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Arid Alarms: Conservation Scenarios and Priorities for the Vanishing Great Indian Bustard in Western India

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Abstract

The Great Indian Bustard (*Ardeotis nigriceps*), a critically endangered species emblematic of India's arid grassland ecosystems, faces existential threats from habitat fragmentation and anthropogenic pressures in Western India. This review synthesizes extant scientific literature, Supreme Court judgments, mining proposals, and contemporary research to delineate conservation priorities, scenarios, and the impacts of limestone mining on the species' survival.

Current population estimates indicate fewer than 150 individuals globally, with the majority concentrated in Rajasthan (approximately 122 in the Thar Desert) and fragmented subpopulations in Gujarat, Maharashtra, Karnataka, and Andhra Pradesh. This represents a drastic decline from historical abundances, driven by factors including habitat loss, power line collisions, poaching, and inherently low reproductive rates. Studies by the Wildlife Institute of India (WII) elucidate these vulnerabilities, highlighting population viability analyses predicting extinction within decades absent intervention, alongside habitat selection models favoring open grasslands with minimal disturbance.

Conservation scenarios encompass optimistic trajectories involving captive breeding, habitat restoration, and community engagement, potentially stabilizing populations at 200–300 individuals by 2050; moderate outcomes with partial mitigations maintaining ~100 birds but risking genetic erosion; and pessimistic projections of extirpation by 2040 under unchecked development. Limestone mining exacerbates these threats, particularly in the Thar Desert and Kutch regions, through direct habitat alteration, hydrological disruption, dust pollution, and indirect effects such as increased predation and human encroachment. Empirical evidence from

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ecological assessments demonstrates biodiversity declines and ecosystem degradation in mined landscapes.

Supreme Court verdicts, notably the 2021 ruling in M.K. Ranjitsinh v. Union of India mandating underground power lines in priority habitats to avert collisions (estimated at 18 annually), and the 2024 judgment affirming constitutional rights against climate impacts while balancing renewable energy imperatives, underscore legal frameworks for protection. Mining proposals incorporate wildlife conservation plans advocating habitat offsets, anti-poaching measures, and monitoring; however, implementation deficiencies persist, as revealed in environmental compliance audits.

The present article advocates for integrated, multi-stakeholder strategies, including enhanced enforcement of environmental regulations and landscape-scale planning, to mitigate mining interference and secure the species' persistence. Such approaches are imperative to avert irreversible biodiversity loss in Western India's grasslands.

1. Introduction

The Great Indian Bustard (*Ardeotis nigriceps*), classified as critically endangered on the IUCN Red List since 2011, represents a flagship species of India's arid grassland ecosystems and exemplifies the pervasive challenges of biodiversity conservation in the context of anthropogenic development (IUCN, 2025). Historically distributed across extensive regions of the Indian subcontinent, including areas from Punjab to Tamil Nadu and extending into Pakistan, the species' range has undergone a substantial contraction, now limited to fragmented populations primarily in Western India, with core strongholds in Rajasthan and Gujarat (BirdLife International, 2025). The global population estimates indicate fewer than 150 individuals, reflecting a significant decline from approximately 1,260 in 1969 and 250 in 2011 (Dutta et al., 2011; WII, 2020). Recent assessments by the Wildlife Institute of India (WII) and BirdLife International corroborate this, documenting around 122 individuals in Rajasthan's Thar Desert landscape, alongside smaller, isolated subpopulations in Gujarat, Maharashtra, Karnataka, and Andhra Pradesh (WII, 2023; Dookia & Rawat, 2024). This demographic collapse, corresponding to a 90% reduction in historical range, arises from multifaceted threats, including habitat degradation, poaching, infrastructure-related mortality, and intrinsic life-history constraints such as low reproductive output (Rahmani, 2012).

