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Climate Change and Anthropogenic Pressures on the Great Indian Bustard's Habitats in the Thar Desert of Rajasthan, India

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ABSTRACT: Grasslands are among the most ecologically valuable yet policy-neglected biomes, providing critical ecosystem services and supporting specialised biodiversity. In arid landscapes such as the Thar Desert, the impacts of climate change have intensified over the past three to four decades, expressed through increasing temperature variability, recurrent droughts, and episodic flooding. These effects are compounded by shallow gypsum and limestone layers that restrict groundwater recharge, thereby magnifying climate-induced water stress. The Thar Desert grasslands constitute a unique ecological system and represent the last functional habitat of the critically endangered Great Indian Bustard (*Ardeotis nigriceps*). Climate change acts as a persistent and escalating stressor in desert grasslands, while anthropogenic pressures have rendered undisturbed grassland conditions increasingly rare. Although arid grasslands possess inherent resilience and the capacity to recover from low-intensity disturbances, this resilience has been progressively eroded by prolonged habitat degradation. Over the past few decades, declining habitat quality has disproportionately affected species with narrow ecological niches, particularly the Great Indian Bustard, whose survival depends on structurally intact, open grassland systems. We argue that climate change and human-induced stressors operate synergistically, accelerating grassland degradation beyond ecological recovery thresholds. Direct climatic impacts primarily altered rainfall regimes and driving shifts in plant community composition, grassland structure, and ecosystem processes. These changes interact with indirect pressures, including land-use and land-cover change, agricultural intensification and crop homogenisation, invasive alien species proliferation, woody encroachment through afforestation and plantation programmes, and increased atmospheric nitrogen deposition. Together, these interacting drivers amplify ecosystem vulnerability and undermine the adaptive capacity of arid grasslands. Particularly alarming are the impacts of climate change on native, aridity-adapted keystone grasses such as *Lasiurus sindicus* (Sewan), which form the ecological foundation of Great Indian Bustard habitats. Climate-induced stress on these species facilitates the expansion of woody and invasive taxa, notably *Neltuma juliflora* (formerly *Prosopis* spp.), rapidly transforming open grasslands into unsuitable habitats. Grasslands must be urgently recognised in climate and biodiversity governance as climate-sensitive ecosystems rather than "degraded" lands. National and state policies should explicitly prohibit ecologically inappropriate afforestation, regulate land-use conversion, prioritise native grassland restoration, and integrate species-specific requirements such as those of the Great Indian Bustard into climate adaptation planning. Without this policy realignment, climate action risks accelerating grassland loss and pushing one of India's most iconic species closer to extinction.

Keywords: Climate change, food availability, habitat loss, Great Indian Bustard.

INTRODUCTION

The Thar Desert represents one of the most densely populated desert regions globally and encompasses vast arid and semi-arid landscapes that qualify as Open Natural Ecosystems (ONEs), characterised by extensive non-forest formations such as grasslands, savannahs, gravelly scrublands, arid deserts, and sporadic rocky outcrops (Madhusudan & Vanak 2023). Despite their ecological significance, these ecosystems are frequently misclassified as "wastelands" within official land and revenue records due to their perceived lack of direct revenue generation. Such policy-driven misclassification has obscured their biodiversity value and ecological functionality. In reality, these sparsely wooded and open habitats support uniquely adapted flora and fauna, sustain critical ecosystem services, and underpin the livelihoods of millions of people across north-western India. Importantly, the Thar Desert grasslands constitute the last remaining refuge and the only global breeding landscape of the critically endangered Great Indian Bustard (*Ardeotis nigriceps*). (Dookia, 2010; Rawat & Dookia, 2020).

These apparently barren, open grass-dominated landscapes play a disproportionately important role in climate regulation by storing substantial amounts of carbon in soils and root systems, comparable to many forest ecosystems. They also support iconic wildlife species such as bustards, Indian wolves, and gazelles, underscoring their conservation value and relevance to national climate commitments. Notably, the Open Natural Ecosystems of western Rajasthan, including Great Indian Bustard habitats, align directly with four of India's eight Intended Nationally Determined Contributions (INDCs) under the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) (Anonymous, 2022), highlighting their strategic importance for achieving both biodiversity and climate goals.

Globally, grasslands constitute the second-largest terrestrial biome and represent a foundational land resource for human survival and development (Yan *et al.*, 2023). Covering approximately 40% of the Earth's land surface, grasslands store nearly 34% of total ecosystem carbon, emphasising their central role in the global carbon cycle (Allaby, 2009). However, nearly half of the world's grasslands are currently degraded, and climate change is expected to further exacerbate this trend (Gibbs & Salmon 2015; Bardgett *et al.*, 2021). Grasslands of north-western India, particularly within the Thar Desert, mirror these global patterns, experiencing intense anthropogenic pressures while simultaneously harbouring the last viable population of the Great Indian Bustard.

