CHAD

Strategic Landscape Restoration for Resilience:
Leveraging Ecosystem Services to Secure Livelihoods in Chad

PROGREEN

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1. "Landscape Restoration Opportunities in Chad," Natural Capital Insights, Eric Lonsdorf, Chris Nootenboom, Adrian Vogl, and Sepul Kanti Barua, April 15, 2025",
2. "Assessing Nature's Contributions to People in Ouadi Rime Ouadi Achim Wildlife Reserve and Surroundings, Chad, Phase I," ETIFOR and HAMERKOP, Colm O'Driscoll, Juan Diego Restrepo, Federica Bosco, Jihane Khairallah, Fabien Castel, Hassane Abdoulaye, and Olivier Levallois, November 20, 2024", and
3. "Assessing Nature's Contributions to People in Ouadi Rime Ouadi Achim Wildlife Reserve and Surroundings, Chad, Phase II", ETIFOR and HAMERKOP, Colm O'Driscoll, Jihane Khairallah, Juan Diego Restrepo, Elena Vissa, John Newby, Violeta Barrios, Olivier Levallois, and Solene Kechavarzi, March 14, 2025".

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Abbreviations

BaU	Business as Usual
BCR	Benefit Cost Ratios
CbT	Community-based Tourism
ES	Ecosystem Services
FAO	Food and Agricultural Organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gas
ha	Hectares
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and ES
IRR	Internal Rate of Return
IPCC	Intergovernmental Panel for Climate Change
MEA	Millennium Ecosystem Assessment
MoEF	Ministry of Environment, Water, and Fisheries
MEFSD	Ministry of Environment, Fisheries, and Sustainable Development
MoTDCH	Ministry of Tourism Development, Culture, and Handicrafts
NbS	Nature-based Solutions
NbT	Nature-based Tourism
NCP	Nature's Contribution to People
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
NWFP	Non-Wood Forest Products
ONPTA	Office National de Promotion du Tourisme, de l'Artisanat et des Arts
OROA	Ouadi Rimé-Ouadi Achime Wildlife Reserve
PES	Payments for Ecosystem Services
PV	Present Value
SCF	Sahara Conservation Fund
SDR	Sediment Delivery Ratio
SWY	Seasonal Water Yield
TEV	Total Economic Value
TLU	Tropical Livestock Unit
TTDI	Travel and Tourism Development Index
VNU	Verifiable Nature Units
WB	World Bank
WBCCKP	World Bank Climate Change Knowledge Portal

Foreword

The World Bank remains firmly committed to tackling the pressing challenges of climate change and land degradation in the world's most vulnerable provinces. In the Sahel, where the effects of climate change are particularly severe, extreme weather events, land degradation, and dwindling natural resources undermine the livelihoods of millions.

The World Bank Group's Country Climate and Development Report for five countries in the Sahel – Burkina Faso, Chad, Mali, Mauritania, and Niger – highlights the significant opportunities for resilient, lower-carbon development. With strategic investments and sound policies, these countries can diversify their economies in more inclusive and climate-resilient ways. They have the potential to reverse environmental degradation and ensure that climate action directly benefits the poorest communities. Accelerating rapid, resilient, and inclusive growth is not only the most effective adaptation strategy to climate change but also the most sustainable path to achieving development goals. Crucially, the cost of inaction far exceeds the cost of action. By taking early and targeted steps, the Sahel countries can advance toward a greener, more resilient, and inclusive future.

Chad is ranked as the most climate vulnerable country in the world, and its economy and livelihoods depend heavily on agriculture, livestock, and fishing. Consequently, natural resource management and biodiversity are essential for sustainable development and the well-being of people. The country's fragile ecosystems—particularly in the Sahelian belt and the Lake Chad basin—support millions but face increasing threats from climate change, overuse, and land degradation.

Effective restoration efforts are crucial to maintaining water availability, fertile land, and healthy ecosystems, which in turn are vital to food security, economic stability, and resilience to environmental shocks. Furthermore, protecting wildlife creates opportunities for eco-tourism and job creation that can drive inclusive growth, as seen in the Ouadi Rimé-Ouadi Achim Wildlife Reserve, one of Africa's largest protected areas. This report identifies priority restoration areas in Chad through a detailed analysis of degradation and climate vulnerability hotspots. These findings can guide the World Bank and other development institutions in making targeted investments to strengthen natural resource management and promote sustainable development across the country.

The World Bank is dedicated to working alongside the Chadian government to improve environmental governance and strengthen adaptive capacities. Through the promotion of sustainable land management practices and inclusive policies, we seek to reduce vulnerabilities and enhance resilience to land degradation and climate-related shocks. By leveraging our global expertise across sectors such as agriculture, water management, and urban development—and by fostering strategic partnerships—we strive to shape a more sustainable and resilient future for the generations to come.

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Executive Summary

Land degradation and climate vulnerability threaten Chad's ecosystems. Yet, there is significant potential to not only reverse these negative trends but also generate employment and livelihood opportunities. Spatially targeted efforts will be required, drawing on analysis of Chad's diverse landscapes.

Healthy ecosystems contribute to Chad's prosperity, stability, and long-term development, and are vital for food security, sustainable value chain development, and the diversification of the economy. About 40 percent of Chad's territory is devoted to agricultural land, with traditional agropastoralism serving as the foundation of rural livelihoods (World Bank n.d.). However, these landscapes are increasingly threatened by land degradation[1] and desertification, driven by both anthropogenic and natural forces. Declining soil fertility and rapidly increasing water scarcity, including shrinking of water sources have led to reduced crop yields and diminished pasture productivity, imposing a growing economic burden—particularly on the agricultural sector.

At the same time, Chad faces significant climate risks, including rising temperatures, erratic rainfall, and drought. As emphasized in Chad's National Food and Nutrition Policy (Government of Chad 2013), environmental degradation and climate change exacerbate problems linked to malnutrition, risking initiatives aimed at reducing poverty and malnutrition. Chad's Nationally Determined Contribution (NDC; Government of Chad 2021) also stresses the increased vulnerability imposed on the agricultural, animal husbandry, fisheries, health, social, and education sectors by the compounding effects of climate change and ecosystems degradation.

In light of these intersecting pressures, identifying geographic hotspots where land degradation and climate vulnerability overlap can inform the prioritization of restoration efforts that will strengthen ecosystem services (ES) and build resilience. This report aims to provide guidance to development partners on addressing land degradation and climate risk and leveraging ecosystem services to secure livelihoods in Chad. The report covers the above aspects at the national level and includes a case study in the form of a deep dive into the invaluable Ouadi Rimé-Ouadi Achim Wildlife Reserve (OROA), which is one of the largest in Africa, and is in the Batha province in central Chad.

In Chad, ES support economic and social well-being, including soil retention, water regulation, food production, biodiversity conservation, and carbon sequestration. In the OROA Wildlife Reserve, the most critical ES for sustainable development are grazing, habitat creation and maintenance, and nature-based tourism (NbT). Forage for grazing represents a vital natural asset for the pastoral economy in the Reserve. Managing the supply of forage through sustainable grazing practices and environmental restoration is therefore critical to maintain long-term productivity of rangelands. As for habitat creation and maintenance, this plays a crucial role in supporting biodiversity, combating desertification, and maintaining ecological connectivity. There is potential to develop market mechanisms to protect and enhance this ES, such as through conservation funding, ecotourism, and global biodiversity markets. Finally, NbT represents a great opportunity

1 As per the National Program of Action to Combat Desertification (Ministry in charge of Environment 2003), Chad has approximately 428,000 km^2 of degraded area accounting for 33.43 percent of its total area. Overgrazing is the main cause, accounting for 62 percent of this damage.

in OROA and in Chad more broadly, considering the presence of the threatened Sahelo-Saharan fauna and flora, unique landscapes, and rich traditional cultural heritage (Box E.1). However, with Chad currently ranked last globally in the Travel and Tourism Development Index (TTDI), tapping into this opportunity requires a coherent vision and enhanced collaboration between public and private sectors as well as local communities.

The annual average costs of inaction on land degradation in Chad are estimated to be over US$920 million in present value (PV) terms from 2025 to 2050, equivalent to 7.46 percent of the country's gross domestic product (GDP). The inaction costs are incurred through foregone crop and livestock production, greenhouse gas (GHG) emissions, foregone ecosystem services and damage to infrastructure. In PV terms, the global costs, that is, GHG emissions, constitute 38 percent, while the local costs account for the remaining 62 percent of the total costs of inaction, including 29 percent by the forgone crop production. The annual inaction costs are expected to increase for all land cover types considered in this analysis (Table E.1) with the agricultural sector (croplands and pastures) being the biggest quantifiable contributor to GHG emissions and to the costs of inaction––nearly 58 percent of the total costs of inaction, or 4.3 percent of Chad's GDP. The forest sector (forests and shrublands) is estimated to contribute 41 percent of the costs.

Table E.1. **Costs of restoring degraded lands in Chad (2025 - 2050)**

Land cover types	Cost of inaction (US$/ha)	Cost of action (US$/ha)	Benefits of Action (US$/ha)		Benefit-Cost Ratio (BCR)	
			With GHG emissions reduction benefit	Without GHG emissions reduction benefit	With GHG emissions reduction benefit	Without GHG emissions reduction benefit
Croplands	6,125	1,394	5,941	5,601	4.26	4.02
Pastures	788	235	1,303	931	5.53	3.95
Forests	4,257	1,331	3,570	2,216	2.68	1.67
Shrublands	1,404	1,331	2,259	1,952	1.70	1.47
Wetlands	2,033	316	2,201	752	6.96	2.38
Average for all land cover types	**1,844**	**601**	**2,274**	**1,822**	**3.78**	**3.03**

Source: World Bank

Investing in spatially targeted restoration efforts in Chad is crucial to maximize impact of limited resources, with strategies tailored by ecosystem type and land use pressures. Reflecting differences in ecological zones, land degradation severity, and land use history across the country, this study identified the areas where restoration actions would have the greatest impact, in forest, shrubland, grassland, cropland, and wetland areas. Forest restoration benefits were found to be the most beneficial in the central and southern provinces which have areas prioritized for reforestation. Shrubland restoration would be more effective in eastern Chad, home to areas vulnerable to desertification that would be recommended for regreening efforts. Grassland restoration benefits are greatest in the western provinces that have areas prioritized for improvement of forage and soil stability. Cropland restoration is suggested for prioritization in southern and eastern provinces that have areas where it is recommended to enhance soil fertility and productivity. Wetland restoration is likely to be the most effective in western Chad, with priority given to areas that would benefit from enhanced water regulation and improved fisheries and agriculture. With projected ES benefits varying significantly by province and land cover type, it is essential to tailor restoration efforts to maximize the returns of NbS across Chad's diverse landscapes.

Land restoration investments through nature-based solutions (NbS) in Chad are economically viable (Table E.2). If just under US$22 million (PV terms, on average) is invested in NbS per year over 2025–2050, nearly one million hectares (ha) of Chad's degraded lands located in hotspots can be restored to yield substantial ES benefits and potentially foster revenues of US$83 million annually on average over the same period. Almost 80 percent of the total restoration investments (US$457 million out of US$570 million in PV terms) are required in the next 15 years, which is when the most intensive NbS actions are needed. The best-suited restoration actions include conservation of agriculture and crop diversification in croplands; rotational grazing and silvo-pastoral system in pasture; conservation and vegetation management, agroforestry, afforestation and reforestation in forests and shrublands; and retaining walls as needed for stabilizing the banks of watercourses to support NbS actions. Such actions are expected to foster benefits through reducing crop production costs, increasing production of crops and livestock (milk and meat), reducing infrastructure damage, enhancing ecosystem services, and curtailing GHG emissions.

Restoration actions in Chad are expected to have significant positive impacts on employment generation and livelihoods. Over 2025–2050, the investments in restoration actions are expected to directly generate nearly 4,000 new long-term jobs and support or create an additional nearly 6,000 jobs in upstream and downstream segments of the value chain across agriculture, livestock, forestry, and other land-based sectors. Together, these newly created jobs will generate income and support the livelihoods of nearly 59,000 people in Chad. As women constitute most of the workforce in agriculture, animal husbandry and forestry in Chad, a significant share of these jobs, as well as the livelihood benefits will go to women.

Table E.2. **Costs and benefits of restoration action in Chad (2025–2050)**

Investment required to take restoration actions to avoid further degradation of 0.98 million ha of land	Benefits of the restorative actions			Costs of inaction on land degradation (13.52 million ha in total)
	GHG emissions reduced	Revenues fostered	Livelihoods supported	
Annual	Annual	Annual	Total	Annual
US$22 million	>0.25 million tCO_2e	US$83 million	58,538 people	US$920 million, or 7.46% of Chad's GDP

Note: All US$ amounts are in PV terms

Source: World Bank

In the absence of investments in restoration, Chad is projected to experience a wide range of impacts on key ES by 2050 due to ongoing land degradation. There is uneven spatial distribution of degradation across the country, with some areas showing potential improvement while others face severe declines, particularly in agriculturally intensive and degraded landscapes. Carbon sequestration is expected to decline sharply in the southern and southwestern provinces, with projected losses reaching up to -43.85 t/ha. However,

in less disturbed or recovering landscapes in central and eastern Chad, carbon storage may increase by as much as 28.17 t/ha. Sediment retention is also projected to decline especially in southern erosion-prone areas, with losses of up to -0.096 kg/ha/year, while eastern provinces may see improvements of up to 0.03 kg/ha/year, reflecting localized vegetation recovery. Flood mitigation capacity is estimated to decrease most significantly in southern provinces, with potential losses reaching -43.36 m^3/ha/year, whereas gains of up to 9.54 m^3/ha/year may occur in central and southeastern areas with more stable land cover. Forage biomass or net primary productivity (NPP) shows the most extreme contrast, with productivity expected to decline by as much as -356 kg/ha/year in degraded southern zones, while increasing by up to 117 kg/ha/year in parts of the central and eastern Sahel. These estimates emphasize the need for regionally tailored restoration strategies to avoid escalating losses and build ecosystem resilience where gains are still possible.

Efforts to reverse land degradation in Chad must account for the compounding effects of climate change, and the complex nexus between land degradation and climate risk. Central Chad's Sahelian belt faces the greatest climate risk, with high temperatures, extreme precipitation variability, frequent droughts, and increased flooding risk, threatening already fragile landscapes. Restoration efforts in this province should prioritize climate resilience, with an emphasis on reforestation in agroforestry systems to help restore soil structure and enhance long-term productivity; sustainable cropland management including conservation agriculture and crop diversification; and soil stabilization techniques to improve water retention and reduce land degradation. Land degradation, on the other hand, is projected to be the most severe in the agricultural provinces of southern Chad and parts of central-eastern Chad with high population density, where land-use pressures related to increased refugee populations (soil erosion, nutrient depletion) may be rapidly reducing productivity. Taking no action in response to the land degradation and climate risk nexus will result in carbon sequestration losses, decline in flood mitigation capacity, and increase in the vulnerability of agricultural lands. Implementing targeted interventions in high priority cropland areas, such as sustainable cropland management and reforestation through agroforestry systems, could reverse degradation trends, improve food security, and secure the livelihoods of farming communities that depend on the land.

Box E.1. OROA—An investment opportunity

While land degradation trends are generally negative across Chad, there is potential to improve, as noted in the OROA Reserve and its surroundings. Evaluations from the study on land cover change data from 2002 to 2020 indicate that while the Reserve and its surroundings are showing signs of both positive and negative changes, a large portion of the landscape remained unchanged, and the Reserve's relative ecological integrity suggests that targeted conservation efforts could yield significant benefits. Chad is experiencing greatest degradation in the south where it is also highly populated and ecologically dense, and while the central and northern areas are also degraded, because of the Reserve, these provinces are expected to improve in terms of siltation, changes in erosion and provision of ES. The OROA Reserve plays a critical role in conservation, ecological connectivity and bringing in additional economic returns to the local communities. Therefore, it is crucial to support the Reserve and surrounding areas to maintain ES and promote resilience in the face of potential future degradation.

The OROA Reserve's relative ecological integrity suggests that targeted efforts could yield significant benefits, and this presents a great opportunity for conservation efforts. Expansion of sparse vegetation, pressures from agricultural land use, and presence of artificial water points, highlight both risks and opportunities for sustainable development. Targeted efforts are needed to balance economic needs with conservation goals and help maintain ES while promoting resilience.

Beyond restoration efforts, agro-pastoral systems in Chad can benefit from enhanced investments in non-wood forest products (NWFP) such as Gum Arabic and Desert Date, which offer important export opportunities. The desert date (leaves, pods) also serves as livestock fodder which forms a greater portion of environmental income than forests, as grazing areas are often composed of natural grasslands, savannahs, and shrublands, where forage is abundant, and livestock management is more feasible. However, to tap into the opportunities offered by NWFP, farmers must collectively organize themselves to bolster their bargaining power in the value chain.

To accelerate restoration efforts in Chad and ensure alignment with government priorities, additional work is necessary to guide development partners in a timely manner. Future studies should focus on creating a step-by-step action plan for implementing restoration and adaptation activities, in line with key milestones set by national policies and plans. Such studies should also aim to quantify the expected benefits in terms of both beneficiaries and productivity. Additionally, further analysis should inform upcoming national policy initiatives, such as the National Land Use Plan and the National Development Plan, with the goal of fostering connections between ecosystem preservation, food security, population growth projections, and sustainable value chain development. In addition to national-level work, a more in-depth analysis at the regional level can provide tailored action plans for Chad's most affected areas. At both national and local levels, successfully implementing priority restoration and adaptation efforts will require addressing current funding limitations, ensuring strong stakeholder engagement, and building sufficient technical capacity.

CHAPTER 1.

Introduction

Though agro-pastoralism contributes to almost half of Chad's GDP, it is plagued by land degradation and climate change. This report studies the diversity of Chad's landscape, the different risks and restoration potential of different provinces, and identifies hotspots to implement landscape management interventions.

1.1 Country Context and Climate Risk Profile

Chad is a landlocked, low-income, low-density and climatically diverse country. Spanning over 1.3 million km^2 with a population of 19.3 million inhabitants in 2023 (World Bank 2024a), Chad is situated in Central Africa and shares borders with Libya, Sudan, the Central African Republic, Cameroon, Nigeria, and Niger. Chad is characterized by three main ecological zones, ranging from the hot and arid Sahara Desert in the north to the more vegetated and semi-arid Sahelian zone in the center, which transitions to the more subtropical Sudanese zone in the south.

Globally, Chad is considered to be the most vulnerable to adverse effects of climate change and the least resilient (ND-GAIN n.d.). The country experiences recurrent droughts, shifting rainfall patterns, and extreme weather events that exacerbate soil erosion and desertification, impacting agricultural and pastoral systems. Chad's adaptive capacity is constrained by widespread poverty, limited infrastructure, and weak institutional frameworks for environmental governance. Climate projections suggest that by 2050, Chad could experience substantial GDP losses due to climate impacts on rainfed agriculture, livestock productivity, human health, and infrastructure damage (WBG 2022). Chad's socio-economic landscape is further strained by conflict, security threats from neighboring countries, a high influx of refugees, and chronic food insecurity, which hinder development efforts. Chad ranks among the last on the World Bank Human Capital Index. Its Human Development Index of just 0.394 is the fifth lowest in the world and third worst in Sub-Saharan Africa (UNDP n.d.).

More than 55 percent of Chad's land territory is bare, with grassland at 34 percent, cultivated land at 8.5 percent, forests and savannahs at about 2 percent, and permanent wetlands at 0.1 percent. Chad has about 39 million ha cultivable land and 5.6 million ha irrigable land (UNCCD 2020). Agricultural lands cover a significant portion of Chad, with traditional agro-pastoralism forming the backbone of rural livelihoods. It employs more than 85 percent of the workforce and contributes 44 percent of the GDP. Crop production is concentrated in the more humid southern provinces, where millet, sorghum, maize, and rice are cultivated, while cattle, camel, sheep, and goats are reared in the drier central and northern provinces. However, increasing pressure on land and water resources, overgrazing, and unsustainable agricultural practices are contributing to soil degradation, loss of vegetation cover, and reduced productivity (FAO 2020). These changes threaten agricultural productivity, food security, and water availability, increasing vulnerability among rural populations (WBG 2022; WBCCKP 2024).