In Western India, where the species maintains its primary populations, anthropogenic development constitutes the predominant threat. The arid grasslands of this region, characterized by open vistas conducive to the bustard's nesting behavior and k-selected reproductive strategy, have been progressively fragmented by agricultural expansion, renewable energy infrastructure, and

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extractive industries (Dutta, 2011). Among these, limestone mining emerges as a particularly acute driver of habitat disruption, leading to landscape alteration, water resource contamination, and the obliteration of breeding sites in key locales such as the Thar Desert and Kutch district (Mongabay, 2020). These operations not only diminish habitat availability but also amplify secondary impacts, including elevated human disturbance, acoustic pollution, and heightened predation risks from feral canines associated with mining encampments (Dookia, 2023). Empirical evidence from site-specific studies, such as those in Maharashtra's eco-sensitive zones, illustrates how unregulated mining activities exacerbate hydrological imbalances and biodiversity erosion, thereby compounding the species' vulnerability (Mongabay, 2020).

Contemporary research on the Great Indian Bustard encompasses diverse domains, including ecological dynamics, genetic analyses, and ex-situ conservation methodologies. The Wildlife Institute of India (WII), operating under the auspices of the Ministry of Environment, Forest and Climate Change (MoEFCC), coordinates a significant portion of these initiatives via the Bustard Recovery Program (WII, 2023). Notable ongoing endeavors include satellite telemetry studies, which have documented extensive movements exceeding 2,200 km in sub-adult individuals across Maharashtra and Karnataka, emphasizing the imperative for landscape-level conservation frameworks (PMC, 2025). Genetic investigations by Ishtiaq et al. (2022) and Dutta (2011) reveal diminished genetic diversity attributable to a historical population bottleneck occurring 20-40,000 years ago, rendering the species susceptible to inbreeding depression and reduced adaptive potential (Ishtiaq et al., 2022). Advancements in captive propagation, exemplified by the inaugural successful artificial insemination in 2024 yielding a viable chick at WII facilities, provide avenues for population augmentation (BBC, 2024). By 2025, this technique has facilitated the rearing of nine chicks, with protocols in place for subsequent reintroduction into natural habitats (Mongabay, 2025). Complementary community-engaged programs, such as the Godawan Conservation Project, incorporate local stakeholders as monitors and educators, fostering habitat protection through participatory mechanisms (Mongabay, 2020). These efforts are informed by broader ecological modeling, including climate change projections that anticipate shifts in suitable habitats, necessitating transboundary cooperation with Pakistan (Chavan et al., 2025).

Judicial interventions by the Supreme Court of India have played a critical role in delineating conservation imperatives for the species. The 2021 judgment in M.K. Ranjitsinh v. Union of India imposed mandates for underground cabling of power transmission lines within designated priority habitats to mitigate collision-induced mortality, projected at 18 individuals annually (Supreme Court of India, 2021). This ruling addressed the species' physiological limitations, such as constrained frontal vision, which predispose it to infrastructure-related fatalities. The subsequent 2024 verdict extended these protections by affirming a constitutional right to safeguards against climate change adversities, while reconciling biodiversity objectives with renewable energy

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development through expert oversight committees (Supreme Court of India, 2024). These legal precedents have implications for mining activities, requiring rigorous environmental impact assessments and compliance with habitat preservation norms (CEEW, 2024).

Mining proposals within Great Indian Bustard habitats, such as those submitted by Saurashtra Chemicals and JSW Cement Limited, typically incorporate wildlife management plans that propose measures including habitat restoration, anti-poaching surveillance, and compensatory afforestation (Parivesh Portal, MoEFCC). However, discrepancies in implementation efficacy have been documented, with instances of non-adherence undermining intended mitigation outcomes (DownToEarth, 2024). Such plans often overlook cumulative ecological effects, including synergies with ancillary infrastructure development that amplify fragmentation and disturbance.

This article systematically reviews scientific literature sourced from platforms such as ResearchGate, ScienceDirect, and WII publications, integrated with legal judgments and mining documentation, to articulate conservation priorities. It incorporates population viability assessments and habitat selection models from Dutta et al., alongside WII's strategic recovery frameworks and evaluations of mining-induced ecological perturbations. Through the projection of conservation scenarios, ranging from population recovery via holistic management to extirpation under prevailing developmental trajectories, the analysis emphasizes the necessity for evidence-informed, adaptive interventions to ensure the species' long-term viability.

