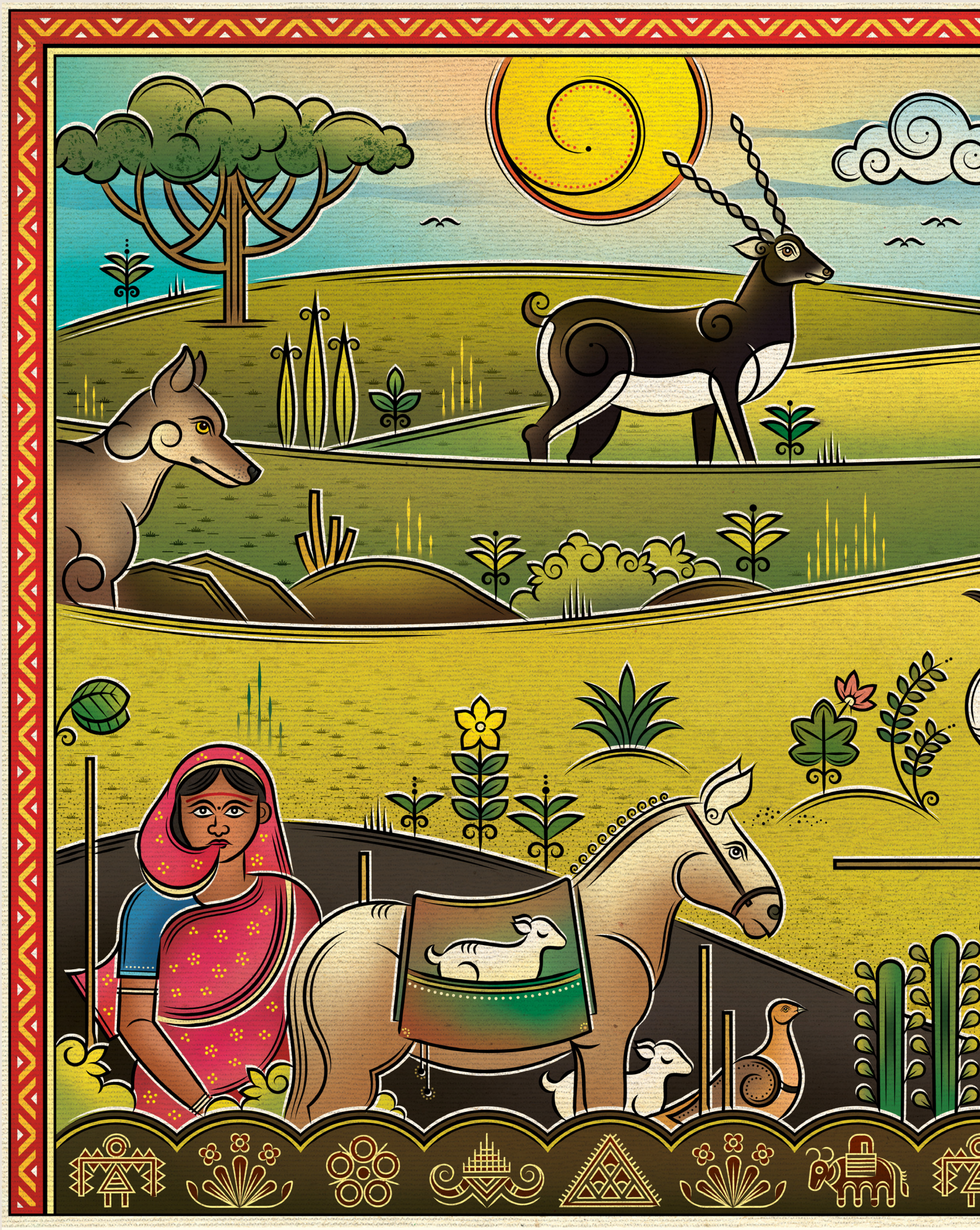
Managing Open Natural Ecosystems for People, Climate and Biodiversity

Centre for Policy Design
Ashoka Trust for Research in Ecology and the Environment (ATREE), Bangalore



Open Natural Ecosystems of India rendered in Indica art style by artist Sudarshan Shaw

Photo credit: Abi T. Vanak

Contents

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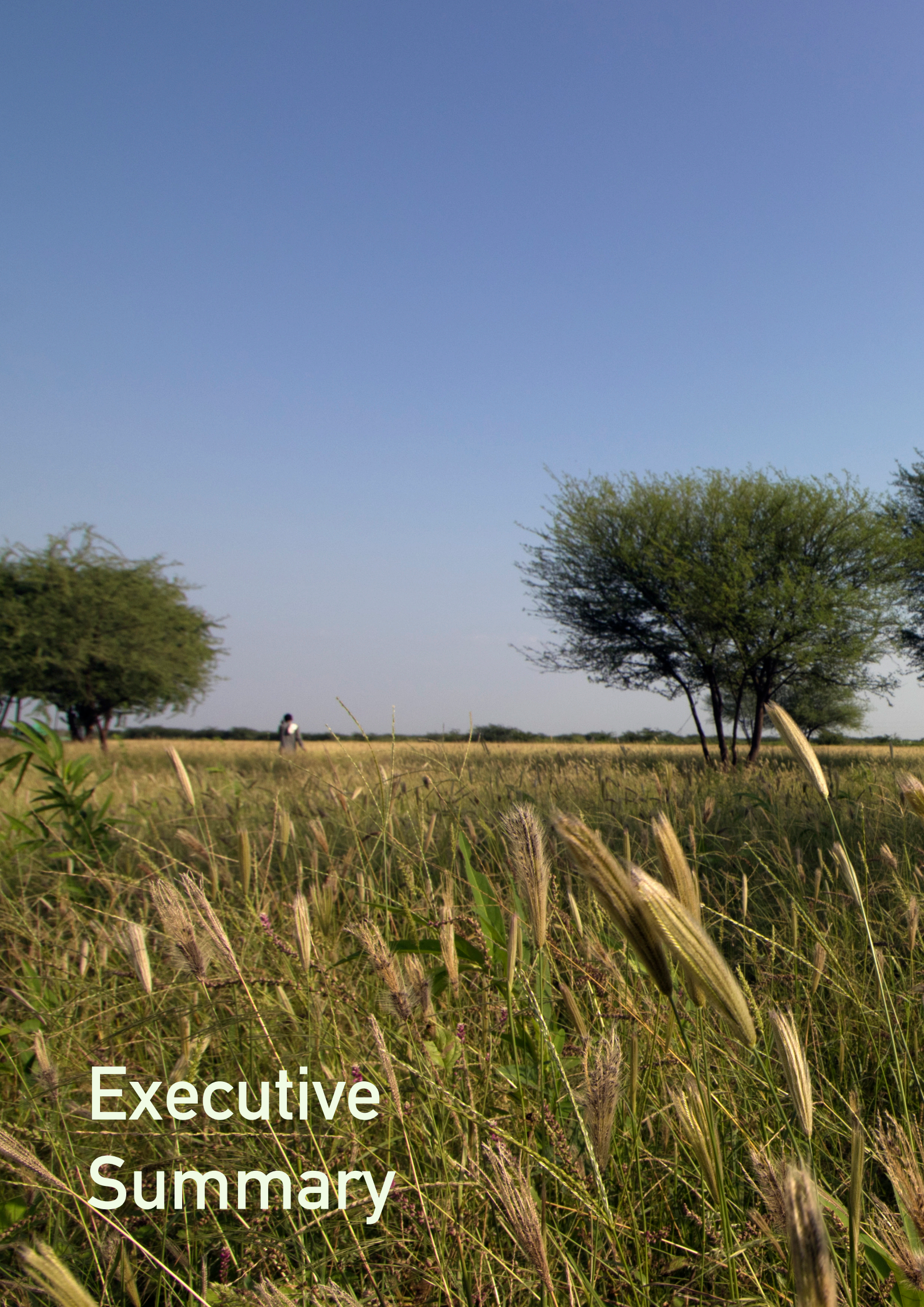
List of Abbreviations

C/ha/year	Carbon per hectare per year
COP	Convention of Parties
DNTs	Denotified Nomadic and Semi-Nomadic Tribes
FAO	Food and Agriculture Organisation
IYRP	International Year of Rangelands and Pastoralists
MNRE	Ministry of New and Renewable Energy
MoAH	Ministry of Fisheries, Animal Husbandry and Dairying
MoEFCC	Ministry of Environment, Forests and Climate Change
MoJS	Ministry of Jal Shakti
MoRD	Ministry of Rural Development
NLM	National Livestock Mission
ONE(s)	Open Natural Ecosystems
SA-ONE(s)	Semi-arid Open Natural Ecosystems
SDG	Sustainable Development Goals
SOC	Soil Organic Carbon
tC/ha	tonnes of carbon per hectare
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change

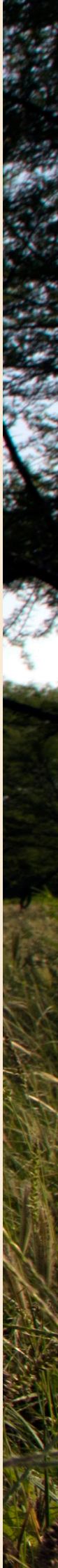


Executive Summary

Semi-arid Open Natural Ecosystems (ONEs), such as savanna grasslands and deserts, are unique ecosystems that make up more than 10% of India's geographical area. They support natural resource-based livelihoods that contribute to India's national economy and cultural heritage and have the potential to sequester high amounts of below-ground carbon while also harbouring rich and unique biodiversity. ONEs are found across the drier parts of western and central India, in states such as Gujarat, Rajasthan, Maharashtra, Karnataka, Tamil Nadu, Madhya Pradesh and Telangana.

ONEs, however, are often neglected by mainstream conservation narratives and misunderstood as degraded ecosystems or barren lands. Seventy per cent of ONEs in India still carry the colonial legacy of being classified as 'wastelands'. This misclassification makes them vulnerable to land-use conversions and ignores the immense value these landscapes add in terms of faunal and floral biodiversity, socio-economic and cultural sustenance, climate adaptation and carbon sequestration. ONEs are a latent cornucopia* that can help meet India's climate, rural livelihoods and development and biodiversity goals.

The aim of this white paper is to call for the government to institute a land management ethic for the conservation, restoration and management of India's ONEs. The white paper showcases the significance of three aspects of India's ONEs – people, carbon and biodiversity.



* The word cornucopia comes from the Latin "cornu copiae", which translates literally to "horn of plenty". A traditional staple of feasts, the cornucopia is believed to represent the horn of a goat from Greek mythology.

The paper highlights the following key takeaways:

1. Benefits of Open Natural Ecosystems

i) ONEs promise **resilient and water-efficient soil carbon storage** in arid and semi-arid regions – These landscapes store carbon below ground, thereby holding carbon that is more permanent and stable as against above-ground carbon stocks in forests (that may be susceptible to loss through fires and felling). Rather than aiming to green these landscapes through tree plantation programmes that are resource-intensive and have low success rates, conservation and restoration of degraded ONEs through locally relevant measures, such as native grass plantations, can contribute to higher carbon sequestration gains. Ecologically suitable management has the potential to conserve the existing stocks (avoiding losses) and restore depleted carbon stocks in degraded soils.

ii) ONEs **support rural livelihoods** in arid and semi-arid areas – They sustain approximately 1.3 crore (13 million) pastoralists who generate an economic output of Rs. 1.31 lakh crore (approximately USD 15.6 billion USD).[1] Extensive pastoralism is a low-cost and low-input livelihood that produces about 53%of India's milk and 74% of its meat.[2] Pastoralist livelihoods are particularly important in arid areas, given the high climatic variation and unpredictability of these landscapes. Mobility, a crucial aspect of this livelihood, enables pastoralists to make optimal use of dry, fragile and marginal landscapes, migrating according to seasonal resource availability (of forage and fodder).

iii) ONEs **harbour unique biodiversity** – Spanning across various biogeographic zones, ONEs are critical habitats for several endangered and endemic species of fauna and flora. A recent study found that Indian savannas harbour 206 endemic species of plants, nearly half of which were described only in the last twenty years.[3] As these habitats shrink, their co-dependent wildlife, such as the great Indian bustard (*Ardeotis nigriceps*), lesser florican (*Sypheotides indicus*), sociable lapwing (*Vanellus gregarius*), and Jerdon's courser (*Rhinoptilus bitorquatus*) have also been pushed to the brink of extinction. Although not as diverse as African savannas, these ecosystems still harbour an impressive assemblage of predators such as the Indian grey wolf (*Canis lupus pallipes*), striped hyena (*Hyaena hyaena*) and Indian fox (*Vulpes bengalensis*), and herbivores such as the Indian gazelle (*Gazella bennetti*) and blackbuck (*Antilope cervicapra*). The ONEs of India also provide refuge to migratory species such as harriers, several species of vultures, cranes and other long-distance migrants from Europe and elsewhere. Understanding the spatial distribution and ecological characteristics of these ecosystems is crucial for informed conservation and land management strategies in the country.

2. Management of ONEs must account for:

i) **Tenurial arrangements** – The tenurial arrangements vary across these landscapes, i.e., ownership of these lands is not uniform. ONEs fall under common lands, privately owned land, revenue or forest department land.

ii) **Governance** – The governance of these lands falls under the ambit of various government departments, cutting across sectors such as industry, agriculture, rural development, irrigation and forests.

iii) **Wastelands classification** – Their classification as 'wastelands' makes them susceptible to conversion.

iv) **Multiple goals** – India has a number of climate, development and conservation goals that are to be negotiated within this landscape. For example, large swathes of land are often required for industries or development projects such as renewable energy. However, such expanses of land are also essential for biodiversity and peoples' livelihoods. Prioritising areas for these multiple, and sometimes conflicting goals, becomes an important process to ensure human well-being and environmental conservation.

3. Tools for the improved management of ONEs

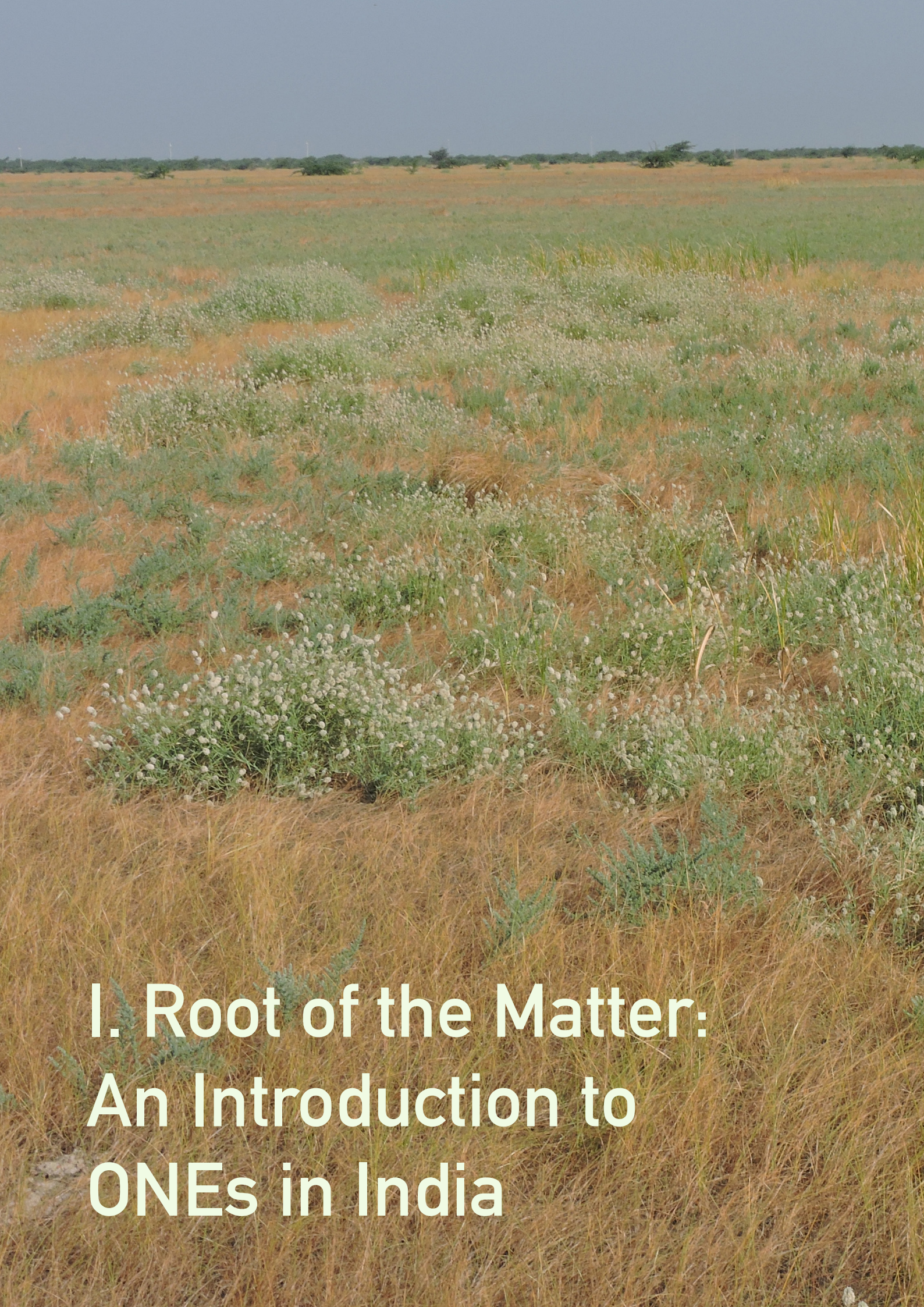
ATREE has come up with tools to initiate socio-ecologically beneficial management of ONEs which can aid the government, civil society and private sector in meeting climate, rural development and biodiversity goals. The tools include:

i) **India's first map of ONEs** at 30m resolution – An updated version is now available for improved land management. This tool can aid policymakers, land-use planners and other agencies interested in land management.

ii) **Biodiversity prioritisation maps** – These are maps for the top eight states with the highest ONE area in India, to showcase conservation priority areas. These maps have been stratified into Level I, Level II and Level III conservation priority areas based on key wildlife species. Level I areas are the highest priority areas that need protection and are highly significant for conservation, while Level II and III are moderately important for biodiversity conservation. These areas can be managed alongside certain anthropogenic activities that do not alter the ecology of the region and are not harmful to wildlife and biodiversity in the region. Additionally, the maps provide a district-wise breakdown of the available area under each priority ranking category.

iii) **Livestock grazing sustainability maps** – These maps highlight grazing priority areas for pastoralists. These areas need to be conserved or restored, keeping in mind the needs of the pastoralist communities. The maps can assist in managing biodiversity and rural livelihoods in these areas.

iv) **A nine-fold policy action classification** – ATREE found 96 policy tools under 24 ministries that directly and indirectly influence ONEs. The policy actions proposed are aimed at existing policy tools and include actions listed as activate, adjust, modify, support, nudge, mitigate and assess.



I. Root of the Matter: An Introduction to ONEs in India

Open Natural Ecosystems (ONEs) are landscapes with naturally open vegetation, patchy or continuous ground cover of grasses and/or herbaceous vegetation, and sparse tree cover. Approximately 10% of India's total geographical area – totalling 319,675 sq. km – comprises low-elevation semi-arid ONEs, such as open savannas, shrublands, woodland savannas, deserts, saline areas and ravines.[4] However, such landscapes in India have historically been unrecognised and undervalued despite sustaining biodiversity, people and their livelihoods and sequestering carbon. Less than 5 per cent of ONEs fall under India's Protected Areas Network,[5] and about 70 per cent of ONEs fall under the government's wasteland classification. However, these landscapes are critical and need to be recognised as distinct ecosystems with unique socio-ecological characteristics.

Photo credit: Chetan Misher

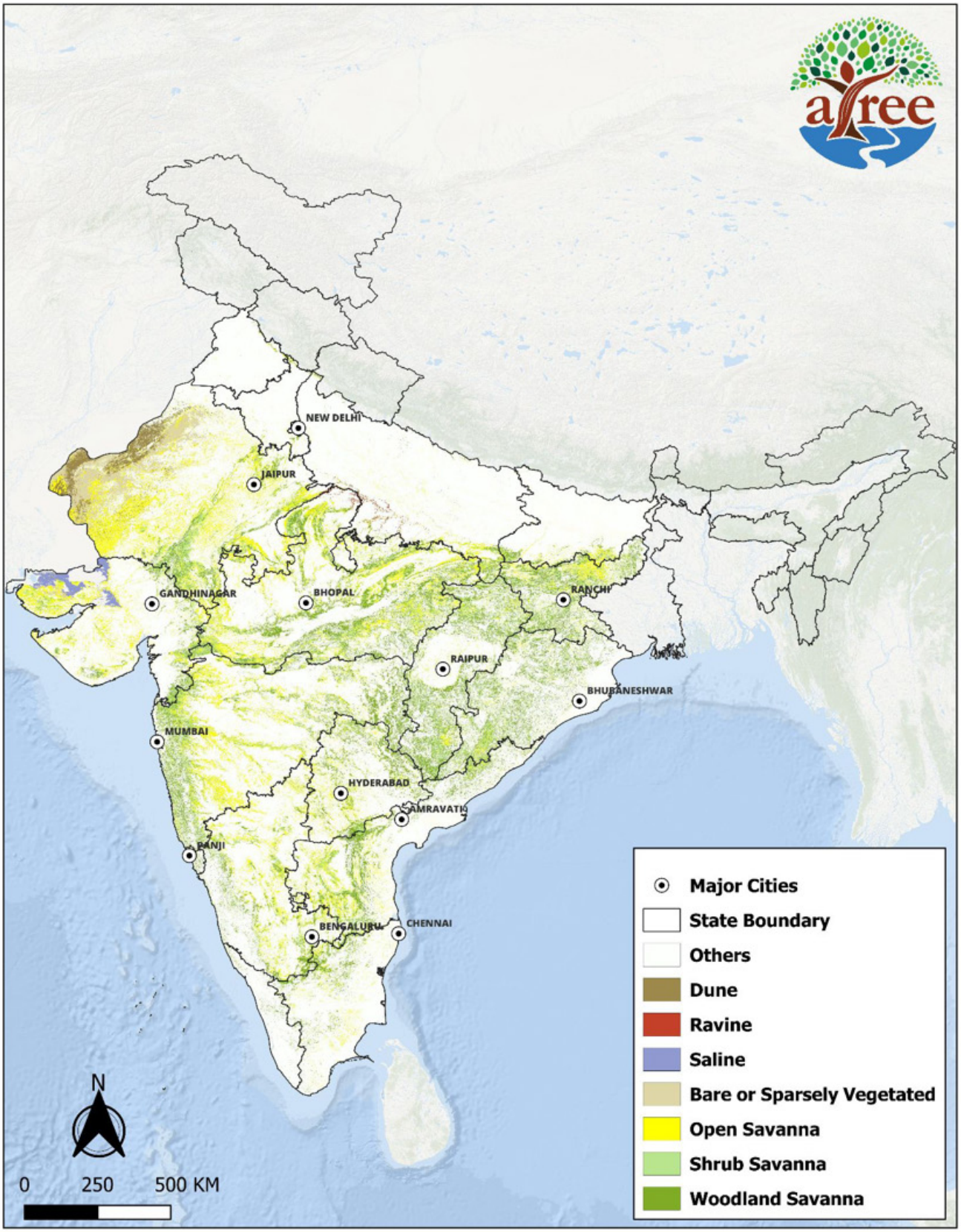


Figure 1: First-ever high resolution map (30 metres) of non-forest ONEs in India based on Madhusudan and Vanak (2023). Map presented prepared by ATREE Ecoinformatics Lab, September 2024.
Source: Pradeep Koulgi & M.D. Madhusudan (2024).

Photo credit: Abhijeet Kulkarni

Unique ecological characteristics of ONEs

Nearly two-thirds of the Earth's terrestrial habitats consist of ONEs.[6] These open ecosystems are diverse in structure and composition, ranging from cold and hot deserts and rocky outcrops to grasslands and savanna ecosystems.

Although their geological, climatic, ecological and anthropological histories vary – ranging from boulder fields to pure grasslands to tall woodlands and differing in their vegetation, dominant species and soil characteristics[7] – ONEs across the world share several characteristics. The vegetation structure in ONEs is driven by differences in annual rainfall, rainfall seasonality and soil properties. Factors like fire and herbivory are additionally integral to these ecosystems rather than being external stressors.[8]

ONEs host high levels of endemic and often endangered fauna and flora.[9] [10] For example, tropical savannahs support the highest density and diversity of wild mammals in the world.[11] In particular, herbivores, depending on their body size, population density and feeding modes, have influenced the structure of ONEs by suppressing vegetation cover and woody encroachment. ONEs have also been critical to the survival of a range of other animals, including birds, reptiles and invertebrate groups. Recent discoveries in ONEs have revealed great biological diversity. There has been an exponential rise in the discovery of plant species from India's ONEs, besides several new species of snakes, lizards and arachnids.