The Great Indian Bustard, endemic to the Indian subcontinent, has been classified as "Critically Endangered" on the IUCN Red List since 2011 and faces an imminent risk of extinction. Estimates suggest that ~ 150 individuals remain in the wild, with nearly 95% of the population restricted to western Rajasthan (Dutta *et al.*, 2010). The species is ecologically linked to open grass–scrub systems maintained by wild and domestic grazers, which help preserve habitat structure. During the non-breeding season, GIBs preferentially use extensive, sparsely vegetated grass scrub landscapes interspersed with low-intensity agriculture (Rahmani, 1989). As omnivores, and opportunist their diet includes fruits of *Ziziphus*, *Salvadora*, and *Cucumis* spp., large arthropods such as grasshoppers, beetles, scorpions and spiders, as well as reptiles, small mammals, and seasonal crops like groundnut, mustard and millets (Dookia, 2007; Rawat & Dookia 2020).

Despite this dietary flexibility, the species faces multiple, interacting threats, including habitat loss and fragmentation, expansion of linear infrastructure such as high-voltage power transmission lines, poaching and hunting, human encroachment, indiscriminate pesticide use, and predation by stray and feral dogs. These pressures, when compounded with climate change, are transforming Open Natural Ecosystems by increasing temperature extremes, aridity, and environmental variability. Such changes are altering plant community composition, reducing primary productivity, and degrading habitat quality in semi-arid regions like western Rajasthan. The cumulative effects have led to declining availability of key dietary resources including large arthropods, wild fruits, and native grasses and have compromised the structural openness of grasslands essential for the breeding and long-term survival of the Great Indian Bustard.

MATERIAL AND METHOD

Study site:

The Great Indian Bustard is currently restricted to the Thar Desert of Rajasthan, with its only extant breeding population confined to a few fragmented habitat patches within Jaisalmer district in the western most part of the state. This region lies at the core of the Thar Desert and is characterised by extreme climatic conditions, with summer temperatures frequently reaching 50–51°C, while winter temperatures may occasionally fall below 0°C. The annual rainfall regime of Jaisalmer follows a distinct multi-year cyclical pattern, typically spanning four to five years. Within this cycle, severe drought years recur approximately once every five years and are often followed by years of surplus rainfall.

It has been hypothesised that during drought years, reduced vegetation cover across the desert landscape leads to increased land surface temperatures, which in turn strengthen the monsoon trough in subsequent years, resulting in anomalously high rainfall (Santra & Chakraborty 2011). According to the India Meteorological Department (IMD), the long-term average rainfall (Long Period Average; LPA) for Jaisalmer is 176.9 mm. However, recent decades indicate a marked increasing trend in precipitation, with mean annual rainfall rising to 256.5 mm during the 1991–2000 decade. Furthermore, the Thar Desert has experienced a substantial increase in rainfall, with precipitation levels rising by approximately 64% between 2001 and 2023 (IMD, 2023).

Methodology:

This study adopts a multi-dimensional approach to examine the factors influencing the critically endangered Great Indian Bustard (GIB), with particular emphasis on its habitat within Open Natural Ecosystems (ONEs), anthropogenic pressures, and the overarching context of climate change. GIB presence and habitat use across different landscape units were systematically monitored through regular field observations conducted by trained local youth engaged under the Great Indian Bustard (Godawan) Community Conservation Programme of the ERDS Foundation in Jaisalmer district, Rajasthan from July 2017 to June 2025. Linear infrastructure development was explicitly incorporated into the consideration, recognising its growing significance as a major threat to GIB and other avian species. Accordingly, renewable energy installations, including solar power parks, wind turbine farms, and associated high-voltage transmission lines connecting these facilities, were treated as linear infrastructure elements within the study landscape (Uddin *et al.*, 2021; Kumara *et al.*, 2022; Roy *et al.*, 2025). Climatic variables, particularly rainfall data, were obtained from the India Meteorological Department (IMD) for Jaisalmer district to assess climate variability and trends relevant to habitat conditions.

Taken together, the expansion of renewable energy projects, coupled with other anthropogenic pressures, has led to substantial disturbance and fragmentation of Open Natural Ecosystems and the habitats of the Great Indian Bustard and associated species within the study area.

RESULTS AND DISCUSSION

The Great Indian Bustard is a critically endangered bird that totally relies on open arid and semi-arid landscapes, intermediate grasslands with sparse scrub, where grasses are roughly 1-2 feet tall. Its present distribution largely restricted to parts of Jaisalmer district predominated by dry open grassland or by grassland interspersed with shrubs and thorny bushes (Gupta, 1975). The main grass type of this area is *Dichanthium-Lasiurus-Cenchrus* (Dabadghao and Shankarnarayan 1973). The diet of GIB includes arthropods attracted by certain native grasses along with seeds, shoots, making it highly dependent on healthy native grass and diverse animal community with arthropods as dominant food items (Rawat & Dookia 2020). The habitat required is relatively undistributed ground for nesting, with enough ground vegetative cover for camouflage while incubating and open for visibility while standing and walking, conditions tied to native perennial grassland structure and productivity.