To elaborate further on the historical context, the Great Indian Bustard's decline mirrors broader patterns of grassland ecosystem degradation across South Asia. Early accounts from the 19th century describe abundant populations in semi-arid zones, supported by low-intensity pastoralism that maintained suitable vegetation mosaics (Rahmani, 2012). Post-independence intensification of land use, driven by population growth and economic policies favoring agriculture and industry, initiated the fragmentation process. Quantitative analyses indicate that habitat loss accounts for approximately 60-70% of the range contraction, with infrastructure expansion contributing an additional 20-30% through direct mortality and barrier effects (Dutta et al., 2011). In Rajasthan, the Desert National Park serves as a critical refuge, yet even protected areas face incursions from mining leases and energy projects, highlighting governance challenges in enforcement (WII, 2020).

Regarding limestone mining's specific impacts, environmental impact assessments reveal mechanisms of degradation beyond physical alteration. Dust emissions from quarrying operations reduce vegetation cover, impairing forage availability for the omnivorous bustard, which relies on insects, seeds, and small vertebrates (Dookia, 2023). Hydrological studies document aquifer contamination and altered drainage patterns, leading to desiccation of ephemeral wetlands

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essential for breeding displays (Mongabay, 2020). Socio-ecological dimensions are equally pertinent, as mining displaces pastoral communities, disrupting traditional land-use practices that inadvertently benefited the species through controlled grazing (Dutta & Jhala, 2021).

Research advancements extend to behavioral ecology, with studies employing camera traps and direct observations to quantify disturbance thresholds. For instance, GIBs exhibit avoidance behaviors in proximity to mining sites, relocating to suboptimal habitats and incurring elevated energetic costs (Habib et al., 2021). Genetic metrics, derived from non-invasive sampling techniques, inform prioritization of conservation units, advocating for gene flow enhancement through corridor establishment (Ishtiaq et al., 2022). Ex-situ programs, while promising, confront challenges in post-release survival, necessitating refined protocols for soft releases and predator acclimation (WII, 2023).

2. Background and Literature Review

The evolutionary trajectory and ecological requirements of the Great Indian Bustard furnish essential context for comprehending its contemporary conservation challenges. As an obligate inhabitant of arid and semi-arid grassland ecosystems, this species exhibits a pronounced preference for expansive, flat terrains characterized by low vegetation density and minimal anthropogenic disturbance. Such landscapes facilitate its behavioral adaptations, including lek-based mating displays and ground-nesting strategies, while supporting a mosaic of short grasslands for foraging on insects, seeds, and small vertebrates, interspersed with taller grasses for cover during breeding (Dutta & Jhala, 2021). Historical accounts, derived from colonial-era naturalist observations and museum specimens, attest to a formerly extensive distribution across the Indian subcontinent and adjacent regions in Pakistan, encompassing diverse biomes from the Thar Desert to the Deccan Plateau (BirdLife International, 2025). However, escalating anthropogenic pressures, encompassing habitat conversion for agriculture, infrastructure spread, and overhunting, have precipitated extirpation from approximately 90% of its historical range, confining extant populations to fragmented territories in Western India (Rahmani, 2012). This contraction not only diminishes available habitat but also exacerbates demographic stochasticity and genetic erosion, rendering the species acutely susceptible to extinction vortices.

Important contributions by Wildlife Institute of India constitute the foundational corpus of empirical research on the Great Indian Bustard. Dutta et al. (2011) employed population viability analysis (PVA) models to forecast demographic trajectories, projecting local extinctions within two to three decades under prevailing threat regimes dominated by habitat loss and recruitment deficits (Dutta et al., 2011). This modeling framework illuminated the species' k-selected life-history traits, characterized by delayed sexual maturity (attained at 3-4 years), single-egg clutches, and protracted inter-breeding intervals, as factors conferring limited resilience to additive mortality

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sources (Dutta & Rahmani, 2011). Subsequent investigations refined these insights; for instance, Dutta and Jhala (2021) delineated behaviorally explicit habitat selection patterns through resource selection functions, demonstrating avoidance of high human-density zones and seasonal affinity for agro-grassland mosaics during non-breeding periods, thereby underscoring the compatibility of low-intensity pastoralism with conservation objectives (Dutta & Jhala, 2021). Genetic inquiries further elucidated population structure as Ishtiaq (2012) revealed diminished mitochondrial DNA diversity across Indian subpopulations, attributable to historical bottlenecks, and advocated for delineating evolutionarily significant units to inform ex-situ breeding protocols (Ishtiaq & Dutta, 2012). These findings have been instrumental in prioritizing genetic augmentation strategies to mitigate inbreeding depression.

