjee et al., 2013; Johnson et al., 2018). More recently attempts have been made to dispense compensation that is fair, transparent and corruption-free using mobile phone application-based documentation for authentication of claims and tracing of document processing with direct payment to the recipient's bank account. A quick, handsome monetary compensation dispensed with sensitivity helps ameliorate immediate anger and retaliation.

Compensation for human deaths ranged between 200,000 and 1,000,000 INR as Project Tiger compensation funds were often supplemented with state funds. The highest compensation was paid by the state of Maharashtra at one million INR for a human death. No amount of money can compensate loss of human lives, yet, very high compensation amounts for human deaths can lead to complacency in traditional precautionary systems and false claims of deaths attributed to tigers, especially amongst poverty riddled populations (Jhala & Sharma, 1997). Tigers were responsible for an average of 38 (*SE* 4) human deaths each year for the past 10 years in India. Tigers in the Sundarban tiger reserve (25%), from the Vidharbha region of Maharashtra (25%) and from around Pilibhit-Dudhwa tiger reserves (20%) accounted for 70% of all human deaths. Eleven tigers were eliminated (shot) in eight years (1.4, *SE* 0.46 tigers year^{-1}) from the wild for being threat to human lives. As per the standard operating procedure (SOP) prescribed by NTCA (https://ntca.gov.in/documents/#sop1) a tiger is to be removed from the wild (preferably captured) if it was found responsible for deliberate and consistent human attacks. Most attacks on humans were accidental when humans ventured into tiger habitat in search of non-timber forest produce. However, some tigers did become man eaters and it was only these individuals that were eliminated. A rapid response team constituted by a trained veterinarian and field staff, equipped with safe and rapidly acting anaesthetic drugs, good darting equipment, medical emergency kit and four-wheel drive vehicle was deployed at most tiger reserves or at the State level covering multiple tiger populations to address human–tiger (wildlife) conflict situations. With the advent of camera traps identifying problem tigers with some level of certainty has become easier. Nowhere else in the world is an individual animal involved in an attack on a human (be it accidental, provoked or deliberate) given a second chance. This was possible in India, perhaps due to the high tolerance level amongst the people due to cultural and religious reverence towards tigers. However, with tiger density increasing in multiple use areas, conflicts are on the increase and it may soon become necessary to implement population management either through capture and translocation or through reproductive control. Site-specific strategies would be required for tigers of the Vidharbha landscape and for tigers inhabiting sugarcane plantations around Pilibhit tiger reserve. These populations pose exemplary problems that need planned mitigation for managing conflict caused by locally over abundant tigers. Such problems are likely to increase as conservation measures become more successful within reserves, and there is a scope of increasing tiger density in the surrounding human dominated landscapes due cropping patterns that provide cover and domestic livestock that provide alternate prey.

4.5 | Reintroductions and supplementation

In 2005 and 2009 India witnessed two local extinctions of tigers in its prestigious Sariska and Panna tiger reserves due to poaching. Subsequently, two (one male and female) tigers were initially reintroduced to Sariska in 2008, and three (one male and two females) to Panna in 2009 (Table S3). The reintroduction program in Panna tiger reserve recorded better growth in the tiger population (40.8%) compared to that of Sariska tiger reserve (16% Table S3) perhaps due to more inviolate space available and less human disturbance in Panna compared to Sariska tiger reserve. Tiger supplementation was attempted in Satkosia tiger reserve in 2018 but it failed due to community opposition and poor status of tiger prey. Tigers have been successfully reintroduced in Nauradehi wildlife sanctuary and translocated to Satpura tiger reserve so as to reinforce low tiger density areas by the Madhya Pradesh Forest Department.

Tiger reintroductions/reinforcements attempted in India were done using (a) wild tigers captured and introduced into the wild at another site, (b) hand reared tigers introduced into the wild and (c) orphaned or abandoned cubs cared for in-situ by food supplementation and veterinary care. The survival beyond first year of wild tigers ($n = 27$; survival 72%) did not differ from that of hand reared tigers ($n = 13$; survival 77%) introduced to the wild. All cubs ($n = 7$) assisted in-situ by supplementation of food survived beyond the first year. Successful reproduction in the wild after introduction was recorded in 50% ($n = 12$), 55% ($n = 9$) and 75% ($n = 4$) of wild, hand reared and supplemented tigresses respectively. The success of introductions was not dependent on the origin (hand reared vs. wild caught) of the tiger being introduced, but more on the conditions at the site of the introduction. Introductions were more successful in areas with no or low tiger density, good prey density, good law enforcement mechanisms and friendly neighbouring communities. Introduction of tigers should be done only after proper assessment of these factors and only after these conditions are found to be optimal. Considering a kill rate of one medium-sized ungulate (50–80 kg) every 3–4 days by an adult tiger and realized finite growth rate (λ) of ~1.3 for ungulates (Duncan et al., 2007), as a thumb rule 450 ungulates to one adult tiger was considered as a minimum prey requirement (see Fuller, 1989). For reintroduction to be considered at a site, sufficient prey for at least 12–15 tigers was considered a prerequisite at the site (Table S3). With good protection and management, depressed prey populations at such sites would increase further along with the introduced tigers. Once reintroduced tigers start to breed, reintroduction programs often do not follow-up with continued reinforcement of additional tigers as per the reintroduction plan, resulting in poor genetic diversity in these newly established populations. Immigration, either natural through corridors, or through managed reinforcement is essential for long-term survival of these tiger populations.