Land degradation and desertification in Chad result from both anthropogenic and natural factors. Human-induced factors include unsustainable land management practices, overgrazing, deforestation, expansion of cropland into marginal areas, and inefficient water use. The decline of Lake Chad, which has shrunk by over 90 percent in the last 60 years, illustrates the broader environmental challenges that the country faces. As the lake recedes, millions of people and livestock go without water, leading to conflicts (World Bank Group 2022). The economic cost of land degradation in Chad is significant, particularly in the agricultural sector, where declining soil fertility and water scarcity reduce crop yields and pasture productivity. Given the scale of these challenges, it is crucial to identify hotspots where land degradation and climate risks intersect with opportunities for restoration. By adopting a strategic approach, Chad can prioritize interventions that provide the greatest potential for reversing land degradation, enhancing resilience, and improving livelihoods.

1.2 Objectives of the Study

This report is a synthesis of three studies[2] undertaken separately. The objectives below derive from those studies.

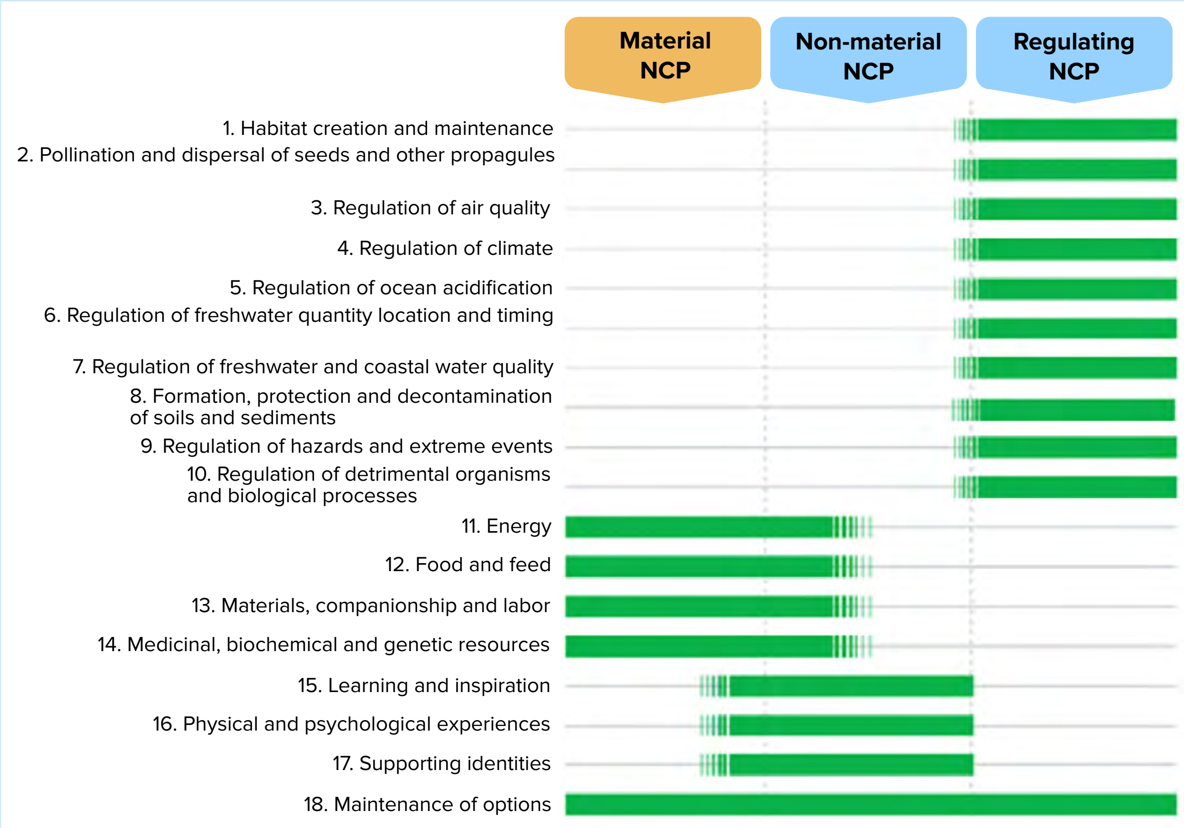
- **Develop** a land degradation hotspot map at a national scale that identifies provinces that are most vulnerable to multiple risks from climate change, land degradation, and associated decline in ecosystem services.
- **Determine** how much, where, and what type of land should be restored to off-set losses from land degradation, using a cost-benefit analysis.
- **Identify** hotspots with high potential for landscape restoration using spatial modeling of ecosystem services and a set of integrated landscape management interventions.
- **Undertake** a deep dive into assessing nature's contributions to people in the OROA Reserve and its surroundings.

1.3 Ecosystem Services and their Holistic Value to People and Biodiversity

ES are the multiple benefits provided by ecosystems to humankind (MEA 2005). MEA (2005) classified ES into the four large categories of provisioning, regulating, cultural and supporting services (MEA 2005). More recently, the Intergovernmental Science-Policy Platform on Biodiversity and ES (IPBES) has proposed the conceptual framework of *nature's contribution to people* (NCP) to embody different notions such as ecosystem goods and services, nature's gifts and many others, and facilitate respectful collaboration and mutual enrichment between different knowledge systems and worldviews (Diaz et al. 2018). The NCP concept offers a pluralistic way of understanding how the status and trends of nature (including biodiversity and ecological processes) link with people's lives, livelihoods and quality of life, while at the same time acknowledging manifold perspectives and worldviews about human-nature relations. From a generalizing perspective, IPBES works with 18 reporting categories of NCP, which are organized into three broad groups: regulating, material and non-material NCP (Figure 1.1). The reporting categories are overlapping, often indistinct and fluid, not the least due to the pervasive influence of culture on how people view and value nature and nature's contributions. That is because IPBES' NCP allows for a more holistic and integrated understanding of ES, which fosters inclusive stakeholder engagement and considers cultural, social, and economic dimensions, ultimately leading to better policymaking and conservation strategies (Pascual et al. 2017). The NCP framework was applied in preparing the OROA case study in this report.

2 This report contains synthesized information from the following three studies: (i) "Landscape Restoration Opportunities in Chad," Natural Capital Insights, Eric Lonsdors, Chris Nootenboom, Adrian Vogl, and Sepul Kanti Barua, April 15, 2025; (ii) "Assessing Nature's Contributions to People in Ouadi Rime Ouadi Achim Wildlife Reserve and Surroundings, Chad, Phase I," ETIFOR and HAMERKOP, Colm O'Driscoll, Juan Diego Restrepo, Federica Bosco, Jihane Khairallah, Fabien Castel, Hassane Abdoulaye, and Olivier Levallois, November 20, 2024; and (iii) "Assessing Nature's Contributions to People in Ouadi Rime Ouadi Achim Wildlife Reserve and Surroundings, Chad, Phase II," ETIFOR and HAMERKOP, Colm O'Driscoll, Jihane Khairallah, Juan Diego Restrepo, Elena Vissa, John Newby, Violeta Barrios, Olivier Levallois, and Solene Kechavarzi, March 14, 2025.

Figure 1.1. **Categories of nature's contributions to people**



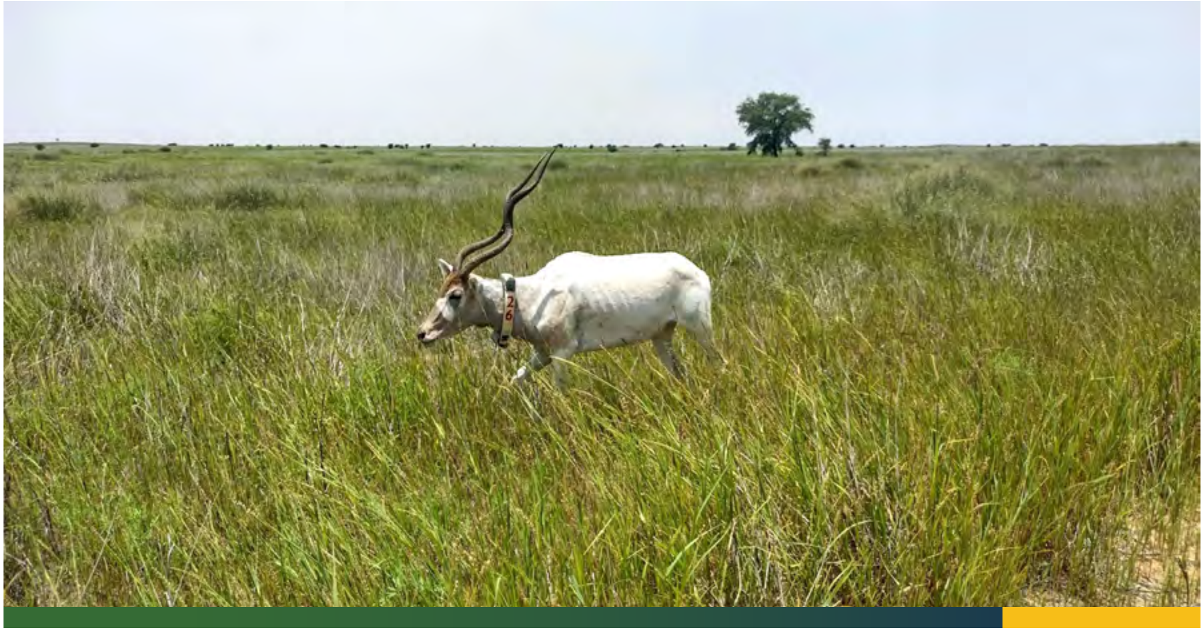
Source: IPBES (2018)

1.4 Methodology of Study

The study methodology that fed into this report relied on the below approaches to assess the extent and impact of land degradation in Chad and to identify areas with the greatest potential for restoration.

a. **Analyze trends in indicators of climate change and land degradation:**
   - **Climate risk assessment:** Climate change data from the World Bank Climate Change Knowledge Portal (WBCCKP) was processed using the model ensembles approach for pessimistic scenarios SSP 3–7.0 for a mid-century time horizon (2050). This information was used to develop an index of future climate change risk based on the magnitude of change from baseline to future conditions in a selected set of variables.
   - **As proxies for landscape productivity and health, changes in the Normalized Difference Vegetation Index (NDVI)** were evaluated over the 20-year period 2001–2020. The average of these measurements as well as the magnitude of their trend were used as indicators of historical and potential future land degradation.

b. **Model the impact of future land degradation on ecosystem services:**
   - Changes in ecosystem services from land degradation in the business-as-usual scenario were calculated using the **InVEST ecosystem service modeling** suite and custom modeling frameworks. Services include erosion control, water regulation (runoff and baseflows), grassland productivity, and carbon storage.



c. **Identify hotspots with the greatest restoration opportunity:**
   - Hotspots of restoration opportunity were identified based on target locations or **their potential for restoration,** thus helping prioritize interventions for maximum ecological and economic impact.

d. **Conduct cost-benefit analysis to evaluate the economic feasibility of restoration options:**
   - To estimate the costs of land degradation, **a market valuation approach** was used for valuation of lost crop and livestock production, with **benefit-transfer method** used to estimate value of degraded ecosystem services.

e. **Undertake a deep dive on the OROA Reserve:**
   - Land cover accounts were developed to show the extent and types of land cover changes from 2001 to 2020, by combining spatial data analysis and economic valuation techniques. An analysis was conducted to assess the economic costs associated with ecosystem degradation of the main land cover types in the Reserve. The potential role of the Reserve in reducing land degradation is also noted. The impact of degradation on the ES provided by the Reserve and on the local rural population is highlighted.
   - Literature review, key informant interviews and stakeholder consultations were undertaken to identify, prioritize and assess a selection of ES in the Reserve.
   - Market analysis and value chain of NWFPs in use in the Reserve identified.
   - The Reserve's contribution to climate-smart sustainable livelihoods which bolster economic resilience of rural communities is highlighted.

SUMMARY

The identified patterns of vulnerability and ecological diversity underscore the importance of developing spatially informed approaches to restoration. Understanding the value of ecosystem services and the differentiated risks across Chad's provinces is a first step toward identifying areas where targeted action can build resilience and secure sustainable livelihoods. With this foundation in place, we now turn to the intersecting pressures of climate risk and land degradation and their potential to further compromise the country's natural capital.

CHAPTER 2.

Climate Risk Outlook, Land Degradation, and Ecosystem Services

Climate risk and land degradation will impact all of Chad but will particularly hit the south. If no restoration efforts are taken up, carbon storage, flood mitigation capacity, sediment retention, forage biomass may decline. However, as the OROA Reserve case study shows, there is still time for restoration efforts before anthropogenic and natural pressures trigger more significant degradation.

2.1 Introduction and Key Terms

Chad is severely impacted by land degradation (Box 2.1) driven mainly by agriculture, mining, infrastructure, fuelwood, and settlements. These challenges arise from rapid shifts in climate and from unsustainable forest and land resource management. Deforested land is usually converted to small scale cropland and in Chad this has happened up to 68 percent between 2001 and 2020 (Masolele et al. 2024).

Box 2.1. Key terms and indicators used in the assessment of risk and opportunity hotspots

Climate risk: an index of climate risk that aggregates changes in five indicators that directly impact the provision of ES from landscapes: changes in long, medium, and short-term precipitation, long-term temperature trends, and the frequency of extreme temperature events.

Land degradation risk: the projected decline in vegetation quality based on a historical trend analysis of remotely-sensed vegetation data.

Baseline condition: the state of land use land cover and vegetation condition in 2021.

Business-as-Usual: (BaU, or “no action”) a scenario that assumes the continuation of current land-use trends that result in the land degradation assessed in 2050.

Restoration scenario: a counterfactual scenario that reflects the potential of landscape restoration. It identifies areas where restoration is most likely to be effective in confronting ongoing degradation and its impact on ecosystem services.

Future hotspots of restoration opportunity: region-level summaries of the differences in ecosystem services between the optimized restoration scenario and the BaU scenario.

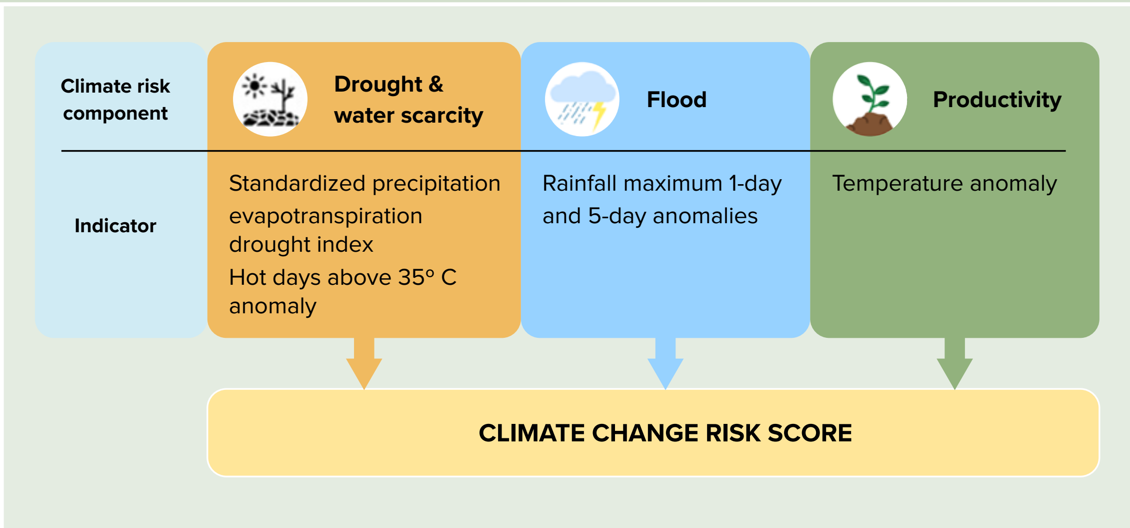
2.2 Climate Risk Outlook to 2050 in Chad

While all provinces in Chad are at risk from climate change across all seasons, the risks are not distributed evenly (Figure 2.2; Table 2.1). The analysis shows that averaged across the year, the most risk occurs in a band south of the Sahel province, with the greatest risk accruing to Wadi Fira on the center-west border. Temporally, climate risks primarily occur during the rainy season (June through November). These risks pose a threat to local ecosystems and the services they provide. Any restoration actions taken in provinces of high climate risk should be designed with an eye to the expected future climatic conditions.

Box 2.2. Methodology for assessing climate risk across Chad's provinces

An equal-weighted climate risk score integrating five component indicators into a single value (Figure 2.1) was applied (World Bank 2025). The aggregated climate risk score ranks each province in the country based on its potential exposure to the combined effects of each risk factor (Figure 2.2). Land degradation, measured by changing trends in NDVI, was projected out to 2050 and used to modify the inputs to ES models (Figures 2.3, 2.4, and 2.5). The resulting changes in ecosystem services were reported by province (Table 2.1).

Figure 2.1. **Components of the composite climate change risk score**



Source: World Bank

Note: This is based on the historical record for Standardized Precipitation Evapotranspiration Index (SPEI) from 1981–2022 and average deviation of future (2050) climate variables from observed pre-2015 conditions (all other variables), using Coupled Model Inter-comparison Project (CMIP6) pessimistic 3–7 scenario data from WBCCKP

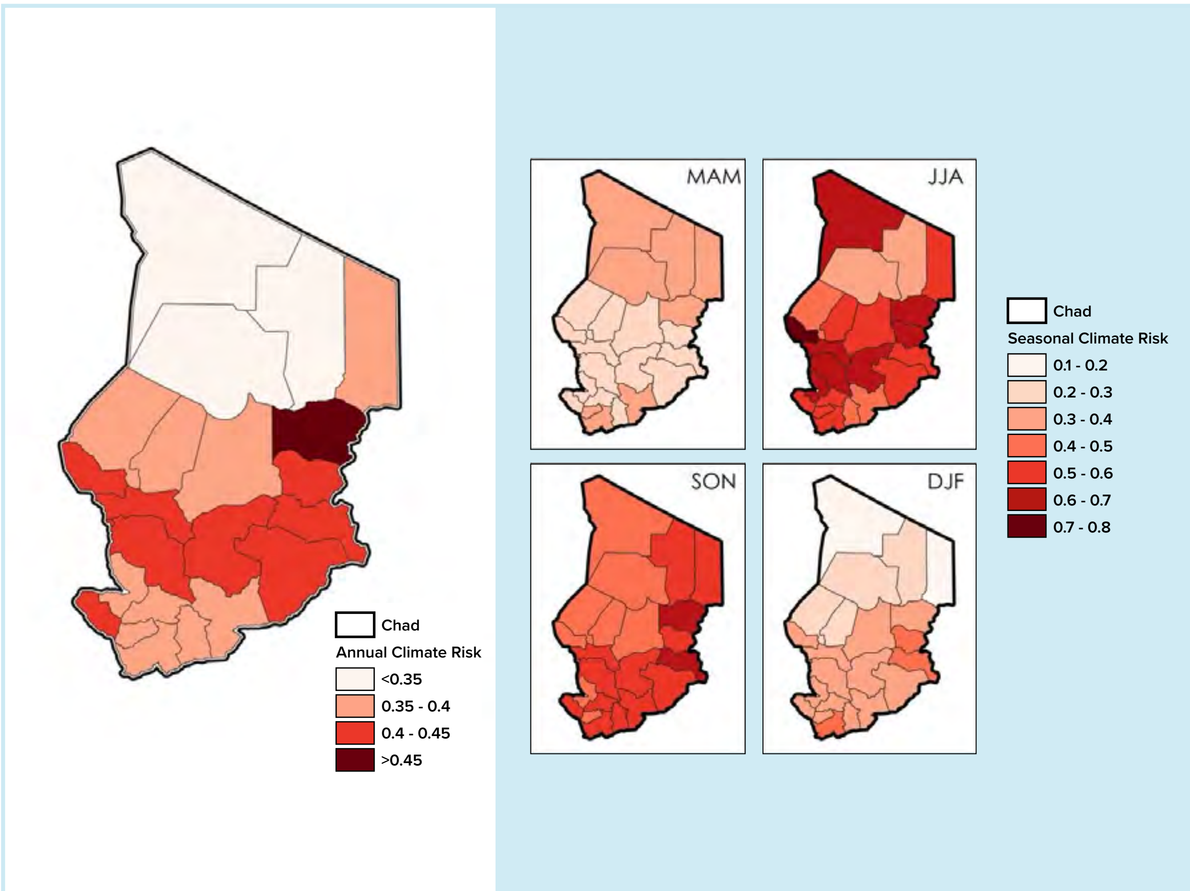
Each region's seasonal climate risk score was calculated based on projected changes in five climate sub-indicators, selected as proxies for specific climate risks:

- Monthly anomalies in precipitation (water scarcity)
- Maximum consecutive 5-day precipitation (potential for flooding)
- Maximum 1-day precipitation (potential for flooding)
- Average temperature (heat-related risks)
- Number of days above 35°C (heat-related risks)

The focus was only on the pessimistic climate scenario 3–7 by 2050 of the CMIP6 ensemble (World Bank 2025). To give the context of which provinces had greater risks associated with changes in precipitation or temperature, historical trends were analyzed with the SPEI, a measure of drought index, from 1981 to 2022 (Gebrechorkos et al. 2023). However, there were no persistent patterns of seasonal drought across the country (Appendix A), and it was assumed that all provinces were equally at risk from climate change across all seasons. The ranking approach reclassified each climate sub-indicator into a 0–1 index based on that sub-indicator's maximum and minimum value across all provinces in the country. Then, all sub-indicator scores were combined using an equal-weighted averaging approach. Seasonal risk scores were annualized for a single climate risk value per region. The climate change risk ranking implies that the provinces with the greatest deviation in future climate from baseline (2021) are assigned the highest risk scores (Appendix C).