The Wildlife Institute of India (WII) has undertaken comprehensive field investigations, yielding pivotal data on population dynamics and threat mitigation. Their 2020 report, "Conserving the Great Indian Bustard Landscape," quantified the Thar Desert population at approximately 128 individuals and proposed a multifaceted recovery paradigm encompassing protected breeding enclosures, adaptive land-use zoning, and community stewardship initiatives (WII, 2020). Longitudinal surveys spanning 2017-2020 documented six fatalities attributable to power line collisions, reinforcing infrastructure as a paramount mortality driver and advocating for retrofitting measures such as bird diverters (WII, 2020). The WII's Bustard Recovery Program, updated in 2023, synergizes in-situ habitat enhancement with ex-situ conservation breeding, allocating resources for grassland restoration in delineated priority zones and integrating artificial insemination techniques to bolster captive populations (WII, 2023). Recent telemetry-based studies under WII supports, employing satellite transmitters, have unveiled intricate seasonal movement corridors exceeding 2,200 km, facilitating informed transboundary conservation dialogues with Pakistan to address potential habitat shifts under climatic perturbations (PMC, 2025). These endeavors underscore the necessity of landscape-scale approaches to counteract fragmentation.

Complementary scholarship extends the discourse beyond core ecological parameters. Collar et al. (2014) synthesized global bustard conservation paradigms, extrapolating lessons from congeners such as the European Great Bustard (*Otis tarda*) to advocate for integrated threat abatement in *Ardeotis nigriceps*, including anti-poaching patrols and habitat corridors. Habib et al. (2021) quantified avian electrocution and collision risks associated with power infrastructure, estimating an annual toll of 84,000 birds across India, with the Great Indian Bustard disproportionately affected due to its large body size and low maneuverability (Habib et al., 2021). This analysis projected severe demographic repercussions, with PVA simulations indicating quasi-extinction probabilities exceeding 50% absent mitigation. Climate modeling by Chavan et al. (2025) projected habitat suitability under coupled land-use and climatic scenarios, identifying 70,092 km²

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of presently viable terrain but forecasting contractions of up to 40% by mid-century, predominantly in Rajasthan, thereby necessitating adaptive management inclusive of cross-border sanctuaries (Chavan et al., 2025).

Advancements in genetic research have further illuminated conservation imperatives. Ishtiaq et al. (2022) conducted a comprehensive assessment of nuclear and mitochondrial markers, revealing low heterozygosity levels and subtle population structuring, with Rajasthan exhibiting the highest diversity, attributable to larger effective population sizes, and advocating for prioritized sourcing of breeders from this metapopulation to optimize genetic rescue efforts (Ishtiaq et al., 2022). This aligns with broader syntheses, such as those in the IUCN SSC Bustard Specialist Group report (2023), which documented community training programs in bustard strongholds, yielding enhanced monitoring capacities and reduced incidental threats (IUCN SSC, 2023). Recent ex-situ breakthroughs, detailed in accounts of artificial insemination protocols, have resulted in viable captive-raised chicks, offering a lifeline for supplementation programs amid wild population declines (Mongabay, 2025). A pan-Asian perspective by the Bombay Natural History Society (BNHS) emphasizes synergistic threats, including mining-induced habitat loss, and calls for regional accords to avert extirpation (BNHS, 2012).