4.6 | Assessment and monitoring

The four-yearly monitoring of tiger status based on modern animal abundance estimation science commenced since 2006, and covers all potential tiger bearing forests of India (~381,000 km^2). The monitoring protocol also evaluates the status of co-predators, prey and habitat. The protocol involves ground surveys by ~44,000 personnel who now collect information using mobile phone GPS enabled application MSTrIPES (Ecological module) in an occupancy (MacKenzie et al., 2017) and distance sampling framework (Buckland et al., 2005). Spatial sampling units consist of forest beats (~15 km^2) or 25 km^2 grids (Jhala et al., 2020). Spatially explicit data are digitally recorded with photo-evidence of wildlife signs stamped with date, time and geographic coordinates, that are sampled as occupancy surveys; ungulate sightings on line transects; vegetation, pellet density and human disturbance are sampled on plots. Subsequently, camera traps are used to obtain data on photo-captures that are analysed in a spatially explicit capture–recapture framework (Borchers & Efford, 2008) to estimate densities of tigers and leopards. While for other species relative abundance is indexed (RAI) using number of independent photo-events corrected for sampling effort (trap-nights). All potential tiger habitats (tiger reserves, protected areas, reserve forests, protected forests and revenue forests) from all tiger occupied States were surveyed in 2006, 2010, 2014 and 2018 (Table S4). Though camera trap sampling coverage has increased over the years, tiger population has been estimated (using covariates) almost across the entire occupied range of tigers for each assessment [except in 2006 when Sundarban Landscape (accounting for ~75–80 tigers) was not assessed]. For the 2018–2019 assessment 26,838 camera trap locations were sampled that resulted in 34,858,623 photographs of which, 76,651 photographs were of tigers. This effort has been acknowledged as a Guinness world record (https://www.guinnessworldrecords.com/world-records/601784-largest-camera-trap-wildlife-survey). ExtractCompare software (Hiby et al., 2009) was used to identify 2,461 individual tigers (excluding cubs) from these photo-captures for the 2018–2019 survey. Spatially explicit capture–recapture analysis using covariates of prey, human impacts and habitat estimated the tiger population to be 2,967 (*SE* range 2,603–3,346). Considering only the consistently assessed areas for all four population estimation cycles, the tiger population across India has been growing at a rate of 6 (*SE* 0.6) % per annum (Figure S1). Besides the four-yearly national assessment, all tiger reserves (harbouring ~65% of India's tiger population) are monitored each year through camera traps to estimate the minimum number of tigers and thereby keep the pulse of all source populations on a shorter time span.

Tiger recovery was not uniform across landscapes. Western *Terai*, parts of central India and central Western Ghats recorded good recovery. While eastern parts of central India (states of Chattisgarh, Jarkhand, Odisha) and Northern West Bengal recorded declines in tiger status (Figure 2). Tiger status recovery in Northern Western Ghats, and North Eastern Hills has been slow and requires focused investments for community benefits and protection. India now houses eight populations that have over 100 tigers each (Figure 2). The two largest tiger populations are in the central Western Ghats and western *Terai* landscape each having over 700 and 600 tigers respectively (Figure 2). Each of these populations has more tigers than any other single range country (Table S1). Incidentally, the largest Asiatic elephant *Elephas maximus* populations too are found in these two habitats, highlighting the umbrella role of tiger conservation. The strategy of prioritizing conservation of tiger source populations within each landscape and simultaneously connecting these sources amongst themselves and sink habitats through corridors, has resulted in tiger occupancy across suitable habitats within landscapes and helped recover these populations (Bisht et al., 2019; Walston et al., 2010).

Since substantial investment goes into tiger reserves, these reserves were evaluated for their management effectiveness every four years since 2006, by a team of independent evaluators. Tiger reserves are evaluated for 34 criteria covering the themes of status, appropriateness, resources, efficiency of effectiveness, outputs and outcomes following Hockings et al. (2006). Tiger reserves management effectiveness performance (Figure S2, and data sources) was then discussed with the tiger reserve managers and State bureaucrats in an open forum along with NTCA officials and Wildlife Institute of India scientists, resulting in adaptive management. High performing tiger reserves are acknowledged and awarded at international or national conservation events. This recognition of good management amongst peers encourages managers to perform better and the management effectiveness exercise brings to light resource, logistic and infrastructural limitations that can then be addressed by the State and NTCA. An improvement in the current management effectiveness assessment would be a move towards more objective quantitative data-based assessment (Hockings et al., 2009) using MSTrIPES-generated data on law enforcement and ecological indicators.

Often Protected areas are considered as lacking sufficient economic justification by politicians, legislators and bureaucrats especially in countries like India where there is a high demand for land due to dense human population and poverty. In such cases, it becomes difficult to justify setting aside large areas as tiger reserves where *usual* extractive human use is prohibited. However, when tiger reserves are valued in terms of their economic contribution and are shown to be competitive in terms of monetary gains compared with other economic activities, it becomes easier to convince the decision makers of their importance. Select tiger reserves were evaluated for their tangible economic value based on standing crop, carbon sequestering, employment generation, direct profits and ecosystem services, amongst other values that could be monetized (Costanza et al., 2014). Based on these evaluations the value of annual flow of benefits from a tiger reserve ranged between 76,900 and 292,300 US$/km^2 (Verma et al., 2017). The language of economics appeals to decision makers and if appropriate safe-guards and caveats (to ensure that monetary value is not the sole criteria for evaluating Protected Areas) are appropriately communicated, support for tiger reserves is garnered across most sections of the society.