While all provinces in Chad are at risk from climate change across all seasons, the risks are not distributed evenly (Figure 2.2; Table 2.1). The analysis shows that averaged across the year, the most risk occurs in a band south of the Sahel region, with the greatest risk accruing to Wadi Fira on the center-east border. Temporally, climate risks primarily occur during the rainy season (June through November). These risks pose a threat to local ecosystems and the services they provide. Any restoration actions taken in provinces of high climate risk should be designed with an eye to the expected future climatic conditions.

Figure 2.2. **Annual and seasonal maps of climate risk**



Source: World Bank

Note: Reported as a 0–1 index where higher values indicate greater risk. These are composite scores that synthesize five sub-indicators from the CMIP6 ensemble (Appendix C). Seasons were grouped as March, April, May (MAM); June, July, August (JJA); September, October, November (SON); and December, January, February (DJF).

Table 2.1. **Climate risk per province for each season and annually**

(Units are a 0–1 index of risk, with 1 representing high risk)

Administrative zone	Annual	MAM	JJA	SON	DJF
Bahr-El-Gazel	0.38	0.22	0.62	0.47	0.23
Batha	0.40	0.24	0.60	0.47	0.28
Borkou	0.32	0.24	0.46	0.41	0.18
Chari-Baguirmi	0.41	0.30	0.57	0.49	0.27
Ennedi Est	0.39	0.32	0.58	0.53	0.14
Ennedi Ouest	0.32	0.27	0.39	0.46	0.16
Guéra	0.41	0.25	0.57	0.54	0.28
Hadjer-Lamis	0.42	0.29	0.61	0.50	0.28
Kanem	0.36	0.24	0.58	0.43	0.19
Lac	0.41	0.21	0.74	0.45	0.25
Logone Occidental	0.39	0.30	0.46	0.50	0.32
Logone Oriental	0.39	0.29	0.45	0.51	0.32
Mandoul	0.38	0.28	0.43	0.55	0.28
Mayo-Kebbi Est	0.38	0.27	0.55	0.44	0.28
Mayo-Kebbi Ouest	0.41	0.30	0.47	0.57	0.30
Moyen-Chari	0.40	0.28	0.46	0.57	0.28
N'Djamena	0.42	0.31	0.63	0.46	0.28
Ouaddaï	0.45	0.26	0.62	0.58	0.34
Salamat	0.42	0.27	0.54	0.57	0.31
Sila	0.44	0.29	0.54	0.58	0.36
Tandjilé	0.40	0.25	0.53	0.55	0.27
Tibesti	0.34	0.28	0.56	0.37	0.15
Wadi Fira	0.47	0.31	0.66	0.67	0.24

Source: World Bank

2.3 Land Degradation Assessment for Chad from 2021 to 2050

The assessment of landscape productivity and health across Chad (measured by NDVI trends) reveal a conflict between climatic shifts and human-driven land degradation (Box 2.3). Across much of the southern half of the country, NDVI is improving, indicating increasing vegetation that may be due to a variety of factors such as climatic shifts, reduction in grazing pressures, range shifts in native vegetation, invasive species spread, changes in irrigation regimes, etc. The analysis assumed such trends in land management will continue, although some may be transient. Lands surrounding population centers in the southwest show persistently worsening degradation tends over the past 20 years and are at risk of increased degradation by 2050, indicating potential overuse from agricultural or developmental pressures (Figures 2.3, 2.4, and 2.5).

Box 2.3. Methodology for assessing land degradation

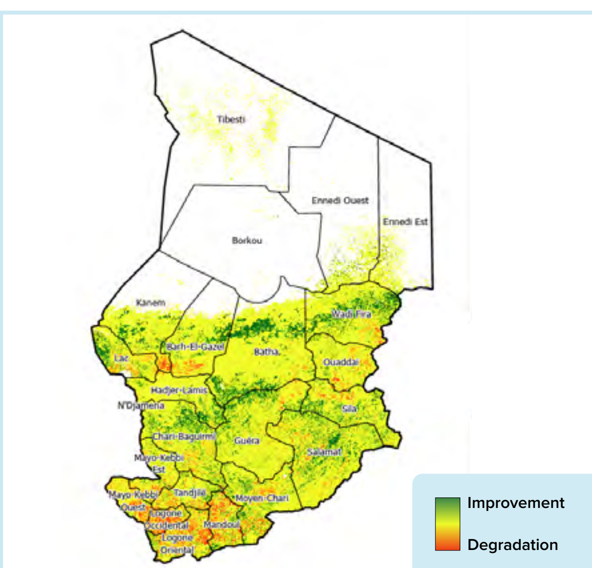
A land degradation assessment was conducted to project how the quality of existing land cover may change between 2021 and 2050, exclusive of any change in land cover type (forest to agriculture). The year 2021 was chosen as a base year due to availability of high-quality land cover data (Zanaga et al. 2022) aligned with UN-FAO's Land Cover Classification System, and has been generated in the framework of the ESA WorldCover project. The ESA WorldCover 10m 2021 v200 product updates the existing ESA WorldCover 10m 2020 v100 product to 2021 but is produced using an improved algorithm version (v200). A historical 20-year trend analysis was performed on vegetative productivity to identify areas currently at risk of land degradation and areas that may continue to degrade over the next 30 years. Spatial patterns and temporal trends in land degradation were evaluated at the ~250m pixel level using the 2001-2020 time-series of the NDVI from MODIS (Didan 2021).

Measuring NDVI trends at the pixel level captured specific local changes in vegetative quality that could contrast with broader regional or country-wide NDVI scores for a single landcover type. This allowed to identify forested areas with deteriorating NDVI when compared with the average NDVI for forests in the region. Pixel-level trend analysis also allowed for nuanced categorization of land quality: cropland, for instance, was categorized into poor, fair, and good.

For each NDVI pixel, a trend between 2001 and 2020 was calculated, then the trendline was applied to predict NDVI condition in 2021. This then mitigated any annual variability in NDVI in the base year (2021) that would distort longer-term trends: by using a predicted version of 2021 rather than the observed, comparability was ensured with the predicted future NDVI in 2050. NDVI in 2021 was then categorized based on the standard deviation from the mean within each land use class: forest NDVI values that were more than one standard deviation greater than the mean of all forest NDVI values were classified as "good condition" forests, while those more than one standard deviation below the mean were classified as "poor condition".

The historical NDVI trends for each pixel were projected to 2050 under the BaU scenario to identify areas in vegetative decline. Those areas in a declining trend show the risk of a shift in baseline vegetative conditions, such as moving from good to fair, fair to poor, or even good to poor conditions. The 2021 means and standard deviations were used to classify projected NDVI in 2050 into the three categories (poor, fair, good). All maps (2021, 2050) presume current landcover extents, with only changes in vegetative quality resulting from the degradation analysis. For example, while deforestation is not addressed in the analysis, forest degradation is.

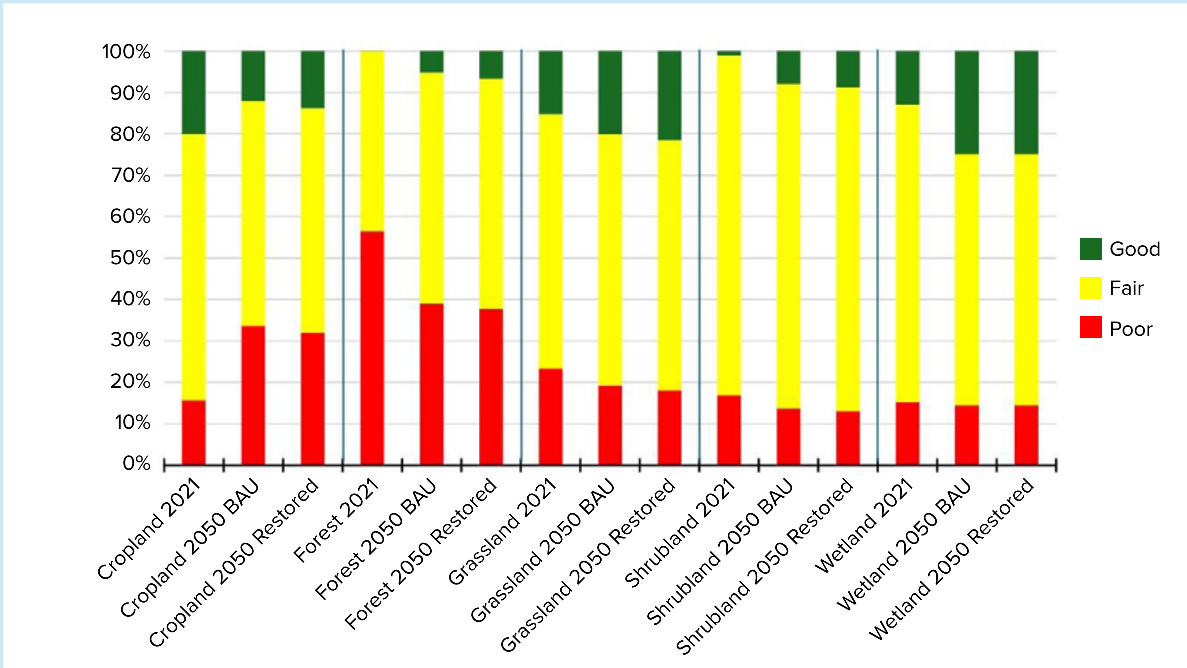
Figure 2.3. **Land degradation patterns in Chad**



Source: World Bank

Note: Areas in red are at the highest risk of land degradation based on current NDVI trends and are found primarily in the southwestern part of Chad. In contrast, much of the central and southern parts of the country may experience land improvement (in green), based on improving NDVI trends across the Sahel province.

Figure 2.4. **Country-wide overview of estimated land cover changes, 2021–2050**

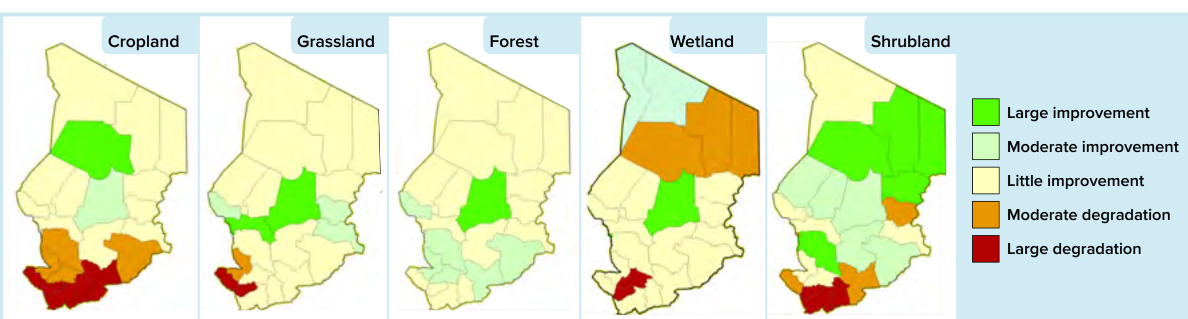


Source: World Bank

Note: The figure shows the estimated share of land cover type in good, fair and poor condition in three scenarios: baseline (2021), 2050 BAU scenario with expected degradation, and 2050 after restoration of poor and fair quality to good quality condition. See Appendix F for the absolute figures.

Areas in southern Chad are expected to see the largest degradation from 2021 to 2050, with crop lands showing the highest declines south of the Sahel. Looking at a regional breakdown, the land degradation assessment indicates that most natural landscapes show improvements in vegetation quality compared to the average baseline (pre-2020) NDVI, with forests showing the largest improvements throughout Chad. Croplands are mostly expected to degrade, with most severe degradations in the southern parts of the country (Figure 2.5).

Figure 2.5. **Land degradation by cover type and province**



Source: World Bank

Table 2.2. **Breakdown across provinces of expected changes in ES from land degradation between 2021 to 2050, assuming no restoration efforts**

Administrative zone	Carbon storage (t/ha)	Sediment retention (kg/ha/yr)	Flood mitigation (m³/ha/yr)	Forage biomass (kg/ha/yr)
Bahr-El-Gazel	2.92	0.003	0.31	24.3
Batha	16.37	0.005	4.08	57.8
Borkou	0.04	0	0	0.3
Chari-Baguirmi	28.17	0.004	7.04	117.2
Ennedi Est	0.19	0.007	0.02	1.3
Ennedi Ouest	0.21	0.004	0.01	1.7
Guéra	23.3	0.009	7.64	55.3
Hadjer-Lamis	21.42	0.004	5.37	78.4
Kanem	1.5	0.004	0.31	12.5
Lac	10.36	0.002	0.4	0.6
Logone Occidental	-43.85	-0.096	-43.36	-356.1
Logone Oriental	-24.65	-0.033	-24.05	-193.8
Mandoul	-21.84	-0.021	-24.59	-173
Mayo-Kebbi Est	0.91	-0.006	-3.16	-23.7
Mayo-Kebbi Ouest	-34.86	-0.057	-28.99	-126.9
Moyen-Chari	4.82	-0.005	1.52	-3.7
N'Djamena	8.45	0.004	-1.09	7.5
Ouaddaï	3.57	0.010	-1.95	6.1
Salamat	27.55	0.005	9.54	108.9
Sila	27.78	0.014	7.47	50.7
Tandjilé	2.59	-0.01	-1.65	-26.4
Tibesti	0	0	0	0
Wadi Fira	9.33	0.03	2.72	64.1

Source: World Bank

Land degradation alters the landscape's provisioning of ES, reducing the vegetation's capacity to retain sediment and runoff and to sequester carbon. To evaluate how land degradation (or improvement) will change ES between 2021 and 2050, assuming no restoration actions are implemented, projected trends in land degradation were input into the InVEST ecosystem service models. The analysis revealed stark regional contrasts (Table 2.2), with some areas experiencing substantial losses in ecosystem services, while others exhibit moderate declines or slight improvements due to land use dynamics. For example, degradation is expected to occur in Logone Occidental, and as a result, we project reductions in carbon storage, flood mitigation, and forage biomass. Other areas may experience unexpected gains in sediment retention, flood mitigation, and NPP. These findings underscore the potential benefits for targeted restoration interventions to mitigate the most severe impacts of land degradation.

The expected changes in ES from degradation between 2021 and 2050, assuming no restoration efforts, can also be summarized for each ES:

- **Carbon sequestration** is expected to decline sharply in southern and southwestern provinces. However, in less disturbed or recovering landscapes in central and eastern Chad, carbon storage may increase by as much as 28.17 t/ha. The highest projected carbon losses in Logone Occidental (-43.85 t/ha), Mayo-Kebbi Ouest

(-34.86 t/ha), and Logone Oriental (-24.65 t/ha). Conversely, Chari-Baguirmi (28.17 t/ha), Sila (27.78 t/ha) and Salamat (27.55 t/ha) show the highest projected increases in carbon sequestration.

- **Sediment retention** is also projected to decline in erosion-prone areas, particularly in the south, while eastern provinces may see some improvement, reflecting localized vegetation recovery. The largest losses are projected in Logone Occidental (-0.096 kg/ha), Mayo-Kebbi Ouest (-0.057 kg/ha), and Logone Oriental (-0.033 kg/ha). These declines indicate worsening soil erosion and sediment transport in agricultural and semi-arid landscapes. However, some areas show improvements in sediment retention, notably in Ouaddaï (0.010 kg/ha), Sila (0.014 kg/ha), and Wadi Fira (0.030 kg/ha).
- **Flood mitigation** capacity is estimated to decrease most significantly in southern districts, whereas gains may occur in central and southeastern areas with more stable land cover. Particularly large losses are expected in Logone Occidental (-43.36 m^3/ha), Mayo-Kebbi Ouest (-28.99 m^3/ha), Mandoul (-24.59 m^3/ha) and Logone Oriental (-24.05 m^3/ha). These declines suggest increased runoff and reduced water retention, likely exacerbated by soil degradation and land use changes. However, some areas, including Salamat (9.54 m^3/ha), Guéra (7.64 m^3/ha), and Chari-Baguirmi (7.04 m^3/ha), are projected to gain flood mitigation capacity.
- **Forage biomass** (NPP) shows the most extreme contrast, with productivity expected to decline in degraded southern zones, while increasing in parts of the central and eastern Sahel. Declines in NPP are among the most severe consequences of continued land degradation, with extreme losses projected in Logone Occidental (-356.1 kg/ha), Logone Oriental (-193.83 kg/ha), Mandoul (-172.95 kg/ha), and Mayo-Kebbi Ouest (-126.88 kg/ha). These provinces, located in Chad's agricultural and pastoral zones, will likely experience substantial declines in vegetation productivity, impacting food security and livestock-dependent livelihoods. However, some areas, particularly Chari-Baguirmi (117.24 kg/ha), Salamat (108.89 kg/ha), and Wadi Fira (64.09 kg/ha), show expected gains in NPP).

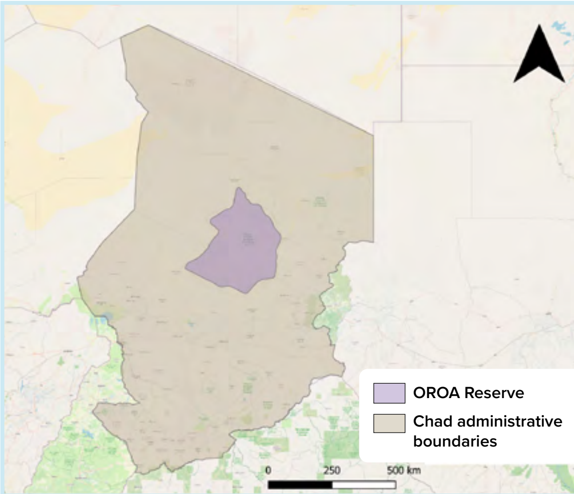
2.4 OROA Case Study: Land Degradation and Changes in Ecosystem Services between 2002 and 2020

The OROA Reserve provides a useful case study to highlight changes in ES from land degradation in Chad (Box 2.4). Designated a national reserve in 1969, the Reserve is one of the largest in Africa, covering approximately 77,950 km^2 (Figures 2.6 and 2.7). Spread across the provinces of Batha and Borkou, it is a protected area consisting of terrestrial areas and inland waters. It comprises of three main habitats: Sahelian wooded grassland, sub-desert grassland (main habitat type), and a desert in the north.

The Reserve is owned by the State and coordinated by the Ministry of Environment, Fisheries, and Sustainable Development (MEFSD) Chad, and managed by the Sahara Conservation Fund (SCF). It is an important protected area for wildlife conservation of the Sahelo-Saharan habitats, particularly for the endangered and keystone species of the Sahel province. It also has several artificial water points constructed to increase the animal-carrying capacity of the land and support agriculture (Sissoko et al. 2011). Wadis (river valleys) flowing east to west, are key to local biodiversity, with flood plains, water pools, and inundation zones being important natural seasonal sources of water (Brugiere and Scholte 2013).