Threat-specific inquiries have increasingly focused on anthropogenic interfaces. Studies on mining impacts, particularly limestone extraction in the Thar region, document cascading effects: soil erosion, aquifer depletion, and vegetation denudation that erode foraging substrates (Dookia, 2023). Quantitative assessments reveal density-dependent avoidance, with bustard occurrence probabilities diminishing by 70% within 5 km of active quarries (Semantics Scholar, 2020). Integration of remote sensing data in habitat models further highlights cumulative stressors, including renewable energy sprawl, which fragments connectivity and amplifies collision risks (Habib et al., 2021). Socio-economic analyses embedded in conservation frameworks advocate for incentive-based models, such as payments for ecosystem services to pastoralists, to sustain compatible land uses (WII, 2023).

3. Conservation Priorities and Scenarios

The conservation imperatives for the Great Indian Bustard in Western India are predicated on a tripartite framework encompassing habitat safeguarding, threat amelioration, and demographic reinforcement. These priorities are codified in the National Guidelines for Bustard Recovery (MoEFCC, 2013), which advocate for rigorous protection of lekking and nesting sites, promotion of symbiotic low-impact land utilization such as pastoralism, and establishment of ex-situ populations as demographic safeguards.nationalcampa.nic.in This strategic blueprint aligns with the IUCN Species Survival Commission's directives, emphasizing adaptive management to counteract the species' precipitous decline (IUCN SSC, 2023). Habitat protection remains

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paramount, necessitating the delineation of inviolable sanctuaries to preclude encroachment by extractive industries and infrastructure. Threat mitigation targets anthropogenic mortality vectors, including power transmission collisions and poaching, while population augmentation leverages captive breeding innovations to supplement wild stocks.

Prospective conservation scenarios are contingent upon the intensity and efficacy of interventions, as modeled through population viability analyses. In an optimistic paradigm, holistic landscape management, integrating subterranean infrastructure retrofitting, community-based incentives for grassland stewardship, and transboundary habitat corridors, could facilitate population stabilization at 200–300 individuals by 2050 (Dutta et al., 2011). Such outcomes assume stringent enforcement of judicial mandates, such as the Supreme Court's 2021 and 2024 edicts mandating underground cabling in core habitats to avert annual collision mortalities estimated at 18 birds (Supreme Court of India, 2024). Complementary initiatives, including the Bustard Recovery Program's phase extending to 2033, incorporate habitat restoration and artificial insemination protocols that have yielded nine viable chicks by mid-2025, heralding potential reintroduction successes (WII, 2023; Mongabay, 2025). Genetic prioritization, informed by assessments revealing low heterozygosity and historical bottlenecks, would further enhance resilience by optimizing breeder selection from diverse subpopulations, particularly Rajasthan's Thar metapopulation (Ishtiaq et al., 2022).

Conversely, a pessimistic trajectory envisions extirpation by 2040 under unmitigated developmental pressures, including unabated limestone mining and renewable energy proliferation, which fragment habitats and exacerbate indirect stressors such as predation and hydrological disruption (Rahmani, 2012). Empirical projections indicate that without intervention, demographic stochasticity and inbreeding could precipitate quasi-extinction probabilities exceeding 90% within two decades (Habib et al., 2021). A moderate scenario posits sustenance of approximately 100 individuals through piecemeal mitigations, such as bird diverter installations and partial mining moratoriums; however, this harbors latent risks of genetic erosion, potentially compromising adaptive capacity amid climatic variability (Ishtiaq et al., 2022).

Operational priorities include designating "no-go" zones for industrial activities, exemplified by the fortified protections within Rajasthan's Desert National Park, where egg rescue protocols have been implemented to bolster juvenile survival amid escalating threats (Rajasthan Forest Department, 2025). Cross-border collaboration with Pakistan is indispensable, given ensemble modeling forecasts of habitat shifts under coupled climate and land-use scenarios, projecting a 40% contraction in suitable arid expanses spanning 70,092 km² (Chavan et al., 2025). Telemetry-derived insights into migratory patterns, documenting traverses exceeding 2,200 km, further underscore the need for bilateral accords to preserve connectivity (PMC, 2025). Community engagement, via initiatives like the Godawan Project, fosters participatory monitoring and

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sustainable livelihoods, mitigating human-wildlife conflicts. These priorities, if rigorously pursued, offer a viable pathway to avert extinction, harmonizing ecological integrity with developmental imperatives in Western India's fragile grasslands.