5 | WAY AHEAD

Within India, tiger conservation efforts and the associated increase in tiger populations is not evenly distributed across tiger habitats.

In many tiger habitats such as the North Eastern Hills bordering Myanmar, and in the states of Odisha, Jharkhand and Chhattisgarh, forest communities still consume bushmeat. In these areas, forests are almost devoid of wild prey and therefore of tigers. Wild ungulates are often poached here with the use of snares that do not discriminate between species, often killing large carnivores like tigers as well. Some tiger habitats in these same states are strongholds of left-wing extremist element (Naxalites) making management activities difficult to implement. Once habitats within these States are restored to law and order, and communities made economically secure they may be weaned off bushmeat. Prey and subsequently tigers would respond and recover since the habitat is good. Some biodiversity-rich and promising areas like Guru Ghasidas National Park, in this landscape, would benefit from focused conservation investment and should be notified as a Tiger Reserve. This would allow resources of Project Tiger to be accessed for incentivized voluntary relocation, community upliftment activities, prey and predator population reinforcement, amongst other activities that will hasten ecosystem recovery. Once prey populations are restored, another 1,000–1,500 tigers can be accommodated in these regions.

The establishment of Tiger Conservation Foundations, sharing of tiger-profits with buffer zone communities, and a handsome package for incentivized voluntary relocation have gone a long way in winning over local communities. Yet, more needs to be done for the communities that actually bear the costs associated with tiger conservation, especially when tiger populations expand beyond protected areas. Tiger and associated eco-tourism have a lot to offer in this regard. Besides a few jobs, profits rarely percolate to local communities from the tourist industry. Community-based home stays with a menu of options like trail walks, birding, night safari and campfire-based activities in the buffer zone and outside tiger reserves (which are prohibited in the core zone of tiger reserves) hold promise of attracting a different clientele of wildlife tourists, those who seek a greater immersion in the experience of the wilderness. Communities were observed to be more tolerant to carnivore damage and even encouraged large carnivores in their neighbourhood if they could realize remunerative livelihoods from them (Jhala et al., 2019). Village consortiums that manage their lands for wildlife values and have rights to earn revenues from wildlife resources on their lands would be a major conservation paradigm shift for India (Jhala et al., 2019). Some states like that of Rajasthan, have yet to enact legislation that transfers gate receipts of Tiger Reserves directly to Tiger Conservation Foundations instead of the State treasury. The monetary package of one million Rupees for incentivized voluntary relocation requires enhancement to keep pace with inflation and cost escalations.

Implicit in the efforts for conserving wild tigers are the objectives that tigers survive not only as a species but more importantly, that they continue to play their ecological role as top-predators and retain their evolutionary potential. This entails conserving intact ecosystems at landscape scales. Tigers across their range are currently struggling to survive, it is only in a few well-protected areas, that ecosystems are still intact for tigers to perform their ecological role. The IUCN Cat Specialist Group (Kitchener et al., 2017) has lumped the erstwhile five extant mainland tiger subspecies into one subspecies with two management units. Yet, tigers vary phenotypically (Figure 3), ecologically and behaviourally inhabiting diverse