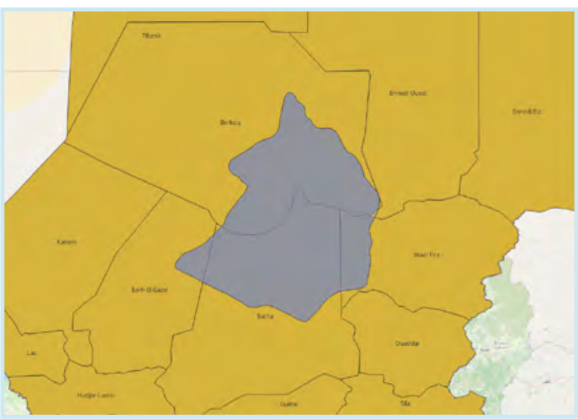
The Reserve serves as an important pastoral zone for about 70,000 people, 70 percent of whom are nomadic and 30 percent are semi-nomadic (APEF 2020). Living on the edge of the Reserve, these local communities practice pastoralism, subsistence farming/agriculture, and livestock rearing (cattle, camels, goats, sheep). Sahelian populations rely heavily on natural resources, with 70–92 percent engaged in agriculture or livestock production as their main source of livelihood (Goffner et al. 2019).

Figure 2.6. **Location of the OROA Reserve in Chad**



Source: Protected Planet UNEP-WCMC.

Figure 2.7. **Administrative provinces of Chad that intersect the OROA Reserve**



Source: IUCN 2024.

The Reserve could potentially provide a wide number of ES. These include:

a. **Habitat creation and maintenance:** The Reserve is known for its rich biodiversity, particularly for its populations of large mammals such as the critically endangered dama gazelle (Nanger dama) and the vulnerable addax (Addax nasomaculatus).

b. **Regulation of climate:** Like many natural ecosystems, vegetation within the Reserve has the potential to influence the local climate such as water and temperature sensitivity. While the direct impact of the Reserve on climate regulation may be limited at a global and wider regional scale, its conservation efforts contribute to maintaining local climate stability by preserving habitats and vegetation cover.

c. **Regulation of freshwater quantity, location, and timing:** The Reserve contains seasonal rivers and wetlands, which provide water for wildlife and support vegetation growth.

d. **Physical and psychological experiences:** The Reserve could attract tourists and researchers interested in experiencing and studying its heritage, unique ecosystems, and wildlife.

Formation, protection, and decontamination of soils: The vegetation within the Reserve helps prevent soil erosion and maintain soil stability, which is important for sustaining ecosystem productivity and preventing land degradation.

Land cover changes within the OROA Reserve have occurred in about 13 percent of its area, while 87 percent have maintained the same cover as in 2002 (72,108 km^2) (Appendix B, Table B.3). Sparse vegetation is by far the cover that has increased the most between 2002 and 2020 in the Reserve, with an increase of nearly 6,300 km^2 (62 percent more compared to its area in 2002). This increase has occurred mainly in the central part of the Reserve, from West to East, in the transition zone between the vegetated zone and the bare lands. Another land cover that significantly increased was the herbaceous croplands (283 km^2), which also increased the most in percentage concerning its area in 2002 (+4,700 percent). On the other hand, the coverage that has lost the most area in the analysis period is the sparse herbaceous cover (-3,689 km^2), which has decreased by nearly 36 percent compared to its area in 2002. The second coverage that lost the most area with respect to 2002 was the bare areas (-2,359 km^2), although their decrease is low in relative terms (-4.95 percent).

Box 2.4. Methodology to Assess Land Degradation in the OROA Reserve

The assessment sought to understand the implications of land degradation for ES, drawing on land cover change data within the Reserve and its surroundings. An economic valuation approach based on the costs of land degradation was applied: persistent or long-term loss of ES (Nkonya et al. 2016), complemented by an analysis of the Normalized Difference Vegetation Index (NDVI) as a proxy variable of land productivity, providing a more comprehensive assessment of the ecosystem's status.

Methodologies combining spatial data analysis and economic valuation techniques were used for the analysis of land cover change and estimation of costs of environmental degradation in the Reserve and surroundings. Spatial data on land cover study came from the Climate Change Initiative (CCI) of the European Space Agency (ESA). Land cover classifications, based on quantitative information on the extent and types of land cover change over the reference period, were analyzed for the years 2002 and 2020. This allowed tracking changes over a period of nearly 20 years, offering insights into landscape trends and patterns (Lambin et al., 2003). The analysis was conducted for two units: (i) the OROA Reserve, and (ii) a buffer zone of 100 km (Figure 2.8). (See Appendix B, Table B.1 for the definitions of land cover types applied in the analysis).

A land use change matrix was created to determine which areas had transitioned from one land cover type to another between 2022 and 2020 (Turner et al. 2007). The economic valuation of land degradation was calculated based on the land degradation costs derived from land use change (Nkonya et al. 2016). This approach sought to determine the loss of the Total Economic Value (TEV), defined as the sum of all ES of a biome, due to land use changes that replace biomes of high ecosystem value with those of lower value.

To complement the study of ES degradation, an analysis of the NDVI was carried out, as a proxy variable of land productivity (Yengoh et al. 2016). The NDVI change between 2002 and 2020 was calculated creating five-year average images, to soften potentially distorted pictures due to high annual variability. Instead of using the NDVI for 2002 alone, the mean for 2000–2005 was used, and for 2020, the mean for 2018–2023 was used. By comparing the NDVI evolution with the precipitation trends in the province, an apparent paradox was observed: areas in the south, which experienced the most significant decrease in precipitation, show the greatest improvement in NDVI, which can indicate an overexploitation of groundwater resources. Areas that exhibited a statistically significant decline in NDVI after accounting for the impacts of precipitation trends were considered degraded (Wessels et al. 2007).

In the OROA Reserve, sparse herbaceous cover has decreased the most with a loss of 3,689.4 km^2, representing the largest absolute decrease among land cover types (Appendix A: Land use change matrix). Bare areas have also decreased significantly, with a reduction of 2,358.9 km^2 (5 percent less with respect to 2002). Both covers were replaced mainly by sparse vegetation covers. Grasslands have decreased from 12,044.8 km^2 to 11,453.3 km^2 (a reduction of 5 percent with respect to 2002). Regarding the cover increases, sparse vegetation has shown the most substantial increase, growing from 10,104.6 km^2 to 16,461.5 km^2 (+62.9 percent). This expansion has mainly come from areas previously classified as bare areas and sparse herbaceous cover. Herbaceous cropland has increased significantly, from 6.0 km^2 to 289.2 km^2 (+4,720 percent). Mostly natural vegetation in a mosaic with cropland has increased from 275.4 km^2 to 426.3 km^2 (+67.9 percent). In the OROA Reserve and buffer zone as well, sparse herbaceous cover has seen the most significant decrease, from 19,568.7 km^2 to 12,410.5 km^2 (-36.6 percent). This significant reduction has primarily transitioned to sparse vegetation and grassland cover, although grasslands have also decreased. Most of their areas have transitioned to sparse vegetation, and a significant portion is also converted to various types of croplands.

On the other hand, sparse vegetation has experienced the most substantial increase which has mainly come from areas previously classified as bare areas, some grassland, and sparse herbaceous cover. Rainfed cropland has shown a moderate increase, mainly expanding into areas previously classified as grassland. Likewise, herbaceous cropland has also seen a significant relative increase, mainly at the expense of grassland and sparse herbaceous cover. Urban areas, while still limited in total area, have shown a relative increase from 12.5 km^2 to 18.5 km^2 (+48 percent). Other land cover types such as shrubland, irrigated or post-flooding cropland, and bodies of water have experienced relatively minor changes.

Land cover changes have occurred in about 9 percent of the total area of the Reserve and its 100 km buffer zone, while 91 percent (216,689.2 km^2) of this area has maintained the same cover as in 2002 (Appendix B, Table B.4). Consistent with the results for OROA and the buffer zone, sparse vegetation has increased the most between 2002 and 2020, with an increase of nearly 12,544 km^2. Another land cover that significantly increased was herbaceous cropland, which grew by 846.1 km^2. This represents the highest percentage increase (263.7 percent) relative to its area in 2002, indicating a considerable expansion of agricultural activities in the province. On the other hand, sparse herbaceous cover has lost the most area in the analysis period is (-7,158.2 km^2), which has decreased by 36.6 percent compared to its area in 2002. This substantial loss aligns with the increase in sparse vegetation, suggesting a transition towards even sparser vegetation cover in many areas. The second coverage that lost the most area with respect to 2002 was bare areas (-4,436.1 km^2). However, given its large initial extent, this decrease is relatively small in percentage terms (-3.4 percent). Grassland also experienced a notable decrease of 2,419.6 km^2 (-4.2 percent), indicating a reduction in more densely vegetated areas. It is worth noting that while some agricultural classes like herbaceous cropland increased significantly, others like rainfed cropland showed more modest growth (278.3 km^2, 5 percent increase). Urban areas, although small in absolute terms, showed a significant relative increase of 48 percent.

The comparison for the OROA Reserve and the buffer zone shows a decrease in bare areas. The reduction is more pronounced in the core OROA Reserve (about 5 percent decrease) compared to the larger area (about 3 percent decrease). Both areas have seen a substantial increase in sparse vegetation cover. Interestingly, while the larger area showed an increase in rainfed cropland, the core OROA Reserve showed a slight decrease. Herbaceous cropland areas show a significant increase in both areas. However, the growth is much more dramatic within the confines of the OROA reserve — 4,720 percent increase, vs. 264 percent increase in the larger area.

The economic valuation of land degradation for the OROA Reserve estimated a net loss of US$76,645,077 between 2002 and 2020, meaning US$3.8 million per year (US$9.23 per ha in 20 years). This cost of degradation resulted from several land cover change dynamics that overall produced a lower TEV for the latter period. The most significant economic impact is attributed to the increase in sparse vegetation, leading to a loss of US$262.2 million in ES value. On the other hand, there are positive economic impacts arising mainly from three significant changes that, in any case, do not compensate for the above-mentioned losses:

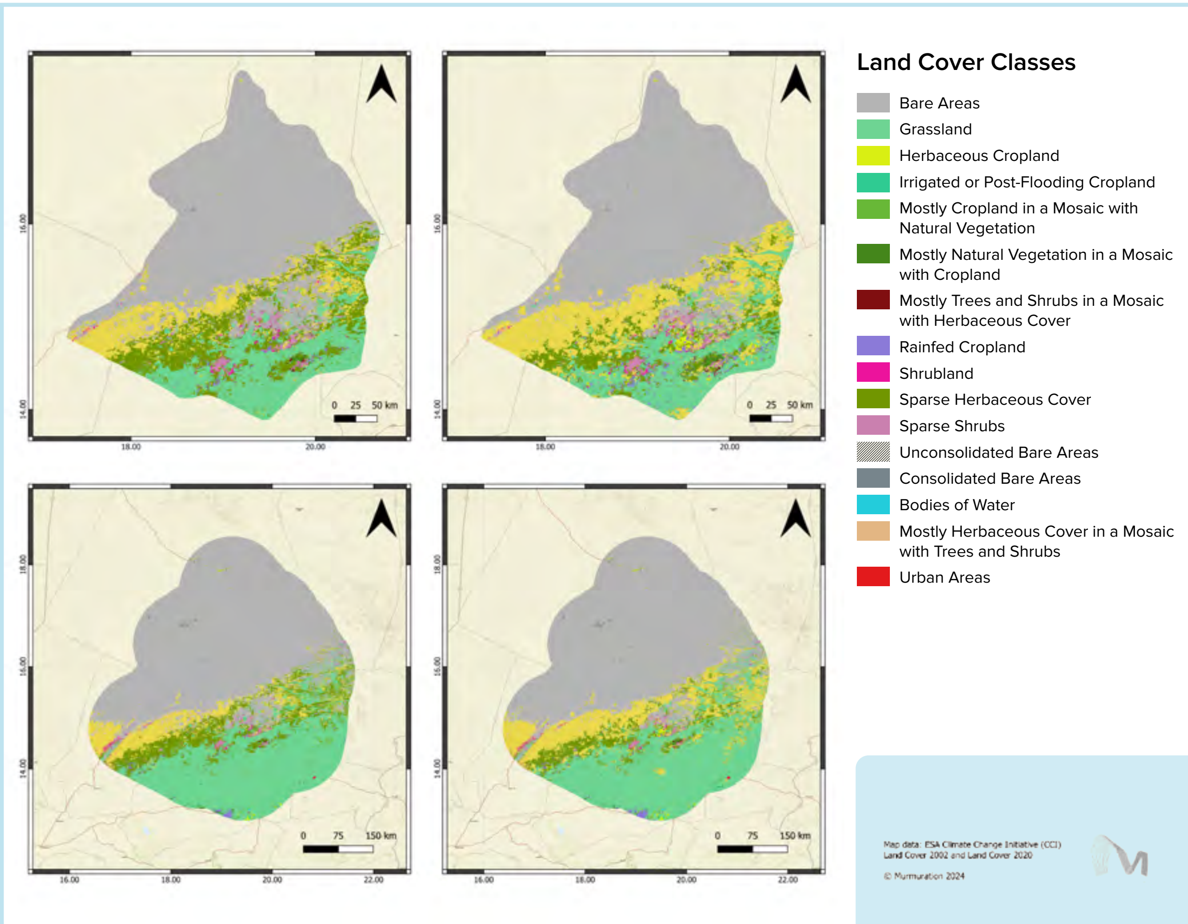
- Increase in rainfed cropland (valued at US$120.5 million)
- Reduction in bare areas (adding US$284.8 million in value)
- Expansion of herbaceous cropland (adding US$107.3 million)

For the larger OROA area including the buffer, the valuation of land degradation shows a complex scenario of land use changes. The overall economic valuation reveals a net land "improvement" worth US$266,846,964. An increase in rainfed cropland, a decrease in bare areas, and an expansion of herbaceous cropland primarily drive this positive outcome. These gains are partly counterbalanced by significant adverse impacts, primarily due to the reduction in grasslands (causing a loss of US$320,432,856) and the decline in sparse vegetation (accounting for a loss of US$452,489,910). Despite these losses, the net result is a positive economic impact of US$266,846,964, interpreted as an overall land "improvement" due to the decrease in bare areas and expansion of both rainfed and herbaceous croplands.

Calculations made for NDVI show that it has increased for all the land cover types involving vegetation, namely the southern half of the reserve

(Appendix A). Unconsolidated and consolidated bare areas corresponding to the northern areas were not considered in the analysis since these land covers do not involve vegetation. The data indicates an overall increase in NDVI across all vegetation types, suggesting that the vegetation within each land cover type is greener and therefore "more productive" than in 2002, both for the area of the reserve and its surroundings. Interestingly, while the NDVI has increased, the data for precipitation show a decrease across the whole area during the 2002–2020 period, with a more significant reduction in the south than in the north, where initial precipitation was minimal.

Figure 2.8. **Land cover of the OROA Reserve**



Source: World Bank

Note: (a) corresponds to 2002, (b) corresponds to 2020, (c) corresponds to 2002 for the Reserve with a 100km buffer and (d) corresponds to 2020 for the Reserve with a 100km buffer.

OROA Land Degradation Case Study: Discussion and Conclusion

The analysis of land cover change and economic valuation of land degradation in the OROA Reserve and its buffer zone suggest a trend towards vegetation expansion. There is a decrease in bare areas and an increase in sparse vegetation, particularly within the Reserve. This shift reveals a complex interplay of ecological and economic factors and could indicate natural revegetation processes or land rehabilitation efforts. However, the expansion of agricultural land, often at the expense of grasslands, points to increasing human influence on the landscape.

The economic valuation presents an intriguing paradox. While the reduction of bare areas and expansion of croplands are viewed as economically beneficial, the spread of sparse vegetation is considered a form of land degradation. For this analysis, loss of TEV was used to estimate land degradation costs, and the assumptions of this method highlight the potential tension between economic development and ecological conservation (Lead et al. 2009). It is crucial to note that the economic values assigned to different land covers may not fully capture the complexity of ES. For instance, croplands may provide significant provisioning services that benefit local populations, while shrublands and grasslands offer important regulating and cultural services that are often undervalued in economic terms. In this context, it is worth noting that agricultural productivity and the provision of ES in the Reserve and its buffer area can be improved simultaneously by applying the Nature's Frontier approach, which ensures sustainable management of natural capital (Damania et al. 2023).

Further work to better understand the land degradation costs within the Reserve could complement the land degradation estimation in this study. This analysis focused solely on land cover change deepening land degradation due to other variables such as management practices on croplands and grazing lands. This integration could tackle, at least partially, the limitation posed by the loss of the TEV approach. Moreover, the presence of artificial water points, particularly in the southern and western areas of OROA, as identified by Owen et al. (2015), adds another layer of complexity. While these water points may support agricultural expansion, they could also lead to increased competition between domestic livestock and native wildlife, potentially impacting conservation efforts such as the reintroduction of the Scimitar-horned oryx. These water points might also contribute to the increase in NDVI. Since precipitation has decreased during the analysis period, vegetation improvement might likely have been derived from groundwater irrigation, questioning the sustainability of this activity.

Despite the observed changes, it is notable that a large portion of the landscape remained unchanged over the 18-year period studied (87 percent in the Reserve and 91 percent for the Reserve and surroundings). This suggests that while the Reserve is experiencing pressures, widespread degradation has not yet occurred. However, the Reserve appears to be at a critical juncture, where anthropogenic and natural pressures could trigger more significant degradation processes soon. These findings align with global assessments of land degradation. For instance, studies have estimated that Chad's land degradation has resulted in a 9 percent loss in the total value of its ES, which is close to the global average of 9.2 percent (Sutton et al. 2016).

It is worth noting that while the OROA Reserve and its surroundings are showing signs of both positive and negative changes, the area remains relatively intact. The Reserve's relative ecological integrity suggests that targeted efforts could yield significant benefits. This scenario poses a significant opportunity for conservation efforts to support and protect the ecosystem before more severe degradation occurs. Observed trends, such as the expansion of sparse vegetation, pressures from agricultural land use, and the presence of artificial water points, highlight both risks and opportunities for sustainable development. Efforts targeted to support practices that balance economic needs with conservation goals can help maintain ecosystem services while promoting resilience in the face of potential future degradation.

SUMMARY

The insights from both national and Reserve-level assessments confirm the urgency of acting before degradation becomes irreversible. While some areas may still recover naturally, others are nearing a tipping point. With a deeper understanding of the spatial distribution of ecosystem losses and emerging restoration potential, it becomes vital to assess the cost of inaction—and the toll it may take on Chad's people, economy, and future.

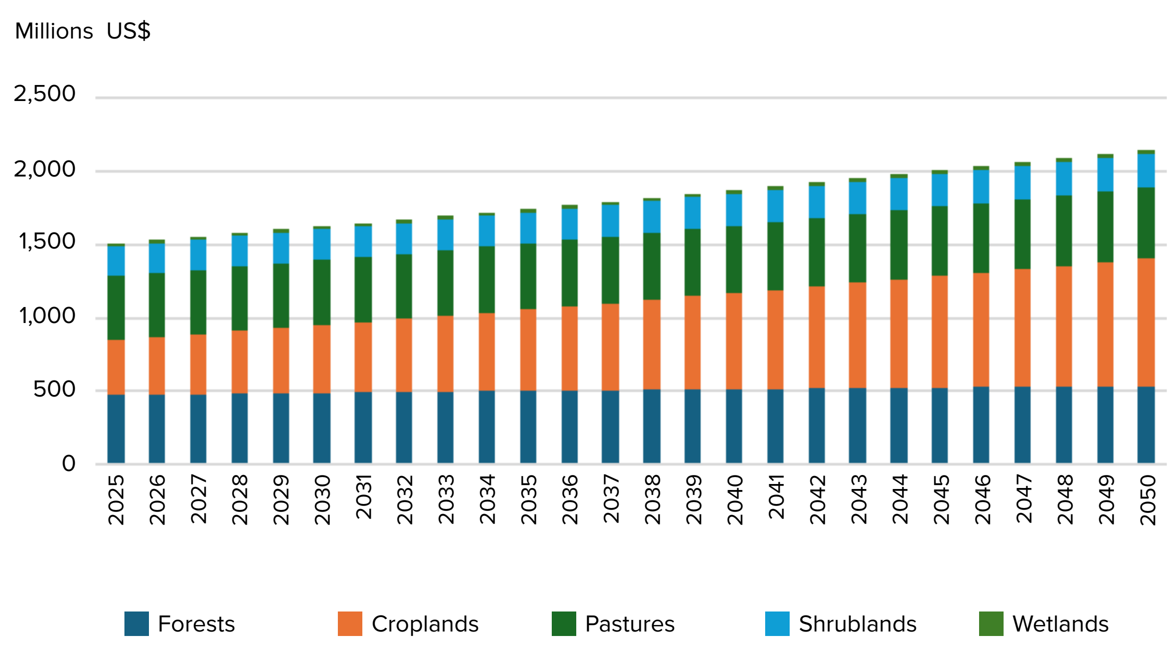
CHAPTER 3.