4. Effects of Human Development Interference, Especially Limestone Mining

Anthropogenic development has profoundly compromised the habitats of the Great Indian Bustard, precipitating widespread ecological degradation in Western India. Agricultural intensification and infrastructural expansion have systematically converted pristine grasslands into fragmented mosaics, diminishing the spatial extent and quality of suitable environments for this obligate grassland species. These transformations not only curtail foraging and breeding opportunities but also amplify edge effects, fostering invasive species proliferation and heightened predation pressures (Rahmani, 2012). Infrastructure, including roads and renewable energy installations, further exacerbates habitat dissection, impeding dispersal and gene flow among isolated subpopulations (Dutta et al., 2011). Among these disturbances, mining activities, particularly limestone extraction, emerge as a salient driver of direct and cascading impacts, altering geomorphology, hydrology, and biodiversity dynamics in core regions such as the Thar Desert and Kutch district.

Limestone mining operations in these arid landscapes engender topographic modifications through open-pit excavation, resulting in irreversible habitat loss and soil destabilization. Empirical assessments document how such quarrying disrupts ecosystem integrity, generating dust aerosols that impair vegetation productivity and avian respiratory functions (Semantics Scholar, 2020). Concurrently, mining-induced alterations in surface hydrology lead to water stagnation in abandoned pits, fostering mosquito breeding and vector-borne diseases while contaminating groundwater aquifers essential for grassland sustenance (Yulex, 2023). In the context of the Great Indian Bustard, these perturbations manifest as reduced forage availability, given the species' reliance on insect-rich grasslands, and compromised breeding success due to noise and vibrational disturbances during lekking displays (Dookia, 2023).

Site-specific investigations in Maharashtra underscore the insidious effects of illicit mining within eco-sensitive zones, where limestone extraction has precipitated aquifer contamination and diminished recharge rates. This hydrological impairment cascades to vegetation desiccation, curtailing the bustard's access to seasonal foraging patches and exacerbating nutritional stress in an already k-selected species (Mongabay, 2020). Broader biodiversity ramifications are evident, with studies in Kachchh revealing opencast mining as a primary catalyst for avian habitat destruction, precipitating declines in species richness and abundance among ground-nesting birds (International Journal of Biodiversity, 2013).

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Ancillary impacts from mining-related infrastructure compound these threats. The proliferation of power transmission lines, necessitated by energy demands for extraction processes, heightens collision risks for the bustard, whose limited frontal vision and heavy flight render it particularly vulnerable (Habib et al., 2021). Estimates suggest such collisions contribute substantially to adult mortality, with annual losses potentially offsetting low recruitment rates (WII, 2020). Moreover, labor influxes associated with mining encampments intensify resource exploitation, introducing feral predators and escalating human-wildlife conflicts (WII, 2025). In the Thar Desert, synergistic effects with climate variability amplify desertification, as mining disrupts aeolian processes and vegetative stabilizers, fostering rock desertification and biodiversity erosion (Chavan et al., 2025).

Cumulative analyses indicate that limestone mining not only fragments habitats but also undermines ecosystem services, including soil retention and carbon sequestration, critical for arid zone resilience (Biodiversity Loss Due to Mining Activities, 2024). In saline wetlands proximal to Kutch mining sites, gypsum and limestone extraction has led to conversion into industrial pans, eroding wetland-dependent biodiversity and migratory pathways (Saline Wetlands of the Arid Zone, 2018). These disturbances, intertwined with broader developmental trajectories, necessitate integrated mitigation frameworks, including stringent environmental impact assessments and restoration protocols, to avert irreversible declines in bustard populations (Environmental Sustainability of the Thar Desert, 2021). Future research should prioritize longitudinal monitoring to quantify threshold effects, informing adaptive management in this biodiversity hotspot.

5. Supreme Court Verdicts on GIB Conservation

Judicial pronouncements by the Supreme Court of India have constituted pivotal milestones in the conservation discourse surrounding the Great Indian Bustard, harmonizing ecological imperatives with developmental exigencies. These interventions underscore the Court's invocation of constitutional provisions, including Articles 14, 21, 48A, and 51A(g), to affirm environmental stewardship as an intrinsic facet of fundamental rights.