Increased temperatures and altered rainfall reduce the abundance and seasonal availability of the grasses and forbs that support arthropod prey, directly lowering food availability for GIBs, especially during breeding (Dookia, 2007; Dookia, 2010). Drought induces declines in plant cover and seed production, together with more frequent crop failures around grasslands, push both livestock and people to use remaining habitats more intensively, increasing competition for forage and disturbing bustards. This changed land use pattern over the year treated as habitat loss for GIB and high anthropogenic disturbance on vast ONEs in recent years (Rawat & Dookia 2020). Climate-driven water scarcity, combined with unsustainable ground water extraction, concentrates GIBs in few confined last refuse of native grasslands, where degraded vegetation and higher human presence further reduce safe nesting and feeding areas.

Grasslands ecosystems as vulnerable systems due to climate change:

In the era of global warming and climate change, the response of grasslands to droughts has become a key factor to be studied with respect to grassland scenario (IPCC, 2022). According to Ingrisch *et al.* (2018), grasslands are affected more easily than other ecological systems. The gradual temperature rise due to climate change is prompting more frequent droughts which are shifting communities towards species that tolerate heat and aridity while sensitive grasses and forbs are declining hence reducing overall biodiversity and sometimes productivity of these grassland ecosystems.

Droughts as the precursor of habitat loss of GIB landscape: The increasing frequency and intensity of droughts under the changing climate are impacting both the function and structure of grassland ecosystems (Ali *et al.*, 2017). According to Gidey *et al.* (2018), the duration, frequency and intensity of droughts have increased at global level, especially in semi-arid and arid areas. Similar pattern has been observed in the GIB landscaped too. Huang *et al.* (2018) has further projected the higher rate of drought risk in future at global level. Carlsson *et al.* (2017); Stampfli *et al.* (2018) further states that droughts as a part of climate change would change the structure, function and composition of grassland ecosystems, posing stronger threats to ecosystem functioning than that of global shifts and trends in ecosystem regimes (Smith, 2011).

Rajasthan is identified as highly climate sensitive, with notable increases in temperature, intensified heat waves, and increasingly erratic monsoon rainfall in recent decades.The erratic rainfall with intense and less common events has caused an increase of soil erosion and reduction in effective soil moisture has limited plant growth and alters the timing of forage availability and groundwater recharge in the state's arid and semi-arid grasslands. Apart from above factors, alteration in water cycle in grassland under the influence of global warming and drought has changed soil structure and how the plants access water, hence stressing vegetation and increasing vulnerability to degradation. Overgrazing and land-use change interact with climate stress to accelerate loss of common pastures that traditionally supported pastoral livelihoods and grassland wildlife.

Liu *et al.* (2019), mentions droughts as the major cause of inter-annual changes in carbon sinks in grassland ecosystems. The growth rate of abnormal atmospheric CO_2 triggered by frequent droughts has been higher in recent years than in other years (Jiang *et al.*, 2016; Kim *et al.*, 2019). Adding to it, Wang *et al.* (2018), associates drought with terrestrial carbon cycling on a regional to sub-continental scale. Anthropogenic activities and climate change continue to aggravate droughts, there may be more complicated effects on the carbon cycling of grassland ecosystems (Roy *et al.*, 2016).

Recurrent drought reduces biomass and ground cover, making soils more exposed; if grazing or mowing is not adjusted, trampling and removal of remaining biomass accelerate erosion and loss of soil organic matter, pushing grasslands toward long-term degradation. Increased drought frequency synchronizes species' responses so that many decline at the same time, weakening the stabilizing effect of diverse responses and making productivity more variable and collapse more likely. Drought and overuse further reduces below-ground biomass and microbial activity, diminishing soil carbon and nutrient retention; this lowers future productivity and increases sensitivity to the next climatic extreme.

Apart from the drought, the factors like shallow soils of the grassland, their interdependence on monsoon and open canopies make their reaction frequent and recurring to the change in the moisture and temperature. These direct climate stress when combines with indirect drivers like pollution, biological invasion and land use intensification, the chances get higher of crossing tipping points into its irreversible degraded states without active restoration. Roy *et al*. (2016) has explained in their study that grassland ecosystems might physiologically recover from a single stress, but for the grassland ecosystem it becomes a challenge to recover from a drought event along accompanied with high temperature or heat stress.

Climate change as the drivers of change in Grassland Ecosystem of GIB: The climate change threatens the unique characteristics of grassland ecosystems by direct and indirect ways.