Costs of Inaction on Land degradation in Chad

Assuming Business-as-Usual, cropland degradation is expected to increase most rapidly among all the land cover types. Apart from incurring a high cost of inaction, land degradation in Chad will have numerous damaging consequences.

The annual average costs of inaction on land degradation in Chad are estimated to be over US$920 million in PV terms (that is, equivalent to 7.46 percent of the country's GDP) from 2025 to 2050 (see Appendix D for the detailed methodology). The undiscounted costs of inaction are currently over US$1,508 million and are estimated to increase to nearly US$2,151 million in 2050 (Figure 3.1) under the BaU scenario. Land degradation in Chad incurs costs through foregone crop and livestock production, greenhouse gas (GHG) emissions and foregone ecosystem services, as well as through damage to infrastructure for irrigation, power, buildings, transportation, and for the delivery of essential public services such as schools, primary health care clinics, and kindergartens. Therefore, the above are the impacts of inaction on land degradation in Chad.

Figure 3.1. **Total cost of inaction on land degradation in Chad (undiscounted)**

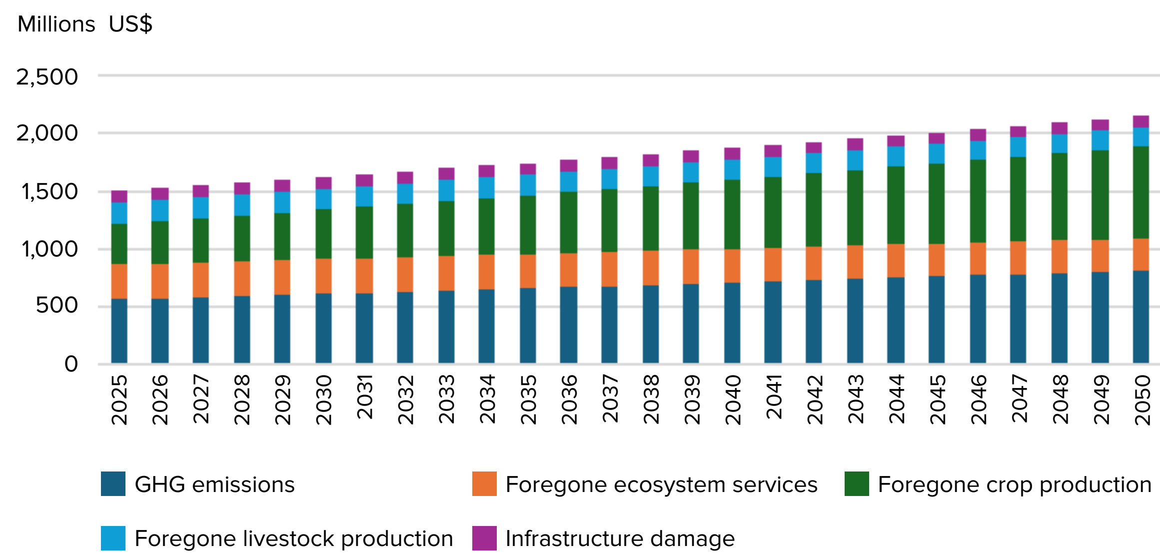


Source: World Bank

The annual costs of inaction on degradation in Chad are estimated to increase for each land cover type. The undiscounted annual costs of inaction on cropland degradation, in particular, is estimated to increase most rapidly from nearly US$380 million in 2025 to US$873 million in 2050 (Figure 3.1). This rapid increase is the combined effect of expansion of degraded areas and increase in the severity of degradation in croplands under the BaU scenario. Under the same scenario, the annual costs of inaction on the degradation of forests, pastures, shrublands, and wetlands are estimated to increase marginally between 2025 and 2050 (Figure 3.2). This increase in annual costs of inaction in these land cover types will be driven by the increasing severity of degradation only. The total degraded area of forests, pastures, shrublands, and wetlands is estimated to increase slightly between 2025 and 2050.

The agricultural sector (croplands and pasturelands combined) is the biggest quantifiable contributor to land degradation costs in Chad. Through foregone crop and livestock production and ecosystem services and GHG emissions, the sector is estimated to contribute—on average—over US$531 million in PV terms in costs of land degradation each year over 2025–2050. This means the sector accounts for nearly 58 percent of the total costs of inaction on land degradation in Chad which is equivalent to 4.3 percent of the country's GDP. The forest sector (including shrublands) accounts for 41 percent, and wetlands account for the remaining 1.3 percent of the total costs of inaction.

Figure 3.2. **Impact-wise distribution of the total cost of inaction on land degradation in Chad (undiscounted)**



Source: World Bank

Among the impacts of inaction on land degradation, the highest annual cost is incurred through GHG emissions followed by foregone crop production. Due to inaction on land degradation in Chad over 2025–2050, on average annually, the GHG emissions are estimated to cost over US$347 million[3] and foregone crop production nearly US$268 million (in PV terms). Over the same period, the foregone livestock production is estimated to cost nearly US$95 million, foregone ecosystem services just over US$156 million and infrastructure damage nearly US$54 million annually in PV

3 A shadow price of carbon of US$108/t$CO_2$e—as per the World Bank's Greenhouse Gas Accounting Guidance for FY 2024—is used for the first year of analysis (2025). The price increases gradually to reach US$190/t$CO_2$e in 2050.

terms. The undiscounted economic values of various impacts of inaction on land degradation are estimated to increase between 2025 and 2050 (Figure 3.2). Both annually (undiscounted, on average over 2025–2050) and in PV terms, the GHG emissions constitute 38 percent, while the other impacts the rest 62 percent of the total costs of inaction. A sensitivity analysis with different market prices of carbon ranging from US$5/t$CO_2$e to US$400/tCO_2e is given in Appendix D.

The unit costs of inaction on degradation in Chad vary widely across the land cover types depending on their respective output levels.[4] Over 2025–2050, in PV terms, croplands have the highest costs (US$6,125 per ha in PV terms) while the pastures have the lowest (US$788 per ha) (Table 3.1). This is because the outputs of pastures, typically under or unmanaged, in terms of livestock production and ecosystem services are much lower than that of other land cover types in the country. Therefore, the loss of yield and productivity in the pastures due to a certain level of degradation is lower than in the country's croplands and other land cover types.

Table 3.1. Unit costs of inaction (2025–2050) on land degradation in Chad

Land cover types	Average unit costs (PV),[5] US$/ha
Forests	4,257
Croplands	6,125
Pastures	788
Shrublands	1,404
Wetlands	2,033
Overall	1,844

Source: World Bank

SUMMARY

As the cumulative burden of inaction grows heavier, the case for proactive investment becomes stronger. The mounting costs—especially within agricultural sectors—point to an urgent need to allocate resources wisely and strategically. To do so effectively, the next step is to pinpoint where restoration can offer the greatest ecological and economic returns across the country's landscapes.

4 The costs of inaction on degradation in all land cover types includes GHG emissions, loss of ecosystem services, and their contribution to infrastructure damage. In addition, the costs of degradation in croplands include loss of crop production, and the costs of degradation in grasslands include loss of livestock production.

5 The average unit costs of inaction on land degraded for a land cover type is estimated first by deriving the average costs of inaction per ha for each year from 2025 to 2050 and then by calculating the PV of these annual average costs. See Appendix D for more details on methodology.

CHAPTER 4.

Identification of Priority Restoration Landscapes and Ecosystem Services

The study has identified restoration hotspots for each land cover type, accounting for landscape diversity and the need for tailored strategies. Restoring these areas will enhance carbon sequestration, sediment retention, flood mitigation capacity, and forage biomass, reflecting regional ecological differences and pressures.

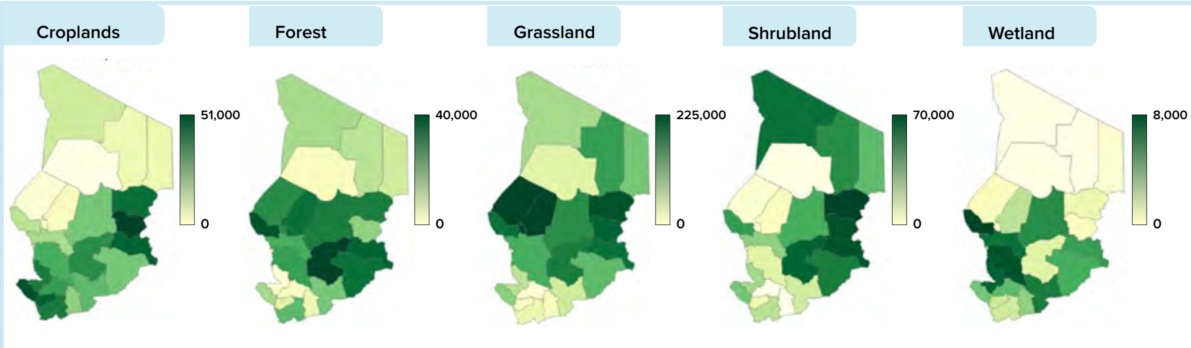
4.1 Identifying Priority Restoration Landscapes in Chad

Projected Benefits of Restoration by Land Cover Types

Restoration efforts, if successfully implemented, could play a crucial role in enhancing ecosystem resilience, improving agricultural sustainability, and mitigating climate change impacts in Chad's diverse landscapes. Restoration efforts across nearly one million ha of degraded land are projected to yield substantial ES benefits, though these vary significantly by region and land cover type. The restoration analysis identifies clear geographic patterns where forest, shrubland, grassland, cropland, and wetland restoration would have the most impact, reflecting differences in ecological zones, land degradation severity, and land use history (Box 4.1).

The restoration analysis also reveals significant spatial variation in how different land cover types are prioritized across Chad's administrative provinces (Figure 4.1). Northern and eastern provinces, such as Wadi Fira, Ouaddaï, and Bahr-El-Gazel, have the greatest benefits associated with shrubland and grassland restoration, combatting desertification and rangeland degradation. Central and southern provinces, including Guéra, Sila, and Mayo-Kebbi Ouest, would be prioritized for benefits associated with forest and cropland restoration, where land productivity and biodiversity losses are key concerns. Meanwhile, wetland restoration would be focused on Lake Chad and major river systems, reinforcing the importance of water resources for local economies. These restoration efforts could play a crucial role in enhancing ecosystem resilience, improving agricultural sustainability, and mitigating climate change impact in Chad's diverse landscapes. Details for each land cover type are presented below.

Figure 4.1. **Spatial distribution of priority land restoration areas (ha) by land cover type**



Source: World Bank

Note: The above figure presents the area (in ha) proposed for land restoration across Chad for the five major land cover types. Each map uses a gradient color scale from white to yellow to green, where darker shades represent stronger potential for restoration.

The potential benefits of **forest restoration** are highest in the Guéra (40,327 ha), Sila (8,116 ha), and Lac (12,353 ha) provinces, which span the Sahelian and Sudanian zones. These provinces historically contained dry forests and wooded savannas that have suffered from deforestation, land conversion, and fuelwood extraction. Meanwhile, many of Chad's northern and central provinces, such as Borkou (250 ha) and Tibesti (1,048 ha), have minimal forest restoration potential, reflecting their hyper-arid conditions where tree growth is severely limited. Notably, Salamat and Bahr-El-Gazel also contain substantial forest restoration areas, despite being semi-arid, indicating the benefits of efforts to regreen areas at risk of further desertification.

The potential benefits of **shrubland restoration** are highest in Wadi Fira (69,688 ha), Ouaddaï (23,309 ha), and Sila (21,323 ha), all located in eastern Chad where desertification and land degradation are severe. In contrast, the potential benefits of shrubland restoration are projected to be very low in the southern and western provinces, where other land uses such as cropland or wetlands take priority.

The potential benefits of **grassland restoration** are highest in Kanem (224,126 ha), Bahr-El-Gazel (164,557 ha), Wadi Fira (100,719 ha), and Ouaddaï (37,310 ha). These provinces are largely arid and semi-arid, with a history of heavy grazing pressure and desertification, making them prime candidates for grassland restoration to improve forage availability and soil stability. In contrast, southern provinces such as Logone Occidental, Logone Oriental, and Mandoul have much smaller grassland restoration potential, likely due to their more productive agricultural landscapes and higher precipitation, which support more permanent cropland.

The potential ecosystem service benefits of **cropland restoration** are highest in Ouaddaï (51,155 ha), Mayo-Kebbi Ouest (16,233 ha), and Sila (10,683 ha), all of which are known for their historical agricultural importance. These provinces likely contain degraded agricultural lands that are being prioritized for soil improvement and land reclamation efforts. Other provinces with significant cropland restoration include Logone Occidental (12,909 ha) and Wadi Fira (5,030 ha), where restoring soil fertility could enhance food security although this was not explicitly incorporated into the ecosystem service assessment. In contrast, cropland restoration potential benefits are negligible in the northern and central desert provinces, including Borkou (1 ha), Kanem (2 ha), and Bahr-El-Gazel (15 ha), where agriculture is less viable due to extreme aridity and lack of water availability.

The potential benefits of **wetland restoration** are highest in Lac (8,010 ha), reflecting the importance of the Lake Chad ecosystem and surrounding floodplains, which support fisheries, agriculture, and pastoral livelihoods. Smaller wetland restoration areas are allocated to Chari-Baguirmi (1,026 ha), Mayo-Kebbi Est (748 ha), and Moyen-Chari (427 ha), all of which contain important river systems and seasonal wetlands. Many provinces, particularly those in the north and northeast, have no wetland restoration at all, which aligns with their arid climate and lack of permanent water bodies.

Projected Benefits of Restoration by ES

When expressed per ha, restoration benefits show strong regional contrasts as follows: (i) carbon sequestration potential reaches up to 8.94 t/ha in semi-arid provinces like Bahr-El-Gazel, while sediment retention benefits peak at 49.25 kg/ha/year in Kanem; (ii) flood mitigation improvements are most significant in southern provinces like Logone Occidental, with projected gains of up to 2,720 m^3/ha/year; and (iii) forage biomass productivity could increase by as much as 51.58 kg/ha/year in Bahr-El-Gazel, offering vital support to pastoralist communities. These findings underscore the value of spatially targeted restoration, with strategies tailored to each region's ecosystem type and land use pressures, maximizing the returns of NbS across Chad's diverse landscapes.

The normalized restoration benefits for Chad's ES reveals distinct spatial patterns, reflecting regional differences in ecological processes and degradation pressures. Since administrative areas of Chad vary in size, results were summarized on a per area basis to allow for comparison of benefits and summarized by administrative area across the country. As noted below, the study highlights regionally specific benefits of ecosystem restoration, demonstrating how different landscapes and land uses drive variation in ES gains across Chad. Outlined below is a summary of each ES, considering the corrected units for carbon sequestration (t/ha), sediment retention (kg/ha/year), flood mitigation (m^3/ha/year), and forage biomass productivity (kg/ha/year). It is worth noting that carbon sequestration potential reaches up to 8.94 t/ha in semi-arid provinces like Bahr-El-Gazel, while sediment retention benefits peak at 49.25 kg/ha/year in Kanem; flood mitigation improvements are most significant in southern provinces like Logone Occidental, with projected gains of up to 2,720 m^3/ha/year; and forage biomass productivity could increase by as much as 51.58 kg/ha/year in Bahr-El-Gazel, offering vital support to pastoral communities. These findings underscore the value of spatially targeted restoration, with strategies tailored to each region's ecosystem type and land use pressures, maximizing the returns of NbS across Chad's diverse landscapes.

Carbon sequestration benefits would be highest in the central and eastern provinces, with Bahr-El-Gazel (8.94 t/ha), Kanem (8.05 t/ha), Wadi Fira (8.01 t/ha), and Ouaddaï (7.97 t/ha) showing the greatest potential for storing carbon. These areas, characterized by extensive grassland and shrubland restoration efforts, highlight the importance of land-based carbon storage in semi-arid landscapes. Other provinces, such as Logone Occidental (3.31 t/ha), Sila (3.16 t/ha), and Mayo-Kebbi Ouest (2.80 t/ha), also show significant carbon sequestration potential, though at lower levels. In contrast, highly arid provinces like Tibesti (0.05 t/ha) and Borkou (0.006 t/ha) offer the lowest carbon sequestration benefits, likely due to minimal vegetation cover.

Sediment retention benefits would vary considerably given the allocation of restoration, with the highest values concentrated in Kanem (49.25 kg/ha/year), N'Djamena (46.23 kg/ha/year), Wadi Fira (44.98 kg/ha/year), and Ouaddaï (44.69 kg/ha/year). These provinces, which experience high levels of soil erosion and runoff, benefit most from restoration strategies that stabilize soils and reduce sediment transport. In contrast, Borkou (0.0005 kg/ha/year) and Mandoul (0.00069 kg/ha/year) have minimal sediment retention gains, likely reflecting differences in land use, precipitation, and topography.

Flood mitigation benefits show a strong spatial contrast, with Logone Occidental (2,720 m^3/ha/year), Mayo-Kebbi Ouest (2,147 m^3/ha/year), and Ouaddaï (2,148 m^3/ha/year) receiving the most significant gains. These provinces, located in southern Chad and along major river basins, benefit from improved water retention and reduced surface runoff. In contrast, the lowest flood mitigation benefits occur in the northern desert provinces, with Tibesti (0.00001 m^3/ha/year), Ennedi Ouest (0.0029 m^3/ha/year), and Ennedi Est (0.0035 m^3/ha/year) showing minimal improvements. This pattern reflects hydrological constraints, where flood risk is primarily a concern in provinces with seasonal or permanent surface water.

Forage biomass productivity improvements are most pronounced in Bahr-El-Gazel (51.58 kg/ha/year), Kanem (47.21 kg/ha/year), and Ouaddaï (31.71 kg/ha/year), highlighting the critical role of grassland and rangeland restoration in these traditionally pastoralist provinces. Wadi Fira (13.89 kg/ha/year) and Mayo-Kebbi Ouest (14.06 kg/ha/year) also show high forage productivity benefits, supporting livestock-dependent communities. In contrast, Salamat (0.0136 kg/ha/year), Moyen-Chari (0.096 kg/ha/year), and Tibesti (0.018 kg/ha/year) have minimal gains, reflecting lower restoration potential or differing land use priorities in these areas.

Box 4.1. Methodology for choosing restoration sites and estimating benefits of restoration

The land degradation analysis foresees what the land conditions would be in 2050, and the restoration undertaken to improve the conditions to "good condition". Given the restoration target includes a limited amount of land within each land cover type, the analysis prioritizes restoring degraded areas that would result in the largest collective benefits across the four modeled ES: climate mitigation (carbon storage), water quality (nutrient export), flood mitigation (surface water flow) and, for grasslands only, the additional benefits of forage biomass (net primary productivity).

To estimate the potential benefits of restoration in Chad, a land cover restoration scenario was created where any degraded areas in 2050 were improved to "good condition" such that all areas characterized as "poor" or "fair" in forests, shrublands, grasslands, croplands, and wetlands were virtually converted to "good". Following this, an ecosystem service model was run on this 'full restoration' scenario, comparing it to the BaU land cover pattern. The pixel-level difference between these two scenarios was used as input to evaluate potential areas to target for restoration.

To choose restoration sites, a greedy algorithm was used to determine which restoration areas maximize improvements across all ES. The approach prioritized restoration sites based on their potential to enhance carbon sequestration, sediment retention, forage biomass productivity NPP, and flood mitigation (surface water yield, SWY). Because each of these ecosystem services is represented by different units, a standardized score or index was developed for each to allow combining benefits across all ES in choosing the best sites for restoration. To compare these benefits across different ES, they were standardized using z-score normalization. This allowed for comparison of improvements across ES on a common scale. For each ES, the z-score was calculated:

$$z = \frac{x - \mu}{\sigma},$$

where x represents the raw improvement in each ES for a pixel, μ is the mean improvement across all eligible pixels, and σ is the standard deviation. This process ensured that pixels with larger-than-average improvements received positive z-scores, while those with below-average improvements received negative scores.