The 2021 judgment in M.K. Ranjitsinh & Ors. v. Union of India & Ors. addressed the species' vulnerability to overhead power transmission lines, which precipitate fatal collisions due to the bustard's anatomical constraints in aerial navigation. The Court demarcated a priority habitat expanse of approximately 80,000 km² across Rajasthan and Gujarat, imposing a categorical prohibition on overhead lines and mandating their subterranean installation alongside bird diverters in extant infrastructure.climatecasechart.com This directive aimed to curtail annual mortality rates estimated at 18 individuals, thereby averting demographic collapse in a population teetering below 150.

Subsequent litigation culminated in the March 21, 2024, verdict (2024 INSC 280), which refined the antecedent order by recognizing a constitutional right to protection against climate change

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adversities under Articles 14 and 21. Acknowledging the tension between biodiversity preservation and renewable energy proliferation, essential for India's net-zero ambitions by 2070, the Court rescinded the blanket moratorium in potential habitats, while upholding safeguards in priority zones.indiaspend.com An expert committee, comprising representatives from the Ministry of Environment, Forest and Climate Change, Central Electricity Authority, and ornithological experts, was constituted to delineate balanced mitigation strategies, including diverter efficacy evaluations and habitat restoration protocols.

These rulings extend ramifications to limestone mining incursions, necessitating rigorous environmental impact assessments and compliance with wildlife corridors to mitigate habitat fragmentation. By integrating climate justice with species-specific protections, the verdicts exemplify adaptive jurisprudence, fostering multi-stakeholder collaborations to secure the bustard's persistence amid anthropogenic pressures.

6. Mining Proposals and Wildlife Conservation Plans

Mining ventures in priority habitats of the Great Indian Bustard in Western India are mandated to incorporate wildlife conservation plans under the Wildlife (Protection) Act, 1972 and subsequent amendments in 2022, and environmental clearance protocols, aiming to mitigate ecological disruptions while facilitating industrial activities. These plans typically encompass habitat restoration, biodiversity offsets, anti-poaching surveillance, and population monitoring to safeguard Schedule I species like the bustard.

Exemplary proposals include those from Saurashtra Chemicals Limited for limestone extraction near Barda Wildlife Sanctuary in Gujarat. The company's submissions outline compensatory afforestation, habitat enhancement in buffer zones, and periodic ecological assessments to offset mining-induced fragmentation and hydrological alterations (MoEF, 2018). Similarly, JSW Cement Limited's expansion initiatives in Rajasthan's Nagaur district, proximate to bustard habitats, integrate comprehensive conservation strategies for Schedule I fauna. These entail financial allocations for habitat improvement, installation of monitoring infrastructure at sites such as Maldhok Sanctuary, and collaborative surveys with the Wildlife Institute of India to track bustard movements and breeding success (JSW Cement, 2022; Environment Clearance, 2020, environmentclearance.nic.in). Additional measures include anti-collision devices on associated infrastructure and community engagement for poaching deterrence.

Notwithstanding these provisions, empirical audits reveal persistent implementation lacunae, including inadequate enforcement, delayed restoration efforts, and insufficient adaptive management in response to ongoing threats like dust pollution and predation escalation (WII, 2020; Mongabay, 2020). Such discrepancies underscore the necessity for enhanced regulatory oversight, independent verification mechanisms, and integration of scientific monitoring to ensure

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that conservation plans translate into tangible ecological benefits, thereby reconciling mineral extraction with the imperatives of bustard persistence in arid landscapes.

7. Current Researches on GIB

Contemporary investigations into the conservation of the Great Indian Bustard encompass a spectrum of ecological, genetic, and community-oriented approaches, driven by the imperative to reverse the species' trajectory toward extinction. The Wildlife Institute of India (WII) spearheads the Bustard Recovery Program, which has achieved notable milestones in ex-situ breeding. By mid-2025, the program has successfully hatched 11 chicks through artificial insemination, marking India as the inaugural nation to accomplish this feat for the species. This technique, refined since the first viable chick in 2024, integrates semen collection from wild males with controlled incubation, yielding a captive cohort poised for reintroduction following behavioral conditioning (Mongabay, 2025). Parallel efforts in Rajasthan's Desert National Park employ a science-based egg rescue protocol, wherein eggs are retrieved from precarious wild nests, incubated under biosecure conditions, and fledglings released to augment juvenile recruitment amid habitat threats.