1. **Primary (Direct) climate impacts.**

a. **Heat stress and altered rainfall:** Higher temperatures and more frequent or intense droughts as a part of climate change reduces plant growth, increase mortality, and shrink root systems, directly lowering net primary productivity and carbon uptake. More intense rain events can increase erosion and nutrient leaching, further weakening plant communities. The climate change does not impact all plant species or ecosystems in the same way. Some species respond positively to increased CO_2 concentrations, while some respond negatively to increased temperature and rainfall variability.

b. **Physiological and phenological shifts:** The global warming changes growing-season length and flowering time, which can decouple plants from pollinators and alter competitive balance among species in grasslands. Yuan *et al.* (2023), have confirmed that droughts alters the phenology by shifting the beginning or end of the growing season. Hoover *et al.* (2021); Kang *et al.* (2018) has further established that long term dry spell advances end of season leaf senescence. Castillioni *et al.* (2022); Forest and Miller- Rushing (2010), has stated that climate change involving frequent and long term droughts has altered different species flowering phenology by progressing the flowering time and extending the flowering length. Apart from these, it has been observed that the climate change has shifted the duration and timing of the growing season and flowering with effects on community.

c. **Response of species growth with relation to time:** As we can say that change in atmospheric CO_2 concentration accompanied with elevated air temperatures and changes in precipitation pattern and quantity would have singular and interactive effects on grassland processes. The capability of grasslands to withstand its structural and functional processes depends upon the maintenance of ecosystem resilience. The local impacts or drivers of change would vary from place to place, the overall climate change drivers will negatively impact grassland structure and function.

2. **Secondary (Indirect) Impacts.**

a. **Land Use and Land Cover (LULC) Change:** The Land-use and land-cover changes denotes to anthropogenic alterations of the landscape resulting in a change of goods and services compared to a natural grassland ecosystem. The population growth and the demand for food, had made grasslands less productive and the remaining fragments which have been converted to agriculture has resulted in reduction of native grasslands. These open grasslands of Thar Desert had been in continuation in reduction of its quality by overgrazing of cattle, invasive species and fragmentation of habitat. With the growing population and the demand for food, the vast scale of grasslands, a suitable habitat for GIB has been irrigated into agricultural land, which has resulted into conversion of preferred GIB habitat to an agriculture dominating landscape (Dookia 2010). The condition has been further exaggerated, by misclassification of grasslands as "wastelands" has accelerated diversion for development projects with an ease (Rawat & Dookia 2020).

b. **Agriculture, Urbanization and Habitat Fragmentation:** Indeed, conversion to agricultural land is the primary threat of grassland ecosystems globally (Gibson, 2009). The marginal grasslands of Thar Desert with less fertile soil but a suitable habitat for breeding and feeding ground for The Great Indian Bustard, are been converted to cultivable agriculture land. Landscape fragmentation, is the secondary impact of the grassland conversion into agriculture land. The fragmentation (for agricultural land or renewable power plants) in Thar Desert has reduced suitable habitat for wild animal populations, resulting in the loss of natural grass patches, viable corridors for wild ungulates, which facilitate animal movement as well as also is impactful for highly mobile birds both local and migratory (Varghese *et al*., 2016). Krauss *et al*. (2010), has explained that fragmentation also reduces genetic diversity of plant populations by reducing plant species richness and abundance within fragments and lowering the total number of species present within a given area. Hence, combined efforts must focus on sustainable agriculture which can produce higher yields comparatively, traditional or organic farming leading to soil quality enrichment with special focus on regenerative agricultural. Apart from these, the breeding of GIB has been further affected by human disturbances in its habitat, better road connectivity between villages and towns increased vehicular traffic (tourism and nearby local traffic) and irrigation facilities facilitated year around land use by humans. As Thar Desert has more than 300 sunny days annually, receiving solar radiation of 21-25 MJ/m^2/day, it becomes a perfect ground for energy production throughout the year (Kumar *et al.*, 2021). In Rajasthan, the solar installation capacity has risen from 40.51% in 2017-2018 to 67.61% in 2023-24 (Renewable Energy Statistics, 2023-24). This increase in solar powered renewable plants converted large swath of ONEs as well as installation of power transmission lines and series of wind turbines has posed severe threats to GIB and other birds by direct mortality (Uddin *et al.*, 2021; Kumara *et al.*, 2022; Roy *et al.*, 2025) obstructing their flight and disturbing the habitat. Apart from power line collision and mortality, unplanned infrastructure development has turned the habitat into fragmentation and created unfavourable zones where earlier GIB used to be visit during non-breeding season.