Nevertheless, a mere 5% of India's ONEs are formally protected. Several ONE-restricted species, such as the great Indian bustard, lesser florican, Indian grey wolf, four-horned antelope, Elvira rat, Jerdon's courser and the peacock tarantula, are now endangered or vulnerable to extinction.

ONEs, such as savanna ecosystems, also sequester carbon in the soil, and humid tropical savannas store as much as 90% of carbon underground (upto 30-50 tonnes of Soil Organic Carbon [SOC] per hectare).[12]

History of ONEs

ONEs have existed for a long time, with the present-day savanna ecosystems having evolved around 8–10 million years ago. India's ravine and dune ecosystems formed in erosion and depositional environments sometime in the last two million years, respectively.

Around 6,000 years ago, the strengthening of the southwest monsoon changed weather patterns, leading to the growth of savannas. Over the centuries, migratory communities used these lands for raising and rearing livestock. The past and present diversity of agro-pastoralist cultures in the subcontinent underscores the value – both ecological and social – of our ONEs. While ONEs are not ideal for settled agriculture, their high and rapid seasonal productivity patterns have supported pastoralist communities for generations.

An evolving policy landscape of ONEs

Natural resources in India, particularly forests, have long been under the rule and management of the government. The colonial government notably devised state policy to harness resources for its imperial project[13]. The Indian Forest Act 1865 codified British regulatory control over India's forests. This was done particularly for extracting timber and led to the exploitation of forest resources and the communities that depended upon these lands.[14]

Marginalised landscapes and marginalised peoples

While forests were of high significance to the British, ONEs such as grasslands and deserts did not generate taxable revenue. Accordingly, any land that was not cultivated or was being used for a common purpose was considered a 'wasteland'. This referred to land that is supposedly barren and desert-like with little productive value apart from being a grazing land. This was anathema to the colonial British government. The communities that depended on these landscapes were considered marginal as they did not contribute to the colonial state's taxes or treasury. Their nomadic nature made them 'ungovernable' and they were therefore deemed suspicious.[15]

Photo credit: Chetan Misher

The misplaced identity of ONEs

Tragically, the tag 'wastelands' still continues to this day. The Wasteland Atlas of India, published until 2019 by the Ministry of Rural Development, classifies around 70% of ONEs as wastelands with an aim to convert them to more productive uses. This makes ONEs vulnerable to land conversion for tree plantations or industrial development, both of which can have deleterious socio-ecological impacts on the landscape. Sustained and rapid anthropogenic pressure has led to ONEs being highly threatened globally.[16] According to the Indian government's official report to the UN Convention to Combat Desertification, India lost an estimated 23,034 sq. km of grasslands (almost half the size of Punjab) between 2015 and 2019.[17]

Tenure classifications of ONEs

ONEs are spread across a variety of tenurial arrangements – government lands, private lands and forest lands. They also include lands constituting 'common lands' or 'village commons' that are de jure owned by the state or local governments but used (and occasionally managed) by local communities. Consequently, they are subject to varying land ownership and management practices.

Plans by the forest departments primarily centre around afforestation and forested ecosystems. Because ONEs are often seen as 'degraded forest land', several afforestation programmes have been conducted in these landscapes, particularly through the 1980s.[18] A significant example of this is the planting of *Neltuma (Prosopis) juliflora* in the Banni grasslands to "afforest" the landscape by increasing green cover,[19] in the mistaken belief that increased tree cover can lead to higher rainfall and improved groundwater.[20] [21] However, this has the opposite effect on the grasslands as trees further deplete shallow groundwater aquifers. Additionally, these unscientific afforestation and greening programmes waste precious funds and resources.

Concurrently, with growing international climate action commitments, generating renewable energy through solar and wind power parks has become a significant activity. For instance, the states of Rajasthan, Gujarat, Maharashtra and Karnataka, having significant ONE area, have been identified as having high renewable energy potential. More recently, large infrastructure projects have replaced huge swathes of productive ONEs. All these factors lead to a variety of land conversions of ONEs.

Threats to ONEs

1. Conversion of land due to wasteland classification
2. Afforestation and greening programmes on ONEs
3. Expansion of industrial and agricultural lands
4. Lack of sufficient protection and recognition

Photo credit: Abi T. Vanak

International frameworks and global narratives of ONEs

ONEs have been overlooked in key international frameworks, such as the Sustainable Development Goals (SDG 15 'Life on Land' specifically refers to forests, oceans and coastal ecosystems) and the Aichi Biodiversity Targets. This is a drawback for effective conservation and restoration efforts, particularly since ONEs can help meet biodiversity and climate goals such as increased carbon sequestration.

Significantly, however, attention is now being garnered towards such landscapes. International recognition of ONEs is becoming more widespread. The UN has declared 2026 as the International Year of Rangelands and Pastoralists, implemented by the Food and Agriculture Organisation (FAO) in a bid to draw attention to "the important role healthy rangelands play in creating a sustainable environment, economic growth and resilient livelihoods for communities across the world".[22] It aims to raise awareness and advocate the need to build capacity and increase responsible investment in the pastoral livestock sector. This includes sustainable land management practices, improved or restored ecosystems and equitable access to markets, livestock health and breeding. The frameworks within which Nature-based Solutions (NbS) operate are increasingly looking at protecting and recognising drylands and open ecosystems as integral to climate action resilience, food security and the protection of biodiversity.

Commitments under international organisations related to ONEs

Conserving and restoring grasslands is deeply interconnected with the objectives of the UNFCCC (United Nations Framework Convention on Climate Change), the UNCBD (United Nations Convention on Biological Diversity), and the UNCCD (United Nations Convention to Combat Desertification). Here's how ONEs link to each organisation's objective:

1. UNFCCC

• Carbon sequestration – Grasslands act as carbon sinks, storing significant amounts of carbon in their soils. Restoring grasslands helps mitigate climate change by enhancing their ability to capture atmospheric carbon dioxide.

• Reducing emissions from land degradation – Degraded grasslands often release stored carbon into the atmosphere, contributing to greenhouse gas emissions.

• Restoring these ecosystems can reverse this process, aligning with the UNFCCC's goals to reduce emissions.

2. UNCBD

• Conservation of species – Grasslands support a unique variety of flora and fauna, of which many are threatened due to habitat loss. Restoration efforts contribute directly to biodiversity conservation, which is central to the goals of the UNCBD.

• Ecosystem services – Grasslands provide essential ecosystem services such as pollination, water filtration and habitat for wildlife. Their restoration helps safeguard biodiversity and promote ecosystem health.

• Aichi Targets and Post-2020 Biodiversity Framework – Grassland restoration supports global biodiversity targets by increasing protected and restored ecosystems, a key focus of international biodiversity conservation frameworks.

3. UNCCD

• Combating land degradation – Grasslands are vulnerable to desertification, especially in arid and semi-arid regions. Restoring grasslands helps combat land degradation and desertification, directly supporting the goals of the UNCCD.

• Sustainable land management: Restoring degraded grasslands promotes sustainable land use, which is a major component of the UNCCD's mandate to prevent and reverse desertification and land degradation.

• Drought resilience: Healthy grasslands improve soil moisture retention and help restore water cycles, reducing vulnerability to drought, a focus area for the UNCCD.

4. The FAO's International Year of Rangelands and Pastoralists

• FAO's IYRP, proclaimed for 2026, is directly relevant to grassland restoration. The IYRP focuses on promoting sustainable management and restoring these ecosystems, which are vital for biodiversity, climate mitigation, and combating land degradation.

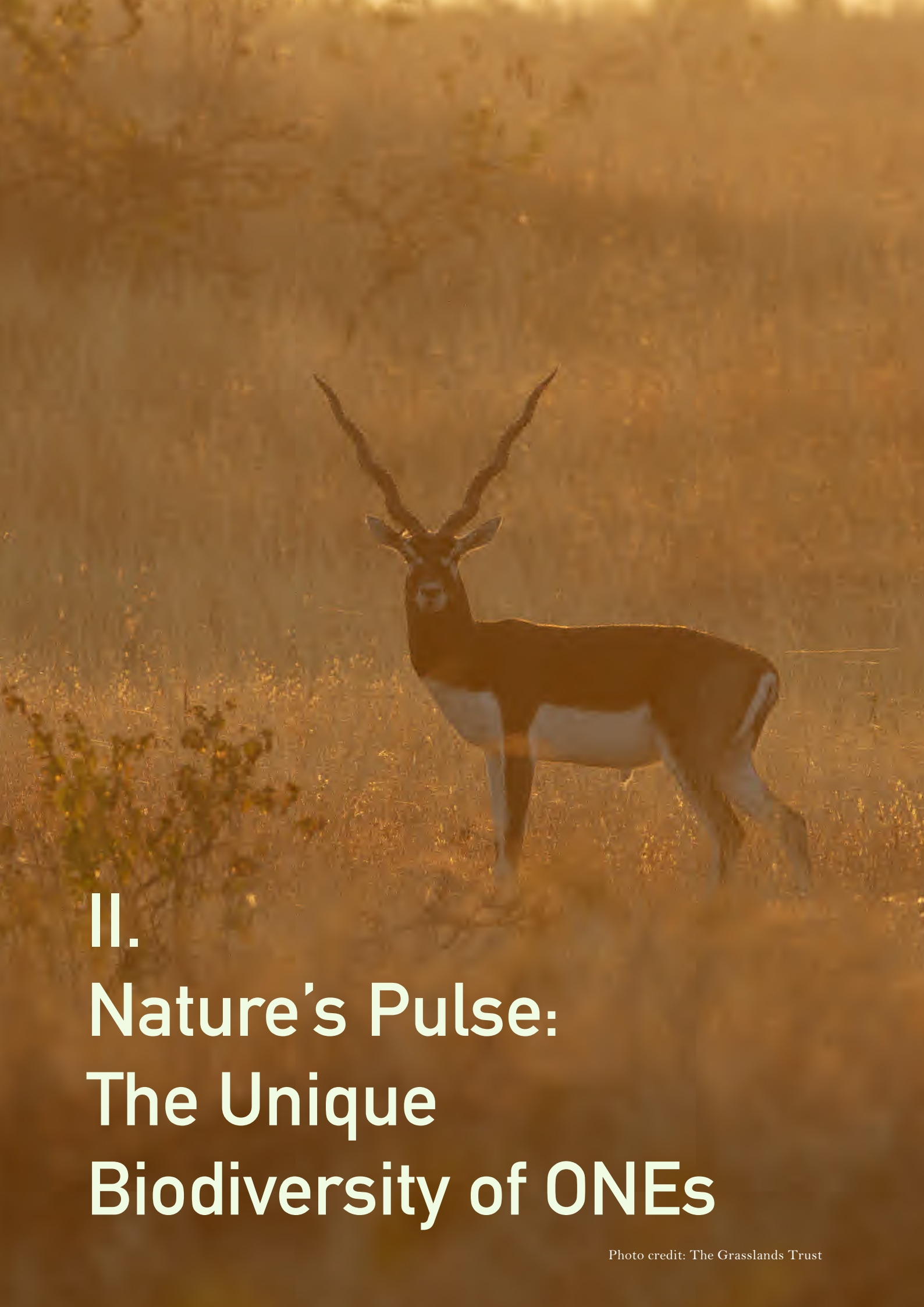
"When we cut down a forest, when we see a 100-year-old tree fall, it rightly evokes an emotional response in many of us. The conversion of ancient rangelands, on the other hand, happens in 'silence' and generates little public reaction."

— Ibrahim Thiaw, UNCCD Executive Secretary, 2024

Making a case for ONEs through people, climate and biodiversity

There are no policies or legal frameworks that recognise and protect Indian ONEs as a distinct category of ecosystems. Even so, ONEs support 1.3 crore pastoralists from 46 pastoralist communities who contribute Rs. 1.31 lakh crore to the economy[23] producing 53% of India's milk and 74% of its meat, and act as crucial carbon sinks capable of sequestering up to 30-50 tC/ha. Indian savannas harbour 206 endemic species, nearly half of which were described only in the last twenty years.[24] This calls for urgent policy action to manage and conserve these important ecosystems. The primary goal of this white paper is to call for greater recognition of ONEs by highlighting their importance for people, climate and biodiversity, as well as developing a new land management ethic for these landscapes through actionable tools such as prioritisation maps and policy action matrices.

Photo credit: Ovee Thorat



II.
Nature's Pulse: The Unique Biodiversity of ONEs

Photo credit: The Grasslands Trust

from the very small
(Sitana)

to the very fast
(Indian wild ass)

the ones who love to wander
(sociable lapwing)

to the ones who love the dark
(striped hyena)

the ones who are hunted
(spiny-tailed lizard)

to the rediscovered
(Jerdon’s courser)

from the rusty
(Indian fox)

to the black-and-white
(variable wheatear)

Critical habitat for endangered species

ONEs in India serve as crucial habitats for many critically endangered faunal species, including the great Indian bustard (*Ardeotis nigriceps*), lesser florican (*Sypheotides indicus*), sociable lapwing (*Vanellus gregarius*), and Jerdon's courser (*Rhinoptilus bitorquatus*), other threatened species such as the pallid harrier (*Circus macrourus*), Macqueen's bustard (*Chlamydotis macqueenii*), striped hyena (*Hyaena hyaena*), and the major predator of these landscapes – the Indian grey wolf (*Canis lupus pallipes*). Notably, these habitats are also primary shelters for the only remaining population of the endangered Asiatic wild ass (*Equus hemionus khur*).

ONEs have often been overlooked in India's biodiversity conservation plans. Only 14,280 sq. km of the identified ONEs are situated within India's Protected Area (PA) network. This is less than 5% of the total ONE area in India.[25]

ONEs are spatially distributed through the semi-arid and arid grasslands of the Thar Desert to the grasslands in peninsular India.[26] [27] Recent evidence suggests that many of India's dry tropical forests are, in fact, savannas (areas with mixed trees and C4 grasses "defined by fire tolerance and shade intolerance" with trees).[28] Proper accounting for these "forests" as ONEs would allow us to manage them better, including bringing back fire cycles that could potentially reduce invasive species such as *Lantana camara*.

While African savannas are globally recognised as iconic wildlife habitats, ONEs in India are left out of conservation efforts. This causes both native and migratory faunal species to face habitat loss, fragmentation and conversion. Many ONE flagship species, such as the great Indian bustard, are on the brink of extinction. This focus on forested ecosystems in conservation and the neglect of non-forested ecosystems in policy is a form of Biome Awareness Disparity.

While African savannas are globally recognised as iconic wildlife habitats, ONEs in India are left out of conservation efforts.

Photo credit: The Grasslands Trust

Prioritise or Perish: Conserving ONEs and biodiversity in human-use areas

Understanding the spatial distribution and ecological characteristics of ONEs is crucial for informed conservation and land management strategies in the country. Therefore, ATREE conducted an area prioritisation exercise that categorises ONE patches based on the habitat suitability of key landscape specialist species.

ATREE's priority maps highlight conservation priority areas in eight states that have maximum ONE area: Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Telangana. These areas have been divided into three levels of priority, with Level 1 identifying areas of highest importance. These maps are a useful tool for the conservation and management of ONEs.

Balancing the trade-off between conservation and development activities requires identifying key areas with high biodiversity values that must be prioritised for conservation. In the prioritisation map (Figure 2), we have used species distribution maps of key fauna of the ONEs to identify critical areas for conserving these endangered species. Level 1 is of the highest importance for the conservation of ONE species. Level 2 and Level 3 are moderately important for biodiversity conservation. These areas can be managed alongside certain anthropogenic activities that do not alter the region's ecology and are not harmful to wildlife and biodiversity in the region.

Priority maps are a useful tool for conservation and management of ONEs.

Photo credit: Abi T. Vanak

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Photo credit: The Grasslands Trust

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State-wise prioritisation maps

Balancing the trade-off between conservation and development activities requires identifying key areas with high biodiversity values that must be prioritised for conservation. We have used species distribution maps of key fauna of the ONEs to identify critical areas for conserving these endangered species. Level 1 is of the highest importance for the conservation of ONE species. This indicates the highest priority areas for conservation. Level 2 and Level 3 are moderately important for biodiversity conservation. These areas can be managed alongside certain anthropogenic activities that do not alter the region's ecology and are not harmful to wildlife and biodiversity in the region.