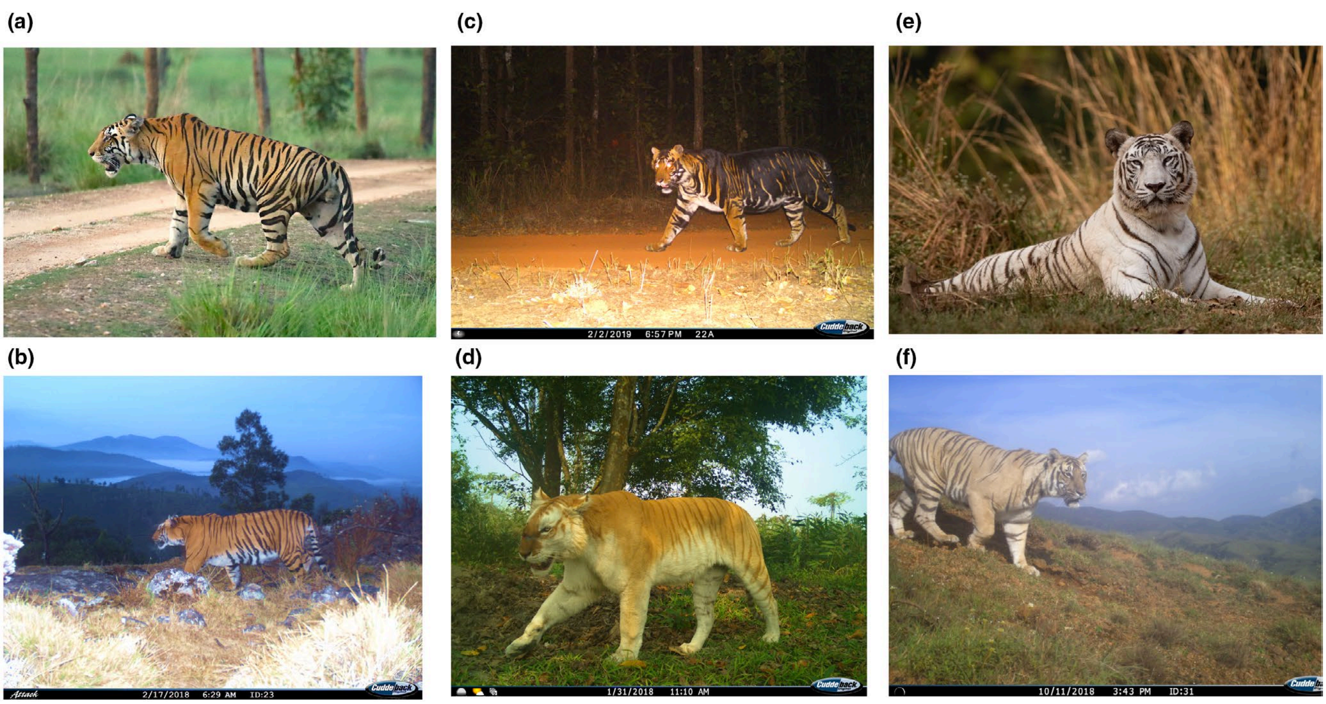

FIGURE 3 Phenotypic variation in coat colours observed in Indian tigers: (a & b) Normal coat colour tiger from central India, (c) Pseudomelenistic tiger from Simlipal tiger reserve, (d) Golden tiger from Kaziranga tiger reserve, (e) White tiger in captivity whose ancestral origin was from the Rewa forests near Sanjay tiger reserve, (f) Light coat variant (almost white) from Western Ghats

habitats, and predating different prey. There is sufficient evidence to suggest genetic differences amongst them due to vicariant events and local selection (Luo et al., 2019). For retaining the evolutionary potential of tigers as a species, we should strive to conserve the entire extant genepool, range of habitats, behaviours that are culturally inherited, and manage populations so as to retain their unique evolutionary trajectories while mitigating fragmentation caused by human activities. Based on genetic diversity, divergence and vulnerability to extinction, tiger populations have been prioritized for conservation within India (Kolipakam et al., 2019). Tiger populations of the North Eastern Hills and those of Southern Western Ghats were considered a conservation priority based on these criteria (figure 6 in Kolipakam et al., 2019). The NTCA has a standard operating procedure for guiding tiger reserve managers on sourcing tigers for reintroductions and supplementation (https://ntca.gov.in/documents/#sop1) so as to retain local adaptations while attempting to prevent inbreeding. A global conservation priority analysis of this kind is likely to prioritize tiger subspecies *P. t. crobetti* and *P. t. jacksoni* since populations of these two subspecies are genetically distinct and precariously low.

India has managed to increase its adult tiger population from around 1,700 in 2010 to about 3,000 by 2019 with tigers currently occupying close to 90,000 km^2. This is no minor feat by global standards (Figure 1), since many tiger range countries that are economically better off than India, have recorded declines in their tiger populations and occupied range. Tiger conservation is no *rocket science*, the road towards recovery begins with the acknowledgement of problems and subsequent management on the scientific principles of conservation biology. Misinformation regarding tiger population numbers by the park authorities, that were subsequently defended by the State bureaucracy led to poaching-driven extinctions in Sariska and in Panna tiger reserve (Chundawat, 2018; Narain et al., 2005). India, Nepal and Bangladesh took a bold step and corrected their national tiger population estimates based on science in 2008, 2011 and 2015 respectively (Table S1). Many range countries still rely on erroneous or misinformed tiger estimates that are obtained through unreliable methods (Table S1). Often the inertia to acknowledge a problem by various levels of bureaucracy makes efficient and timely conservation interventions difficult.

Major credit for India's tiger recovery can be attributed to a multidisciplinary approach fostered by trust and team spirit between wildlife managers, bureaucrats, activists, scientists and legislators. However, conservation practitioners need to put in more effort so as to mainstream biodiversity concerns with the agenda of other government agencies like mining, roadways, electricity, irrigation, public works development agency, etc. Often the objectives of these agencies clash with those of conserving tigers and their ecosystems. It is absolutely essential to engage with and sensitize these public sectors regularly to conservation needs, so that one arm of the government does not undo what the other does, using the same public funds.

The reforms mentioned above would not have been possible without the political will at the highest level of Governance. This commitment to conservation of India's national animal as a flagship and umbrella for the ecosystems it inhabits, transcends political party lines. In the previous decade, Prime Ministers Manmohan Singh and Narendra Modi have shown their commitment towards tiger conservation and pledged resources to make it a reality on the ground. Range countries need to ensure that tiger (and biodiversity) conservation becomes a priority national agenda with appropriate funds allocated by Governments. Funding from national and international conservation agencies/NGO's, although important, should target specific weak links where Governments find it difficult to use public funds. In the post COVID pandemic scenario, a depressed global economy will put huge pressures on tiger habitats, some of which, are rich with coal and mineral deposits. International funding support, for this conservation-dependent species becomes even more important in this period of crisis, when national funding priorities of most range countries will likely shift towards exploitative development activities. How India and other tiger range countries manage to balance their economic growth without compromising the conservation of their natural heritage and ecological security, will decide the fate of wild tigers.