For example, if a pixel had a significantly higher increase in carbon sequestration than the average restoration site, its z-score for carbon would be positive. Conversely, if its improvement was below average, its z-score would be negative, signaling a lower relative benefit. For most land cover types, pixels were ranked by summing their z-scores for carbon sequestration, sediment retention, and flood mitigation. For grasslands, NPP was also included to reflect its ecological importance. After computing the summed z-scores, all pixels were sorted in descending order, ensuring that the pixels with the highest cumulative benefit were prioritized.

Next, the highest-ranked pixels were selected iteratively for restoration for each land cover type. This approach maximized ES gains within the given constraints, ensuring that each restored hectare provided the greatest possible ecological and economic benefit. The result was a spatially optimized restoration plan, strategically targeting areas where restoration would have the most significant impact.

See Appendix E for additional methodology information.

4.2 Identifying Priority Ecosystem Services in the OROA Reserve

Forage for grazing, habitat creation and maintenance, and nature-based tourism (NbT) have been identified as the priority ES for investment in the OROA Reserve (Box 4.2).

Box 4.2. Methodology to prioritize ES for investment in the OROA Reserve

The process of selecting and prioritizing the ES was done through a system-scoping activity followed by a prioritization and scoring matrix based on three steps:

Step 1: Potential ES to be assessed were identified and listed (Table 4.1). This step entailed a literature review on the ES of the OROA Reserve and areas with similar socio-ecological conditions and the identification of potential actors for interviews to contrast the literature review results and delve deeper into the development of markets for ES.

Step 2: A more refined search and review of scientific and gray literature that specifically referred to economic or potential market values was carried out and the selection was further refined and scored. With this first literature-based prioritization, the selection was compared and cross-referenced with the work carried out in Chad's recent Climate Change National Adaptation Plan (NAP), where a series of adaptation measures were prioritized. Those that were coherent with the literature-based selection were scored.

Step 3: To prioritize the specific selection of ES to be assessed, a series of key informant interviews were conducted with stakeholders familiar with the different ES of the OROA Reserve. They were asked to validate and share additional information on the selection and the results of each of the key informant interviews. For each of the validated and most selected ES, a final score was applied, and a final list of ES for assessment derived.

Box 4.2. Methodology to prioritize ES for investment in the OROA Reserve (Contd.)

Table 4.1. **Selection and prioritization of ES as per ecosystem type in the OROA Reserve**

Number	Ecosystem	Ecosystem service	NCP	Category	Question 1 (score 0,1,2,3)	Question 2 (score 0,1,2,3)	Score
1	Desert	Fuel	11. Energy	Provisioning	2	0	2
2	Desert	Generic reources (arid-adapted species, high salinity resistance, excessive temperature)	14. Medicinal, biochemical and genetic reosurces	Provisioning	2	0	2
3	Dssert	Water (drinking, irrigation, sanitation)	6. Regulation of freshwater quantity, location and timing	Provisioning	2	1	3
4	Desert	Air quality (wind-blown dust retention)	3. Regulation of air quality	Regulating	0	0	0
5	Desert	Carbon cycling	4. Regulation of climate	Regulating		1	2
6	Desert	Climate regulation (desert albedo)	4. Regulation of climate	Regulating		1	2
7	Desert / Grass lands and savanna	Wild food sources	12. Food and feed	Provisioning	2	1	3
8	Desert / Grass lands and savanna	Forage and grazing	12. Foof and feed	Provisioning	3	1	4
9	Desert / Grass lands and savanna	Building materials (e.g., fibre)	13. Materials and assitance	Provisioning	1	0	1
10	Desert / Grass lands and savanna	Habitat creation and maintenance	1. Habitat creation and maintenance	Regulating	3	1	4
11	Grasslands and savannas	Tourism	16. Physical and psychological experiences	Cultural	3	1	4
12	Grasslands and savannas	Medicinal and biochemical resources (e.g., gum arabic, shea butler)	14. Medicinal, biochemical and genetic resources	Provisioning	1	1	2
13	Grasslands and savannas	Soil carbon	4. Regulation of climate	Regulating	0	1	1
14	Grasslands and savannas	Erosion control	8. Formation, protection and decontamination of soils	Regulating	0	0	0

Following completion of these three steps, participants were asked to vote on the ES most important to them. This confirmed the importance of the ES selected (3, 7, 8, 10 and 11), with one difference: that water and NWFPs were important choices for many participants.

However, when literature review, key informant interviews, and stakeholder consultation were summed up, the top three ES that emerged were: forage for grazing, habitat creation and maintenance, and NbT. But tourism literature and data on the Reserve was hardly available. Hence a separate, wider national level study was carried out for "nature-based tourism". The methodology for this study was based on the World Bank's Tourism Diagnostics Toolkit.

Priority ES in the OROA Reserve: Forage for Grazing

The Sahel region showcases a diverse array of livestock systems, predominantly pastoral, where animals rely on grazing in rangelands (Behnke and Mortimore 2016). In Chad, overgrazing has been identified as one of the principal factors contributing to environmental fragility and land degradation (UNCCD 2019). Over recent decades, the increase in livestock populations and corresponding fodder needs in Chad has exerted mounting pressure on Chad's rangelands, including those in and around protected areas (Ministry in charge of Environment, Chad 2018).

Ranked as the second most important ES by local stakeholders, forage for grazing is critical to livestock, which contributes 6–7 percent to Chad's GDP (Njinkeu et al. 2024). The pastoral sector is vital to rural populations, especially in the Sahel region of the reserve, where traditional livestock systems predominate, relying almost entirely on rangelands for fodder. Given the large livestock population within the Reserve (approximately 8.9 million livestock units), there is considerable demand for forage, particularly in the dry season when natural grassland resources become limited. Animal carrying capacity and propensity to overgraze in a given area is intrinsically linked to the type and quantity of fodder produced there. Rangeland desertification is almost entirely a consequence of excessive overgrazing (MEA 2005). Therefore, understanding the value of foraging systems and their carrying capacity underscores the potential benefits of sustainable grazing management practices, opening possibilities for the future management of Chad's rangelands. This situation is particularly important in the context of the OROA Reserve and its surroundings, where forage for grazing is a vital ecosystem service for the livelihoods of its local communities.

This ES was valued through the number of Tropical Livestock Units (TLUs) supported by the grazing areas within and around the OROA Reserve through fodder consumption. Subsequently, the economic valuation of the ES was carried out by applying the surrogate market method (Curtis 2004), where cottonseed cake was used as the surrogate market for forage, since the cake obtained from grinding cotton seeds constitutes a vital source of protein for ruminants in Chad (M'bodji et al. 1973; Meliadò et al. 2020). Following this, biophysical and economic estimations were carried out. The result showed that the overall economic value of the forage for grazing ES in the OROA Reserve is estimated at over US$115 million per year.

Priority ES in the OROA Reserve: Habitat Creation and Maintenance

The OROA Reserve is one of the most important examples of almost intact grassland ecosystems in sub-Saharan Africa (Newby and Sahara Conservation 2024). A biodiversity gap analysis conducted by Brugière and Scholte (2013) revealed that the Reserve has the highest irreplaceability index among Chad's protected areas, surpassing even the renowned Zakouma National Park. The Reserve is also important because it supports large numbers of livestock and rare antelopes, including the critically endangered species such as the scimitar-horned oryx (Oryx dammah) and addax (Addax nasomaculatus) (Wacher et al. 2022).

Moreover, the Reserve combats desertification, with its northern wadis acting as natural barriers and serving as biodiversity reservoirs and corridors. Its vast expanse of grasslands, covering 40,000 km^2, is crucial for protecting against land erosion. Its unique ecological features, including wetlands, are essential for threatened large mammals that depend on large-scale migration and migratory waterbird populations. However, these vital habitats are not being managed well, emphasizing the urgent need for conservation efforts.

The ES of habitat creation and maintenance was estimated through the InVEST model for "Habitat Quality". This approach uses habitat quality and rarity to represent the biodiversity of a landscape, estimating the extent of habitat and vegetation types in a landscape and their state of degradation. The model combines maps of land use and land cover (LULC) with data on habitat threats and habitat sensitivity to them. On biophysical estimations, the Habitat Quality Model estimates patterns in biodiversity by analyzing land cover in conjunction with threats to species' habitats, where the model determines the relative quality of a specific habitat based on four factors: (i) capacity of the habitat to support animal and plant life; (ii) impact of each threat on the different habitats; (iii) sensitivity of each habitat to each identified threat; and (iv) distance of habitats from the relative sources of threat that can alter the equilibrium state of the habitats themselves. As the InVEST model does not in itself allow for the attribution of a monetary value to biodiversity, a benefit transfer was used via the TEV (per land cover used in the land degradation analysis). The overall value of the ES referred to the whole area of the Reserve is estimated, on an annual basis, to be more than US$4.7 billion, equivalent to US$529/ha/year.

Priority ES in the OROA Reserve: Nature-based Tourism

Based on the Travel & Tourism Development Index (TTDI) 2021, Chad ranks last among 117 countries. However, the country has seen a 1.3 percent improvement since 2019 below the TTDI average. An assessment was undertaken during this study focusing on the potential to develop a tourism destination using the OROA Reserve as a case study, with the Reserve's unique natural and cultural assets being its key attractions. Its significant biodiversity, including rare Sahelo-Saharan species and unique landscapes, alongside local cultural heritage and handicrafts, align well with the definition of NbT and community-based tourism (CbT).

Global trends show a growing demand for experiential, nature-focused travel, suggesting a market opportunity for destinations like the Reserve that offer authentic wilderness and cultural experiences. However, realizing this potential requires leveraging these assets effectively while addressing significant challenges. For this study, data was collected from secondary sources, including reports from the World Bank, World Economic Forum, Chad's Ministry of Tourism, and local management plans. This was complemented with local stakeholder interviews to understand challenges in tourism management, infrastructure, and economic contributions. Key indicators such as governance, tourism prioritization, destination management capacity, regulatory framework, and tourism offering were examined based on the Tourism Diagnostic Toolkit (WBG 2019).

The Reserve's considerable potential for NbT and CbT remains largely untapped due to these profound challenges. Despite rich natural and cultural resources, significant improvements are needed in strategic planning, governance, infrastructure investment, safety, regulatory processes, and marketing to compete effectively and develop tourism sustainably. Addressing these weaknesses could unlock opportunities for economic growth, diversification, and community benefits, positioning Chad and the Reserve uniquely within the niche ecotourism market (Box 4.3).

Box 4.3. Analysis of strengths, weaknesses and opportunities based on the World Bank Tourism Diagnostic Toolkit for Chad

The OROA Reserve is Chad's unique tourism offering. It is host to unparalleled biodiversity with rare Sahelo-Saharan species, distinct landscapes, and rich cultural heritage, aligning well with growing global trends in NbT and CbT. There is an existing, though small profile of international niche visitors undertaking extended trips. Additionally, the regulatory framework offers some potential tax benefits for businesses investing in remote areas.

A lack of strategic planning and leadership at national and local levels, restrictive visa and permit requirements, and challenges in data collection impede tourism development. The tourism economy suffers from high revenue leakage and a shortage of trained professionals. In effect, it contributes little to the GDP and employment. Infrastructure is severely lacking across transport, sanitation, health, accommodation (especially outside the capital), and telecommunications. Perceived security issues, climate constraints limiting seasonality, ineffective marketing, poor governance, corruption, low human resource capacity, and high gender inequality further compound the challenges.

Despite noted weaknesses, opportunities exist: Strengthening management, easing access regulations, and improving data collection could boost visits and inform strategy. There's significant room to grow international tourism, reduce leakages, and enhance local benefits through targeted training and supply chain development. Developing national itineraries featuring the Reserve's unique assets could capitalize on NbT trends. Infrastructure improvements would benefit both tourism and the broader economy and quality of life. Improving the security image, enhancing marketing efforts, and implementing targeted training and gender empowerment initiatives could further unlock potential.

SUMMARY

By linking the most vulnerable areas to their most valuable services, this overall analysis helps chart a path toward restoration that is both impactful and feasible. With these priority landscapes and ecosystem services identified, the focus shifts to evaluating the viability of action—how much it would cost, what benefits it would yield, and where the returns on investment would be most significant.

CHAPTER 5.

Cost-Benefit Analysis of Land Restoration

With a benefit-cost ratio of 3:1 and a significant cost of inaction, it makes financial, ecological, and social sense to implement restoration actions sooner rather than later in Chad. This study prioritizes the restoration of croplands and grasslands, given their market potential. Women gain the lion's share of the benefits of restoration.

5.1 Estimation of Target Area for Restoration

The study estimated the amount of land to restore in each land cover type: forest, shrublands, grasslands, croplands, and wetlands (Box 5.1; Table 5.1).

Box 5.1. Methodology to estimate the size of restoration areas

The amount of land to restore in each land cover type (forest, shrublands, grasslands, croplands, and wetlands) was estimated by using a structured approach to maximize the benefit-cost ratio (BCR) while aligning with Chad's pledge under the African Forest Landscape Restoration Initiative (AFR100) of the Africa Great Green Wall Project. The approach accounted for the investments required for restoration and the potential returns on such investments.

The most economically productive land cover types were prioritized: croplands and grasslands. Croplands generate the highest market value per ha and Chad's livestock sector relies heavily on pasture-based systems (Table 5.1). As a result, 15 percent of degraded croplands and 7.5 percent of degraded grasslands were allocated for restoration. Conversely, forests and shrublands, which have higher restoration costs relative to their economic benefits (see Chapter 5), were assigned a lower restoration share (5 percent) to promote cost-effectiveness. Wetlands which provide key hydrological services would have an intermediate share (7.5 percent) to balance benefits and costs. The final nationwide restoration target of approximately 983,000 ha was determined using these proportional allocations, ensuring that restoration investments yield the highest possible returns while remaining economically viable and ecologically sustainable.

Table 5.1. **Required investments for restoration action on 0.98 million ha of degraded land in Chad (undiscounted)**

Land cover type	Land in poor condition, (in ha) in 2021	Restoration actions	Restoration target, ha		Share of restoration target by action %
			by action	Total	
Croplands	809,489	Conservation agriculture	42,181	140,603	30%
		Crop diversification (including crop rotation)	98,422		70%
Pastures (grasslands)	8,580,951	Rotational grazing	125,641	628,204	20%
		Silvo-pastoral system	502,563		80%
Forests	1,894,528	Forest protection and management	68,006	90,675	75%
		Agroforestry (forests)	18,135		20%
		Afforestation/ Reforestation	4,534		5%
Shrublands	2,290,568	Shrubland protection and management	83,644	111,525	75%
		Agroforestry	22,305		20%
		Afforestation/ Reforestation	5,576		5%
Wetlands	162,397	Rehabilitation	12,088	12,088	100%
Total			**983,095**	**983,095**	

Source: World Bank

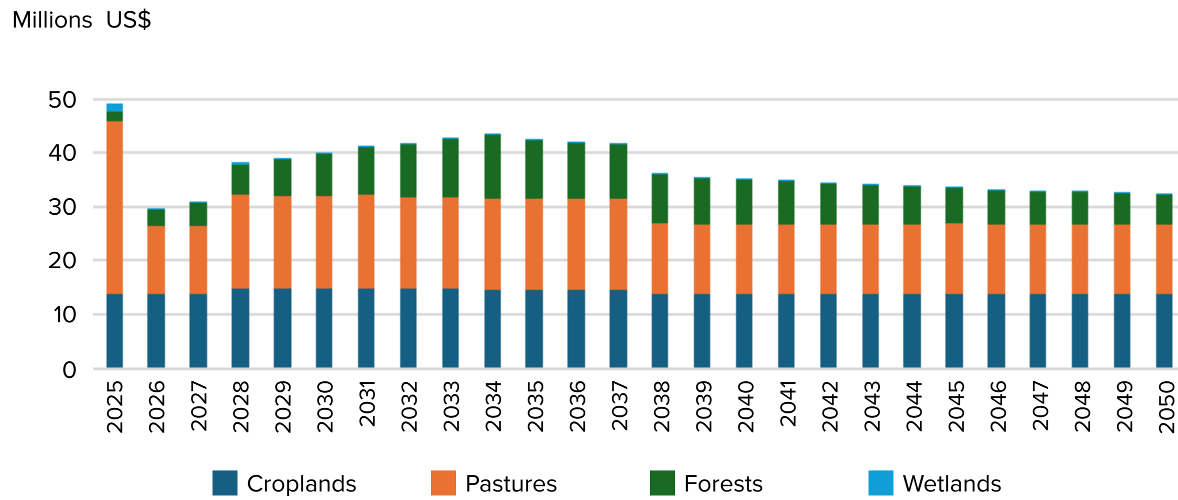
5.2 Costs of Land Restoration

From 2025 to 2050, the average annual investment required to take restoration actions to avoid further degradation of 0.98 million ha[6] of land in Chad is nearly US$22 million in PV terms. Almost 80 percent of the total investments (US$457 million out of US$570 million in PV terms) is required in the first 15 years when most intensive restoration actions are necessary. The degradation can be avoided through several NbS that are best suited for the country's bio-physical, environmental, climatic, and socio-economic conditions: conservation of agriculture and crop diversification (croplands), rotational grazing and silvo-pastoral system (pastures), conservation and vegetation management, agroforestry, afforestation and reforestation (forests and shrublands).

Some infrastructure-based measures notably stabilization of the banks of watercourses through bioengineering and building retaining walls would also be needed. The investments in restoration would reduce crop production costs, increase production of crops and livestock products (milk, meat, and wool), reduce infrastructure damage, enhance ecosystem services and curtail GHG emissions, thus building resilience to climate change. Due to the need for more intensive actions, the undiscounted costs will follow an increasing trend in the first 10 years and then decline gradually (Figure 5.1). Accordingly, the average annual investment required from 2025 to 2030 is the highest and from 2041 to 2050 is the lowest (Table 5.2) (see Appendix D for the detailed methodology for arriving at the costs of restoration).

6 The target area for restoration interventions includes just under 140,000 ha of degraded croplands, 628,000 ha of degraded pastures, 91,000 ha of degraded forests, 111,000 ha of shrublands and 12,000 ha of degraded wetlands. It sums up to just over 8.1 percent of the estimated degraded land in Chad in 2050 under the BaU scenario (Table 5.1). It is assumed in this study that the target area for restoration will be a part, not whole, of the pledge made by Chad for the AFR100 under the Africa Great Green Wall Project.

Figure 5.1. **Required investments for restoration action on 0.98 million ha of degraded land in Chad (undiscounted)**



Source: World Bank

5.3 Estimating Benefits of Land Restoration

The average annual benefits of restoring 0.98 million ha of Chad's degraded land are estimated to be nearly US$83 million in PV terms over 2025–2050 when GHG emissions reduction is accounted for. Unlike the investment required, the average annual benefits are the lowest in the first five years of restoration and the highest in the last 10 years (Table 5.2). This is because as the fertility and vigor of the land are gradually restored, outputs such as crop yield, livestock products, and ecosystem services increase over time and so does the annual benefit. In the first five years of restoration, the required investments are estimated to exceed the benefits, but the trend will be reversed afterward (Table 5.2). The NPV of the benefits (that is, discounted benefits net of corresponding costs) between 2025 and 2050 is estimated to be over US$1.59 billion when GHG emissions reduction is accounted for (US$1.16 billion without accounting for GHG emission reduction). See Appendix D for the detailed methodology to calculate the benefits of restoration.

Taking restoration actions to avoid degradation of 0.98 million ha of land will reduce over 0.25 million tCO_2e GHG emissions annually, on average, from 2025 to 2050. The GHG emissions reduction potential will increase over time as the productivity of the degraded land improves due to restoration actions. The maximum GHG emissions reduction potential of over 0.39 million tCO_2e[7] will be reached in 2048.

Table 5.2. **Required land restoration investments and their benefits during different periods**

Period	Required investment (in PV), million US$		Benefits (in PV), million US$			
			With GHG emission reduction benefit		Without GHG emission reduction benefit	
	Annual average	Total	Annual average	Total	Annual average	Total
2025–2030	32.9	197.2	29.4	176.1	24.54	147.2
2031–2040	26.0	260.0	94.0	940.3	75.28	752.8
2041–2050	11.3	113.0	104.0	1 039.8	82.77	827.7
2025–2050	21.9	570.2	82.9	2,156.1	66.45	1,727.8

Over 2025–2050, the investments in restoration actions are expected to directly generate nearly 4,000 new long-term jobs[8] and support or create an additional nearly 6,000 jobs in upstream and downstream segments of the value chain across agriculture, livestock, forestry, and other land-based sectors. Together these newly created jobs will generate income and support the livelihoods of nearly 59,000 people in the country.[9] As women constitute the majority of the workforce in agriculture, animal husbandry, and forestry in Chad, a significant share of these jobs, as well as the livelihood benefits will go to women (Table 5.3).