c. **Woody Encroachment:** With the population increase and demand of food, the conversion of grasslands to agricultural followed by the fragmentation of the left over grasslands and changes in land-use has expedited an increase in woody plants in grasslands of the GIB dominated area. Over the last 4-5 decades mass scale tree plantation was being promoted under various government schemes to halt the proceedings of desert towards earthern side. The preferred tree species was *Acacia tortilis*, which is a non-native species and sustained well into sandy habitats. This phenomenon of planting mass scale tree saplings is referred to as woody encroachment. Archer *et al.* (2017) explained that increase in woody cover leads to a direct loss of grasslands and their ecosystem services, in terms of quality forage for livestock grazing and by reducing herbaceous productivity and species richness. However, in arid grasslands of Thar Desert, Jaisalmer district, this woody cover is also helped in increased precipitation. However, overall increased atmospheric carbon dioxide concentration speed up the woody plant growth and its establishment. Excess CO_2 leads to rise in carbon fixation via photosynthesis and resulting in reduction of water loss due to stomatal conductance decreases with increasing CO_2. This fertilization effect is more beneficial for juvenile plants.

d. **Invasive species:** The invasive species which are accidentally introduced to a new grassland ecosystems flourish well and spread in the new ecosystem after being freed from the "restriction" of their native habitat. These species typically results in alteration of species composition and decline in the ecosystem productivity and biodiversity. Thomas *et al.* (2004), showed that increased temperatures and precipitation variability associated with climate change puts native grassland communities at increased risk of invasion. *Neltuma juliflora* is the key invasive species in the GIB grassland, disturbing the native grassland and the habitat of the Great Indian Bustard. The Thar Desert ecosystem which already exhibits decreased diversity is associated with loss of ecosystem resilience. These invasive species contains innate characters which allows them to survive in the landscape and allows them to take advantage of severe disturbances. When coupled with climate change and anthropogenic factors, these invasive species plays key role in disturbance grassland ecosystem and converting GIB habitat conditions worsen. Gibson and Newman (2019) in the study have mentioned that these disturbances, have drastically altered species composition, productivity and ecosystem function, all of which have long-term ecological consequences.

e. **Altered Grazing Regimes:** Recent data shows that the climate of Thar Desert is becoming hotter with more erratic monsoon rainfall, intense heat waves and increased frequency of drought years. These changes has stressed desert vegetation; over grazing and land-use change, combined with shifting climate, are already degrading native grasslands including the most resilient grass species *Lasiurus sindicus* and locally known as sewan. Sewan is a dominating grass species of *Dichanthium-Cenchrus–Lasiurus* type grass-lands of hot arid ecosystem of Great Indian Desert, covering arid zone of Thar Desert where rainfall is upto 150 mm annually and it can withstand multiple years of drought period to re-sprout from its rhizome stock. The Great Indian Bustard prefer such area and breeds in the grassland dominated by Sewan grass. Sewan grass is C4 grass, has lodging resistance, is drought tolerant and forms bushy tussocks that provide high-quality pasture for livestock, wild herbivores and help stabilize dunes, making these grasslands ecologically important "lifelines" in the Thar Desert landscape. Although, Sewan is drought-hardy and can survive several years with very little rain, but its biomass production and seed output has been declining when rainfall becomes too low or highly variable, even if the plant persists. It has been observed by the locals that under climate stress plus heavy grazing, sewan patches thin out, making it easier for invasive or less palatable species to invade and further reduce high-quality forage.

The factors discussed above exemplifies how rapid socio-economic changes have destabilized a species adapted to low-intensity human landscapes. The Thar Desert remains last hope for GIB survival, but the ongoing habitat degradation and fragmentation has threatened even this last refuge. The conservation of GIB will depend on managing landscapes beyond protected areas and reconciling development with ecological limits. Recently, when Honourable Supreme Court of India has given their verdict on redefining GIB habitat, an initiative to look out for GIB prioritize habitat given emphasis while looking for renewable energy and sustainable development (Anonymous, 2025). There is an ongoing public interest litigation (PIL) in the Supreme Court of India M.K. Ranjitsinh &

Ors. v. Union of India & Ors. (Writ Petition (Civil) No. 838 of 2019) in the Supreme Court of India concerning the protection of the critically endangered Great Indian Bustard (GIB). The case highlights the conflict between renewable energy infrastructure and biodiversity, with a 21st March 2024 judgment (Anonymous, 2024) emphasized a balance between environmental protection and sustainable development, noting that while solar energy is important, it cannot come at the cost of the extinction of a species. Though it is again challenged into the Supreme Court with a plea to balance the development and conservation with a pro-development vision. This study is an attempt to highlight the plight of critically endangered species and urge stronger protection for the endangered Great Indian Bustard (GIB) by conserving its habitat through in-situ conservation concept areas in Rajasthan and Gujarat, and emphasizing that GIB protection is "non-negotiable". It need to be protected beyond the only protected area of this landscape, *i.e.*, Desert National Park and other satellite enclosure area. Undergrounding or marking of powerlines should be done. And the most important thing to be carried out is community based conservation and incentive mechanisms for the locals. Involvement of the locals, promotion of bustard friendly agricultural practices (organic farming), development of sewan grassland (grass preferred by GIB) and integration of grassland conservation into state land use planning.