Currently, tigers across their range are primarily threatened by direct poaching and secondly by prey depletion (Chapron et al., 2008). As long as there is a demand for tiger parts and products, there will be poachers who will be willing to take high risks. The global community needs to build pressure to eradicate the demand for wildlife parts and products, especially in light of the current pandemic that has likely arisen due to this trade that not only threatens endangered species but even puts human survival at risk.

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CONFLICT OF INTEREST

P.G. served as Secretary Ministry of Environment, Forest & Climate Change, Govt. of India; Economic Advisor and Additional Secretary to the Prime Minister. S.N. is an environmentalist and political activist; heads the Centre for Science and Environment and Society for Environment Communications; editor Down to Earth, Chair of the Tiger Task Force 2005. R.G. is the Director General Global Tiger Forum; served as Director of Project Tiger and NTCA and as Field Director of tiger reserves. S.P.Y. is the Additional Director General Project Tiger and Member Secretary NTCA. H.S.N. served as a Field Director in tiger reserves and Inspector General NTCA. A.M. served as a Field Director in tiger reserves and Inspector General NTCA. V.M. is an Assistant Inspector General NTCA. RGar has been a Field Director in a tiger reserve and Additional Inspector General NTCA. Q.Q. is a Professor at the Wildlife Institute of India. Y.J. is the Dean and Professor at the Wildlife Institute of India. The authors declare no additional conflicts of interest.

AUTHORS' CONTRIBUTIONS

R.G.: provided information, designed policy and implemented reforms through NTCA. P.G.: Guided legislation to incorporate tiger conservation policy reforms, critical edits of MS. S.N.: Chaired the

Tiger Task Force, conceived tiger conservation policy reforms. V.M.: Implemented reforms and provided information from NTCA. H.S.N.: Field implementation of conservation reforms, provided information for MS. S.P.Y.: Implemented legal mandate through NTCA and provided information. A.M.: As tiger reserve manager and NTCA official implemented reforms and provided information. R.G.: As tiger reserve manager and NTCA official implement reforms and provided information. Q.Q.: Scientific support for monitoring and conservation policy, provided information for the MS. Y.J.: Conceived the paper, analysed information and wrote the MS; provided technical and scientific support for tiger conservation policy and monitoring. All authors read and commented on the MS.

DATA AVAILABILITY STATEMENT

No primary data were generated for this study. All data sources are appropriately cited in the paper.

ORCID

Yadvendradev Jhala https://orcid.org/0000-0003-3276-1384
Qamar Qureshi https://orcid.org/0000-0003-3469-6993

REFERENCES

Badam, G. L., & Sathe, V. G. (1991). Animal depictions in rock art and palaeoecology—A case study at Bhimbetka, Madhya Pradesh, India. In S. A. Pager, B. K. Swatrz Jr, & A. R. Willcox (Natal) (Eds.), *Rock art—The way ahead: South African rock art research association first international conference proceedings* (pp. 196–208). Natal.

Banerjee, K., Jhala, Y. V., Chauhan, K. S., & Dave, C. V. (2013). Living with lions: The economics of coexistence in the Gir forests, India. *PLoS ONE*, *8*(1), e49457. https://doi.org/10.1371/journal.pone.0049457

Bharadwaj, A., & Bharadwaj, A. K. (2020). *Best practices for resettlement of communities from protected areas – A case study of Satpura Tiger reserve, Madhya Pradesh, Wildlife Institute of India, Dehradun, India*. Retrieved from https://wii.gov.in/images/images/documents/publications/rr_2020_best_practices_resettl_str.pdf

Bisht, S., Banerjee, S., Qureshi, Q., & Jhala, Y. (2019). Demography of a high-density tiger population and its implications for tiger recovery. *Journal of Applied Ecology*, *56*(7), 1725–1740. https://doi.org/10.1111/1365-2664.13410

Borchers, D., & Efford, M. (2008). Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics*, *64*, 377–385. https://doi.org/10.1111/j.1541-0420.2007.00927.x

Buckland, S. T., Anderson, D. R., Burnham, K. P., & Laake, J. L. (2005). Distance sampling. *Encyclopedia of Biostatistics*, *2*, 1–6. https://doi.org/10.1002/0470011815.b2a16019

Chapron, G., Miquelle, D. G., Lambert, A., Goodrich, J. M., Legendre, S., & Clobert, J. (2008). The impact on tigers of poaching versus prey depletion. *Journal of Applied Ecology*, *45*(6), 1667–1674. https://doi.org/10.1111/j.1365-2664.2008.01538.x

Chundawat, R. S. (2018). *The rise and fall of the emerald tigers*. Speaking Tiger Publishing Pvt. Ltd. ISBN 978-93-86582-65-2.

Clevenger, A. P., & Huijser, M. P. (2011). *Wildlife crossing structure handbook: Design and evaluation in North America*. Federal Highway Administration, Central Federal Lands Highway Division, USA. No. FHWA-CFL-TD-11-003.