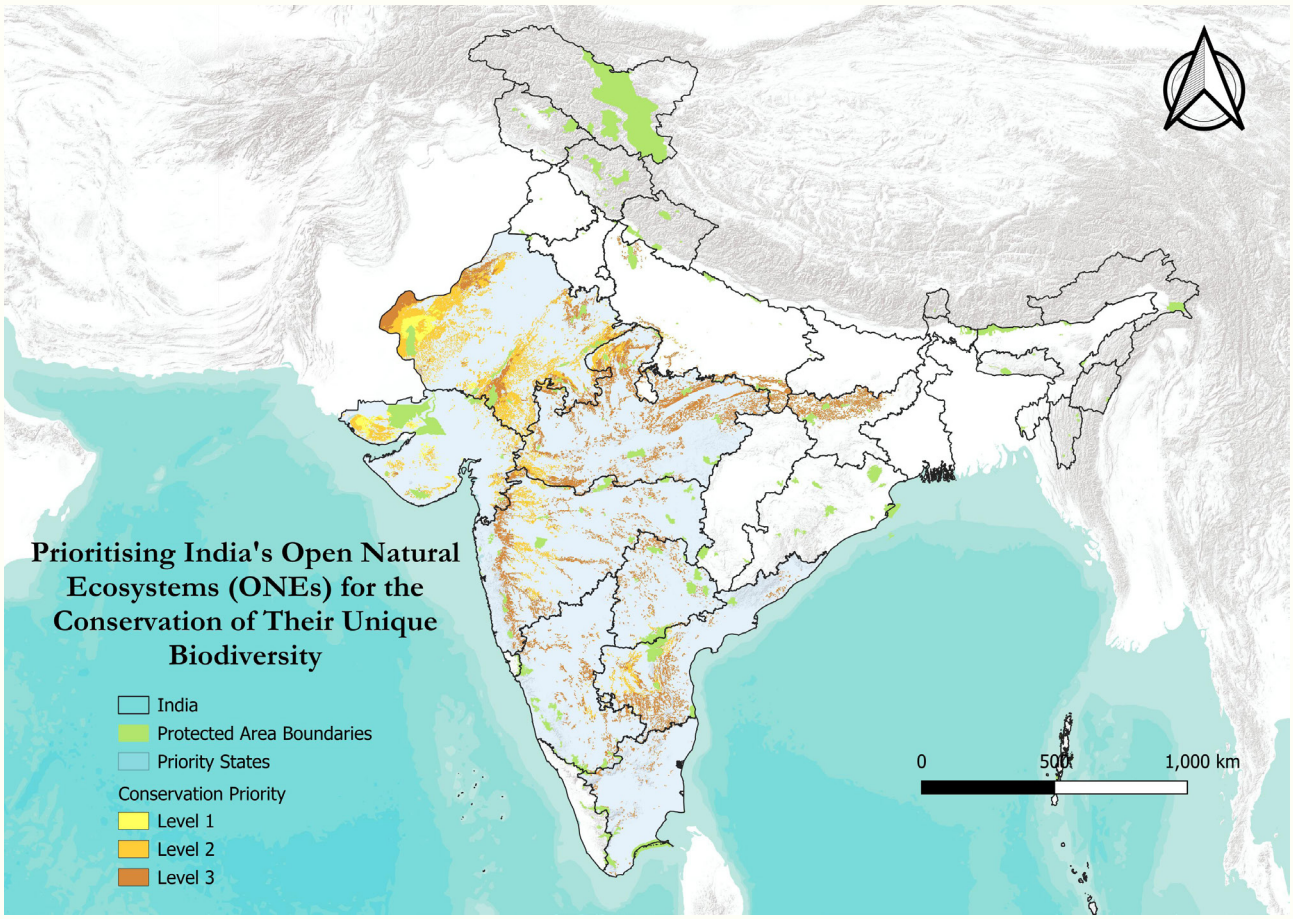


Figure 2: Biodiversity prioritisation map of India

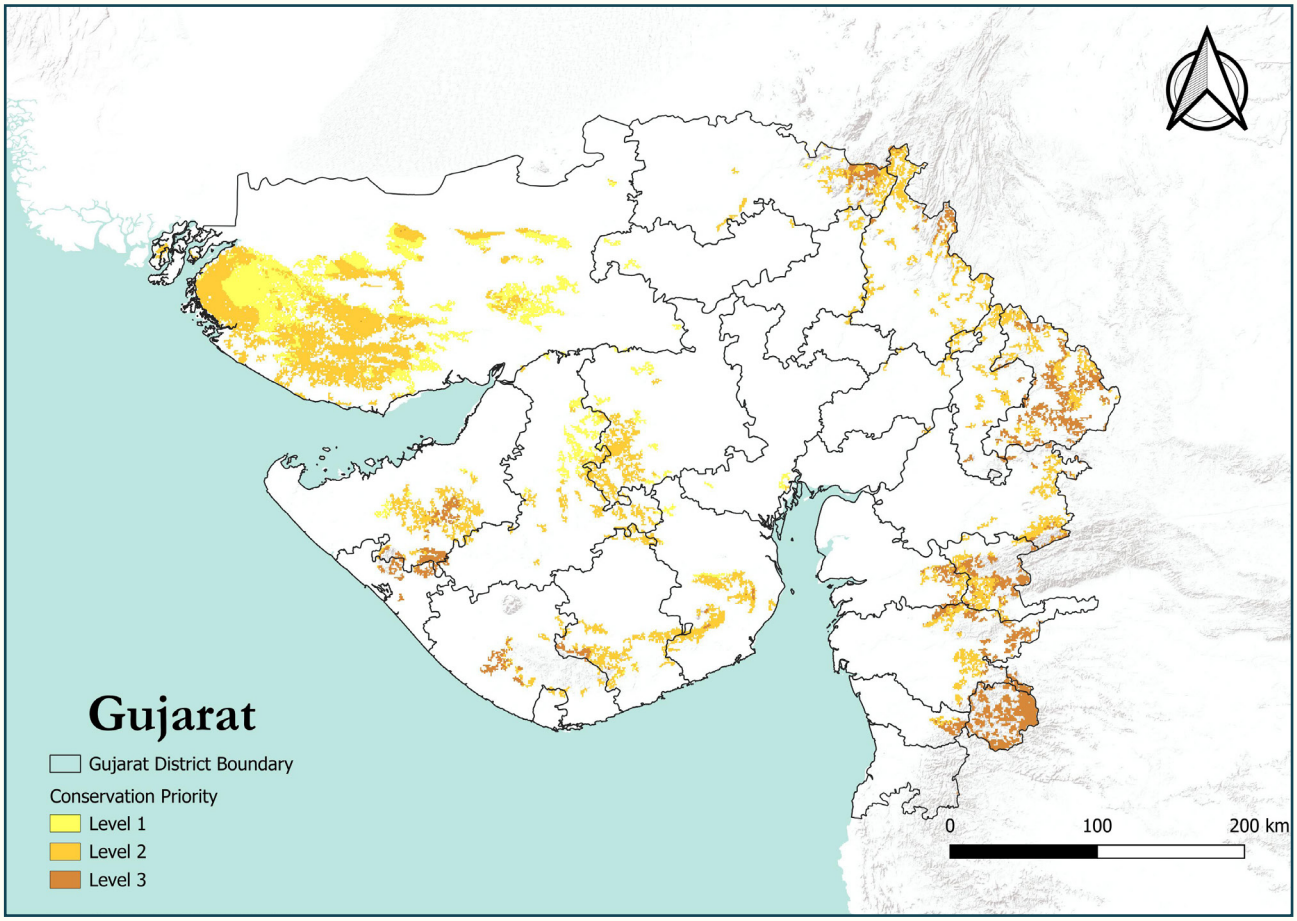


Figure 2.1: Prioritisation of key areas in Gujarat

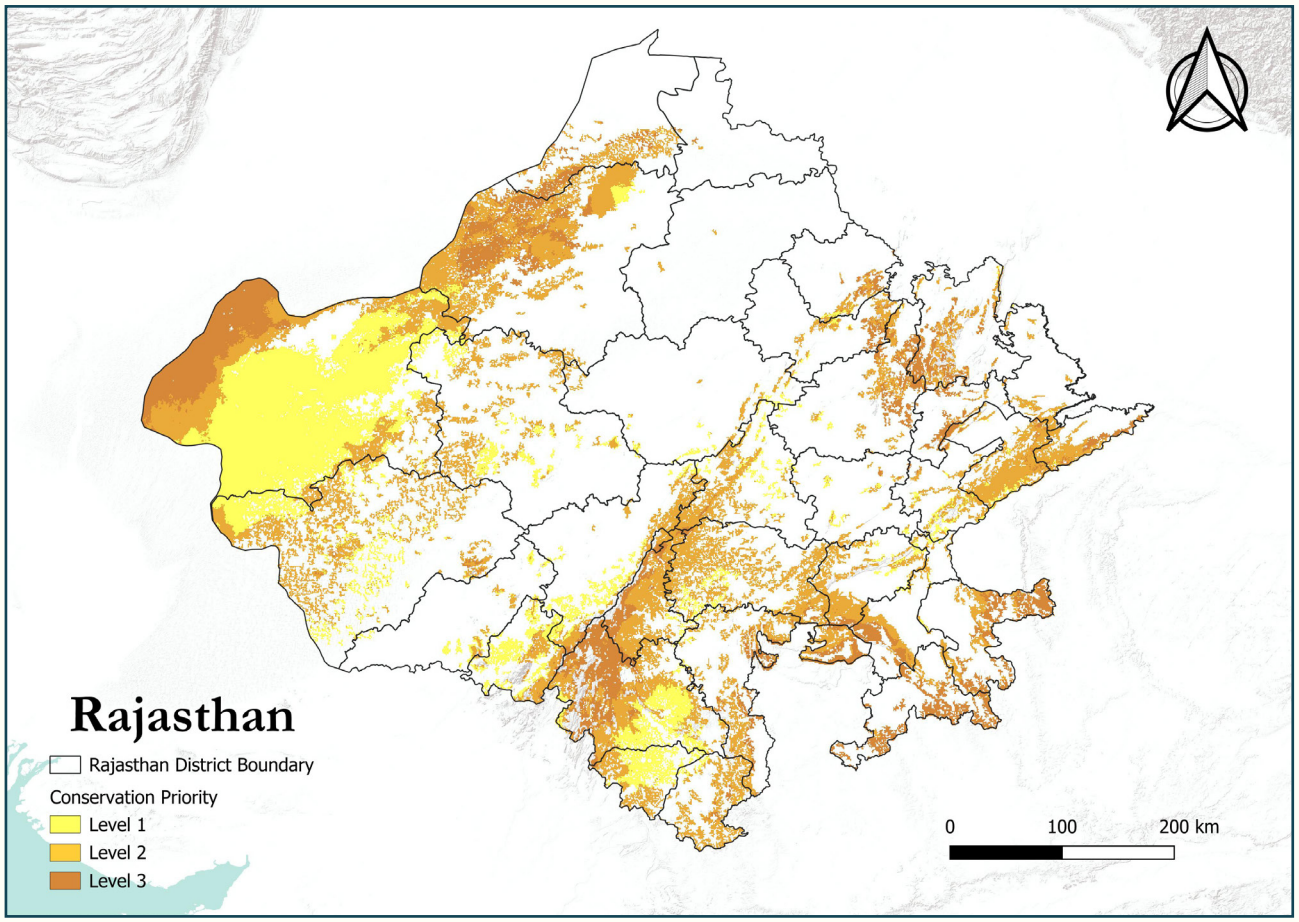


Figure 2.2: Prioritisation of key areas in Rajasthan

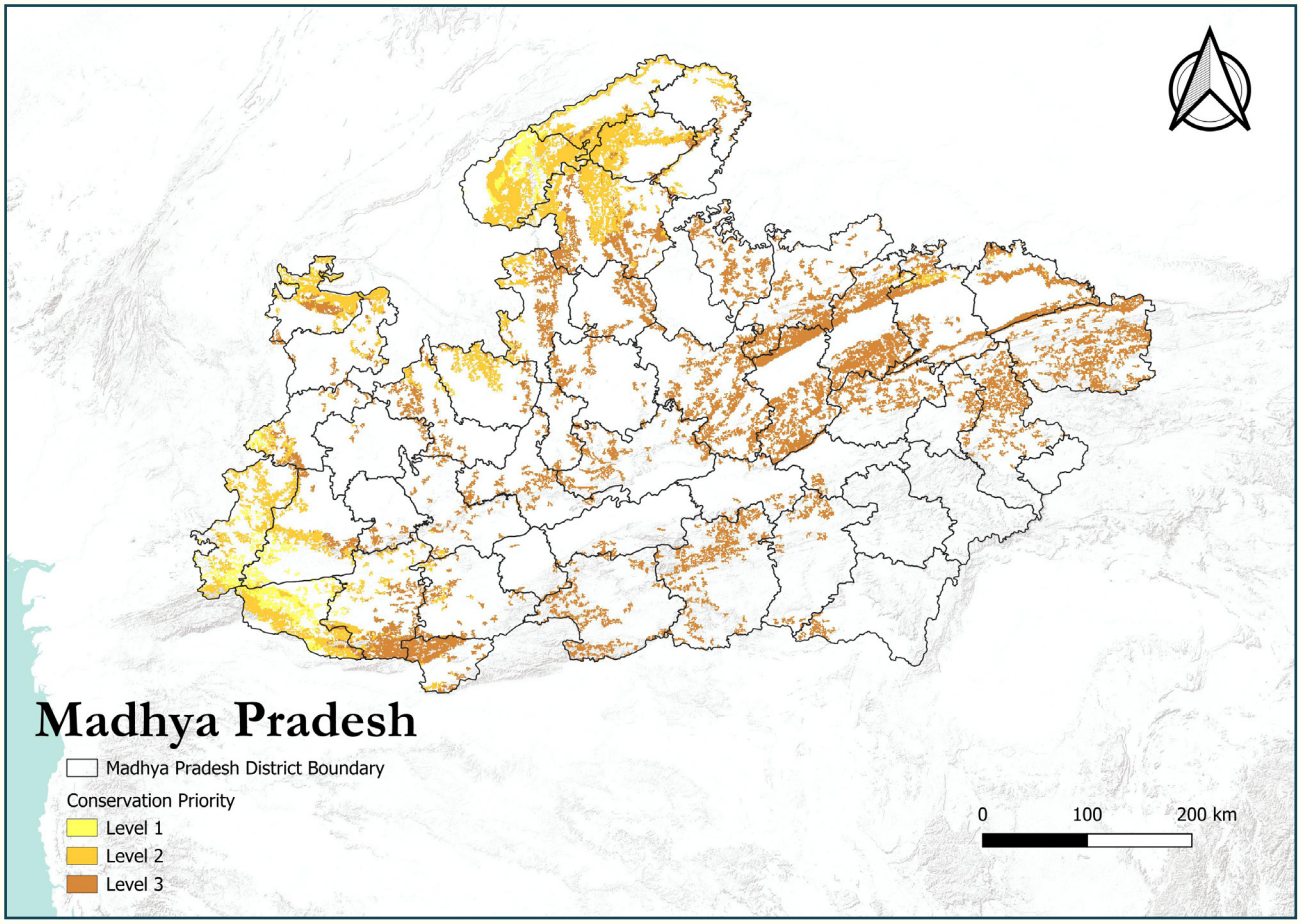


Figure 2.3: Prioritisation of key areas in Madhya Pradesh

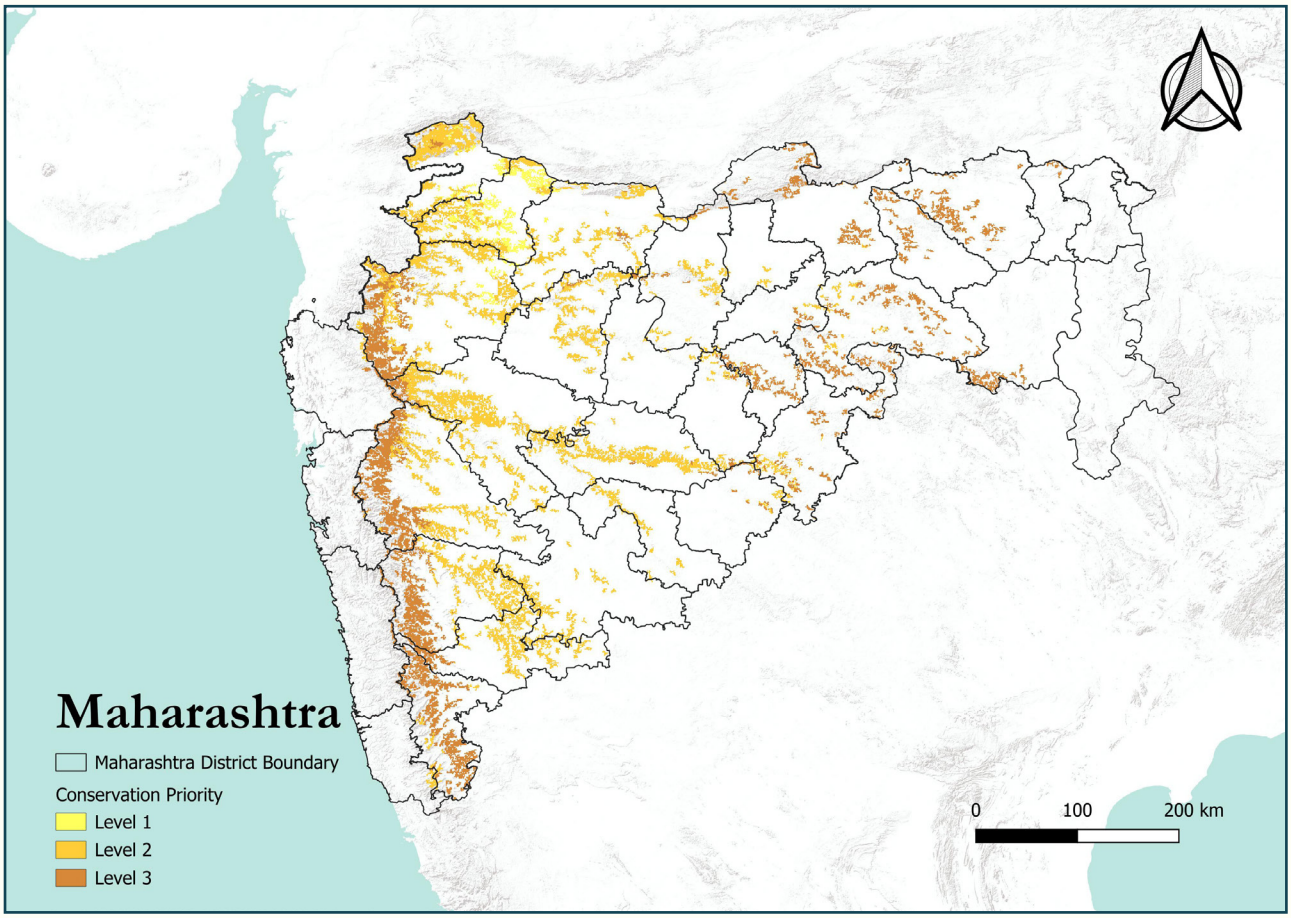


Figure 2.4: Prioritisation of key areas in Maharashtra

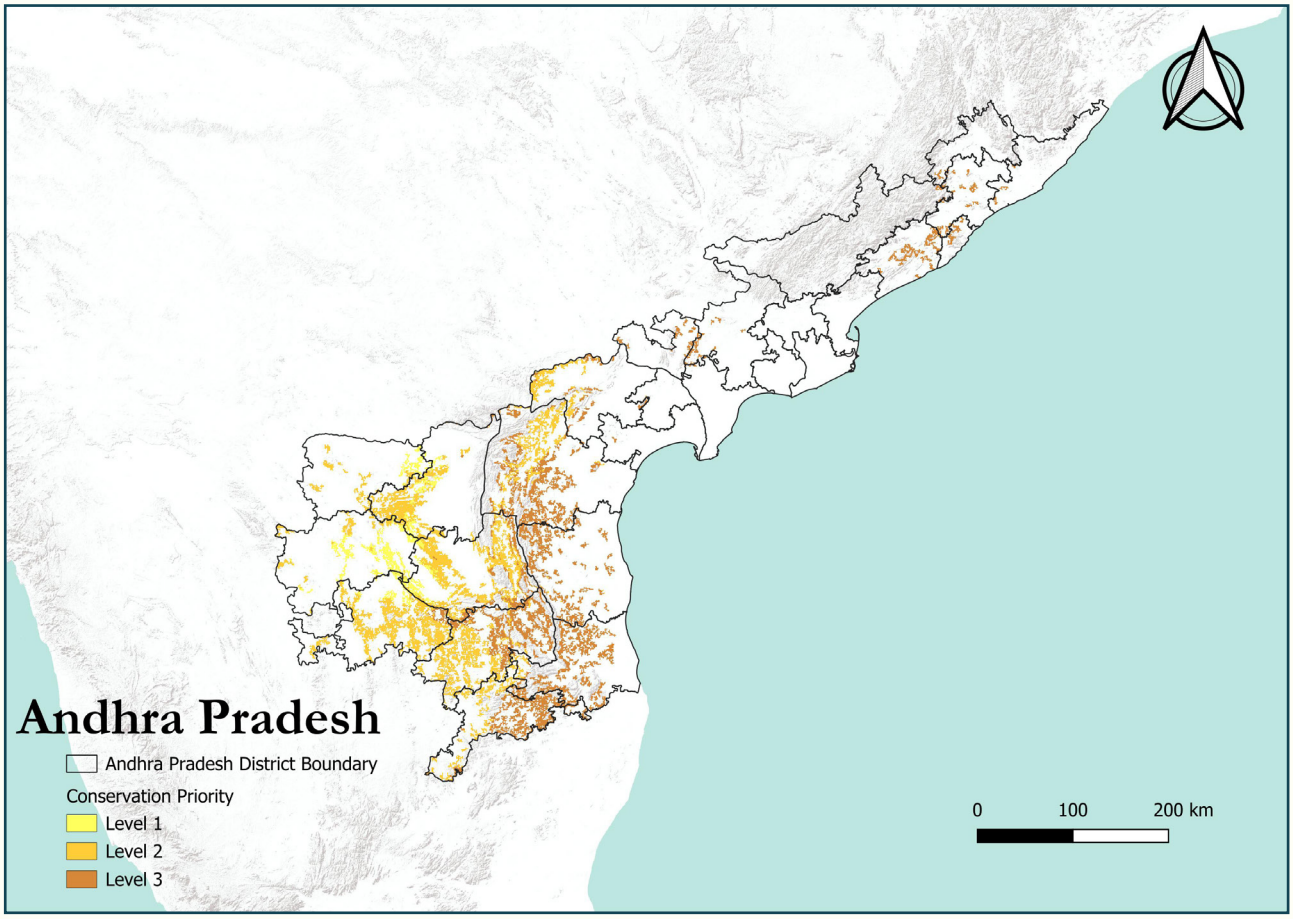


Figure 2.5: Prioritisation of key areas in Andhra Pradesh

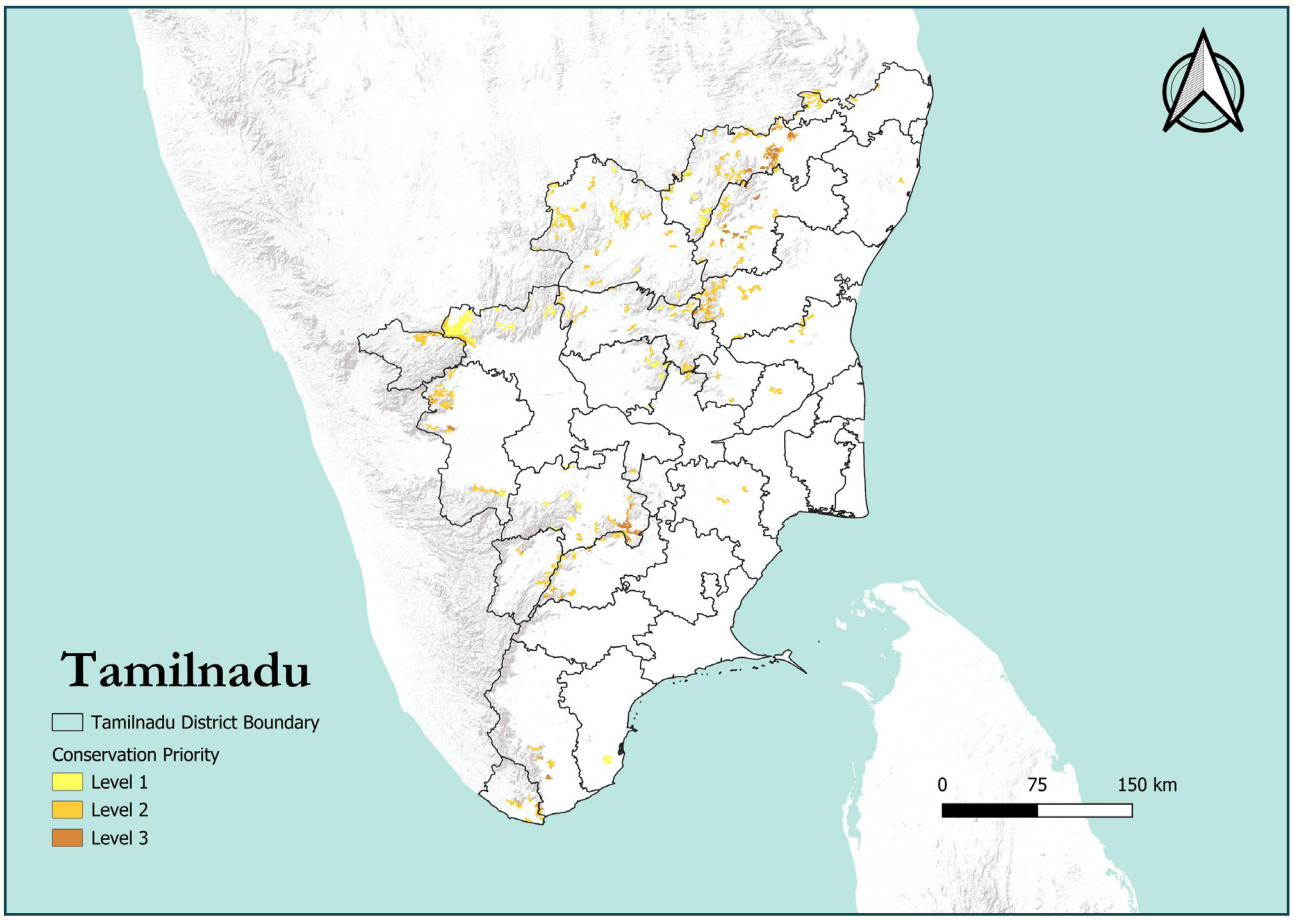


Figure 2.6: Prioritisation of key areas in Tamilnadu

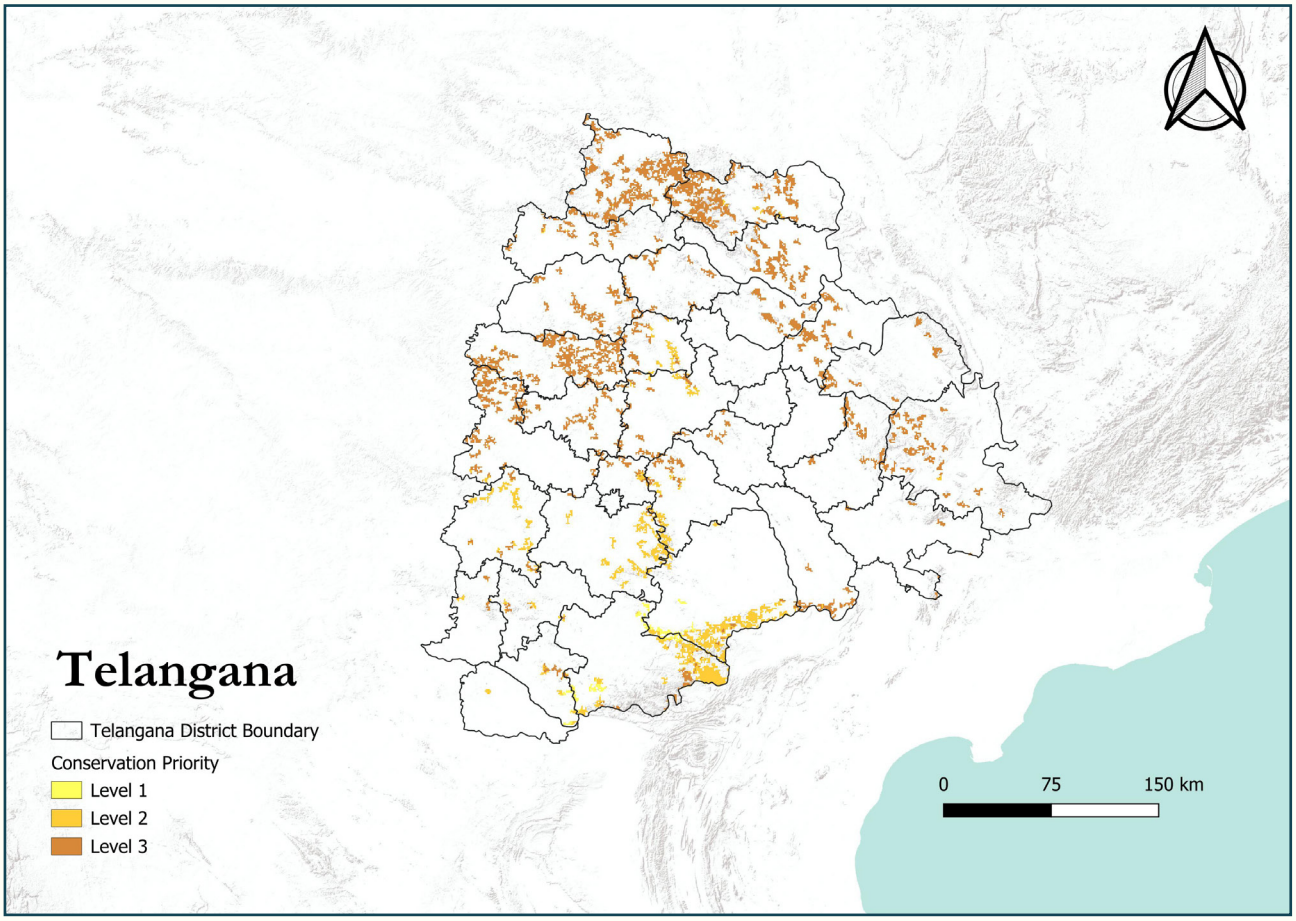


Figure 2.7: Prioritisation of key areas in Telangana

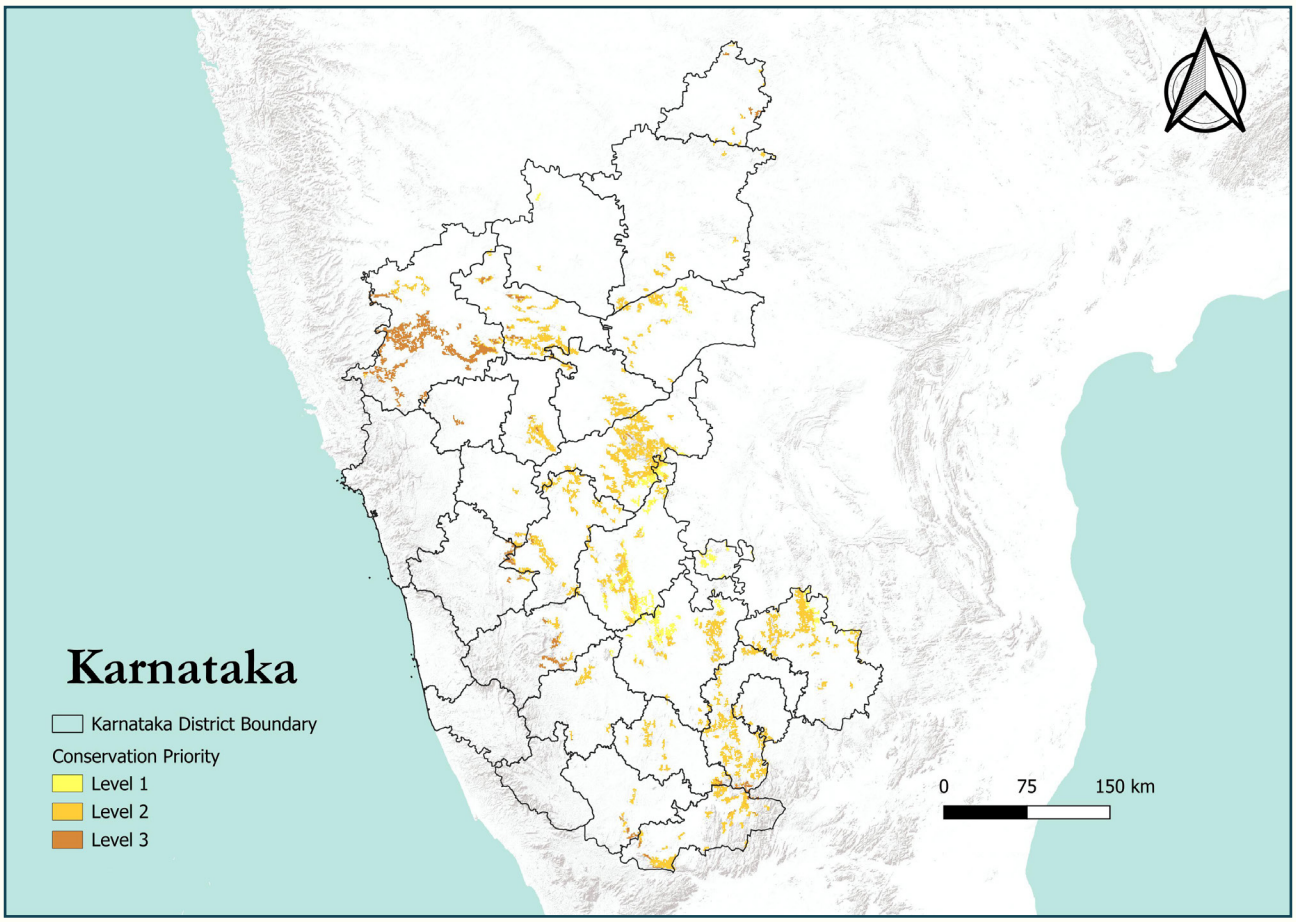
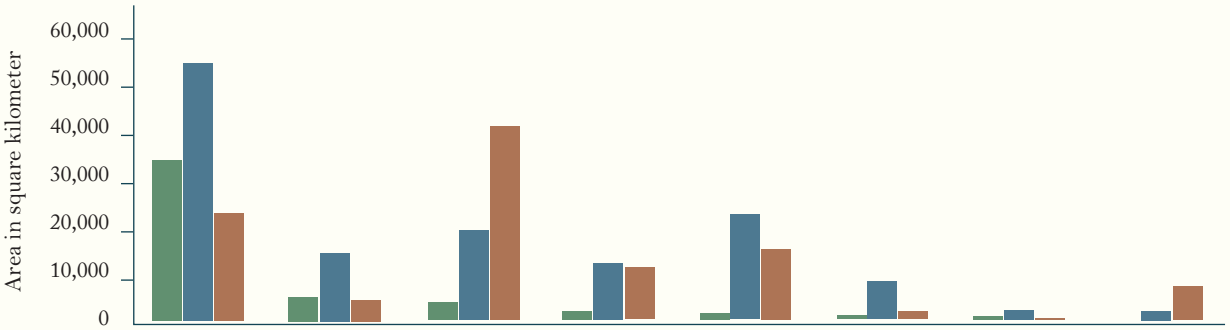


Figure 2.8: Prioritisation of key areas in Karnataka

The maps outline priority areas in each state according to Level 1, Level 2 and Level 3. Rajasthan and Gujarat have the highest area of Level 1 priority areas. Rajasthan, Maharashtra and Madhya Pradesh are the top 3 states with the highest area of Level 2 states. Most states have the highest area of Level 2 priority areas; while Madhya Pradesh has the highest Level 3 priority area.