Table 5.3. **Employment and livelihood impact of restoration in Chad over 2025–2050**

Impact category	Men	Women	TOTAL
Long-term jobs directly created (number)	1,190	2,649	3,839
Additional jobs created or supported (number)	1,785	3,973	5,758
Livelihoods supported (people)	18,147	40,391	58,538

Source: World Bank

Table 5.4. **Average unit investment required and benefits of land restoration in Chad**

Land cover types	Average (PV) over 2025–2050, US$/ha		
	Required investment	Benefits	
		With GHG emissions reduction benefit	Without GHG emissions reduction benefit
Croplands	1,394	5,941	5,601
Pastures	235	1,303	931
Forests	1,331	3,570	2,216
Shrublands	1,331	2,259	1,952
Wetlands	316	2,201	752
Average for all land cover types	601	2,274	1,822

Source: World Bank

5.4 Comparing Costs and Benefits of Land Restoration

From the economic point of view, it is significantly cheaper to take restoration actions than not taking any actions at all and letting the degraded area expand with increased severity of degradation in Chad. The benefits of the actions far exceed the costs. Over 2025–2050, while the overall average costs of inaction on land degradation are estimated to be US$1,822 per ha (Table 3.1), the required investment in restoration actions is estimated to be US$601 per ha. The average benefits of actions over the same period are estimated to be US$2,274 per ha (Table 5.4). The internal rate of return (IRR) is over 39 percent when GHG emissions reduction is accounted for and nearly 32 percent when that benefit is not accounted for.

7 The GHG emissions reduction potential is adjusted for risks. The likely risks are that fertility, health, and vigor of the land being restored are not regained at the rate anticipated and buffer zones are required to be created making land unavailable for productive uses. Fire, pests and diseases, and other natural disasters can also cause damage to the vegetation in the restored lands in Chad. The above will result in a decrease in the emissions reduction potential. Considering the above, it is assumed that 10 percent of the potential GHG removal by restored lands is not realized in year 1, and the non-realization rate is gradually reduced to 5 percent in year 10 and remains so until 2050. The reduction of the non-realization rate is because the resilience and management practices on the restored land are expected to improve over time.

8 These jobs could be in planting and maintenance in degraded forests and shrublands, crop harvesting and processing, building and maintenance of infrastructure, e.g., retaining walls for stabilizing the banks of watercourses to support NbS actions.

9 According to Hillbrand et al. (2017), each million invested in restoration in the Sahel creates 83 new jobs. Every two jobs directly created by an investment further create and/or support another three jobs across the value chain in relevant sectors (World Bank, 2020). It is assumed that income from one job supports the job holder's entire household. According to Global Data Lab (n.d.), the average household size in Chad is 6.1 members. This means every 10 long-term jobs directly created or supported by the restoration investment in Chad support the livelihoods of 61 people.

5.5 Benefit-Cost Ratios of Land Restoration

The BCRs suggest that every dollar invested in land restoration actions in Chad will yield a return of over 3.8 dollars with GHG emissions reduction (that is, when GHG emissions are accounted for, and by applying a shadow price of carbon) and 3 dollars without considering such benefits. Croplands have the highest BCR of just over 4 while GHG emissions reduction is not accounted for (Table 5.4). This is because croplands are the most productive land cover types in Chad in terms of yield,[10] and therefore, the unit costs of inaction on degradation (Table 3.1) and the unit benefits of restoration of such land are the highest (Table 5.5). This is coupled with the fact that the unit cost of restoring croplands is low compared with the benefits resulting in the highest BCR for such lands when GHG emissions reduction benefits are not accounted for (Table 5.5). When the reduction of GHG emissions is accounted for, wetlands have the highest BCR because of GHG removal rate.

Table 5.5. **BCR of restoration of different land cover types in Chad**

Land cover type	BCR	
	With GHG emissions reduction benefit	**Without GHG emissions reduction benefit**
Croplands	4.26	4.02
Pastures	5.53	3.95
Forests	2.68	1.67
Shrublands	1.70	1.47
Wetlands	6.96	2.38
Average for all land cover types	3.78	3.03

Source: World Bank

Investment by the Government of Chad in land restoration is expected to leverage private investment and bring a high return. It is estimated that about 45 percent of the required investment (US$257 million out of US$570 million in PV terms) for restoration of 0.98 million ha of land over 2025–2050 will have to be financed by the government. Government investments of this magnitude, which would be equivalent to 0.1 percent of Chad's GDP, should go towards actions that create public good and benefit all citizens.

If the government investments materialize, it may attract the remaining 55 percent of the required investment from the private sector.[11] Private sector investments will usually be in actions such as conservation agriculture and crop diversification in croplands that primarily benefit private actors. As private actors are also part of the general public, all benefits—private and social[12]—will ultimately be public benefits. As a result, the BCR of government investment in Chad is high, with each dollar invested giving a return of over US$8 when GHG emissions are accounted for and nearly US$7 without accounting for such benefits. Each dollar of private investment in land restoration gives a return of nearly US$4 (Table 5.6).

Table 5.6. **BCR of private and public investments in land restoration in Chad**

Investment source	BCR	
	With GHG emissions reduction benefit	**Without GHG emissions reduction benefit**
Government	8.39	6.72
Private	3.97	3.97

Source: World Bank

The economic analysis is robust. According to the sensitivity analysis, the cost-benefit analysis indicators are sensitive in varying degrees to the changes in the key parameters and the direction of sensitivity is plausible (Appendix D).

10 According to the USDA Foreign Agricultural Service, the average crop yield in the last five years in Chad is over 761 kg/ha/year which brings a revenue of US$ 525 ha/year. Sources: USDA n.d.; FEWS n.d.

11 As far as land restoration in Chad is concerned, the private sector refers to private citizens and entities and includes farmers, households and community members, and private companies.

12 The private benefits primarily go to the private actors and include reduction in crop production cost, increase in crop and livestock production, and marketable provisioning ecosystem services, including NWFP resulting from land restoration. The social benefits go to the entire society and include GHG emissions reductions, all non-marketed provisioning services, and reduction in infrastructure damage.

SUMMARY

This compelling case for restoration not only demonstrates economic value but also highlights its potential for improving livelihoods, particularly for women and rural communities. With restoration now established as both financially sound and socially beneficial, the next section explores how these ecosystem services can be valued in real-world markets, and how these markets can further incentivize and sustain restoration efforts over time.

CHAPTER 6.

Value and Payments Associated with ES Restoration

Sizing the market for ES such as forage for grazing, habitat creation and maintenance, and nature-based tourism help in understanding their true economic as well as ecological value. This understanding in turn motivates restoration efforts, when stakeholders realize the potential of Payments for ES.

6.1 Unraveling the Markets for the Prioritized ES in the OROA Reserve

Markets for ES refer to economic systems in which the benefits provided by ecosystems, such as clean air, water filtration, carbon sequestration, and biodiversity, are bought, sold, or traded (Duraiappah 2006). They are also referred to as Payment for Ecosystem Services (PES) (Ecosystem Marketplace n.d.). These services are often provided by natural ecosystems, but their value is usually not captured by traditional markets because they are considered public goods (non-excludable and non-rivalrous). Markets for ES aim to internalize these values, making them visible and providing economic incentives for conservation and sustainable use of natural resources.

Understanding the markets of the selected ES in the OROA Reserve is crucial because it is key to balancing economic development and biodiversity conservation. Understanding the markets for: i) forage for grazing; ii) habitat creation and maintenance; and iii) nature-based tourism, can frame the unique value of each ES. It can help connect and map the potentially interested parties and their roles in order to financially incentivize environmental stewardship, conservation, and rehabilitation of the natural ecosystems of the OROA Reserve.

Unraveling the market potential of selected ES can drive conservation funding through PES, ensuring sustainable land use by providing integrated or supplementary income to land users and stewards. The sections below outline the potential markets for selected ES in the OROA Reserve, highlighting realistic and current situation and potential towards maintaining habitats for endangered species, traditional land-use practices where possible and mitigating desertification, which provides both local and global benefits. Further, identifying market forces and threats enables better management and protection of these ecosystems.

Markets for the Forage for Grazing ES

Forage for grazing in the OROA Reserve represents a significant natural resource market, particularly for the pastoral communities that depend on it for sustaining livestock, a key contributor to the country’s economy.

Forage availability and pressure is dependent on the use of key land cover types that produce forage—shrublands, grasslands and sparse vegetation—and their ecological health. These three land cover types that produce forage all lost land cover between 2002 and 2020 probably due to intense pressure of overgrazing. Overgrazing has been linked to an estimated 62 percent of land degradation.

Moreover, seasonal variations, including the migration patterns of nomadic pastoralists and changing water availability, further impact the availability of forage. Additional pressures on forage availability are wildfires, though the extent of damage is currently unknown. Many stakeholders mentioned it as an important challenge in accessing forage.

Changing land use types by irrigation via seasonal wadis and water extraction, too, exerts further pressure on forage. This is mostly because of local communities growing crops, rather than pastoralists. The extent of this land use change is not known.

The Reserve supports an estimated 3 million TLUs which consume over 4.55 million metric tons of forage during the two-month dry season. This demand is largely driven by continued access of grazing livestock to the Reserve's rangelands, more specifically the shrublands, grasslands, sparse vegetation, and other similar land cover types. These lands contain forage species favored by grazing animals and their pastoralists. Some forage types are also critical wild foods for human consumption such as "Kreb" (Panicum laetum). The pastoral system that includes cattle, camels, goats, and sheep provide the main economic and subsistence benefits to local communities. Cattle, sheep, and goats constitute most of the livestock population, with each of them consuming different amounts of forage. As Chad's livestock numbers grow, there is mounting pressure on the forage resources, creating competition for grazing space. During periods of drought or low rainfall, the scarcity of forage exacerbates conflicts over land use, putting additional stress on the ecosystem.

The main market challenges are seasonality and variability, environmental degradation, and economic livelihood implications. The market for forage is highly seasonal, with grazing demand spiking during the dry season when natural forage becomes scarce. This seasonality can lead to fluctuations in both supply and demand, affecting the stability of the market. Overgrazing remains a major challenge in terms of environmental degradation, reducing the long-term supply of forage. Unsustainable grazing practices can lead to further desertification, lowering rangeland productivity and threatening the entire pastoral economy. Investments in sustainable grazing practices and land rehabilitation are crucial for maintaining the market. Regarding economic and livelihood implications, the valuation highlights how important the forage market is not only for the environment but for the livelihoods of the local communities. This ES supports a vast livestock population, crucial for food security and income in rural Chad.

Markets for the Habitat Creation and Maintenance ES

This ES in the OROA Reserve is crucial as it supports unique biodiversity, ecosystem stability, and the livelihoods of both local communities and wildlife. The Reserve is a key biodiversity hotspot in sub-Saharan Africa, with 40,000 km^2 of predominantly intact grassland ecosystems. It has the highest irreplaceability index of Chad's protected areas (Brugière and Scholte 2013), indicating its critical role in preserving biodiversity (Ministry in charge of Environment, Chad 2016). It supports rare and endangered species, including the reintroduced scimitar-horned oryx and addax, along with migratory species such as large mammals and waterbirds. The Reserve provides essential habitat maintenance that combats desertification and promotes ecological connectivity, making it indispensable for both local wildlife and pastoralism-based human livelihoods. Its wetlands and wadis also act as natural barriers against land erosion and serve as biodiversity corridors, which further highlight the Reserve's significance in maintaining ecosystem balance in an otherwise arid and fragile environment.

The Reserve provides three main habitat types: Sahelian wooded grassland, sub-desert grassland (covering 66 percent of the reserve), and desert. The Reserve is owned by the MoEF and co-managed by the Sahara Conservation Fund (SCF). SCF has extensively mapped and inventoried plant and animal species for the first time. The Reserve is currently home to 23 species of mammals, according to the OROA Management Plan (Ministry in charge of Environment, Chad 2023). Its seasonal grasslands and wetlands form a habitat network that ensures the survival of migratory and endangered species. Habitat quality in the Reserve is relatively high, with an average index value of 0.79 (on a scale of 0 to 1), reflecting the predominance of natural vegetation in its central and northern areas. However, southern provinces face pressures from agriculture and infrastructure development, which threatens habitat quality.

The demand for the ES in the Reserve stems from the wildlife populations, including critically endangered species like the oryx and addax, which depend on intact and well-maintained habitats, and strict management and conservation of these populations. The Reserve also supports local communities, pastoralists and their livestock who forage for food, grazing, and medicines. Habitat creation and maintenance is also a critical focus for tourists, most of whom consist of science and nature enthusiasts. Moreover, the Reserve contributes to global conservation goals and acts as a model for ecosystem preservation in arid provinces. As species reintroduction programs continue, the need for secure and high-quality habitats becomes even more critical.

The main market challenges are ecotourism potential, environmental degradation and threats, global biodiversity and climate markets, and species-specific markets. Given the Reserve's unique biodiversity and critical role in species conservation, there is potential for the development of ecotourism markets that could provide sustainable income streams for both conservation and local communities. However, this would require significant investment in infrastructure and management to prevent habitat degradation from human activities. The Reserve faces ongoing threats to habitat quality from roads, agriculture, and artificial water points, highlighting the need for stronger management and regulation. The proximity of human activities and increase in infrastructure development may fragment habitats, threaten survival of species, and reduce overall quality of the ecosystem.

As international efforts to combat climate change and preserve biodiversity intensify, the Reserve could become part of the carbon market and emerging biodiversity markets. The soil carbon sequestration potential of grasslands and the role of the Reserve in mitigating desertification could attract international investments aimed at preserving critical habitats. There is also emerging evidence of carbon markets potentially looking at a wider range of carbon projects that also deliver social and environmental co-benefits.

The emerging importance of biodiversity markets as a mechanism to restore and protect biodiversity in recent years is in response to the huge impact of unsustainable land use, climate change, pollution and invasive alien species on ecosystems. These markets are driven by biodiversity offsets and credits, which is a nascent field, but several initiatives are underway globally to design biodiversity credits and test the voluntary market for these credits. There may be species-specific conservation markets for critically endangered species like the scimitar-horned oryx. Other emblematic species could be introduced over time such as cheetahs and wild dogs. Additionally, the Reserve's role in maintaining ecological corridors for migratory species places it in a strategic position for regional biodiversity conservation. Conservation organizations, non-profits, and governments may invest in these species' habitats, recognizing their global conservation value.

6.2 Opportunities for PES schemes in the OROA Reserve

To promote sustainable management and conservation of the Reserve's habitats, three PES schemes are proposed: (i) wildlife conservation and ecotourism, (ii) wildlife conservation and biodiversity markets, and (iii) carbon sequestration and carbon markets. However, these would work only if conditions were conducive.

Wildlife Conservation and Ecotourism

Piloting of a PES area within the Reserve to improve and support conservation activities could enhance the flow of ecotourism to the main faunal Reserve areas. This would result in improved local economies through alternative livelihoods. Land users and pastoralists can provide local food, beverage, accommodation, artisanal products and services, tourism guides, infrastructure and facility enhancement, etc. Expanding the "strictly-protected" zones within the Reserve would allow key and endemic wildlife species to thrive. However, if such zoning restricts access to traditional grazing areas, it may unintentionally trigger leakage effects whereby displaced grazing activities shift to other, unprotected or ecologically sensitive areas, thus undermining the conservation objectives.

To mitigate such risks, SCF and MoEF could consider allowing controlled grazing in other designated parts of the Reserve. This would help accommodate the needs of pastoralists while preserving conservation outcomes. Additionally, expanding strictly protected areas for flagship species could open up further opportunities for attracting public or private financing, including through biodiversity markets (as discussed in the next section), and for enhancing habitat protection and anti-poaching efforts.

The main expected benefits of a wildlife conservation and ecotourism PES scheme include economic incentives, biodiversity protection, and community engagement. Communities can earn income from sustainable tourism; wildlife conservation helps maintain healthy wildlife populations, which in turn protects biodiversity; and community engagement fosters local stewardship of natural resources.

Wildlife Conservation and Biodiversity Markets

To protect, restore, and manage the biodiversity market of the Reserve, a proposal could be the scaling up of the Verifiable Nature Units (VNU) model of African Parks in Zakouma (and the Greater Zakouma Ecosystem, incorporating Siniaka Minia Wildlife Reserve, Bahr Salamat Wildlife Reserve, and connecting areas). This model provides for a nature credits scheme to receive financing for reserves under their management. Revenues generated can be used as payment to local communities and pastoralists to encourage moving away from harmful land use practices and favoring conservation of wildlife and natural habitats, that in turn can attract ecotourism. Other potential biodiversity credit schemes are emerging for which the Reserve could be considered, such as ValueNature, Verra, and Savimbo (Maczik et al. 2024).

Targeted ecological outcomes include protection, regeneration, stewardship and adaptation. Wildlife conservation and biodiversity markets focus on preserving existing biodiversity; regeneration activities are aimed at restoring degraded ecosystems to improve biodiversity; stewardship involves maintaining the ecological value of areas over time; and achieving adaptation targets enhances ecosystem resilience, particularly in the face of climate change.

Carbon Sequestration and Carbon Markets[13]

A PES scheme could compensate landowners or communities for maintaining and restoring soils and vegetated areas that sequester carbon. There is a potential for such a scheme in areas of the Reserve where soil and vegetation can absorb and store carbon. The stored carbon needs quantification to determine a baseline, followed by interventions focusing on restoring degraded soils, increasing natural vegetation through NbS to benefit local communities and land stewards (including agroforestry practices that deliver human and animal benefits, NWFPs, climate-smart agriculture, forestry etc.). Local capacity would also need to be strengthened to plan, implement, manage, and monitor the interventions while measuring the change in carbon stock over time. This carbon could potentially be sold on the carbon market to investors and its revenue fed back into the maintenance of the Reserve. Depending on the quantity of carbon stored and the revenue generated, local communities and pastoralists could be paid to facilitate changes in harmful land practices or grazing that impacts soil and land degradation and reduces carbon storage capacity.

There are four main expected benefits: (i) climate mitigation: helps combat climate change by increasing carbon storage in vegetation; (ii) funding

13 While carbon was not one of the prioritized ES selected for the assessment, it appeared prominently in literature, key informant interviews and consultations, and hence described here as an opportunity to explore and propose a scheme based on the results.

opportunities: attract international private funding from the carbon markets or other climate change initiatives; (iii) habitat restoration: encourages practices that enhance biodiversity and restore degraded ecosystems; and (iv) supplementary income: encourages alternative livelihood through practices that restore degraded ecosystems and practice more sustainable agriculture and agroforestry.

6.3 Development of Non-Wood Forest Products (NWFP) Value Chains

NWFPs provide an important source of livelihood in Chad. A quarter of a billion people live in and around dry forests in Sub-Saharan Africa. Dry forest resources provide basic needs and essential materials such as building supplies, food, cropland, fuelwood, and NWFPs to about 320 million people (Haile et al. 2021). In the wider Sahel region, wild products support rural livelihoods and foster environmental conservation, particularly in the face of drought, land degradation, and climate variability (Rachid et al. 2023). NWFPs provide foodstuffs, medicines, and raw materials, helping diversify income sources and reducing vulnerability to agricultural risks (Sacande and Parfondry 2018).

In Chad's Sahel region, the Acacia senegal (source of gum arabic) and the desert date (Balanites aegyptiaca) are among the most valuable and multifunctional NWFPs which are also NbS. They offer marketable products while contributing to soil fertility, fodder, and shade. They help improve the economic resilience of vulnerable rural populations and act as safety nets during poor agricultural seasons.

With the desert date, gum arabic contributes significantly to the economy. It is the fourth largest export product after oil, livestock, and cotton and represented about 7 percent of Chad's global export value in 2019. In 2022, about 30,000 tons of gum arabic were produced. Chad is the third largest exporter of Gum Arabic in the world. However, it can potentially contribute much more to the economy if processing facilities are available in-country.