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Dey, T. K., Kabir, M. J., Ahsan, M. M., Islam, M. M., Chowdhury, M. M. R., Hassan, S., Roy, M., Qureshi, Q., Naha, D., Kumar, U., & Jhala, Y. V. (2015). Wildlife Institute of India and Bangladesh Forest Department, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh. Retrieved from https://bforest.portal.gov.bd/sites/default/files/files/bforest.portal.gov.bd/page/a0c8004a_4699_4467_a009_af893261a710/Tiger%20Status%20Report.pdf

Dinerstein, E., Loucks, C., Wikramanayake, E., Ginsberg, J., Sanderson, E., Seidensticker, J., Forrest, J., Bryja, G., Heydlauff, A., Klenzendorf, S., Leimgruber, P., Mills, J., O'Brien, T. G., Shrestha, M., Simons, R., & Songer, M. (2007). The fate of wild tigers. *BioScience*, *57*(6), 508–514. https://doi.org/10.1641/B570608

Duncan, R. P., Forsyth, D. M., & Hone, J. (2007). Testing the metabolic theory of ecology: Allometric scaling exponents in mammals. *Ecology*, *88*(2), 324–333.

Fairservis, W. A. (1983). The script of the Indus Valley civilization. *Scientific American*, *248*(3), 58–67. https://doi.org/10.1038/scientificamerican0383-58

FRA. (2006). *Forest Rights Act*. Ministry of Tribal Affairs, Government of India, New Delhi. Retrieved from https://tribal.nic.in/FRA/data/FRARulesBook.pdf

Fuller, T. K. (1989). Population dynamics of wolves in north-central Minnesota. *Wildlife Monographs*, *105*, 3–41.

Global Tiger Initiative. (2011). *Global tiger recovery program 2010–2022*. Global Tiger Initiative (GTI).

Gopal, R., Sinha, P. R., Mathur, V. B., Jhala, Y. V., & Qureshi, Q. (2007). *Guidelines for preparation of tiger conservation plan*. National Tiger Conservation Authority, Ministry of Environment and Forests, Government of India.

Hanski, I., Moilanen, A., & Gyllenberg, M. (1996). Minimum viable metapopulation size. *The American Naturalist*, *147*(4), 527–541.

Hiby, L., Lovell, P., Patil, N., Kumar, N. S., Gopalaswamy, A. M., & Karanth, K. U. (2009). A tiger cannot change its stripes: Using a three-dimensional model to match images of living tigers and tiger skins. *Biology Letters*, *5*(3), 383–386. https://doi.org/10.1098/rsbl.2009.0028

Hockings, M., Stolton, S., Dudley, N., & James, R. (2009). Data credibility: What are the "right" data for evaluating management effectiveness of protected areas? *New Directions for Evaluation*, *122*, 53–63.

Hockings, M., Stolton, S., & Leverington, F. (2006). *Evaluating effectiveness: A framework for assessing management effectiveness of protected areas*. IUCN.

Jhala, Y. V., Banerjee, K., Chakrabarti, S., Basu, P., Singh, K., Dave, C., & Gogoi, K. (2019). Asiatic lion: Ecology, economics and politics of conservation. *Frontiers in Ecology and Evolution*, *7*, 312. https://doi.org/10.3389/fevo.2019.00312

Jhala, Y. V., Qureshi, Q., & Nayak, A. (Eds.). (2020). *The status of tigers, co-predators and prey in India 2018*. National Tiger Conservation Authority, Government of India, New Delhi and Wildlife Institute of India Dehradun. ISBN 81-85496-50-1.

Jhala, Y. V., & Sharma, D. K. (1997). Child lifting by wolves in eastern Uttar Pradesh, India. *Journal of Wildlife Research*, *2*(2), 94–101.

Johnson, C. N., Balmford, A., Brook, B. W., Buettel, J. C., Galetti, M., Guangchun, L., & Wilmshurst, J. M. (2017). Biodiversity losses and conservation responses in the Anthropocene. *Science*, *356*(6335), 270–275. https://doi.org/10.1126/science.aam9317

Johnson, M. F., Karanth, K. K., & Weinthal, E. (2018). Compensation as a policy for mitigating human-wildlife conflict around four protected areas in Rajasthan, India. *Conservation and Society*, *16*(3), 305–319.

Joshi, A. R., Dinerstein, E., Wikramanayake, E., Anderson, M. L., Olson, D., Jones, B. S., Seidensticker, J., Lumpkin, S., Hansen, M. C., Sizer, N. C., Davis, C. L., Palminteri, S., & Hahn, N. R. (2016). Tracking changes and preventing loss in critical tiger habitat. *Science Advances*, *2*(4), e1501675. https://doi.org/10.1126/sciadv.1501675

Karanth, K. U., Nichols, J. D., Seidenstricker, J., Dinerstein, E., Smith, J. L. D., McDougal, C., Johnsingh, A. J. T., Chundawat, R. S., & Thapar, V. (2003). Science deficiency in conservation practice: The monitoring of tiger populations in India. *Animal Conservation*, *6*(2), 141–146.

Kitchener, A. C., Breitenmoser-Würsten, C., Eizirik, E., Gentry, A., Werdelin, L., Wilting, A., Yamaguchi, N., Abramov, A. V., Christiansen, P., Driscoll, C., & Duckworth, J. W. (2017). A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN Cat Specialist Group. *Cat News*.

Kolipakam, V., Singh, S., Pant, B., Qureshi, Q., & Jhala, Y. V. (2019). Genetic structure of tigers (*Panthera tigris tigris*) in India and its implications for conservation. *Global Ecology and Conservation*, *20*, e00710. https://doi.org/10.1016/j.gecco.2019.e00710

Linnell, J. D., Odden, J., & Mertens, A. (2012). Mitigation methods for conflicts associated with carnivore depredation on livestock. In L. Boitani, & R. A. Powell (Eds.), *Carnivore ecology and conservation: A handbook of techniques* (pp. 314–332). Oxford University Press.