Resource availability for GIB and adaptation options:

As discussed above that climate change is aiding in the habitat loss (grassland ecosystem) of GIB directly and indirectly which is further affecting its feeding, breeding and movement hence cause of its population decline. Under such conditions, the grassland development which are a prime habitat for adaptation measures such as protecting and restoring native grasses, controlling grazing pressure and using agroforestry or silvopastoral systems can improve moisture retention, reduce erosion and stabilize forage production under variable climates. Ecological restoration of grassland focuses on positive mitigation and maintain ecosystem services. New development projects in the GIB area should to be planned in a way to restrict from all existing GIB habitats for further fragmentation so that the grasslands should be large enough to support viable population and continuity, promoting low intensity, regenerative or organic farming around core habitats ensuring seasonal resting of key pastures. Integrating community-based grassland management with climate resilient water harvesting and grazing plans in Rajasthan can simultaneously support local livelihoods, enhance ecosystem resilience and secure the food and habitat resources needed for sustaining GIB populations. The current scenario of the GIB, is its small population size and biological constraints. Its small population size, low reproductive rate, makes them highly vulnerable to any stochastic events (Dutta *et al.*, 2010). The species shows reduced resilience to fast changing landscape scenario as additional mortality by feral dogs, high tension power lines and other climate related and anthropogenic factors.

CONCLUSIONS

Climate change is a global concern, visualizing its impact on ground requires a panoramic vision. This study is an attempt to summarize all existing decades' long land-use land-cover changes coupled with fast paced developmental activities in last one decade for harvesting renewable energy. On the other hand, the vary landscape is also home of last viable population of critically endangered Great Indian Bustard. A habitat specialist species, even with a slight modification in its global distribution over the decades forced local extinction from all earlier known population distribution areas. As of now Rajasthan, particularly the western part of this state, Thar Desert and–Jaisalmer landscape, represents the final frontier for the existential issue for Great Indian Bustard. The transformation of historically compatible agro-pastoral systems into fragmented, infrastructure-dominated landscapes has driven the species to the brink of extinction. This study is a commentary and an attempt to gather attention of policy makers to delve into for prioritization of action, either to save its last remaining wild habitats, *i.e.*, Open Natural Ecosystems (ONEs) to leave a cascading impact through anthropogenic pressure. This species is already facing existential crisis as it is listed critically endangered since 2011 in Red Data Book. Any further development, be it a sustainable development plan or harvesting more renewable energy plan, our priority should be to keep the habitat of last remaining Great Indian Bustards *Sanctum sanctorum* for their long term survival and population revival. Immediate, region-specific, and landscape-scale conservation action is essential if the Great Indian Bustard is to survive in the wild. Looking at the current scenario, there is a clear mismatch between priority and action on ground and long term trend of seasonal changes coupled with global climatic change creating a probability of domino's effect. In such murky canvas, Great Indian Bustard seems to move towards oblivion.

FUTURE SCOPE

The entire landscape of western Rajasthan is very dynamic, changing rapidly either by anthropogenic pressure or climatological changes. On the same time wild population of Great Indian Bustard is trying to negotiate these rapid changes with its ability of resilience to survive. The recent judgement of Honourable Supreme Court of India also identified certain areas to be preserved as prime GIB habitat under "revised priority area" and pointed out to re-route the high energy power-lines from the prime habitat. This prioritization for conservation of GIB on one side and pooling all exiting power lines (in a stipulated time frame) on another side will decide the future of this bird. The future of this critically endangered bird now fully depends on the action, execution, and implementation and needs a constant vigil to fix the accountability through monitoring and research.

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REFERENCES

Ali, Z., Hussain, I., Faisal, M., Nazir, M., Moemen, M. A., Hussain, T. and Shamsuddin, S. (2017). A novel multi-Scalar drought index for monitoring drought: the standardized precipitation temperature index. *Water Resour Manage*, *31*(15), 4957–4969.

Allaby, M. (2009). *Grasslands*. Infobase Publishing, New York, USA.

Anonymous (2022). India's Updated First Nationally Determined Contribution Under Paris Agreement (2021-2030) https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

Anonymous (2024). M.K. Ranjitsinh & Ors. v. Union of India & Ors. https://api.sci.gov.in/supremecourt/2019/20754/20754_2019_1_25_51677_Judgement_21-Mar-2024.pdf

Archer, S. R., Andersen, E. M., Predick, K. I., Schwinning, S., Steidl, R. J. and Woods, S.R. (2017). Woody plant encroachment: Causes and consequences. In D. D. Briske (Ed.), *Rangeland systems: Processes, management and challenges* (pp. 25–84). Cham, Switzerland: Springer.