Movement ecology research provides critical insights into the species' spatial dynamics. A 2025 study utilizing satellite telemetry tracked a sub-adult bustard across 2,200 km in Maharashtra and Karnataka, elucidating diurnal foraging patterns, seasonal migrations aligned with monsoon cycles, and Lévy flight behaviors indicative of optimal resource exploitation. These findings underscore the necessity for expansive conservation corridors transcending state boundaries to mitigate fragmentation (PMC, 2025).

Genetic studies continue to inform prioritization strategies. Ishtiaq et al. (2022) delineated low genomic diversity via nuclear and mitochondrial markers, attributing it to Pleistocene bottlenecks and advocating for targeted gene flow enhancement through selective breeding. Recent modeling integrates these data with climate projections, forecasting cross-border habitat shifts under shared socioeconomic pathways, with current suitable areas spanning 70,092 km² across India and Pakistan, potentially contracting by 40% by mid-century (Chavan et al., 2025).

Community-centric initiatives in Rajasthan, such as the Godawan Conservation Project, empower local pastoralists as citizen scientists for habitat surveillance and threat reporting, fostering symbiotic land-use practices that sustain grassland mosaics (Current Conservation, 2025). Complementary research quantifies anthropogenic mortality, including power line collisions claiming 84,000 avian lives annually, with bustards disproportionately affected due to morphological vulnerabilities. These endeavors, amalgamating technological innovation with participatory governance, represent a multifaceted paradigm essential for the species' persistence amid escalating developmental pressures.

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8. Conclusion

The Great Indian Bustard stands at a precipice, its fate emblematic of the fragile equilibrium between progress and preservation in India's arid heartlands. This synthesis reveals a species beleaguered by habitat loss, infrastructure perils, and mining encroachments, yet buoyed by scientific ingenuity and legal fortitude. With populations hovering below 150 as of July 2025, the imperative for concerted action is unequivocal (BirdLife International, 2025). Conservation priorities must prioritize "no-go" zones in core habitats like the Desert National Park, enforcing stringent protections against limestone mining that scars landscapes and disrupts hydrological cycles (Rajasthan Forest Department, 2025). Judicial frameworks, evolving through landmark rulings, affirm environmental rights while navigating energy transitions, mandating innovations like underground lines to curb collisions (Supreme Court of India, 2024).

Research trajectories offer promise: captive breeding has yielded 11 chicks in 2025, heralding reintroduction strategies that could bolster wild stocks (Rajasthan Forest Department, 2025). Movement ecology and genetic studies guide landscape connectivity, advocating cross-border initiatives amid climate-induced shifts (PMC, 2025; Ishtiaq et al., 2022). Community engagement, as in participatory monitoring, transforms locals into guardians, fostering sustainable coexistence (Current Conservation, 2025).currentconservation.org Yet, mining proposals' conservation plans, while aspirational, demand rigorous enforcement to transcend rhetoric, addressing gaps in restoration and cumulative impact assessments (MoEF, 2018).

Scenarios project divergent futures: integrated management could revive populations, but unchecked development risks extirpation by 2040 (Rahmani, 2012). To avert this, multi-stakeholder alliances, encompassing governments, NGOs, and industries, must prioritize evidence-based policies, investing in alternatives like eco-friendly mining technologies and incentives for grassland stewardship. The bustard's revival is not merely ecological but a testament to human resolve, preserving a flagship species that embodies India's grassland heritage. As threats intensify from solar expansions and agriculture, urgent, scalable interventions are essential to secure its persistence, ensuring future generations witness this majestic bird striding across open plains (Insightful Take, 2025). In essence, safeguarding the Great Indian Bustard demands a holistic ethos: one where development sustains, rather than supplants, biodiversity.

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