Luo, S. J., Liu, Y. C., & Xu, X. (2019). Tigers of the world: Genomics and conservation. *Annual Review of Animal Biosciences*, *7*, 521–548. https://doi.org/10.1146/annurev-animal-020518-115106

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L., & Hines, J. E. (2017). *Occupancy estimation and modelling: Inferring patterns and dynamics of species occurrence*. Elsevier.

McRae, B. H., Shah, V. B., & Mohapatra, T. K. (2013). *Circuitscape 4 user guide*. The Nature Conservancy. Retrieved from http://www.circuitscape.org

Milanovic, B. (2011). *Worlds apart: Measuring international and global inequality*. Princeton University Press.

Narain, S., Panwar, H. S., Gadgil, M., & Singh, S. (2005). *Joining the dots: The report of the Tiger Task Force*. Project Tiger Directorate, Union Ministry of Environment, Government of India, New Delhi.

Panwar, H. S. (1982). What to do when you've succeeded: Project Tiger ten years later. *Ambio*, *11*(6), 330–337.

Qureshi, Q., Saini, S., Basu, P., Gopal, R., Raza, R., & Jhala, Y. V. (2014). *Connecting tiger populations for long-term conservation*. National Tiger Conservation Authority and Wildlife Institute of India, Dehradun. TR 2014–02.

Rangarajan, M. (2005). *India's wildlife history: An introduction*. Orient Blackswan.

Sharma, R. K., Jhala, Y., Qureshi, Q., Vattakaven, J., Gopal, R., & Nayak, K. (2010). Evaluating capture–recapture population and density estimation of tigers in a population with known parameters. *Animal Conservation*, *13*(1), 94–103. https://doi.org/10.1111/j.1469-1795.2009.00305.x

Verma, M., Negandhi, D., Khanna, C., Edgaonkar, A., David, A., Kadekodi, G., Costanza, R., Gopal, R., Bonal, B. S., Yadav, S. P., & Kumar, S. (2017). Making the hidden visible: Economic valuation of tiger reserves in India. *Ecosystem Services*, *26*, 236–244. https://doi.org/10.1016/j.ecoser.2017.05.006

Walston, J., Robinson, J. G., Bennett, E. L., Breitenmoser, U., da Fonseca, G. A. B., Goodrich, J., Gumal, M., Hunter, L., Johnson, A., Karanth, K. U., Leader-Williams, N., MacKinnon, K., Miquelle, D., Pattanavibool, A., Poole, C., Rabinowitz, A., Smith, J. L. D., Stokes, E. J., Stuart, S. N., … Wibisono, H. (2010). Bringing the tiger back from the brink—The six percent solution. *PLoS Biology*, *8*(9), e1000485. https://doi.org/10.1371/journal.pbio.1000485

Wani, M., & Kothari, A. (2007). Protected areas and human rights in India: The impact of the official conservation model on local communities. *Policy Matters*, *IUCN*, *15*, 100–115.

White, L. (1967). The historical roots of our ecologic crisis. *Science*, *155*(3767), 1203–1207. https://doi.org/10.1126/science.155.3767.1203

Wikramanayake, E., Dinerstein, E., Forrest, J., Loucks, C., Seidensticker, J., Klenzendorf, S., Sanderson, E. W., Simons, R., Heydlauff, A., Ginsberg, J., & O'Brien, T. (2010). Roads to recovery or catastrophic loss: How will the next decade end for wild tigers? In R. Tilson, & P. Nyhus (Eds.), *Tigers of the world* (pp. 493–506). William Andrew Publishing.

Woodroffe, R., Hedges, S., & Durant, S. M. (2014). To fence or not to fence. *Science*, *344*(6179), 46–48.

Woodroffe, R., Thirgood, S., & Rabinowitz, A. (2005). *People and wildlife conflict or coexistence?* Cambridge University Press and The Zoological Society of London.

WPA. (1972). *The Wildlife (Protection) Act 1972; amended (2006)*. Ministry of Environment, Forests, and Climate Change, Government of India, New Delhi. Retrieved from http://legislative.gov.in/sites/default/files/A1972-53_0.pdf

Yumnam, B., Jhala, Y. V., Qureshi, Q., Maldonado, J. E., Gopal, R., Saini, S., Srinivas, Y., & Fleischer, R. C. (2014). Prioritizing tiger conservation through landscape genetics and habitat linkages. *PLoS ONE*, *9*(11), e111207.

DATA SOURCES

Amirkhanov, A. M., & Aramiliv, V. V. (2015). *The Amur tiger census in Russia 2014–2015.*. Amur Tiger Center, World Wide Fund for Nature, Ministry of Natural Resources and Environment of the Russian Federation. Retrieved from https://amurinfocenter.org/upload/iblock/1fd/leaflet_tiger_2015_census_with_flag_interactive.pdf

Ash, E., Hallam, C., Chanteap, P., Kaszta, Z., McDonald, D. W., Rojanachinda, W., Redford, T., & Harihar, A. (2020). Estimating the density of a globally important tiger (*Panthera tigris*) population: Using simulations to evaluate survey design in Eastern Thailand. *Biological Conservation*, *241*, 1083349.