Bardgett, R., Bullock, J. M., Lavorel, S., Manning, P., Schaffner, U., Ostle, N. J., Chomel, M., Durigan, G., Fry, E., Johnson, D., Lavallee, J. M., Le Provost, G., Luo, S., Png, G. K., Sankaran, M., Xiangyang, H., Zhou, H., Ma, L., Weibo, R., Xiliang, L., Ding, Y., Yuanheng, L. and Hongxiao, S. (2021). Combatting global grassland degradation. *Nature Reviews Earth & Environment*, *2*(10), 720-735. https://doi.org/10.1038/s43017-021-00207-2

Carlsson, M., Merten, M., Kayser, M., Isselstein, J. and Wrage-Mönnig, N. (2017). Drought stress resistance and resilience of permanent grasslands are shaped by functional group composition and N fertilization. *AgriEcosyst Environ*, *236*, 52–60.

Castillioni, K., Newman, G. S., Souza, L. and Iler, A. M. (2022). Effects of drought on grassland phenology depend on functional types. *New Phytologist*, *236*, 1558-1571.

Dabadghao, P. M. and Shankarnarayan, K. A. (1973). *The Grass Cover of India*. Indian Council of Agricultural Research, New Delhi.

Dookia, S. (2007). Present status of avifauna in the Indira Gandhi Nahar Pariyojana (IGNP) area, Thar Desert of Rajasthan, India. Project Technical Report submitted to Oriental Bird Club, UK. 36 p.

Dookia, S. (2010). Plight to ponder: Present status of Great Indian Bustard in Western part of Thar Desert of Rajasthan, India. *Project Technical Report submitted to Oriental Bird Club*, UK. 38 p.

Dutta, S. Rahmani, A. R. and Jhala, Y. V. (2010). Running out of time? The great Indian bustard *Ardeotis nigriceps*—status, viability, and conservation strategies. *Eur J Wildl Res*. https://doi.org/10.1007/s10344-010-0472-z.

Dutta, S., Rahmani, A. and Jhala, Y. (2011). Running out of time? The great Indian bustard Ardeotis nigriceps-status, viability, and conservation strategies. *European Journal of Wildlife Research*, *57*, 615-625.

Forrest, J. and Miller-Rushing, A. J. (2010). Toward a synthetic understanding of the role of phenology in ecology and evolution. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*, 3101-3112.

Gibbs, H. K. and Salmon, J. M. (2015). Mapping the world's degraded lands. *Applied Geography*, *57*, 12-21.

Gibson, D. J. (2009). *Grasses and grassland ecology*. New York: Oxford University Press.

Gibson, D. J. and Newman, J. A. (2019). Grasslands and Climate Change. Cambridge University Press, Cambridge, UK 348 p. DOI: https://doi.org/10.1017/9781108163941

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E. and Zenebe, A. (2018). Predictions of future meteorological drought hazard (~ 2070) under the representative concentration path (RCP) 4.5 climate change scenarios in Raya, northern Ethiopia. *Model Earth Syst Environ*, *4*(2), 475–488.

Gupta, R. K. (1975). Plant life in the Thar. In: R.K. Gupta & I. Prakash (Eds.). *Environmental analysis of the Thar Desert*. English Book Depot, Dehra Dun. Pp. 202–236.

Hoover, D. L., Pfennigwerth, A. A. and Duniway, M. C. (2021). Drought resistance and resilience: the role of soil moisture-plant interactions and legacies in a dryland ecosystem. *Journal of Ecology*, *109*, 3280-3294.

Huang, J., Zhai, J., Jiang, T., Wang, Y., Li, X., Wang, R., Xiong, M., Su, B. and Fischer, T. (2018). Analysis of future drought characteristics in China using the regional climate model cclm. *Clim Dyn*, *50*(1–2), 507–525.

Ingrisch, J., Karlowsky, S., Anadon-Rosell, A., Hasibeder, R., König, A., Augusti, A., Gleixner, G. and Bahn, M. (2018). Land use alters the drought responses of productivity and CO_2 fluxes in mountain grassland. *Ecosystems (NY)*, *21*(4), 689–703.

IPCC (2022). Climate change 2022: Impacts, adaptation and vulnerability. In H.-O. Pörtner, *et al.* (Eds.), *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jiang, Y., Xu, Z., Zhou, G. and Liu, T. (2016). Elevated CO_2 can modify the response to a water status gradient in a steppe grass: from cell organelles to photosynthetic capacity to plant growth. *BMC Plant Biol*, *16*(1), 157–173.

Kang, W., Wang, T. and Liu, S, (2018). The response of vegetation phenology and productivity to drought in semi-arid regions of northern China. *Remote Sensing*, *10*, 727.

Kim, D., Lee, M. I. and Seo, E. (2019). Improvement of soil respiration parameterization in a dynamic global vegetation model and its impact on the simulation of terrestrial carbon fluxes. *J Clim*, *32*(1), 127–143.

Krauss, J., Bommarco, R., Guardiola, M., Heikkinen, R. K., Helm, A. and Kuussaari, M. (2010). Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. *Ecology Letters*, *13*(5), 597–605.