	Rajasthan	Gujarat	Madhya Pradesh	Andhra Pradesh	Maharashtra	Karnataka	Tamilnadu	Telangana
Level 1	33,830	5,334	3,775	2,366	1,834	1,382	874	263
Level 2	53,633	13,770	19,077	12,225	22,543	8,364	2,489	2,202
Level 3	22,499	4,513	40,669	11,298	14,993	2,056	481	7,138

Figure 3: States ranked according to the area under different priority levels.

Photo credit: Dhritiman Mukherjee

Prioritisation maps will enable sustainable management and restoration plans

Protected Area Networks (PAN) can enhance biodiversity conservation but may marginalise local livelihoods due to the restrictions this designation imposes. So, while PAN may be one strategy to protect areas with a critical density of key species, sustainable management and restoration plans are necessary for much of the remaining ONEs.

Prioritisation maps can help with:

1. Informed Decision-Making for Development Projects

The priority maps and their analyses offer a comprehensive overview of areas with high conservation significance, providing planners with suitable options for various developmental activities, allowing renewable energy initiatives like solar and wind parks to steer clear of priority areas. This will minimise the ecological impact of development projects, fostering a sustainable coexistence between biodiversity and development activities.

2. Guiding Conservation Plans for Species Recovery and Protection of Their Habitats

The priority maps highlight potential sites of critical conservation importance for 19 grassland species. Concentrating better land management efforts in these zones will maximise their impact and optimise resource allocation. Conservation plans designed for these species will also extend to related ones.

3. Guiding Policies for Land Management and Restoration Plans

The district-wise overview of priority patches within the landscape, superimposed on land tenure maps, will guide institutions in formulating effective land management plans. This can help extend conservation efforts beyond the land under forest department jurisdiction, bringing communities and revenue departments together to develop these commons through biodiversity-friendly land restoration programmes.

While Protected Area Networks (PAN) can be one strategy to protect areas with a critical density of key species, socially just sustainable management and restoration plans are necessary for ONEs.

Great Indian Bustard

Ardeotis nigriceps

District	Area (Sq. Km.)
Jaisalmer, RJ	16,248
Kachchh, GJ	7,679
Bikaner, RJ	5,073
Barmer, RJ	4,462
Sheopur, MP	2,716
Baran, RJ	1,915
Ganganagar, RJ	1,814
Sirohi, RJ	1,491

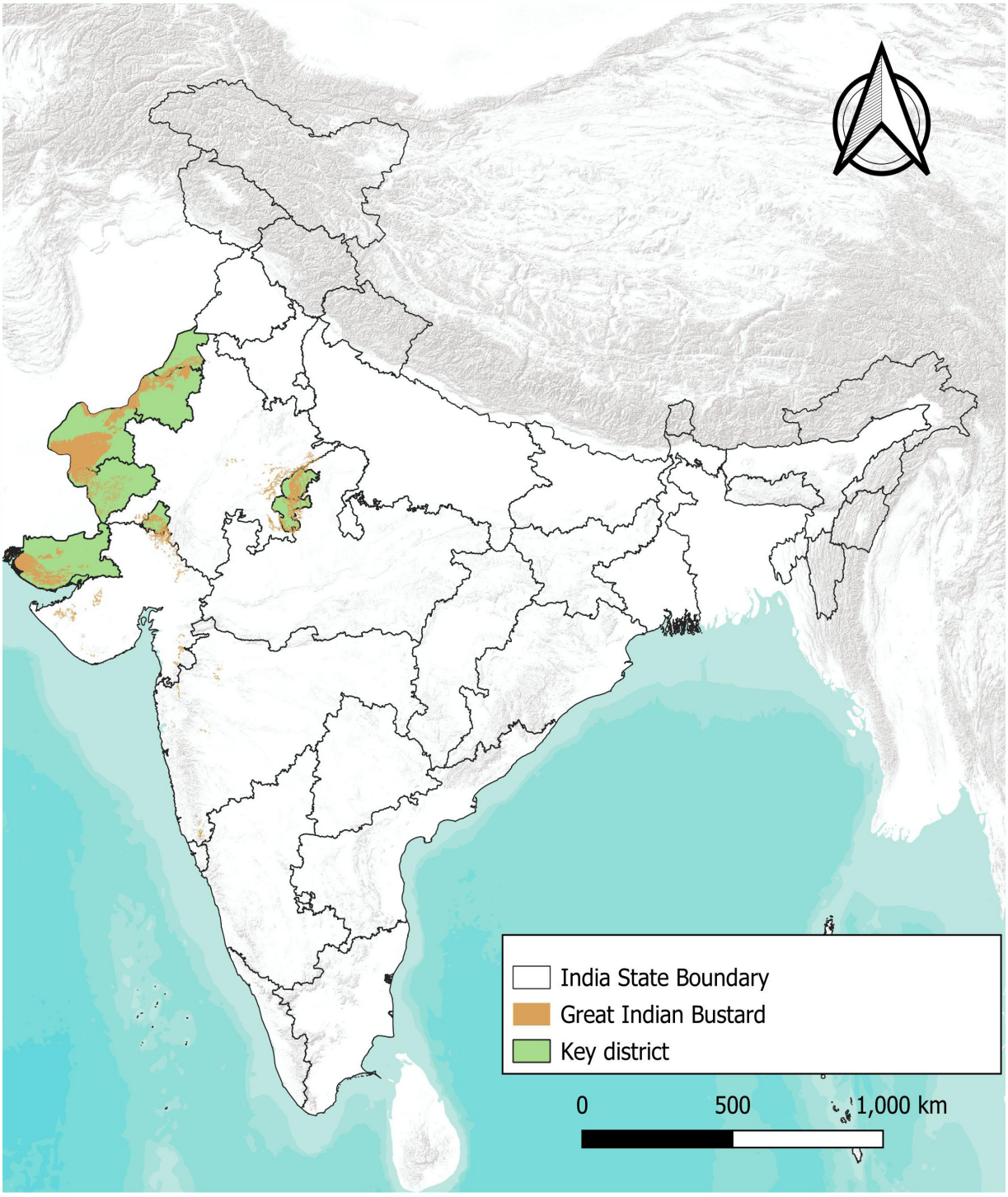


Figure 4.1 : Species prioritisation map for the Great Indian bustard

Indian Wolf

Canis lupus pallipes

District	Area (Sq. Km.)
Kachchh, GJ	5,146
Bhilwara, RJ	3,912
Udaipur, RJ	3,612
Ahmednagar, MH	2,450
Ajmer, RJ	2,443
Dhule, MH	2,441
Pali, RJ	2,338
Barwani, MP	1,888
Bid, MH	1,792
Nashik, MH	1,665
Satara, MH	1,589
Rajsamand, RJ	1,546
Sirohi, RJ	1,509
Pune, MH	1,313
Dungarpur, RJ	1,162
Rajkot, GJ	1,072
Sangli, MH	1,070
Jodhpur, RJ	1,033
Jalgaon, MH	979
Surendranagar, GJ	974
Anantapur, AP	776
Bhavnagar, GJ	776

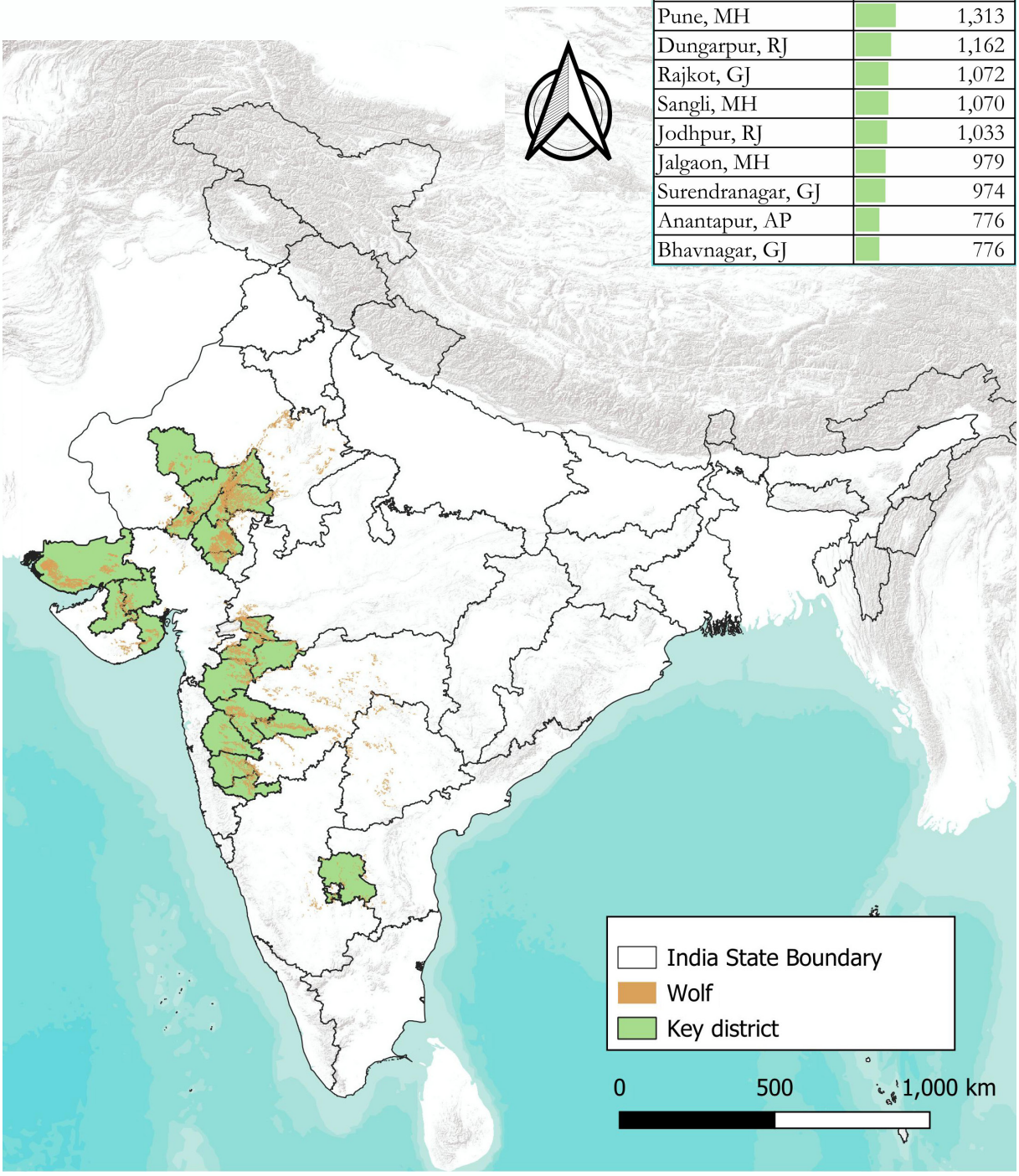


Figure 4.2 : Species prioritisation map for the Indian grey wolf

Lesser Florican

Sypheotides indicus

District	Area (Sq. Km.)
Kachchh, RJ	10,247
Udaipur, RJ	4,395
Bhilwara, RJ	4,055
Barmer, RJ	3,495
Anantapur, AP	3,122
Chittaurgarh, RJ	2,638
Sidhi, MP	2,638
Shivpuri, MP	2,606
Ajmer, RJ	2,470
Ahmednagar, MH	2,449
Pali, RJ	2,223
Barwani, MP	2,143
Dhule, MH	2,120
Sirohi, RJ	2,026
Nashik, MH	1,801
Panna, MP	1,511
Jhabua, MP	1,456
Dungarpur, RJ	1,431
Dhar, MP	1,418
Neemuch, RJ	1,417
Satna, MP	1,232

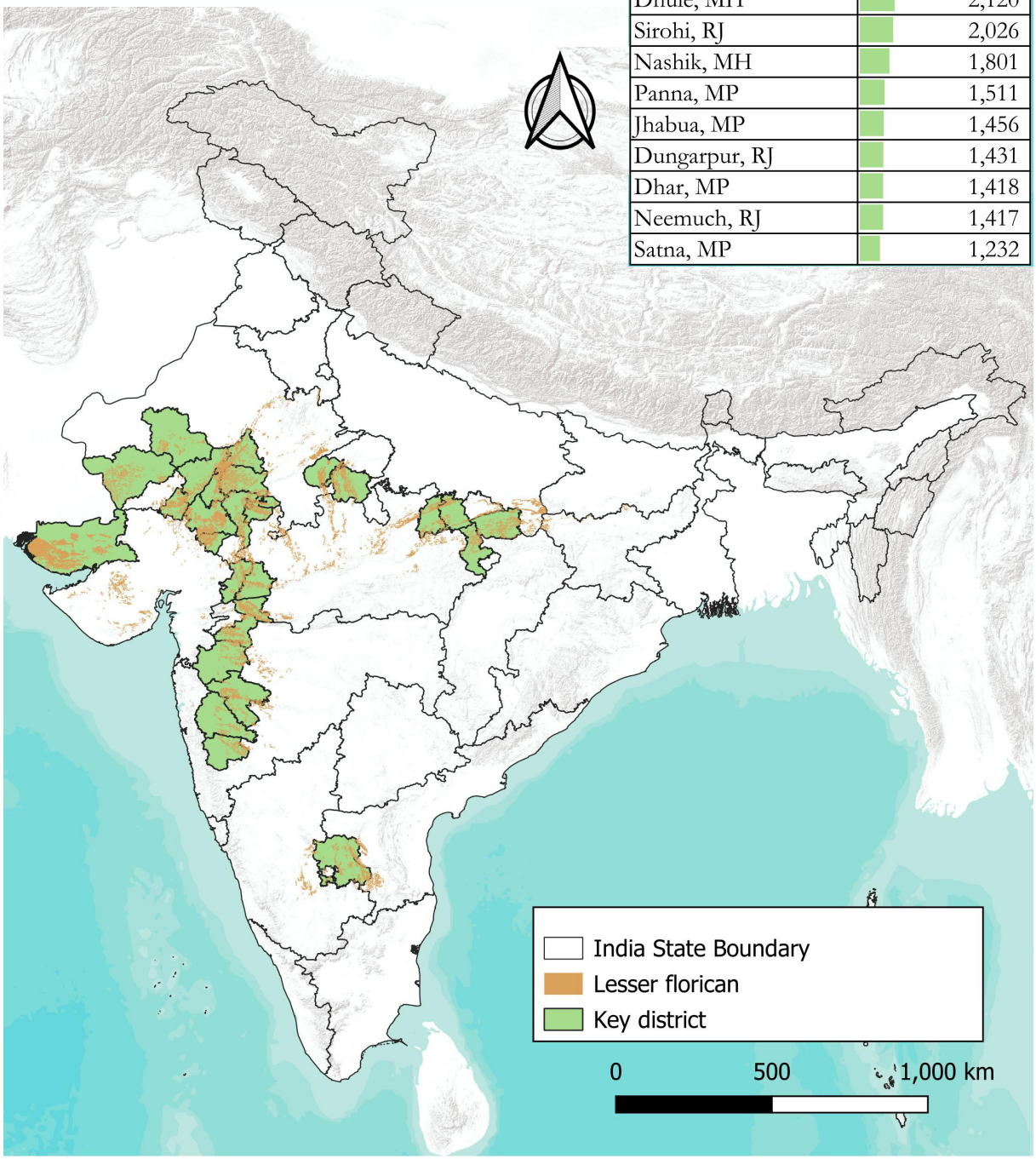


Fig: 4.3 : Species prioritisation map for the Lesser florican

Sociable Lapwing

Vanellus gregarius

District	Area (Sq. Km.)
Jaisalmer, RJ	31,803
Bikaner, RJ	10,486
Kachchh, GJ	9,923
Barmer, RJ	8,624
Jodhpur, RJ	3,831
Cuddapah, AP	3,409
Bhilwara, RJ	2,907
Karauli, RJ	2,370
Sheopur, MP	2,355
Prakasam, AP	2,179
Baran, RJ	2,157
Dungarpur, RJ	2,064
Ajmer, RJ	2,040
Ganganagar, RJ	2,027
Pali, RJ	1,873
Banswara, RJ	1,816
Kurnool, AP	1,787
Jhalawar, RJ	1,728
Jhabua, MP	1,715