Aziz, M. A., Kabir, M. J., Shamsuddoha, M., Ahsan, M. M., Sharma, S., Chakma, S., Jahid, M., Chowdhury, M. M. R., & Rahman, S. M. (2019). *Second Phase Status of Tigers in Bangladesh Sundarban – 2018*. Department of Zoology, Jahangirirnagar University; WildTeam, Bangladesh Forest Department.

Department of National Parks, Wildlife and Plant Conservation, Thailand. (2010). *Thailand Tiger Action Plan 2010–2022*. Department of National Parks, Wildlife and Plant Conservation. Retrieved from https://www.researchgate.net/publication/303881962_Thailand_Tiger_Action_Plan_2010-2022/link/575a8d0908aed884620d674a/download

DoFPS. (2015). *Counting the Tigers in Bhutan: Report on the National Tiger Survey of Bhutan 2014–2015*. Department of Forests and Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan. Retrieved from https://www.researchgate.net/publication/327644943_Counting_the_Tigers_in_Bhutan_Report_on_the_National_Tiger_Survey_of_Bhutan_2014_-_2015

DNPWC and DFSC. (2018). *Status of Tigers and Prey in Nepal*. Department of National Parks and Wildlife Conservation & Department of Forests and Soil Conservation. Ministry of Forests and Environment, Kathmandu, Nepal.

Duangchantrasiri, S., Umponjan, M., Simcharoen, S., Pattanavibool, A., Chaiwattana, S., Maneerat, S., Kumar, N. S., Jathanna, D., Srivathsa, A., & Karanth, K. U. (2016). Dynamics of a low-density tiger population in Southeast Asia in the context of improved law enforcement. *Conservation Biology*, *30*, 639–648.

GTRP. (2010). Global Tiger Recovery Program. Conference document and endorsement. Governments of the tiger range countries and partner organizations of the Global Tiger Initiative of the World Bank. St. Petersburg Tiger Summit Meeting 2010. Retrieved from https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Global-Tiger-Recovery-Program-Nov-4.pdf

Goodrich, J., Lynam, A., Miquelle, D., Wibisono, H., Kawanishi, K., Pattanavibool, A., Htun, S., Tempa, T., Karki, J., Jhala, Y., & Karanth, U. (2015). *Panthera tigris*. The IUCN Red List of Threatened Species 2015: e.T15955A50659951. https://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T15955A50659951.en

Jhala, Y. V., Qureshi, Q., & Gopal, R. (Eds). (2008). *The status of tigers, co-predators and prey in India 2006*. National Tiger Conservation Authority, New Delhi and Wildlife Institute of India. TR 08/001.

Jhala, Y. V., Qureshi, Q., Gopal, R., & Sinha, P. R. (Eds.). (2011). *The status of tigers, co-predators and prey in India 2010*. National Tiger Conservation Authority, New Delhi and Wildlife Institute of India. TR 08/003, 302pp.

Jhala, Y. V., Qureshi, Q., & Gopal, R. (Eds). (2015). *The status of tigers, co-predators and prey in India 2014*. National Tiger Conservation Authority, New Delhi and Wildlife Institute of India, Dehradun. TR2015/021, 456pp.

Jhala, Y. V., Qureshi, Q., & Nayak, A. (Eds.) (2019). *The status of tigers in India 2018–19*. Summary Report, National Tiger Conservation Authority, New Delhi and Wildlife Institute of India. TR No./2019/05.

Karki, J. B., Jnawali, S. R., Shrestha, R., Pandey, M. B., Gurung, G., & Thapa, M. M. (2009). *Tigers and their prey base abundance in Terai Arc landscape*. Government of Nepal, Ministry of Forests and Soil Conservation, Department of National Parks and Wildlife Conservation, and Department of Forests.

Luskin, M. S., Albert, W. R., & Tobler, M. W. (2017). Sumatran tiger survival threatened by deforestation despite increasing densities in parks. *Nature Communications*, *8*(1), 1–9.

Mathur, V. B., Nayak, A. K., & Ansari, N. A. (2019). *Fourth cycle of management effectiveness evaluation (MEE) of tiger reserves in India, 2018*. National Tiger Conservation Authority and Wildlife Institute of India, Ministry of Environment, Forest, and Climate Change, Government of India. 212pp. Retrieved from https://wii.gov.in/images/images/documents/images_2019/mee_tiger_reserves_2018.pdf

Thinley, P., Tempa, T., Wangchuk, N., Namgyel, U., Tshewang, S., Lham, D., & Tandin, T. (2015). Counting the tigers in Bhutan: Report on the National Tiger Survey of Bhutan 2014–2015. https://doi.org/10.13140/RG.2.2.19373.33764

Wang, T. M., Feng, L. M., Mou, P., Wu, J. G., Smith, J. L. D., Xiao, W. H., Yang, H. T., Dou, H. L., Zhao, X. D., Cheng, Y. C., Zhou, B., Wu, H. Y., Zhang, L., Tian, Y., Guo, Q. X., Kou, X. J., Han, X. M., Miguelle, D. G., Oliver, C. D., … Ge, J. P. (2016). Amur tigers and leopards returning to China: Direct evidence and a landscape conservation plan. *Landscape Ecology*, *31*, 491–503.

WWF–GTF. (2016). Global wild tiger population increases, but still a long way to go. *Media Release*. Retrieved from http://tigers.panda.org/wp-content/uploads/WWF-PR-Global-Wild-Tiger-Population-Increases-But-Still-A-Long-Way-To-Go-1.pdf

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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