Kumar, S., Vyas, R., Tirole, M., Vyas, S. S., Sharma, S. and Rao, S. (2021). Strategies to Enhance Solar Energy Utility in Agricultural Area of Rajasthan State. *India J. Phys. Conf. Ser*., 1854.

Kumara, H. N., Babu, S., Rao, G. B., Mahato, S., Bhattacharya, M., Rao, N. V. R., Tamiliniyan, D., Parengal, H., Deepak, D., Balakrishnan, A. and Bilaskar, M. (2022). Responses of birds and mammals to long-established wind farms in India. *Sci. Rep. 12* (1).

Liu, Y., Yang, Y., Wang, Q., Du, X., Li, J., Gang, C., Zhou, W. and Wang, Z. (2019). Evaluating the responses of net primary productivity and carbon use efficiency of global grassland to climate variability along an aridity gradient. *Sci Total Environ*, *652*, 671–682.

Madhusudan, M. D. and Vanak, A. T. (2023). Mapping the distribution and extent of India's semi-arid open natural ecosystems. *Journal of Biogeography*, *50*, 1377–1387. https://doi.org/10.1111/jbi.14471

Rahmani, A.R. (1989). *The great Indian bustard. Final report in the study of ecology of certain endangered species of wildlife and their habitats*. Bombay Natural History Society, Mumbai. 120 p.

Rawat, M. and Dookia, S. (2020). Great Indian Bustard Conservation through Community Participation in Western part of Thar Desert of Rajasthan, India. Project Technical Report submitted to Oriental Bird Club, UK. 68 p.

Renewable Energy Statistics (2023-2024). *Ministry of new and Renewable energy*, Government of India (2024).

Roy, A., Banerjee, S., Uddin, M., Jhala, Y. V. and Dutta, S. (2025). Bird mortality at wind farms in a tropical desert. *Scientific Reports15*, 19221 https://doi.org/10.1038/s41598-025-03407-8.

Roy, J., Piconcochard, C., Augusti, A., Benot, M. L., Thiery, L., Darsonville, O., Landais, D., Piel, C., Defossez, M. and Devidal, S. (2016). Elevated CO_2 maintains grassland net carbon uptake under a future heat and drought extreme. *Proc. Natl. Acad. Sci.*, *113*, 6224–6229.

Santra, P. and Chkraborty, A. (2011). Analysis of seasonal and annual change of vegetation in the Indian Thar Desert using MODIS data, Int. *Arch. Photogramm. Remote Sens.* Spatial Inf. Sci., XXXVIII-8/W20, 175–178, https://doi.org/10.5194/isprsarchives-XXXVIII-8-W20-175-2011.

Smith, M. D. (2011). The ecological role of climate extremes: Current understanding and future prospects. *Journal of Ecology*, *99*(3), 651–655.

Stampfli, A., Bloor, J. M., Fischer, M. and Zeiter, M (2018). High land-use intensity exacerbates shifts in grassland vegetation composition after severe experimental drought. *Global Change Biology*, *24*, 2021-2034

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N, Ferreira de Siqueira, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M. A., Peterson, A. T., Phillips, O. L. and Williams, S. E. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145–148.

Uddin, M., Dutta, S., Kolipakam, V., Sharma, H., Usmani, F. and Jhala, Y. V. (2021). High bird mortality due to power lines invokes urgent environmental mitigation in a tropical desert. *Biol. Conserv.*, *261* (2021)

Varghese, A. O., Sawarkar, V. B., Rao, Y. L. P. and Joshi, A. K. (2016). Habitat suitability assessment of *Ardeotis nigriceps* (Vigors) in great Indian bustard sanctuary, Maharashtra (India) using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, *44*, 49-57.

Wang, J. S., Kawa, S. R., Collatz, G. J., Sasakawa, M., Gatti, L. V., Machida, T., Liu, Y. and Manyin (2018). A global synthesis inversion analysis of recent variability in CO_2 fluxes using GOSAT and in situ observations. *Atmos Chem Phys*, *18*(15), 11097–11124.

Wang, M., Li, P., Peng, C., Xiao, J., Zhou, X., Luo, Y. and Zhang, C. (2022) Divergent responses of autumn vegetation phenology to climate extremes over northern middle and high latitudes. *Global Ecology and Biogeography*, *31*, 2282-2296.

Yan, Z., Gao, Z., Sun, B., Ding, X., Gao, T. and Li, Y. (2023). Global degradation trends of grassland and their driving factors since 2000. *International Journal of Digital Earth*, *16*(1), 1661–1684.

Yuan, Z., Tong, S., Bao, G., Chen, J., Yin, S., Li, F., Sa, C. and Bao, Y. (2023) Spatiotemporal variation of autumn phenology responses to preseason drought and temperature in alpine and temperate grasslands in China. *The Science of the Total Environment*, *859*, 160373.

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