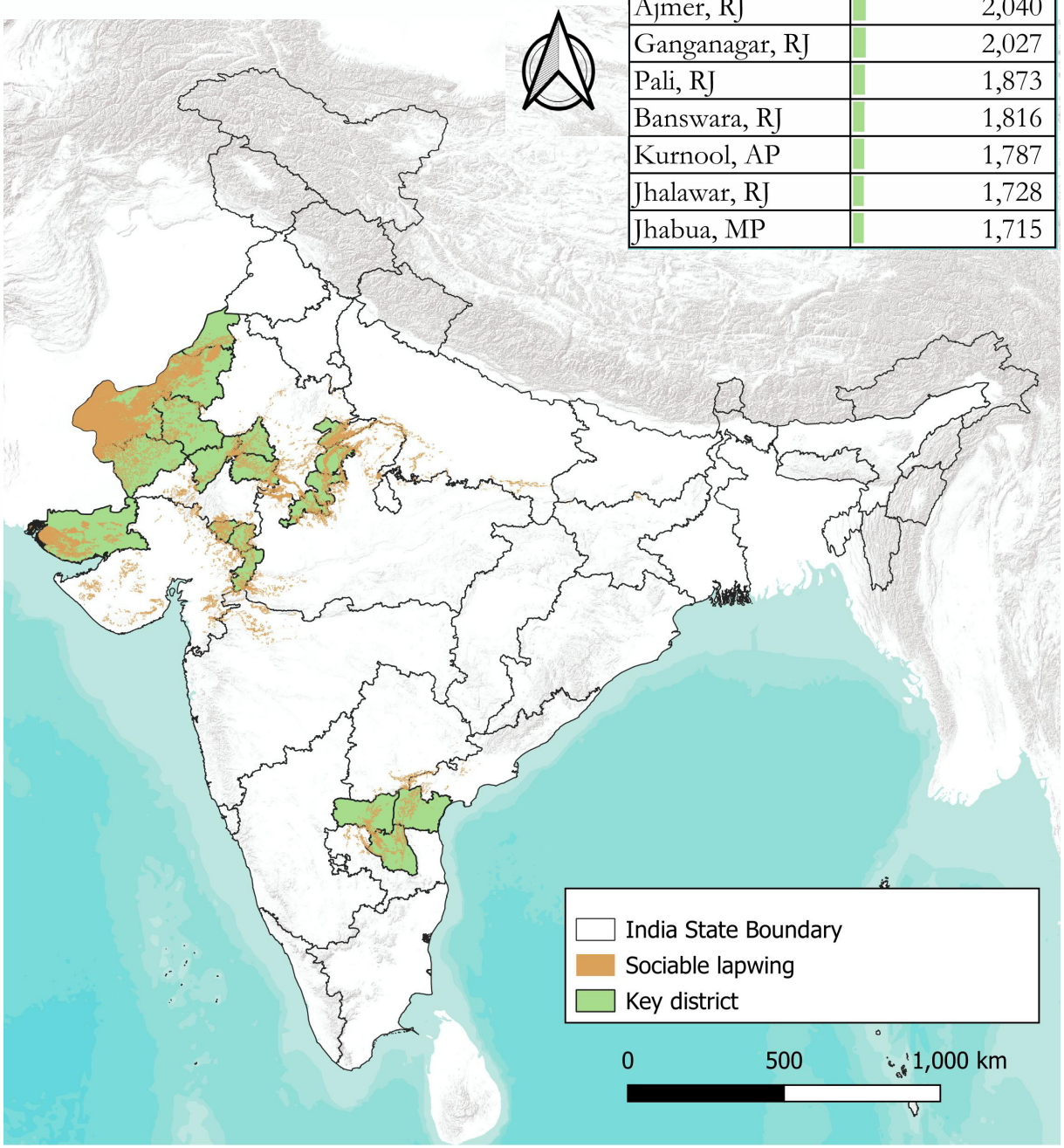
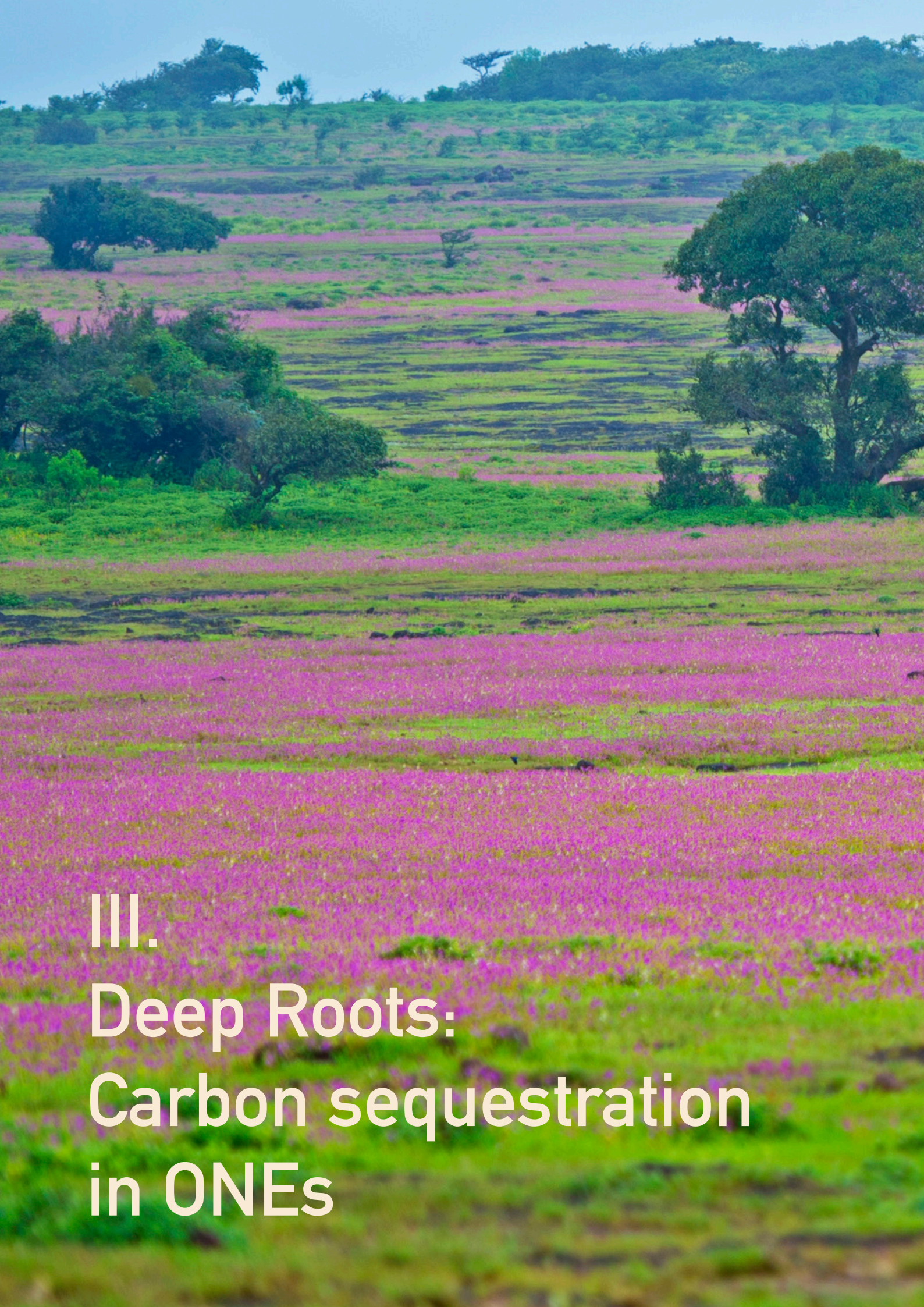
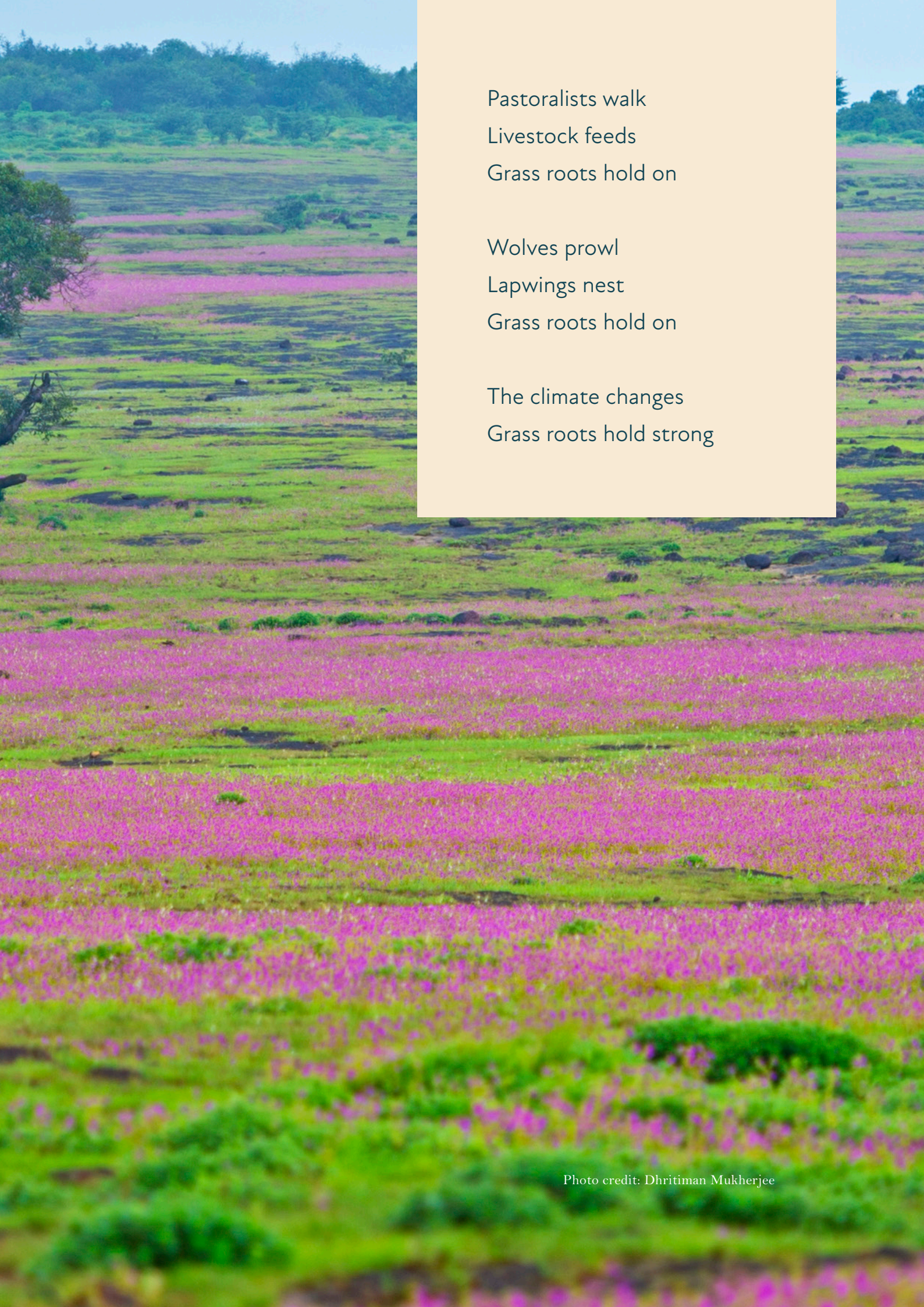


Figure 4.4.: Species prioritisation map for the Sociable lapwing



III.
Deep Roots: Carbon sequestration in ONEs



Pastoralists walk
Livestock feeds
Grass roots hold on

Wolves prowl
Lapwings nest
Grass roots hold on

The climate changes
Grass roots hold strong

Photo credit: Dhritiman Mukherjee

ONEs are carbon sinks comparable to tropical forests

ONEs have the potential to store large amounts of carbon in their soils, contributing to effective and long-term climate action. They play a critical role in climate change mitigation by acting as natural carbon sinks.[29] [30] Current estimates suggest these biomes store over a third of the global terrestrial carbon stocks. About 90% of it is stored below ground in root biomass and as SOC – a more stable and relatively more permanent form of carbon storage than above-ground standing stock in forests, which can be prone to fire and pest attacks.[31] [32] Restoring these landscapes can go a long way in realising this potential.

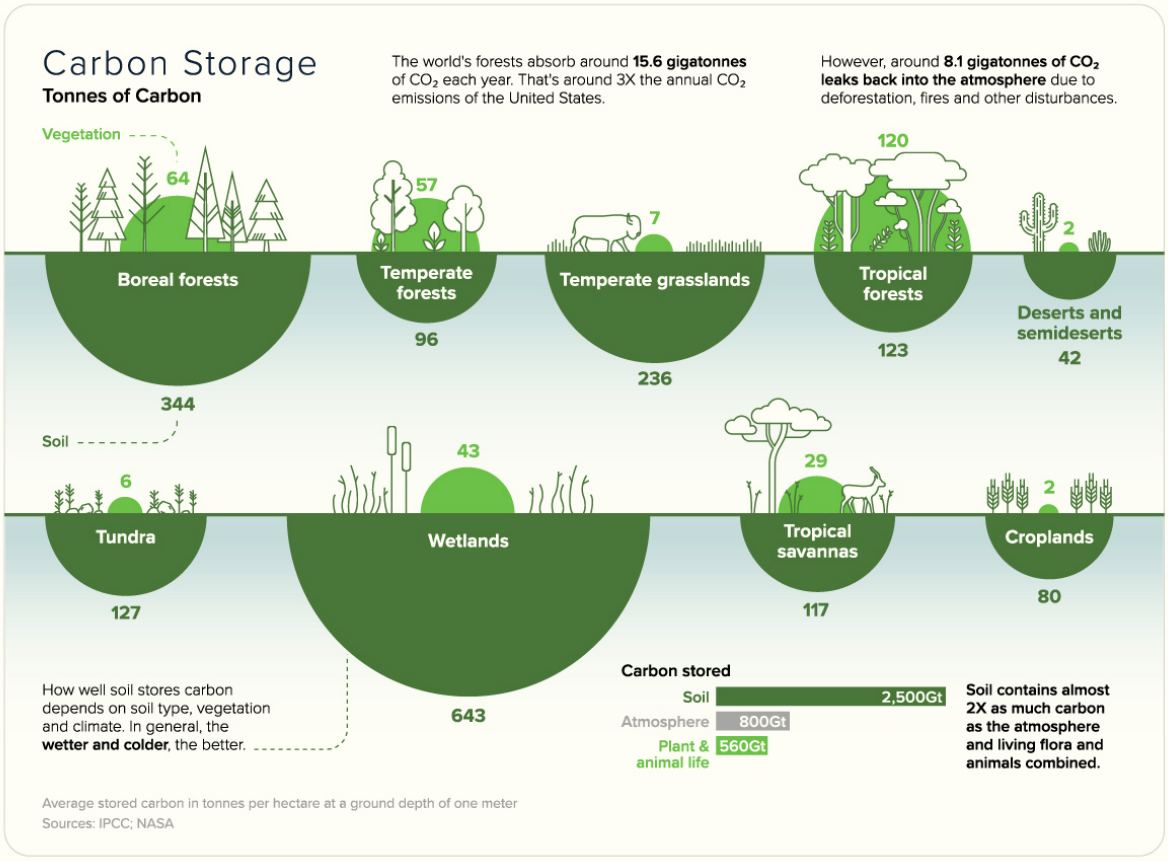


Figure 5. : Visualising Carbon in Earth's Ecosystems. Source: Visual Capitalist, 2023.[33]

Measuring SOC is crucial to meeting land-based carbon goals

Historically, grassland restoration has received less attention than forest restoration, often due to the assumption that they cannot deliver equivalent carbon benefits rapidly and at scale. This view is now changing. There is a global and national recognition of the importance of these unique ecosystems, which has received further impetus by the declaration of the UN Decade of Ecosystem Restoration (2021–2030). Soil carbon sequestration is a well-recognised natural

climate solution, and the need to enhance SOC across land uses across ecosystems is a rising priority. This has been highlighted by adopting the 4 per mille initiative for agricultural lands at the Convention of Parties 21 in Paris in 2015[34] and the formal recognition of SOC sequestration at COP23 in 2017 (COP23 decision 4/CP.23).[35]

Existing programmes fail to capture the diverse nature of ONEs, relegating them to the periphery of climate change discussions despite their vast global expanse. However, their high soil carbon stocks and vast potential for carbon sequestration in ONEs, coupled with the practicality of implementing changes in grazing management across these landscapes, highlight the urgent need to prioritise these ecosystems in climate change mitigation efforts.

Prioritising SOC to meet land-based carbon goals

Tapping into non-forest ecosystems to sequester carbon

In hot, dry climates that characterise much of India, not every region is suitable for high-density tree plantations. In areas of medium to low rainfall, water constrains what grows, resulting in vast tracts of open natural landscapes. Native grasses and dryland plants are adapted to use low water consistent with local rainfall patterns. In these landscapes, indiscriminate tree planting can disrupt this balance by increasing water uptake, reducing recharge and depleting the water table.

One common justification for large-scale tree planting is that trees eventually bring more rain. This, however, is highly context-specific. Only a tiny fraction (~<1%) of the water trees take up is stored in their biomass; the rest goes back into the atmosphere as transpiration and could potentially get recycled and fall back as rain. But there are caveats. The change in vegetation has to be on a large scale (of the order of hundreds of sq. km) to make any appreciable difference to local rainfall patterns, and there is no guarantee that the rainfall will occur in the same location. The rainfall could occur downwind, and the local watershed where trees are planted could still dry out as a recent global modelling study showed[36]. Furthermore, increasing tree cover does not necessarily lead to increasing groundwater. In some systems, it actually diminishes the groundwater recharge because the evapotranspiration rates exceed the infiltration rates. Therefore, the belief that "afforestation = groundwater recharge" is not always true.[37] [38]

India has signed up for ambitious Land Degradation Neutrality targets. However, the below-ground carbon stocks of ONEs – a significant contributor to the carbon pool – do not feature in India's Nationally Determined Contributions under the Paris Agreement. Due to the focus on above-ground carbon, ONEs in India are often targeted for mass tree-planting programmes, which have proven to be detrimental to local hydrological cycles and biodiversity. Such efforts, rather than contributing to effective land-based climate action, endanger the long-term integrity and viability of these ecosystems, as well as of the people and biodiversity that depend on them.

Understanding SOC profiles in ONEs: Evidence from ATREE

We conducted three important pilot studies to develop SOC profiles for the semi-arid grasslands of India –Solapur district of Maharashtra, Deshnok Oran of Bikaner, Rajasthan, and the Banni Grasslands of Kutch, Gujarat. These three landscapes, with varied topographic and climatic conditions, validate our understanding of their large potential for carbon sequestration.

Our comparisons of carbon stocks in Solapur district across unrestored and recently restored patches indicate that grassland habitats can sequester up to 30 tC/ha. This figure is approximately 300% higher than in unrestored semi-arid grasslands of plateau areas but still over 50% short of old-growth undisturbed grasslands in the same district. **Remarkably, just three years of grassland restoration has the potential to increase SOC by 53%** compared to the unrestored baseline.[39]

We found a similar pattern in our pilot study in the Deshnok region of Bikaner in Rajasthan, which also highlighted the negative impact of improper restoration using agricultural methods. Here, a disturbed "old growth" grassland had 11tC/ha, whereas an attempted restoration plot, which had been ploughed and then sown with native grasses 10 years ago, had lower carbon of 8tC/ha. Notably, the effects of the ploughing and soil disturbance had persisted for over a decade. This shows that designing the correct interventions is critical for a sustainable management of these important ecosystems.

Our third pilot in the Banni showed exceptionally high carbon values of up to 142 tC/ha, significantly surpassing the carbon stock in soils affected by invasion under Prosopis juliflora. Banni's substantial carbon stock emphasises the importance of preserving sediment-rich grassland soils, as well as the risk of carbon loss associated with soil disturbance. Our analysis suggests that the Banni grasslands alone serve as a reservoir for 27 megatons of carbon in the form of SOC.

Establishing carbon baselines for these unique grasslands demonstrates the role of grassland restoration in achieving climate mitigation goals. It also provides essential policy recommendations for the management of dry grassland ecosystems.

Below is a comparison of grasslands and forests in terms of their carbon sequestration potential (Table 1). Although the annual precipitation in grasslands is much lower than in forests, they still sequester comparable amounts of carbon (Figure 4).

Site	Annual precipitation (mm)	Ecosystem	Soil Carbon at varying depths (tC/ha)	SOC per 100 mm rainfall
Banni grasslands, Gujarat	~300–350	Arid grasslands	105.56–142.72 (at 30 cm)	43.6
Deshnok grasslands, Rajasthan	~300–350	Arid grasslands	8–11 (at 30 cm)	2.46–3.38
Solapur grasslands, Maharashtra	300–-600	Semi-arid grasslands	7.77–30.78 (at 30 cm)	1.84–2.78
Pune district, Maharashtra	300–600	Semi-arid grasslands	0.94–4.75 (at 30 cm)	0.2–1.05
Western Ghats, Andaman & Nicobars, Mizoram	>2000	Tropical evergreen	24.6–218.4 (at 50 cm)	1.23–10.9
Darjeeling & Mussoorie	1800–2000	Montane temperate	12.1–184.3 (at 50 cm)	0.63–9.7
Chandrapur, Dehradun, Coimbatore	900–1500	Tropical moist deciduous	8.9–177 (at 50 cm)	0.74–14.7
Indo-Gangetic plains, Chhindwara	900–1500	Tropical dry deciduous	7.7–85.6 (at 50 cm)	0.64–7.1
Sundarbans, Konkan	1800–2100	Littoral & Swamp	37.7–153.9 (at 50 cm)	1.93–7.89

Table 1: Mean SOC stocks in forests and ONEs in India. Given the rainfall regime, the soil carbon sequestration rates are comparable between forests and grasslands.
Source: Bhan et al. 2023. * Bhan et al. unpublished ~Vanak et al. unpublished

Did you know?

Popular interventions such as trenching and ploughing are a matter of concern for soil ecology and hydrology. Ploughing and digging trenches disrupt the carbon cycle in three ways: loss of soil moisture, carbon stock and grass biomass. In some cases, poorly planned deep continuous contour trenches that use heavy machinery can severely impact soil health, in addition to scarring the landscape and curtailing animal movement.

Figure 6: Deep continuous trenching in the grasslands of Manmad in Nashik district. Given the low rainfall and flat topography of this landscape, such massive soil disturbance can do far greater damage to SOC, hydrological cycles and soil health than any marginal benefits derived from greater water retention in the landscape

Conserving existing stocks and restoring depleted stocks in ONEs

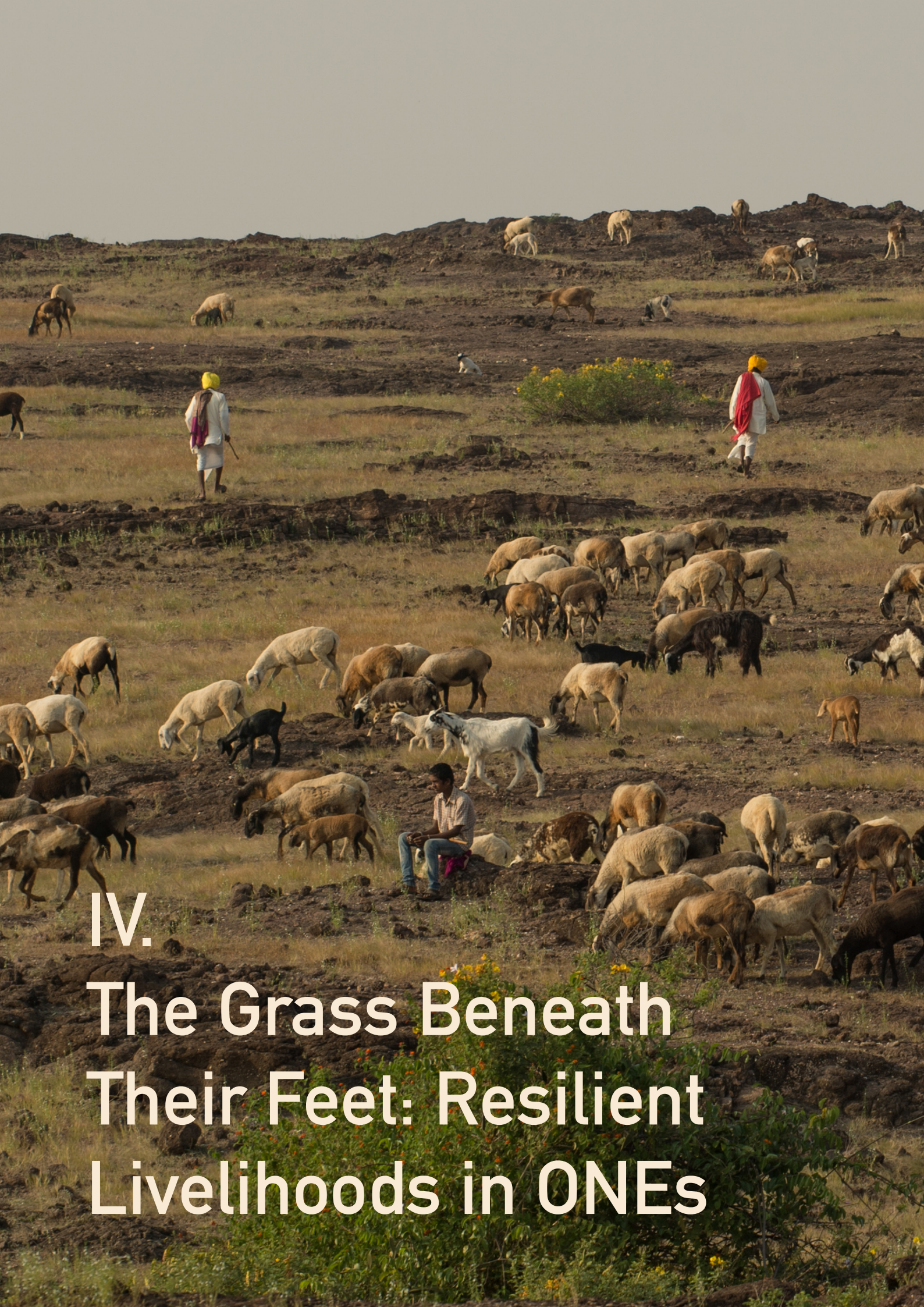
Proper grasslands management, including rotational grazing and reducing ecosystem conversion, leads to a dual benefit – conserving existing stocks (avoiding losses) and restoring stocks in carbon-depleted soils. This also offers co-benefits, such as (1) increasing soil fertility and reducing soil erosion, (2) maintaining or increasing resilience to climate change for communities who derive livelihood benefits from these ecosystems, and (3) providing habitat to endemic species.[40]

The following ecological factors need to be considered for effective carbon recovery in ONEs:

- Restoration should aim to have a greater diversity of long-lived perennial plants; a complex system of below-ground structures that enable re-sprouting after above-ground disturbances such as fire and grazing occur; and substantial below-ground carbon stores, which are characteristics typical to old-growth ONEs.[41]
- Increasing carbon storage has to account for saturation in soils. SOC saturation refers to the maximum capacity of the soil to retain organic carbon, meaning that SOC does not increase indefinitely. Soils saturate at timescales of a few decades and reach a new steady state. This saturation time is also determined by the soil type, management intervention, climate regime and pre-existing SOC depletion. The comparison of our results with national and global averages reveals that a saturation point may still be sufficiently far, implying that ONEs in the region can keep delivering carbon benefits for realistic future timeframes at the very least.
- Maintaining high SOC stocks requires protection and management, even after saturation is achieved and no further mitigation benefits accrue. Sites that are under the management of the Forest Departments and protected from conversion under law can be expected to remain stable at realistic multi-decadal timescales if protection is encouraged and sustained.[42]

Long-term monitoring of carbon storage in ONEs

Decision-making based on grassland carbon sequestration potential is hindered by a lack of data on the extent of carbon stocks.[43] [44] [45] Plot-level carbon inventories are considered the building blocks of carbon storage assessments. These inventories include the measurement of biomass in 5 major carbon pools – grass and woody vegetation (above-ground biomass), roots (below-ground biomass), litter, deadwood and soil (SOC).[46] These estimates are then used as a reference for demonstrating regional and national carbon storage potentials. While plot-level carbon inventories are widespread for forest ecosystems in India, ONEs have been particularly neglected. Reliable estimates of carbon stocks and sequestration potential are prerequisites to plan interventions and measure progress.

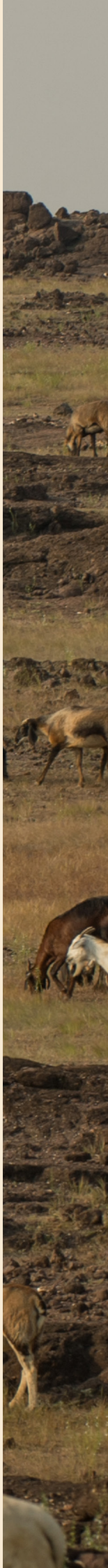


IV.
The Grass Beneath Their Feet: Resilient Livelihoods in ONEs

Photo credit: Kalyan Varma

People love their land
They know how much to take
They know what to give
They know when to stay
And when to walk away

The land looks after them
Their children, their animals
Their future
The land holds its people



ONEs support a dynamic range of livelihoods from extensive pastoralism to rain-fed agriculture. Given the high climatic variation and aridity in these landscapes, people have adapted in several ways to maximise their productivity while increasing resilience.

Extensive pastoralism is the primary land-based livelihood in these regions, wherein people graze their animals over large tracts of land. Mobility is a crucial aspect of this livelihood. It enables pastoralists to make optimal use of dry landscapes unsuitable for year-round agriculture by migrating according to seasonal resource availability (forage and fodder).

ONEs are important for numerous pastoralist and agro-pastoralist communities

About 200 million people from pastoralist communities worldwide depend on ONEs.[47] Pastoralists, have been primary users of such landscapes for centuries grazing their livestock. Pastoralist livelihoods are characterised by a unique set of skills, knowledge, cultural associations and networks that allow them to manage and benefit from these ecosystems.[48]

Pastoralism and wildlife; the interconnection:

Pastoralists, such as the Dhangars, Kurubas and Kurumas of the Deccan Plateau of India, the Maldharis of Kutch, and the Raikas of Rajasthan, share their landscape with rare and endangered species of wildlife, such as the Great Indian bustard, the Indian gazelle, the blackbuck and others and indirectly influence their existence.[49] [50] For example, research has shown that the Indian grey wolf populations are sustained by livestock reared by pastoralists.[51] The decline in nomadic pastoralism and the restriction of sheep and goats from areas under the management of the Forest Departments is likely to negatively affect the grey wolf populations.[52] [53]

Pastoralism is sustainable, low-input, adaptable and climate resilient

Pastoralism is an important occupation, especially in regions where agriculture is not as profitable and not the primary means of production from land.[54] Livestock products comprise 17% of the kilocalorie consumption and 33% of protein consumption globally. This livelihood has begun to be recognised as resilient, sustainable and adaptable to varying climatic and environmental conditions, optimising the use of landscapes they move through.

Pastoralist-reared livestock provide a range of organic, free-range products, including milk, wool and manure. They also perform additional roles, such as acting as a cash buffer and capital reserve. Keeping livestock is thus an important risk reduction strategy for vulnerable communities, as animals can act as insurance in unpredictable biophysical environments.[55] Diversifying resource use provides stability and security in an unpredictable environment and provides a degree of control in the lives of rural households.[56]

Photo credit: Ovee Thorat

Mobility is a crucial aspect of pastoralism. It enables pastoralists to make optimal use of dry landscapes unsuitable for year-round agriculture by migrating according to seasonal resource availability.

‘Grazing’ is not the enemy: Extensive grazing aids the sustainable management of ONEs and helps maintain biodiversity

Land management policies have often viewed ‘overgrazing’ as a threat and a primary cause of land degradation. However, such a blanket assumption is counterproductive for the health of grasslands. Studies from the early 1980s speak about the importance of livestock grazing in managing and maintaining special ecosystems.[57] The Hanumantha Rao Commission report (1998) of the Government of India also concluded that goats were not to be blamed for degrading environments.[58]

Scientific literature suggests a gentle and continuous disturbance is needed to maintain vital ecological functions and grassland health.[59] [60] Livestock plays an important role in contributing to enhanced productivity and biodiversity, nutrient cycling, elevating soil organic carbon and function and benefiting soil microbial species. For example, low-intensity mixed grazing of cattle and sheep has been shown to improve the diversity and abundance of a range of taxa within grazed ecosystems.[61] In turn, native grasses, herbs and shrubs provide important low-cost forage and nutrition for animals. Restored grasslands can enhance the productivity of these animals, ensuring better returns.

Further, movement or mobility is key to pastoralism and is not likely to lead to overgrazing in the same area.[62] By improving access to healthy natural grasslands and open ecosystems and employing better land management policies, the grassland ecosystems, wildlife, livestock and pastoralists can all maintain a harmonious balance.

Photo credit: Kalyan Varma

Pastoralism contributes significantly to India's economy

Pastoralism has considerable economic value and is central to the livelihoods and well-being of millions in rural India.[63] India has approximately 46 pastoralist communities. A majority of them, often economically and socially marginalised, belong to the Scheduled Tribes (STs) and Denotified Nomadic and Semi-Nomadic Tribes (DNTs) and depend on ONEs.[64] However, the exact numbers are not available as the Indian census enumeration does not separately account for pastoralists; instead, it includes them under the category of farmers.

Some of the key pastoralist communities from the top eight states with the largest areas under ONEs include:

1. Dhangars in Maharashtra
2. Rabaris in Rajasthan
3. Maldharis in Kutch, Gujarat
4. Kurubas in Karnataka
5. Konars in Tamil Nadu
6. Banjara in Madhya Pradesh
7. Golla in Andhra Pradesh
8. Lambada in Telangana

These and other pastoralist communities rear 77% of India's livestock (including cattle, goats, sheep and camels) – which constitutes 20% of the world's livestock – producing about 53% of the milk in India and 74% of the meat.[65]

Pastoralist products are produced, consumed or sold locally and are often not accounted for in official statistics. Therefore, the value of the pastoralist sector and livestock production in ONEs remains underestimated. Its contribution to the national Gross Domestic Product (GDP) and foreign currency earnings is also not sufficiently acknowledged. For example, the Ministry of Commerce & Industry, GoI, in 2019, reported an export of approximately Rs. 936 crore worth of sheep & goat meat to Middle Eastern countries.[66]

Data from 2012 estimates that the pastoralists produce Rs. 14,229 crore worth of milk and Rs. 11,757 crore of meat a year in the formal sector alone.[67] In addition to milk and meat production, the manure of pastoralist livestock is a vital source of fertiliser for farmers, contributing to the agricultural sector. For many pastoralists, manure is a significant source of income.[68] **A recent study indicates that contributions to the milk, wool, meat and dung economies generate an estimated Rs. 1.31 lakh crore annually.**[69]

The area of ONEs influences state-wise livestock production

Given that the relationship between ONEs and pastoralist livestock production has not been quantified or recognised, ATREE studied the contribution of ONEs towards India's livestock production. This involved examining the relationship between ONEs and the production of meat and milk from, and population of, indigenous sheep, goats and cattle.

We examine the top 8 states with the highest area under ONEs (more than 12,000 sq. km, viz., Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Karnataka, Telangana and Tamil Nadu comprise 89% of India's ONEs). We include only indigenous sheep, goats and cattle for our analyses and exclude animals like yak, camel, ducks, etc., which are also kept in extensive pastoralism systems but are lower in number and specific to certain regions.

We found that the top eight states with the highest ONEs produce disproportionately higher quantities of small livestock meat and goat and cattle milk compared to their geographical area. This indicates that ONEs influence the amount of meat and milk production from indigenous livestock favourably and can be utilised to ensure sustained extensive production.

Extensive pastoralist production systems can also ensure organic, free-ranging produce as opposed to stall-fed systems, which are energy- and resource-intensive. There is thus a need to recognise this important value addition and appropriately incentivise this climate-resilient and sustainable economic activity.

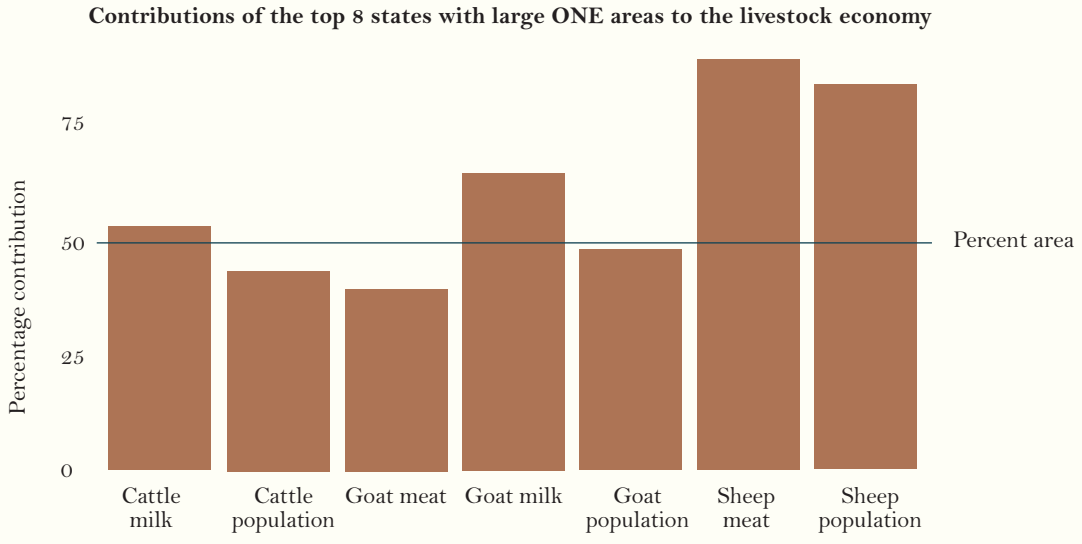


Figure 7: Contribution of top 8 states with highest ONE area to the livestock economy. (The black line in the above graph indicates the per cent area that the eight states under consideration cover in India. Values of animal populations and meat and milk production were taken from the 20th All India Livestock Census & the Basic Animal Husbandry Statistics report, 2023).[70]

Photo credit: Sahjeevan

Photo credit: Sahjeevan

Pastoralism contributes to India's traditions of handloom textiles and weaving

Pastoralists have traditionally relied on the sale of wool as one of their multiple sources of income. Community members are known to both sell wool and weave woollen products.[71]

Weaver communities use wool from sheep and goats to create yarn, fabric and woven tapestry. They engage in weaving and textile-based activities such as wool extraction, felting and embroidery. The traditional livelihoods in these areas need to be supported by improving market linkages and ensuring non-conversion of the landscapes that people, directly and indirectly, depend upon.

In areas with a hot and dry climate, like in the western semi-arid regions and plains of northern India, the fleece is largely coarse. The Chokla breed of Rajasthan and Patanwadi of Kutch are known to produce the best wool in these climatic conditions. In the Deccan region, indigenous breeds like the Deccani and Nilgiri sheep produce carpet-grade wool.

Photo credit: Anirudhh Sheth

The Farmer-Pastoralist Symbiotic Relationship

Pastoralist livestock consume leftover crops and fertilise the farmland across various states. For example, in parts of Haryana and Punjab, migratory pastoralists from Gujarat and Rajasthan form mutual agreements with farmers, arriving on their fields post-harvest. This is particularly useful for organic farming, where manure is used instead of chemical fertiliser.

In Rajasthan, pastoralism and crop cultivation have traditionally been integrated and synergistic.[72] Landowners appreciate the manure provided by herds, who spend the night on their harvested fields and compensate the pastoralists in cash or kind.


Photo credit: Earthen Tunes

Pastoralists face multiple challenges. Restrictions on access, conversion of grazing lands, lack of welfare schemes and activities tailored to the needs of pastoralists, and their poor inclusion in existing welfare scheme criteria make them vulnerable.

Threats to livelihoods in ONEs:

a) Conversion of land, particularly commons, for other uses, such as agriculture, industry, and afforestation
b) Loss of access to grazing lands due to change in land tenure
c) Classification of grazing lands as wastelands that makes them vulnerable to the conversions mentioned above
d) Loss of native flora for foraging
e) Lack of sufficient market access and linkages and welfare such as healthcare and sanitation suited for a migratory livelihood

Land-use conversion is a major threat that needs to be acknowledged, understood and mitigated to strengthen and improve pastoralist livelihoods. Addressing such threats requires extensive pastoralism to be recognised and mapped. Mapping the dependence of pastoralist communities and livestock can help prioritise areas essential for grazing that need to be conserved and managed by communities that depend on them.

Managing and conserving ONEs for livelihoods such as extensive pastoralism

In India, the dependence of pastoralist communities and livestock on ONEs can be understood by mapping grazing sustainability at a district level. "Grazing sustainability" denotes how much grassland productivity is available for every livestock head in that respective district. We calculated grazing sustainability as the dependency of one unit of livestock per unit productivity of ONEs. It is represented as a ratio of land productivity (Gross Primary Productivity in Grams C) and tropical livestock units (TLU).

The higher the ratio, the higher the sustainability of livestock grazing and vice versa. The following maps show the grazing sustainability in ONEs in the top 8 states with the highest ONE area – Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Karnataka and Telangana. The maps examining the relationship between livestock grazing and ONEs highlight a range of districts where the sustainability of grazing changes. On the maps, blue, green and light green colours denote areas that need to be preserved if sustainable grazing is to continue, while yellow and red colours denote areas that need restoration efforts to support livestock grazing.

Photo credit: Kalyan Varma

Figure 8: Relationship between livestock and grazing: Gujarat

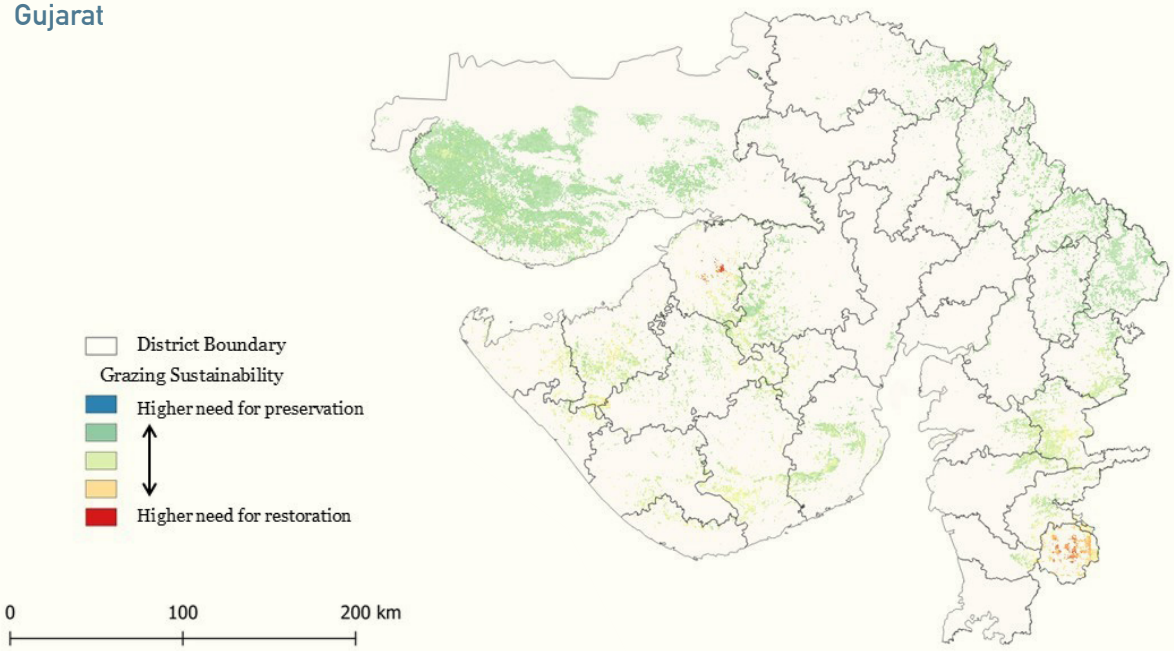


Figure 9: Relationship between livestock and grazing: Rajasthan

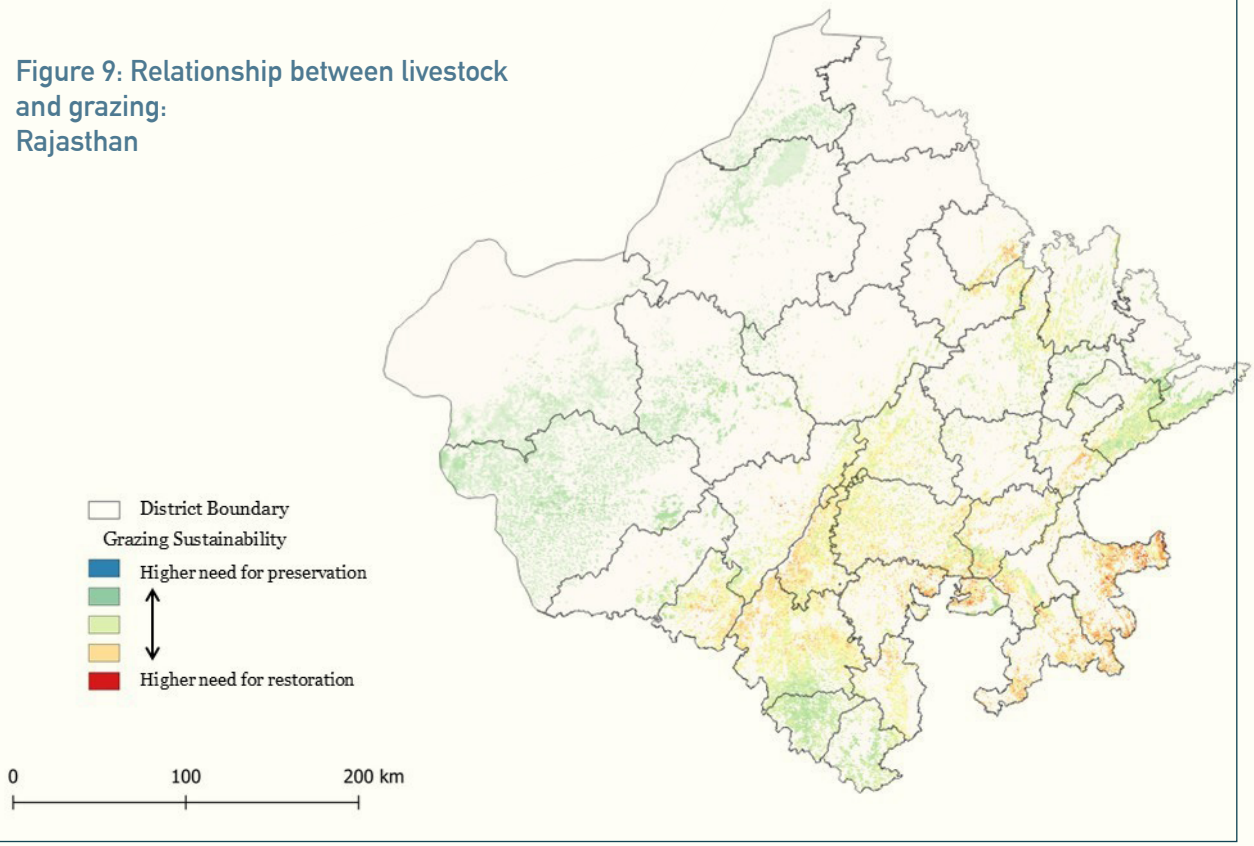


Figure 10: Relationship between livestock and grazing: Maharashtra

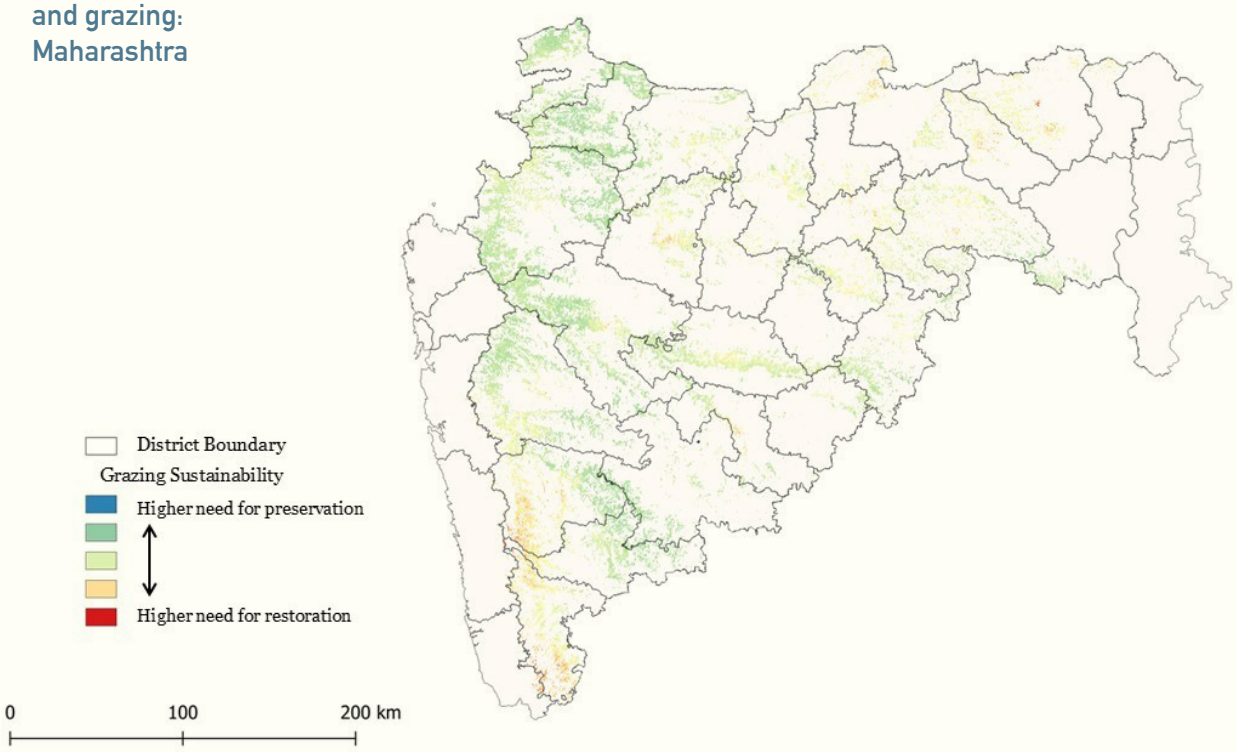


Figure 11: Relationship between livestock and grazing: Madhya Pradesh

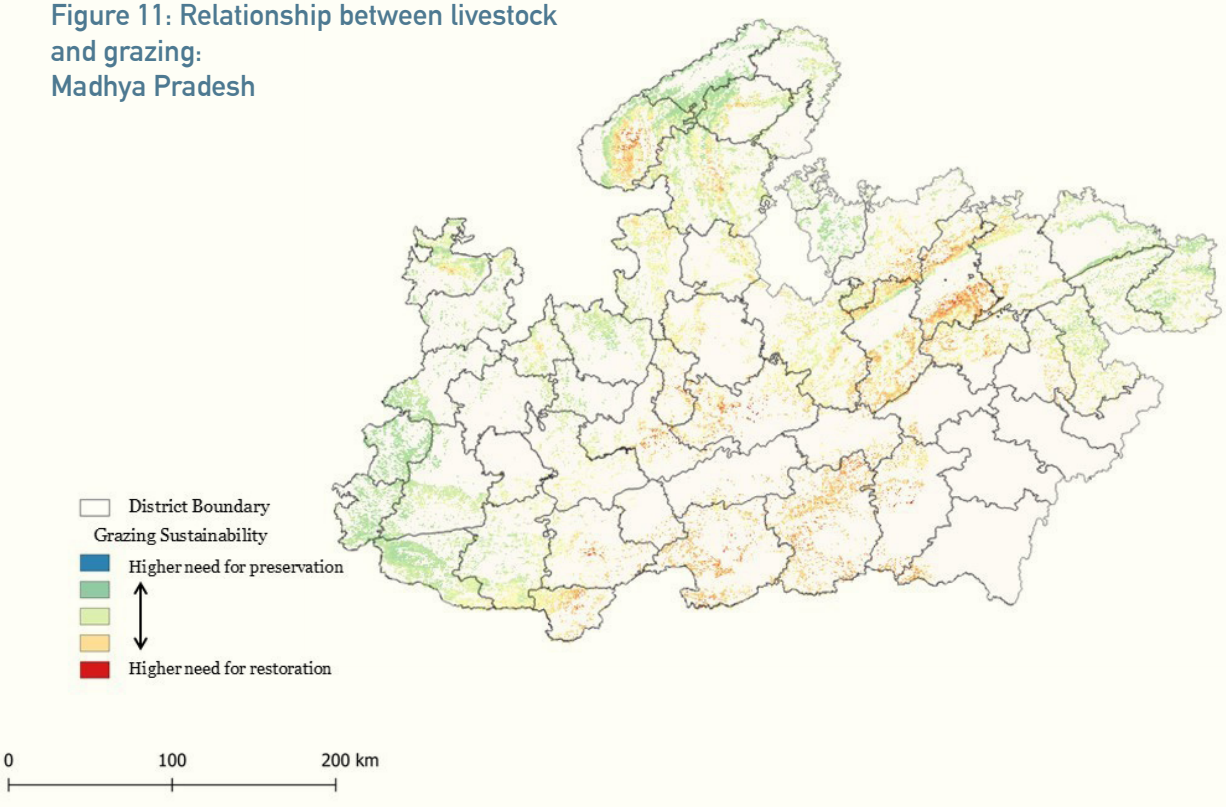


Figure 12: Relationship between livestock and grazing:
Karnataka

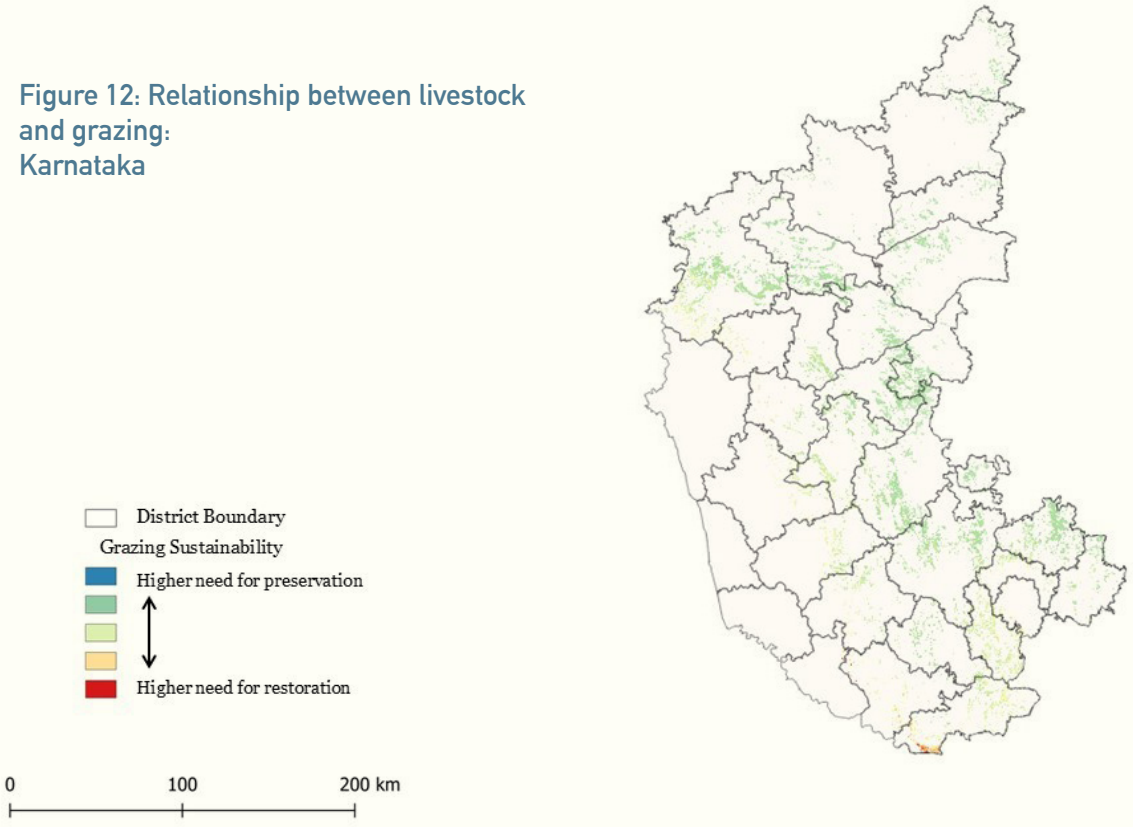


Figure 13. Relationship between livestock and grazing:
Tamilnadu

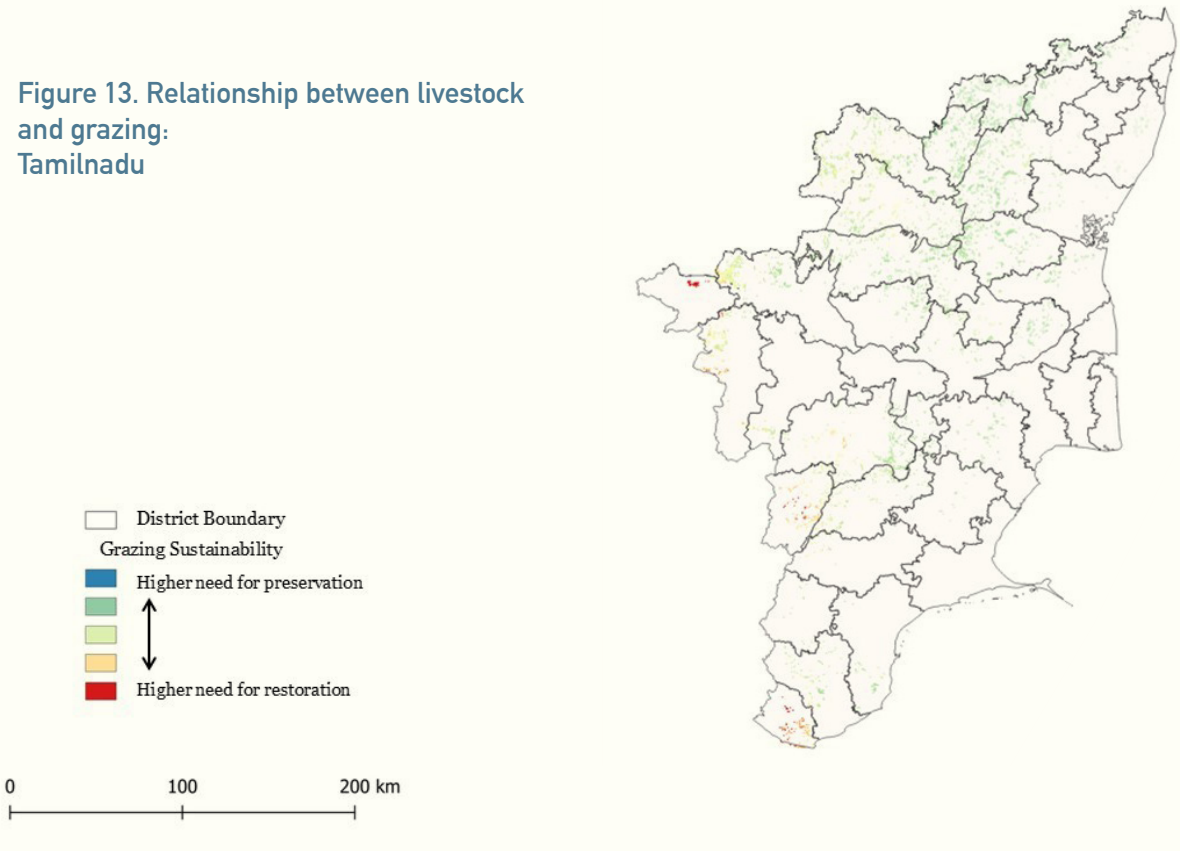


Figure 14: Relationship between livestock and grazing:
Telangana

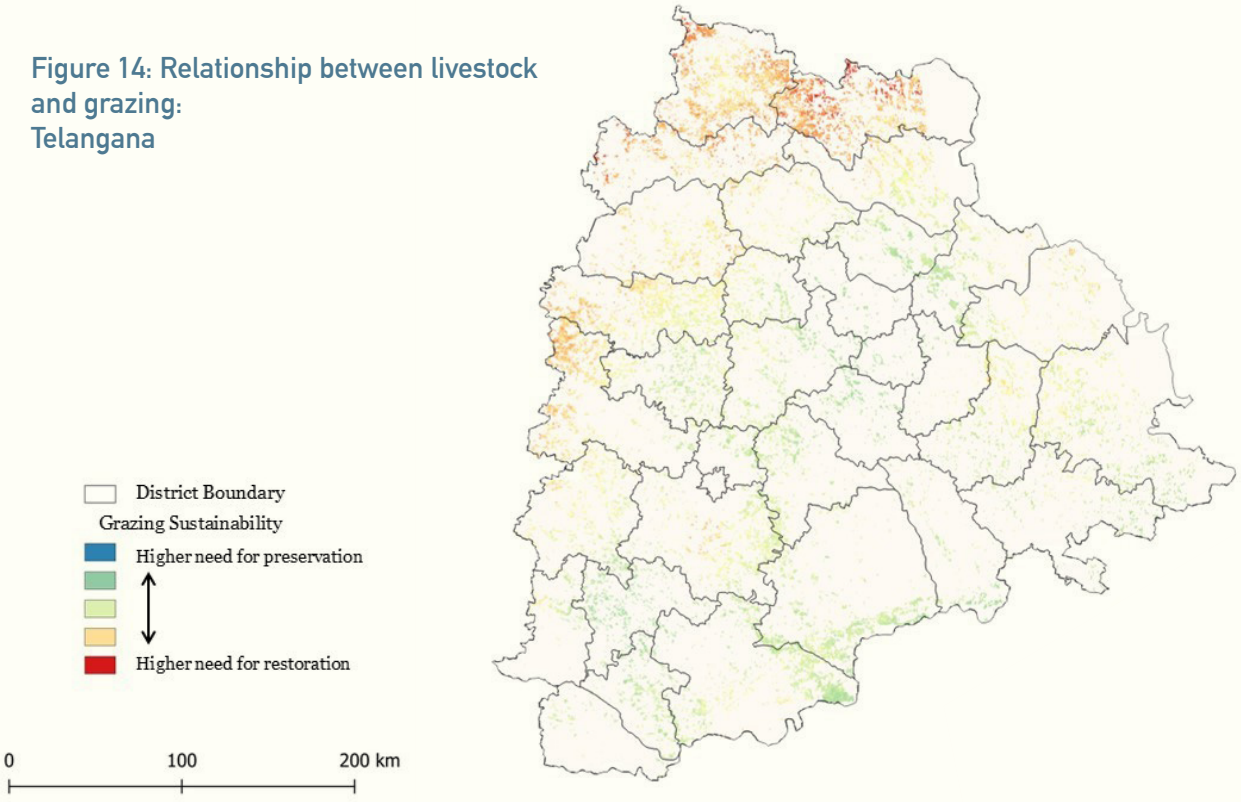
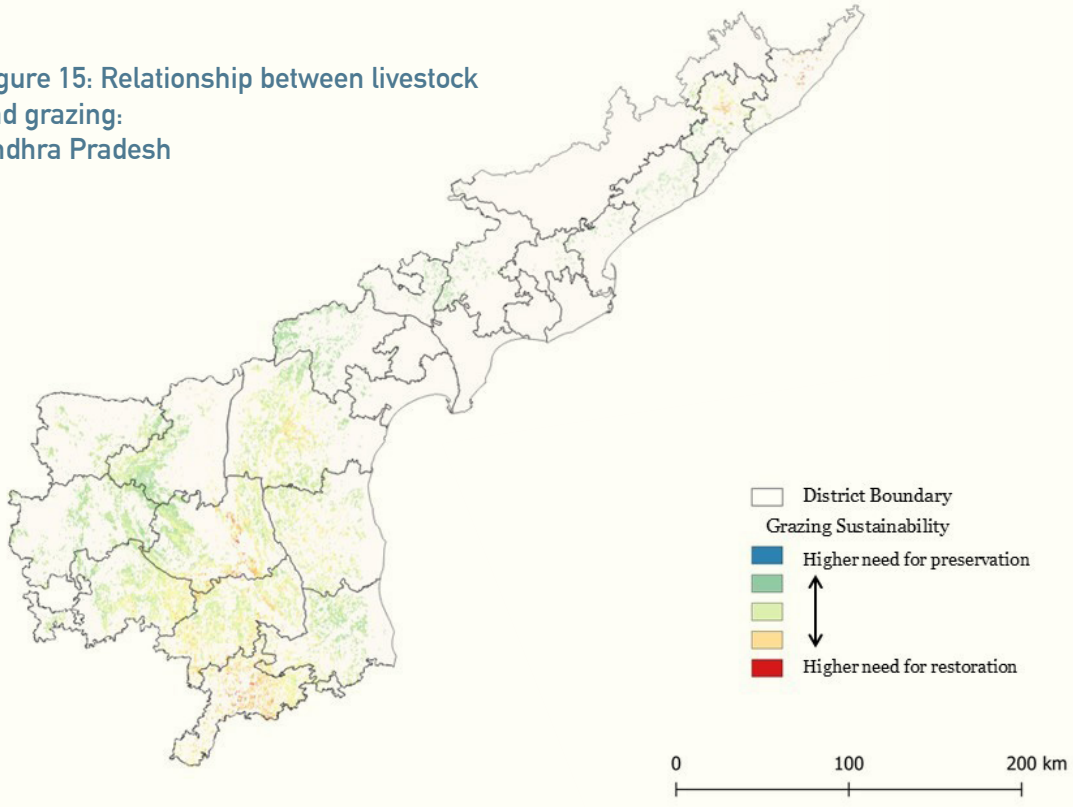


Figure 15: Relationship between livestock and grazing:
Andhra Pradesh



Rethinking actions to boost incomes, safeguard ecosystems and support livelihoods in ONEs

1. Improving access to grazing lands and maintenance of ONEs through community land management can revitalise native flora and keep a check on degradation. Gentle and managed grazing is beneficial to the ecosystem. Extensive pastoralism is, therefore, ideal for ONEs as pastoralists move through patches of land. There is thus a need to expand the area of restored and conserved grasslands to avoid overgrazing on a particular patch of land and also allow communities to conserve and manage ONEs. Prioritisation maps can help frame such management policies.

2. Improving market linkages and boosting opportunities for pastoralist products can significantly add to the existing economic returns from those communities. Additionally, pastoralism reduces the stress on land and water resources in arid regions as compared to what may be required for agriculture, particularly in the context of reducing the sizes of land holdings in rural areas. As a rural livelihood, extensive pastoralism provides a sustainable and climate-resilient means of income generation. Therefore, schemes to improve productivity in dryland regions can also be used to benefit pastoralists.

3. Welfare schemes and programmes tailored to pastoralists can provide them with greater livelihood security. There is a need to design and implement welfare programmes suited to their requirements, including recognising pastoralism as a distinct category and gathering integral data on pastoralists in government censuses. Pastoralists have expressed a need for insurance against livestock loss due to theft or accidents, transit permits and IDs, mobile education and medical facilities, etc.[73]

4. Estimating the exact population of pastoralists as a separate category from farmers by the Indian Census can aid in identifying welfare programmes, population statistics and state-wise programmes required to bolster livelihoods in ONEs.

The UNCCD Global Land Outlook Report (2024) notes that recognition of their land and tenure rights and improved access to markets will be crucial for the future of Indian pastoralists.[74] The report acknowledges a gradual shift towards recognising the socio-ecological role of rangelands and pastoralism in India. For example, in 2022, the Department of Animal Husbandry and Dairying and the Department of Fisheries requested 12 state governments to focus on schemes for the welfare of pastoralist communities and assist pastoralists under the National Livestock Mission, Animal Husbandry Infrastructure Development Fund and Rashtriya Gokul Mission, which stresses on sustainable dairy production. Similar action towards strengthening existing schemes, while also demarcating areas and safeguarding access for pastoralists is important.

V.
Eyes on the Future: Shepherding a Grasslands Policy

Photo credit: Kalyan Varma

The management of land and natural resources in ONEs is influenced by various laws, policies and programmes by the government, collectively referred to as policy tools. Various sectors, including agriculture, energy, environment, water resources and industry, significantly affect these ecosystems. However, many of their actions do not recognise the inherent characteristics of ONEs, viewing them as “wastelands” requiring alternative use and as being poor in environmental benefits. This lack of landscape-specific focus undermines the effective conservation and management of ONEs, which require tailored strategies sensitive to their unique environmental characteristics. The ability of ONEs to contribute to India’s sustainable development agenda calls for an urgent examination of the existing policy framework affecting these landscapes. With the right focus, many of these policies can be realigned to promote the sustainable management of ONEs.

ATREE identified 96 policy tools administered by 24 Ministries that directly or indirectly affect the governance of ONEs.

MoEFCC: Ministry of Environment, Forests and Climate Change (18)	MoAFW: Ministry of Agriculture and Farmers Welfare (8)	MoJS: Ministry of Jal Shakti (8)	MNRE: Ministry of New and Renewable Energy (8)
MoRD: Ministry of Rural Development (7)	MoPR: Ministry of Panchayat Raj (6)	MoP: Ministry of Power (5)	MoST: Ministry of Science & Technology (5)
MoD: Ministry of Defence (3)	MHA: Ministry of Home Affairs (2)	MoAy: Ministry of AYUSH (2)	MoCI: Ministry of Commerce and Industry (2)
MoCu: Ministry of Culture (2)	MPNG: Ministry of Petroleum and Natural Gas (1)	MoTA: Ministry of Tribal Affairs (1)	MoHUA: Ministry of Housing and Urban Affairs (1)
MoES: Ministry of Earth Sciences (1)	MoMi: Ministry of Mines (1)	MoCA: Ministry of Civil Aviation (1)	MoTex: Ministry of Textiles (1)
MoFAHD: Ministry of Fisheries, Animal Husbandry and Dairying (6)	MoTo: Ministry of Tourism (4)	MoCo: Ministry of Coal (2)	MoSJE: Ministry of Social Justice and Empowerment (1)

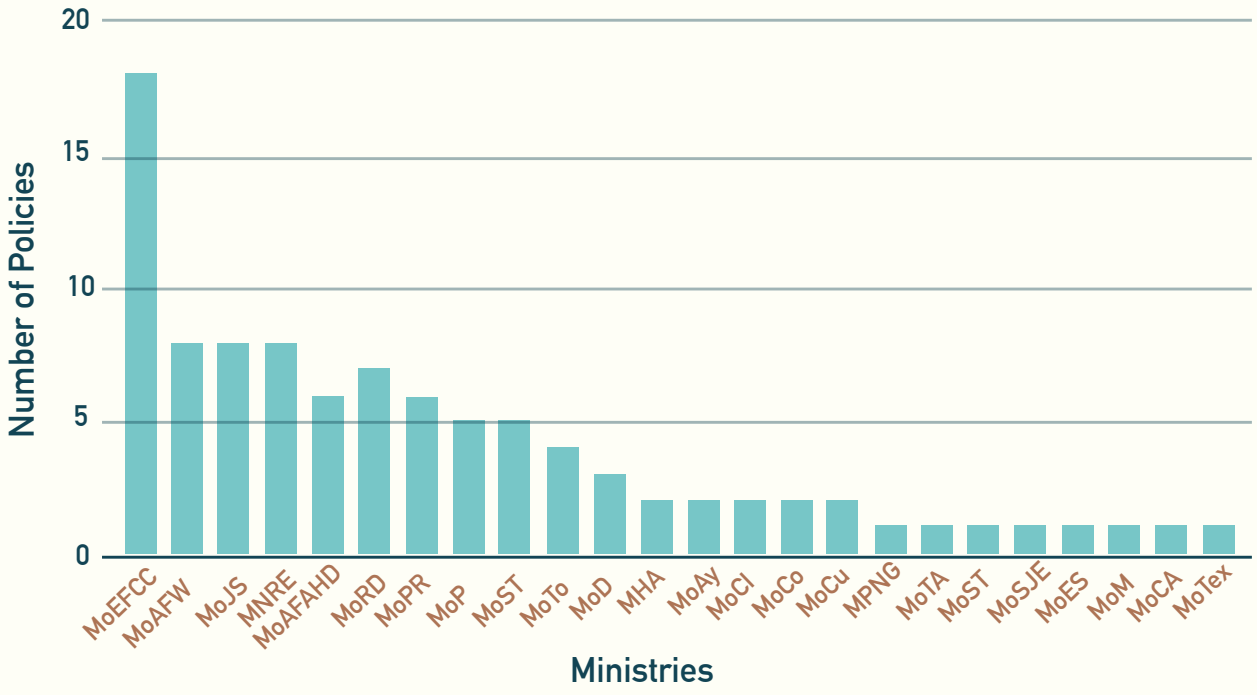


Figure 16: Bar graph of the number of policy tools influencing ONEs across ministries

Photo credit: Anirudhh Sheth

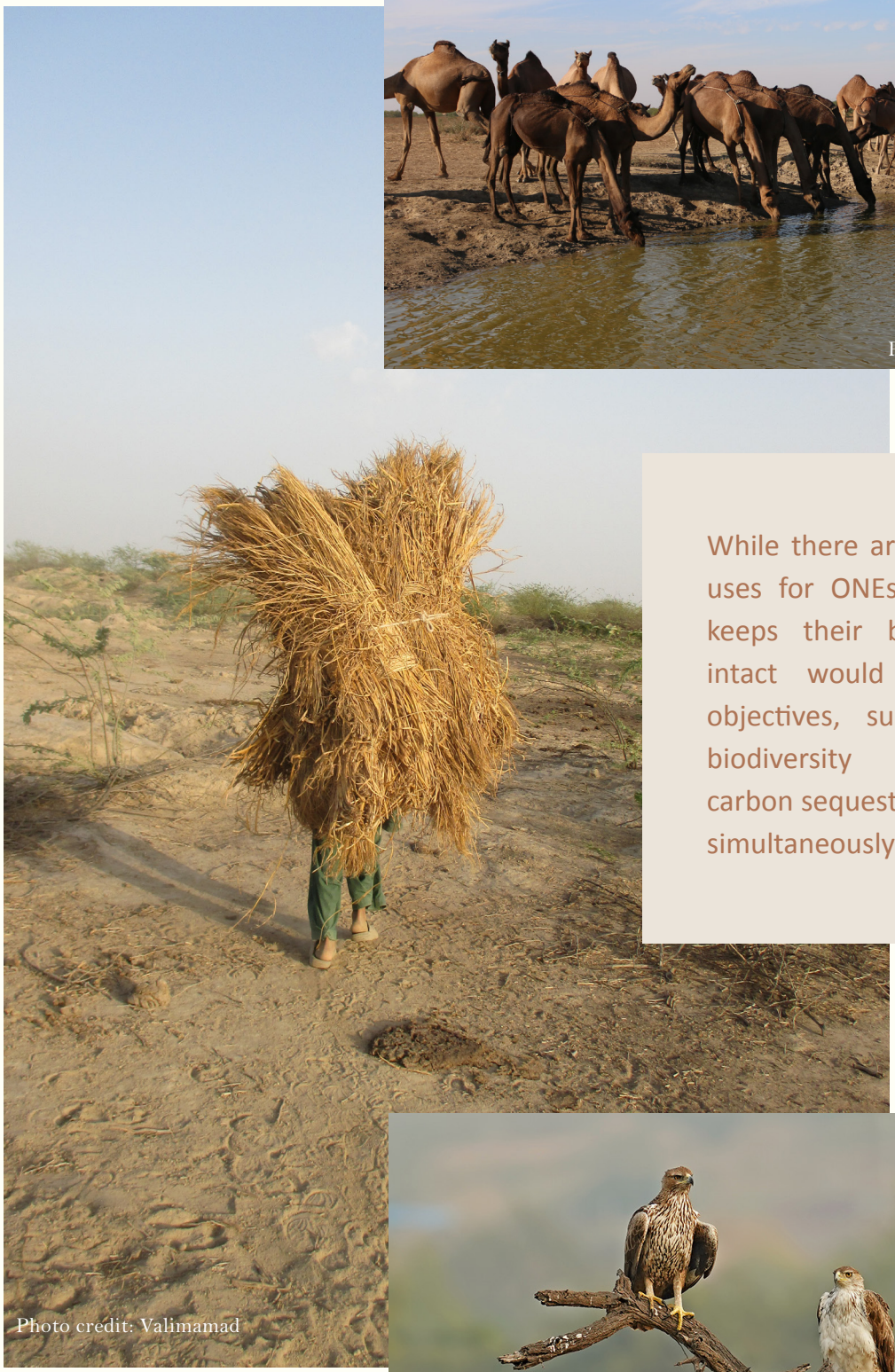


Photo credit: Valimamad

While there are several competing uses for ONEs, an approach that keeps their basic characteristics intact would facilitate multiple objectives, such as pastoralism, biodiversity conservation and carbon sequestration, to be fulfilled simultaneously.

Photo credit: The Grasslands Trust

Policy tools need to adequately recognise ONEs as valuable ecosystems

The Report of the Task Force on Grasslands and Deserts constituted by the Planning Commission in 2006 observed that "grasslands are not managed by the Forest Department whose interest lies mainly in trees, not by the Agriculture Department who are interested in agriculture crops, nor the Veterinary Department who are concerned with livestock but not the grass on which the livestock is dependent. The grasslands are the 'common' lands of the community and are the responsibility of none. They are the most productive ecosystems in the subcontinent, but they belong to all, are controlled by none, and they have no godfathers".[75] This continues to be an apt illustration of the state of governance of ONEs in India. In this context, a comprehensive and coherent governance framework that acknowledges and addresses the issues and opportunities related to ONEs is required.

1. Conservation policies are not sensitive to ONEs as a distinct ecosystem

While India's environmental policy framework has dedicated and landscape-specific policy tools for forests, coastal zones and rivers, it does not recognise or protect ONEs [76] as a distinct category of ecosystems. The strong bias towards forest systems results in the neglect of the socio-ecological importance of ONEs and the incentivisation of large-scale tree planting, which is a growing threat to ONEs in India.[77] Such a bias is also visible in species conservation efforts that focus on charismatic fauna such as the tiger and elephant. However, there is a growing recognition of the importance of grassland ecosystems and species through initiatives such as the inclusion of the Great Indian bustard in the central government's Species Recovery Programme [78] and the rejuvenation of grassland ecosystems to meet the cheetah translocation efforts.[79]

2. ONEs are targeted for active conversion due to their classification as 'wastelands'

Close to 70% of India's ONEs are categorised as wastelands that can be put to 'productive' use.[80] As a result, ONEs are vulnerable to the conversion of land use for various purposes such as urbanisation, industry and agriculture. The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013, while aiming to avoid the acquisition of agricultural and inhabited lands, requires "waste, barren and unutilised public lands" to be prioritised for acquisition. By treating ONEs, including publicly held commons, as devoid of economic value or activity, these policy tools neglect their socio-economic and ecological value.

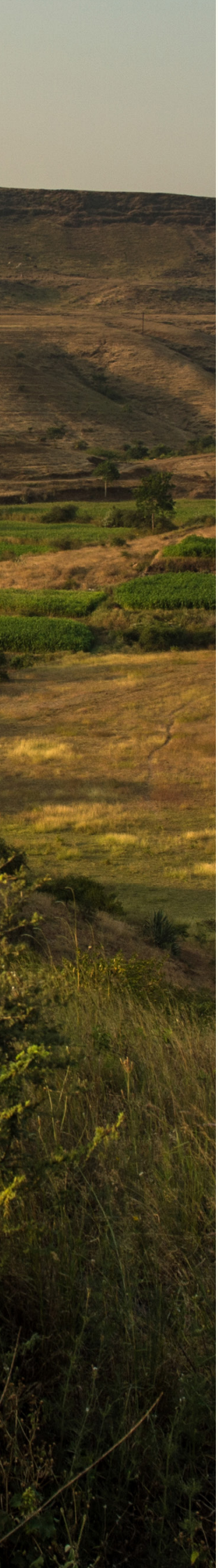
Governance of ONEs is cross-sectoral and trade-offs need to be considered

Given the diverse potential uses of ONEs — such as agriculture, biodiversity conservation, grazing, industry, renewable energy, and urban development — policy tools of various governmental actors significantly shape how these lands are managed. However, many of these policy tools can unintentionally hinder the preservation of ONEs as natural ecosystems, as they often reflect the sectoral priorities of different ministries without fully accounting for the broader impacts. While there are policy tools that could support the conservation and sustainable management of ONEs, they are often underutilised or lack sufficient attention and focus on these ecosystems.

Table 2: Key mandates of ministries and their influence on ONEs

Key Ministry	Mandate	ONEs primarily used for
Ministry of Environment, Forests and Climate Change (MoEFCC)	Prevention and control of pollution; Afforestation and regeneration of degraded areas; Protection of the environment	Afforestation and greening
Ministry of Agriculture and Farmers' Welfare (MoAFW)	Agriculture, food processing and co-operation	Conversion to agriculture and irrigation facilities
Ministry of Jal Shakti (MoJS)	Sustainable development; Maintenance of quality and efficient use of water resources to match growing demands	Expansion of irrigation and water
Ministry of New and Renewable Energy (MNRE)	Development of new and renewable energy technologies, processes materials and components at international standards; Deploying these indigenously developed and/or manufactured products and services in the interest of national energy security	Large-scale solar and wind power plants
Ministry of Rural Development (MoRD)	Livelihood opportunities and security enhancement of livelihood security in rural areas; Rural connectivity roads to provide market access; Social assistance; Improvement of quality of rural life; Capacity development and training; Restoring lost or depleted productivity of the land through watershed development programmes	Wastelands under Wasteland Atlas of India to be converted to productive purposes
Ministry of Fisheries, Animal Husbandry and Dairying (MoAH)	Production of livestock, improving their stocks; Dairy infrastructure development; Provision of healthcare and other services to the livestock for overall development of the Dairy sector	Fodder development programmes

Photo credit:Kalyan Varma



Policy actions must be reoriented to conserve and enhance the multiple benefits of ONEs.

Given the scattered nature of policy tools affecting ONE management in India, there is a need to evolve a framework that can assist in identifying key policy tools for the improved management of ONEs. ATREE's review using the twin criteria of relevance and influence of policy tools has created the following matrix that can enable the government to identify and prioritise policy action. Illustrative examples of recommended actions have been provided under policy tools (PT) that are of 'high' and 'medium' relevance and, therefore, requiring more immediate focus of the government.

	Positive Influence	Variable Influence	Negative Influence
High Relevance	Activate	Adjust	Modify
Medium Relevance	Support	Nudge	Mitigate
Low Relevance	Retain	Assess	Assess

Table 3: Recommended Policy Action Matrix

Description of the typology

1. Activate: PT contains actions that must be supported and/or strengthened, with high priority.
2. Support: PT contains actions that must be supported and/or strengthened, with lesser priority.
3. Retain: PT contains actions that must be retained but may not merit additional support.
4. Modify: PT contains actions that must be discouraged and/or altered, with high priority.
5. Mitigate: PT contains actions that must be discouraged and/or altered, with lesser priority.
6. Assess: PT contains actions that must be assessed for its outcomes but may not merit immediate intervention.
7. Adjust: PT contains actions that must be adjusted to move the variable impact in a positive direction.
8. Nudge: PT contains actions that must be monitored to guide the variable impact in a positive direction.

1. Activate

• [MoEFCC] The Environmental Protection Act can be used to notify high-value ONEs as ecologically sensitive areas, thereby regulating and/or restricting the type of infrastructural and industrial activities that can be undertaken in these areas. The presence of grasslands was proposed as an auxiliary criterion for the declaration of ecologically sensitive areas by the MoEFCC's Committee to Identify Parameters for the Designation of Ecologically Sensitive/ Fragile Areas (Pronab Sen Committee) in 2000.[81]

• [MoEFCC] The Criteria and Guidelines for Identifying Other Effective Area-Based Conservation Measures (OECM) can be used to create community-conserved areas outside protected areas. It expressly identifies village commons/lands as areas amenable to OECM.

• [MoSJ] The Scheme for Economic Empowerment of DNTs, i.e., denotified tribes, nomadic tribes and semi-nomadic tribes, can be used to provide incentives for strengthening location-specific denotified, nomadic and semi-nomadic SHG institutions, thereby conserving traditional practices and strengthening livelihood opportunities.

• [MoEFCC] The Integrated Development of Wildlife Habitats Scheme, which currently includes a dedicated programme for the recovery of the great Indian bustard, can be further expanded to enhance the protection (including of natural habitats) and budgetary allocations for the threatened ONE species.

2. Adjust

• [MoRD]: The Pradhan Mantri Krishi Sinchai Yojana Watershed Development Programme aimed at improving the productivity of land, in convergence with the National Rural Employment Guarantee Scheme (NREGS) that has a strong focus on natural resources management, can be implemented with greater focus on grassland and pasture restoration activities in ONEs.

• [MoAH]: The National Livestock Mission should integrate the focus on extensive grazing systems like pastoralism in ONEs into its objectives, which can provide low-input access to quality forage for livestock. This can alleviate the pressure on agricultural lands for intensive fodder cultivation. Recognising pastoralists as beneficiaries of the scheme can also improve their access to institutional support and resources.

• [MoEFCC]: The rules relating to environmental impact assessments can be strengthened regarding land use in ONEs by mandating such assessments for renewable energy projects currently exempt from environmental clearance under the EIA Notification 2006.

• [MoEFCC]: The Green Credit Rules, 2023, which creates a market for green credits generated through various environmentally positive activities such as tree plantation, sustainable agriculture, water conservation and mangrove restoration, can be expanded to include grasslands restoration

(while also mitigating the risk of tree plantations encroaching upon ONEs).

• [MoEFCC]: The utilisation of the Compensatory Afforestation Fund (commonly called CAMPA) can be reoriented from large-scale tree plantations towards natural regeneration activities that are contemplated within its scope. This will enable a more ecosystem-oriented approach to restoration that is also sensitive to socio-economic dependencies.

3. Modify

• [MoRD]: The Rights to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013, which seeks to avoid the acquisition of agricultural land and habitations and encourages the acquisition of "waste, barren and unutilised public land" must be modified to safeguard ONEs, especially community common lands.

• [MoEFCC] The National Afforestation Program and the National Mission for Green India, which aims to increase and improve forest cover, including through afforestation of non-forested ecosystems, must be altered to limit their implementation in ONEs.

• [MoNRE] The Scheme for the Development of Solar Parks and Ultra Mega Solar Power Projects (CSS) under the National Solar Mission promotes large-scale solar projects for which the use of wastelands is prioritised. This must be modified to include appropriate siting requirements and to enable greater focus on off-grid decentralised energy systems envisaged under the NSM.

• [MoPNG] The National Policy on Biofuels 2018, which aims to increase the production and availability of biofuels, calls for the identification of locations with surplus available biomass and generation of feedstock such as energy grasses and short gestation crops by utilising wastelands should be modified to avoid the encroachment of grazing and other common lands.

4. Support

• [MoRD] Mission Antyodaya seeks to combine different government programmes and schemes to achieve SDG goals. The mission's approach of treating the household and the village as the basic unit of planning can prioritise improved ONE management in villages/clusters that exhibit higher dependence on ONE-based livelihoods.

• [MNRE] Grid Connected Rooftop Solar Programme allows consumers to generate their own electricity (and to sell any surplus), reducing the reliance on large-scale grids and solar farms in ONEs, also reducing transaction costs and the need for long-range transmission lines. Subsidies for the installation of rooftop solar panels under the scheme can be further supported.

• [MoEFCC] The National Environment Policy should also be viewed more holistically and harnessed to draw attention to non-forested ecosystems.

5. Nudge

• [MoEFCC] The definition of forest land under the Van Sanrakshan evam Samvardhan Adhiniyam (Forest Conservation Act, 1980), as interpreted by the Supreme Court in Godavarman Thirumulpad v. Union of India & Others (1997), could apply to certain ONE landscapes, such as the Orans of Rajasthan[82] and Gomalas of Karnataka.[83]

•[MoAH] The National Programme for Dairy Development aims to boost livestock productivity and market linkages, enhance livelihoods and improve access to veterinary care. By promoting native grass varieties for feed and extensive pastoralism, the scheme can support ONEs while relaxing the need for intensive fodder cultivation and avoiding introducing potentially harmful fodder species.

•[MoAH] Rashtriya Gokul Mission focuses on the development and conservation of indigenous bovine breeds, aiming to improve milk production and farm livelihoods. However, this scheme does not consider the needs of pastoralists and agro-pastoralists, favouring stall-feeding over extensive grazing systems, thereby missing a key category of the rural poor.

•[MoT] The National Strategy and Roadmap for Development of Rural Tourism requires identifying village clusters with high potential for tourism development based on characteristics such as local crafts and cuisines, folk music and natural features. Pastoralism offers a unique, traditional and nature-friendly way of living that can be supported through equitable and conscious tourism practices.

6. Mitigate

•[MoCA] The Greenfield Airports Policy, 2008 deals with establishing new airports, including identifying land, requiring specific information on the proposed use of forest and agricultural land. This policy must be altered to ensure that the acquisition of ONEs is appropriately considered.

•[MoCo] The Use of Land Acquired under Coal Bearing Areas (Acquisition & Development) Act, 1957 and the scheme for the Conservation, Safety and Infrastructure Development in Coal Mines, which propose the use of afforestation as a mitigation and/or reclamation technique, must be reconsidered to ensure that conservation and restoration activities are sensitive to the needs of ONEs.

•[MoMi] The National Minerals Policy that seeks to avoid mining activities in ecologically fragile and biologically rich areas must ensure that high-value ONEs are given due consideration in siting decisions for mining zones.

Table 4 : Distribution of the policy intervention types across Ministries

Ministries	Activate	Adjust	Assess	Mitigate	Modify	Nudge	Retain	Support	Total
Agriculture & Farmers Welfare	2	3				3			8
AYUSH			1			1			2
Civil Aviation				1					1
Coal				2					2
Commerce and Industry					2				2
Culture								2	2
Defence			2				1		3
Earth Sciences	1								1
Environment, Forests and Climate Change	9	3			2	2		2	18
Fisheries, Animal Husbandry and Dairying		2				3	1		6
Home Affairs			1				1		2
Housing and Urban Affairs			1						1
Jal Shakti	4	2			2				8
Mines				1					1
New & Renewable Energy		1			4	1		2	8
Panchayat Raj	3							3	6
Petroleum and Natural Gas					1				1
Power			1	1	2	1			5
Rural Development		4			2			1	7
Science and Technology	2						1	2	5
Social Justice and Empowerment	1								1
Textiles							1		1
Tourism						4			4
Tribal Affairs	1								1
Grand Total	23	15	6	5	15	15	5	12	96

Conclusion

Photo credit: The Grasslands Trust

Semi-Arid Open Natural Ecosystems are unique landscapes with distinct fauna and flora, covering about 10% of India's geographical area. They support the lives and livelihoods of about 46 pastoralist communities that generate Rs. 1.31 lakh crore economic output.[84] These landscapes are also critical to meeting our climate mitigation goals, with carbon storage comparable to forest ecosystems for the same amount of rainfall. These landscapes are hardy, climate-resilient and have endured for centuries. However, ONEs are increasingly being converted and altered by development and afforestation efforts. They need improved and targeted management and conservation.

Proper management of these landscapes would positively affect India's climate goals, natural assets and the communities that have lived off these lands for generations. Institutionalising community-based management can help maintain ONEs, benefit their livelihoods and contribute to economic and human well-being in rural landscapes. Maintaining grasslands and savannas will also boost SOC stocks in a resilient and more permanent form. The endemic and migratory species of these landscapes, many of which are threatened or vulnerable, can be protected to meet India's biodiversity goals and conserve unique areas of natural beauty.

By their very nature, ONEs are multifaceted, and so their management involves several ministries, including the Ministry of Environment, Forests and Climate Change, the Ministry of Agriculture and Farmers' Welfare, the Ministry of Jal Shakti, the Ministry of New and Renewable Energy, the Ministry of Rural Development and the Ministry of Fisheries, Animal Husbandry and Dairying. Thus, recognising and identifying goals for each within a management plan for ONEs is an important step for the improved management of ONEs. ATREE's nine-fold policy action classification can assist the government and policymakers in setting up a comprehensive management policy for India's ONEs. Second, the prioritisation of land use trade-offs is an important process in the management of these landscapes. The presented prioritisation maps could be a useful tool in delineating land for various uses.

ONEs must be recognised as valuable landscapes with distinct ecology and ecosystems and unique biodiversity. They are significant for people and their livelihoods and can be a critical addition to India's carbon commitments and climate goals.

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Appendices

Appendix I: Methodology for biodiversity prioritisation mapping

We identified 19 species of grassland specialist fauna for the prioritisation exercise for ONEs. Bird species were chosen based on their status in the 2023 State of India's Bird Report. In the case of mammals and reptiles, we focused on flagship species of grasslands, as their protection is crucial for the well-being of other species within the ecosystem. Occurrence data was collected from online repositories such as E-bird, GBIF, and field data.

We gathered data on 19 bioclimatic variables with a spatial resolution of 30 seconds or 1 kilometre from www.worldclim.org. To enhance the reliability of our modelling, we employed a correlation matrix to analyse the relationship between species occurrence and climatic variables. We specifically selected variables that exhibited correlation values lower than 0.7 to prevent the inclusion of highly correlated variables in the modelling process.

We used the MaxEnt program to create a raster depicting areas with a high probability of occurrence for each of the 19 species of interest. Employing a 10-percentile training presence logistic threshold, we conducted modelling for all 19 species, resulting in the generation of a comprehensive raster illustrating the distribution of each species across the landscape.

The species were assessed and ranked according to their status in three prominent indexes—IUCN, CITES, and WLPA 2022 (Table 1). Each species received a specific ranking based on its position in these indexes. Subsequently, the ranks from each list were averaged to derive a consolidated priority ranking for each species, reflecting their relative conservation importance. These priority rankings were then assigned to the respective species distribution raster.

Species Group	Species Name	Latin Name	IUCN Status	CITES Status	Wildlife Protection (Amendment) Act 2022 Status	IUCN	CITES	WLPA	Species Priority Ranking
Birds	Great Indian Bustard	*Ardeotis nigriceps*	Critically Endangered	Appendix I	Schedule I	1	1	1	**1.00**
	Lesser Florican	*Sypheotides indicus*	Critically Endangered	Not listed	Schedule I	1	0	1	**0.67**
	Pallid Harrier	*Circus macrourus*	Near Threatened	Not listed	Schedule I	0.4	0	1	**0.47**
	Common Crane	*Grus grus*	Least Concern	Not listed	Schedule I	0.2	0	1	**0.40**
	Indian Courser	*Cursorius coromandelicus*	Least Concern	Not listed	Schedule I	0.2	0	1	**0.40**
	Jerdon's Courser	*Rhinoptilus bitorquatus*	Critically Endangered	Not listed	Schedule I	1	0	1	**0.67**
	Macqueen's Bustard	*Chlamydotis macqueenii*	Vulnerable	Appendix I	Schedule I	0.6	1	1	**0.87**
	Sarus Crane	*Antigone antigone*	Vulnerable	Not listed	Schedule I	0.6	0	1	**0.53**
	Sociable Lapwing	*Vanellus gregarius*	Critically Endangered	Appendix I	Schedule I	1	1	1	**1.00**
	Variable Wheatear	*Oenanthe picata*	Least Concern	Not listed	Schedule II	0.2	0	0.67	**0.29**
Mammals	Desert Fox	*Vulpes vulpes pusilla*	Least Concern	Appendix III	Schedule I	0.2	0.33	1	**0.51**
	Indian Wolf	*Canis lupus pallipes*	Least Concern	Not listed	Schedule I	0.2	0	1	**0.40**
	Blackbuck	*Antilope cervicapra*	Least Concern	Appendix III	Schedule I	0.2	0.33	1	**0.51**
	Chinkara	*Gazella bennettii*	Least Concern	Appendix III	Schedule I	0.2	0.33	1	**0.51**
	Indian Fox	*Vulpes bengalensis*	Least Concern	Appendix III	Schedule I	0.2	0.33	1	**0.51**
	Striped Hyena	*Hyaena hyaena*	Near Threatened	Appendix III	Schedule I	0.4	0.33	1	**0.58**
	Asiatic wild Ass	*Equus hemionus*	Endangered	Appendix I	Schedule I	0.8	1	1	**0.93**
Reptile	Sitana spp.	*Sitana ponticeriana*	Least Concern	Not listed	Not listed	0.2	0	0	**0.07**
	Spiny-Tailed Lizard	*Saara hardwickii*	Vulnerable	Appendix II	Schedule I	0.6	0.67	1	**0.76**

Table 1: Showing the list of conservation priority species and their ranking system based on species status under IUCN red list, CITES index, and Wildlife Protection (Amendment) Act 2022.

Category	Ranking	Proportion value
Critically Endangered	5	1.00
Endangered	4	0.80
Vulnerable	3	0.60
Near Threatened	2	0.40
Least Concern	1	0.20
Schedule I	3	1.00
Schedule II	2	0.67
Schedule III	1	0.33
NA	0	0.00
Appendix I	3	1.00
Appendix II	2	0.67
Appendix III	1	0.33
NA	0	0.00

The species distribution raster, post-species priority ranking, was consolidated by stacking them together and combining them using addition in Q-GIS. In the resulting raster, each pixel holds a value obtained by summing the priority ranking values of all species that overlap that specific pixel. Therefore, in the output raster, higher values indicate higher conservation importance for the corresponding area, as it signifies the overlap of multiple species with various ranks in that particular location.

The ultimate species priority raster was intersected with a raster representing patches on ONE's, where each patch had a size equal to or larger than 10 square kilometres. This process aimed to pinpoint priority zones within ONE's patches for biodiversity conservation. Overlaying the species priority information onto these specific patches helped identify and prioritise areas within these larger patches that are crucial for the conservation of biodiversity.

Appendix II: Carbon

SOC % analysis: We determined the SOC% of each soil section using the combustion gas chromatography method in a CHNS analyzer. Approx. ~2 gm of the section was dried for 1 hour at 105°C and a small proportion of soil (0.110 - 0.111 mg) was weighed and packed into a small tin foil to be inserted into the CNHS analyzer to get the SOC % value (Figure 3).

Bulk density: We used direct methods to determine soil bulk density (BD), which is the mass per unit volume of the soil. Here, we estimated BDfine2, denoted as the mass of fine earth per total volume of the soil sample. To estimate the mass of fine earth particles in each soil core, we oven-dried the soil section again at 105°C for 24 hours to ensure complete loss of moisture. BD was then estimated for the fine-earth fraction only using a random sub-sample and extrapolated to the whole soil sample. Comparison of the final weight of the section with the wet weight of the sample allowed us to estimate the proportion of moisture content in the soil section. As we had taken a random sample from the original soil core, we assumed that the original soil core collected on site would have the same moisture content as the sub-sample. In this way, we could calculate the dry weight of the fine earth particles of the original soil core. We then calculated the bulk density estimation of the fine earth expressed per total volume of the soil sample (BDfine2) by combining the volume of the soil core with the dry weight of the fine earth particles of the original soil core (FAO 2019; Poeplau, Vos & Don 2017) (Figure 3).

Finally, SOC stock for each sample was determined by the following equation:

SOC stock (tC/ha) = OCi x BDfine2 x Ti x 0.1

where,

SOC stock (tC/ha) is the soil organic carbon stock of the sampled depth increment;

OCi (mgC/g of fine earth) is the organic carbon content of the fine earth fraction (< 2 mm) in the sampled depth increment;

BDfine2 (g fine earth per cm3 of soil) is the mass of fine earth per total volume of the soil sample (equivalent to the mass (g) of fine earth/total volume of soil sample (cm3) in the given depth increment;

T is the thickness (depth, in cm) of the depth increment;

0.1 is a factor for converting mgC/cm2 to tC/ha.

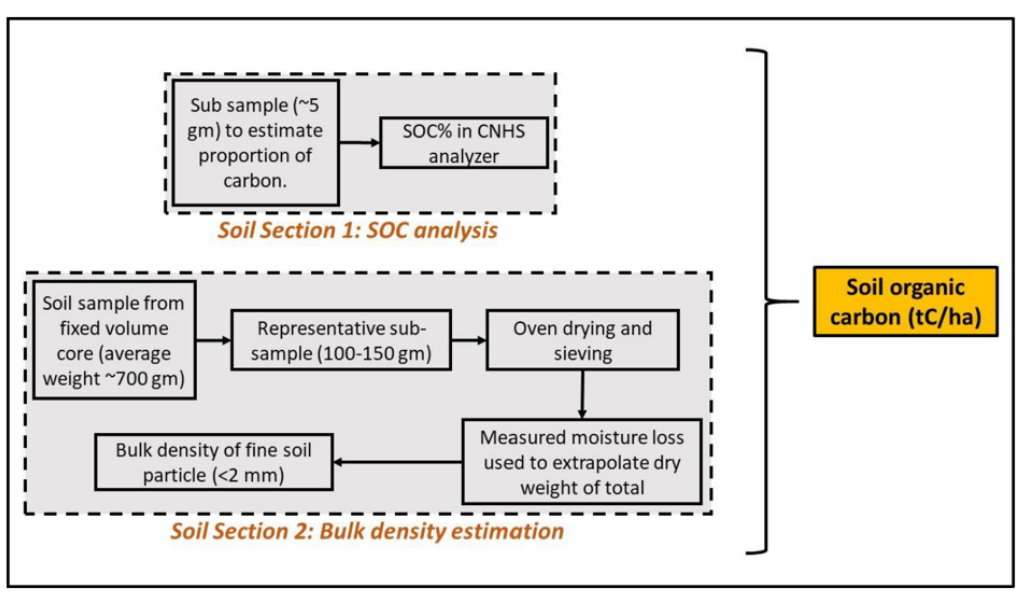

Figure: The steps outlining the procedure for SOC analysis. The soil sample for each part were taken at the depth of 30 cm.

Appendix III: Methodology for grazing sustainability maps

The grazing sustainability of a district was estimated by a ratio of land productivity and the tropical livestock unit (TLU) that is dependent on the unit area of land available for grazing. The land productivity was obtained from the MODIS GPP dataset measured in tonne carbon of available biomass per hectare of land. TLU was calculated using the livestock biomass numbers which was further multiplied by a standard conversion factor . The grazing sustainability ratio value indicates the proportion of livestock dependent on grazing per unit of productive land. The values are measured in tonne carbon per TLU.

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