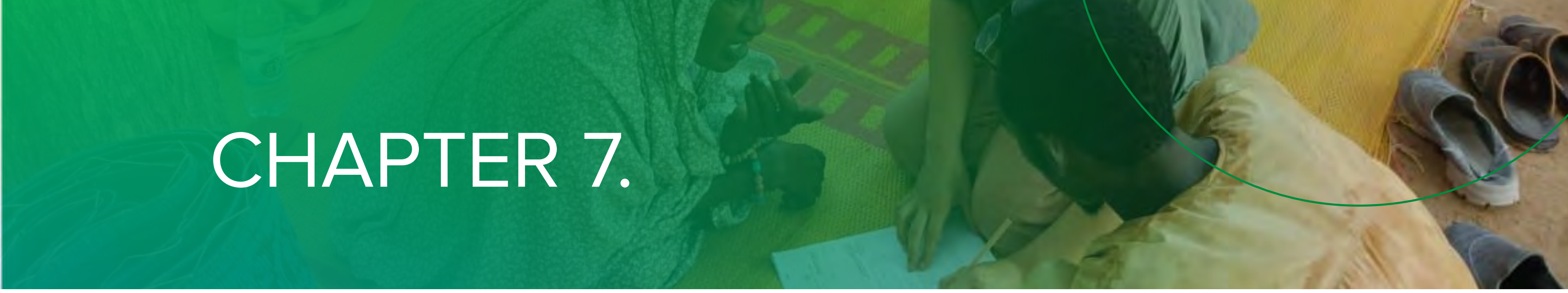
Main Expected Benefits of Investing in NWFP

Multilateral donors recognize the potential of forest products and NWFPs to foster rural economies while contributing to environmental conservation. In Chad, forest products still play a significant role in rural livelihoods. Fodder constitutes a greater portion of the environmental income than forests. This difference is largely because grazing areas are often composed of natural grasslands, savannahs, shrublands, and other open ecosystems where forage is abundant, and livestock management is more feasible. Moreover, in semi-arid and arid zones where natural wooded areas are sparse and scattered, pastoralist communities rely extensively on these landscapes for livestock fodder. These open environments provide essential forage resources, playing a crucial role in sustaining pastoral livelihoods.

NWFPs arguably play a relevant role in livestock farming since the primary source of livestock feed remains rainfall-dependent natural pastures, crop residues, and woody species. NWFPs support resilient value chains, offering economic opportunities for local communities, particularly women and youth. Their involvement in collecting, processing, and marketing NWFPs can increase household income and enhance their resilience.

SUMMARY

Understanding the market dynamics behind ecosystem services makes clear that ecological stewardship can also be an engine of economic growth. When local communities and institutions recognize the value of what nature provides, they are better equipped to protect it. The following chapter draws together the findings of this study, outlining the strategic actions needed to support a resilient and inclusive path forward.



CHAPTER 7.

Conclusions and Recommendations

Without a doubt, the returns on investment in restoration in Chad are promising. Vulnerable hotspots must be restored with targeted and managed efforts.

Land restoration through NbS in Chad is economically viable and it is significantly cheaper to implement restoration actions than not taking any action at all and letting the degraded area expand with increased severity. With annual investments of just under US$25 million over 2025–2050, nearly one million ha of Chad's degraded lands located in the hotspots (areas with maximum restoration potential) can be restored through NbS. Almost 80 percent of the total restoration investments are required in the next 15 years to be effective, thus confirming the urgency to take action in the short and medium term. Over the same period, while the overall average costs of inaction on land degradation are estimated to be US$1,844 per ha, the required investment in restoration actions is estimated to be US$682 per ha. The average benefits of actions over the same period are estimated to be US$2,265 per ha. Every US$ invested in land restoration actions in the country is estimated to yield a return of over US$3.3. This investment is expected to bring an annual benefit of nearly US$83 million on average over the same period.

The best-suited actions for Chad include conservation of agriculture and crop diversification (croplands), rotational grazing and silvo-pastoral system (pastures), conservation and vegetation management, agroforestry, afforestation and reforestation (forests and shrublands). Benefits from NbS actions include reduction in cost of crop production, increased production of crops and livestock, reduction in infrastructure damages, enhanced ecosystem services, and curtailing GHG emissions. Moreover, the restoration investments are expected to generate significant positive impact on employment and livelihood in Chad with women receiving a sizeable share of them.

While climate risks are projected to be greatest in central Chad, land degradation is expected to be most severe in the agricultural provinces of southern Chad and parts of central-eastern Chad, because of land-use pressures related to increased refugee populations (e.g. soil erosion and nutrient depletion). The most affected areas include Logone Occidental, Logone Oriental, and Mayo-Kebbi Ouest, where high population density and unsustainable land-use practices are accelerating land degradation. In Ouaddaï and parts of Sila, additional pressure from refugee movements has contributed to further deforestation and soil depletion.

Without intervention, carbon sequestration losses could reach up to 43.85 t/ha, and flood mitigation capacity could decline by as much as 43.36 m^3/ha, increasing the vulnerability of agricultural lands. Cropland restoration is most urgently needed in Ouaddaï, which has 51,155 ha of land targeted for rehabilitation, followed by Mayo-Kebbi Ouest with 16,233 ha and Sila with 10,683 ha. Restoration in these provinces must focus on sustainable cropland management, including conservation agriculture, crop diversification, and soil erosion control techniques. Targeted reforestation in agroforestry systems can also help restore soil structure and enhance long-term productivity. Implementing these interventions in high-priority cropland areas could reverse degradation trends, improve food security, and secure the livelihoods of farming communities that depend on the land.

Landscape restoration efforts in Chad are projected to yield substantial ES benefits that will vary by region, land cover type, and land use. Restoration of the following land cover types yield benefits as follows:

- Reforestation benefits are concentrated in the central and southern provinces;
- Shrubland restoration benefits are most extensive in the eastern region that is vulnerable to desertification;
- Grassland restoration benefits are the greatest in arid/semi-arid zones affected by overgrazing;
- Cropland restoration benefits are in southern and eastern zones that are agriculturally important. They can bring about increased soil fertility and productivity; and
- Wetland restoration benefits are centered around Lake Chad, to enhance water regulation and support fisheries and agriculture.

When expressed per ha, restoration benefits show strong regional contrasts in increase in carbon sequestration, flood mitigation improvements, and increase in forage biomass productivity. These findings underscore the value of spatially targeted restoration in Chad's diverse landscapes.

The two NWFPs with the biggest potential in Chad are Gum Arabic and Desert Date. The significant export product gum arabic (derived from the Acacia Senegal tree) is Chad's most important NWFP in terms of value chains, and thus, a critical source of income for rural communities especially in the semi-arid zones. The desert date (Balanites Aegyptiaca) palm's fruits and oil-rich seeds are used for food and traditional medicine and its leaves and pods serve as livestock fodder. Both multifunctional NWFPs offer marketable products while contributing to soil fertility, fodder, and shade, thus supporting agro-pastoral systems, and highlight the potential of forest products to underpin sustainable rural development in the Sahel. In more arid zones, fodder constitutes a greater portion of environmental income than forests as grazing areas are often composed of natural grasslands, savannahs, shrublands, and other open ecosystems where forage is abundant and livestock management is more feasible.

NWFP farmers must get better organized to develop the NWFP value chain. Otherwise, the NWFP value chain can be dominated by buyers. If farmers get organized into collectives, it could positively impact their bargaining power in the supply chain.

Restoration efforts must be spatially targeted, with strategies tailored according to ecosystem type and land use pressures. The study recommends targeting restoration efforts per ecosystem type as follows (see Box 8.1 for recommendations for the OROA Reserve):

- Forest restoration is most beneficial in the central and southern provinces which have areas prioritized for reforestation.
- Shrubland restoration is effective in eastern Chad which has areas vulnerable to desertification and are prioritized for regreening.
- Grassland restoration benefits are greatest in the western provinces that have areas prioritized for improvement of forage and soil stability.
- Cropland restoration is prioritized in southern and eastern provinces that have areas targeted for enhancing soil fertility and productivity.
- Wetland restoration is most effective around western Chad with prioritized area to enhance water regulation and support fisheries and agriculture.

To strengthen ongoing restoration efforts in Chad, there is a need to undertake additional targeted work, which will also benefit development partners. Future work should focus on strengthening synergies with existing government policies and inform future policies and plans such as the National Land Use Plan and the National Development Plan. Such work should foster connections between ecosystem preservation, food security, population growth projections, and sustainable value chain development.

Furthermore, there is a need for studies that differentiate between degradation driven by economic activity and by climate change. Spatial data on impact of climate change must be integrated into a coherent modeling framework. An overarching study should be undertaken to assess all ongoing efforts in Chad on land restoration and ES by the government and other actors. A matrix can be prepared with a timeline for actions and identifying gaps and areas for further collaboration. Further studies on ecosystems in Chad could also draw on the World Bank's report on The Changing Wealth of Nations, which estimates values by ES and biome per country (World Bank 2024c). Finally, any further studies undertaken must account for the need for stronger stakeholder engagement and strengthened resource capacity at both national and local levels in Chad.

Box 7.1. Conclusions and recommendations for the protected OROA Reserve

Important actions need to be implemented to preserve the three ES in the OROA Reserve. It is recommended to introduce sustainable grazing practices for environmental restoration and to manage the supply of forage, in alignment with the National Adaptation Plan and OROA Management Plan. Additional research is needed to help frame the market for forage and to develop more accurate data on the livestock unit consumption of specific forage. Furthermore, to preserve the economic and ecological value of habitat creation and maintenance in the Reserve, there is a need for effective management and sustainable land-use practices, in alignment with the National Biodiversity Strategy, the National Adaptation Plan, and the OROA Reserve Management Plan. Finally, there would be value in tapping into the potential for NbT in the Reserve through enhanced collaboration between governmental bodies, private partners, and local communities, and through investments in critical infrastructure such as for transport, water, and technology.

The OROA Reserve's relative ecological integrity suggests that targeted efforts could yield significant benefits. This scenario poses a significant opportunity for conservation efforts to support and protect the ecosystem before more severe degradation occurs. Observed trends such as the expansion of sparse vegetation, pressures from agricultural land use, and the presence of artificial water points highlight both risks and opportunities for sustainable development. Efforts targeted to support practices that balance economic needs with conservation goals can help maintain ecosystem services while promoting resilience in the face of potential future degradation.

There is potential for market development and scale-up of a selection of forest produce, including NWFPs, that can contribute to more resilient and climate-smart livelihoods. There is a strong case for initiatives that support the sustainable development of such products, as they foster rural economic growth and contribute to environmental conservation. NWFPs represent multifaceted contributions to livelihoods of rural communities, act as safety nets during poor agricultural seasons, contribute significantly to local diets, provide traditional medicines, and generate vital income streams. Also, there is a need to valorize the role of local women in NWFP gathering and marketing. Deeper analysis of the market and value chains for critically important NWFPs in use in the OROA Reserve can allow internalizing the economic benefits of restoration.

To promote sustainable management and conservation in the OROA Reserve, potentially promising PES schemes could be implemented. By identifying potential market mechanisms, conservation funding can be enhanced through PES, ensuring sustainable land use while supporting local communities. The OROA Reserve has significant potential for implementing PES schemes aimed at promoting sustainable management and conservation while bringing in additional economic returns for the different stakeholders. Four potential PES schemes are proposed: wildlife conservation and ecotourism; wildlife conservation and biodiversity markets; carbon sequestration and carbon market; and development of NWFP value chains.

Appendix A: Normalized Difference Vegetation Index Results

Table A.1. NDVI land cover comparison results for OROA Reserve

#	Land cover (OROA Reserve)	NDVI 2002	NDVI 2020	NDVI change	NDVI change (%)
1	Rainfed cropland	1,681.135	1,892.2273	211.0923	12.56%
2	Herbaceous cropland	1,542.455	1,857.3613	314.9063	20.42%
3	Irrigated or post-flooding cropland	848.8877	873.7686	24.8809	2.93%
4	Mostly cropland in a mosaic with natural vegetation	1,685.053	1,863.8167	178.7637	10.61%
5	Mostly natural vegetation in a mosaic with cropland	1,630.226	1,797.1918	166.9658	10.24%
6	Mostly trees and shrubs in a mosaic with herbaceous cover	1,657.995	1,823.731	165.736	10.00%
7	Shrubland	1,563.887	1,729.0562	165.1692	10.56%
8	Grassland	1,671.052	1,856.7935	185.7415	11.12%
9	Sparse vegetation	1,382.628	1,528.2538	145.6258	10.53%
10	Sparse shrubs	1,611.146	1,727.7372	116.5912	7.24%
11	Sparse herbaceous cover	1,518.746	1,696.0437	177.2977	11.67%
12	Bare areas	1,116.422	1,141.2058	24.7838	2.22%
13	Unconsolidated bare areas	1,520.636	944.7365	-575.8995	-37.87%
14	Consolidated bare areas	921.9902			

Source: World Bank

Table A.2. NDVI land cover comparison results for OROA Reserve and surroundings

#	Land cover (OROA Reserve and surroundings)	NDVI 2002	NDVI 2020	NDVI change	NDVI change (%)
1	Rainfed cropland	2,052.6211	2,338.602	285.9809	13.93%
2	Herbaceous cropland	2,169.4797	2,285.658	116.1783	5.36%
3	Irrigated or post-flooding cropland	2,285.7012	2,409.945	124.2438	5.44%
4	Mostly cropland in a mosaic with natural vegetation	2,247.6694	2,509.615	261.9456	11.65%
5	Mostly natural vegetation in a mosaic with cropland	2,047.8169	2,262.277	214.4601	10.47%
6	Mostly trees and shrubs in a mosaic with herbaceous cover	1,673.0416	1,887.463	214.4214	12.82%
7	Mostly herbaceous cover in a mosaic with trees and shrubs	1,730.2509	2,120.482	390.2311	22.55%
8	Shrubland	1,423.3055	1,555.902	132.5965	9.32%
9	Grassland	1,868.6096	2,105.698	237.0884	12.69%
10	Sparse vegetation	1,408.2196	1,545.749	137.5294	9.77%
11	Sparse shrubs	1,611.5054	1,730.295	118.7896	7.37%
12	Sparse herbaceous cover	1,530.5354	1,713.268	182.7326	11.94%
13	Urban areas	1,852.2567	1,868	15.7433	0.85%
14	Bare areas	1,035.8832	1,066.619	30.7358	2.97%
15	Consolidated bare areas	1,199.0225	1,173.141	-25.8815	-2.16%
16	Unconsolidated bare areas	757.3099	790.6368	33.3269	4.40%

Source: World Bank

Appendix B: Tables related to Land Cover Analysis

Table B.1. Definition of land cover types in the OROA Reserve and its surroundings (2002 – 2022)

Cover	Where it is present	UN Land Cover Classification System (LCCS) definition
Rainfed cropland	OROA Reserve and surroundings	Agricultural land that relies entirely on natural rainfall for water. It typically includes varlous crops grown without irrigation.
Herbaceous cropland	OROA reserve and surroundings	Agricultural areas primarily used for growing herbaceous plants, which are non-woody plants, including grains and grasses cultivated for food and fodder.
Irrigated or post-flooding cropland	OROA reserve and surroundings	Agricultural lands that receive water through irrigation systems or those that are farmed after natural flooding events, utilizing residual moisture for crop production.
Mostly cropland in a mosaic with natural vegetation	OROA reserve and surroundings	Areas where cropland is the dominant land use, interspersed with patches of natural vegetation. These mosaics include small plots of cultivated land mixed with remnants of natural ecosystems.
Mostly natural vegetation in a mosaic with cropland	OROA reserve and surroundings	Provinces where natural vegetation predominates, with scattered plots of cropland integrated within the natural landscape. These areas often support biodiversity alongside agricultural activities.
Mostly trees and shrubs in a mosaic with herbaceous cover	OROA reserve and surroundings	Land where trees and shrubs form the primary cover, interspersed with herbaceous plants. These mosaics maintain a mixture of woody and non-woody vegetation.
Shrubland	OROA reserve and surroundings	Areas dominated by shrubs, which are woody plants smaller than trees, often found in provinces with ard or semi-arid climates. Shrublands support diverse ecosystems adapted to dry conditions.
Sparse vegetation	OROA reserve and surroundings	Land covered predominantly by grasses and other herbaceous plants. Grasslands can be natural or managed and often serve as Important grazing areas for livestock and wildife habitats,
Grassland	OROA reserve and surroundings	Provinces where vegetation cover is minimal, with widely scattered plants. These areas may Include varlous plant types, such as grasses, shrubs, and small trees, adapted to sparse conditions.
Sparse shrubs	OROA reserve and surroundings	Areas where shrubs are present but widely spaced, leading to low overall shrub cover. These areas are typically found in arid environments with limited water availability.
Sparse herbaceous cover	OROA reserve and surroundings	Land with a low density of herbaceous plants, which are scattered and do not form a continuous cover. This type of cover is often found in provinces with harsh growing conditions.
Bare areas	OROA reserve and surroundings	Provinces with little to no vegetation cover, consisting mainly of bare soil, rock, or other exposed surfaces. Bare areas may result from natural processes or human activities.
Unconsolidated bere areas	OROA reserve and surroundings	Bare provinces where the soil or substrate is loose and not compacted. These areas are prone to erosion and may include sandy or gravelly surfaces.
Consolidated bare areas	OROA reserve and surroundings	Bare land with compacted or hard surfaces, such as bedrock or hardpan soil. These areas are more resistant to erosion but often support very limited vegetation.
Mostly herbaceous cover in a mosaic with trees and shrubs	Surroundings of the reserve	Land cover type predominantly composed of herbaceous plants, with scattered patches of trees and shrubs. This mosaic maintains a balance between open areas dominated by herbaceous cover and areas where woody plants are present.
Bodies of water	Surroundings of the reserve	Areas covered by significant amounts of water, either permanent or seasonal. This category includes lakes, rivers, reservoirs, ponds, and wetlands.
Urban areas	Surroundings of the reserve	Provinces characterized by a high density of human structures and infrastructure, such as buildings, roads, and other developed land. Urban areas indude citles, towns, and other settlements where the land is primarily used for residencial, comercial, industrial, and transportation porpuses.

Source: World Bank

Table B.2. **TEV per land cover used for the land degradation assessment**

Class	TEV (2024 US$/ha/year)	Analogous ecosystem	SOURCE
Irrigated or post-flooding cropland	11,135.23	Adjusted for similarity based on annual croplands	ESVD study 1151 Niger
Rainfed cropland	6,186 24	Annual croplands	ESVD study 1151 Niger
Mostly cropland in a mosalc with natural vegetation	6,062 52	Adjusted for similarity based on annual croplands	ESVD study 1151 Niger
Herbaceous cropland	4,206.64	Adjusted for similarity based on annual croplands	ESVD study 1151 Niger
Mostly natural vegetation in a mosaic with cropland	3,093.12	Adjusted for similarity based on annual croplands	ESVD study 1151 Niger
Bare areas	1150.87	Deserts	Chen & Costanza 2024
Consolidated bere areas	1,093.33	Adjusted for similarity based on deserts	Chen & Costanza 2024
Unconsolidated bare areas	840 14	Adjusted for similarity based on deserts	Chen & Costanza 2024
Mostly trees and shrubs in a mosaic with herbaceous cover	425.43	Adjusted for similarity based on grasslands and shrublands	ESVD study 1215 Ethiopia
Bodies of water	387.99	Water bodies	ESVD study 4 Nigeria
Mostly herbaceous cover in a mosaic with trees and shrubs	375.38	Adjusted for similarity based on grasslands and shrublands	ESVD study 1215 Ethiopia
Grassland	250 25	Grasslands and shrublands	ESVD study 1215 Ethiopla
Shrubland	250 25	Grasslands and shrublands	ESVD study 1215 Ethiopia
Sparse shrubs	212.72	Adjusted for similarity based on grasslands and shrublands	ESVD study 1215 Ethiopia
Sparse vegetation	180.18	Adjusted for similarity based on grasslands and shrublands	ESVD study 1215 Ethiopia
Sparse herbaceous cover	150.15	Adjusted for similarity based on grasslands and shrublands	ESVD study 1215 Ethiopla
Urban areas	0	N/A	N/A

Source: World Bank

Table B.3. **Land cover accounts for thE OROA Reserve between 2002 and 2020**

Land cover	2002 extent (km²)	Unchanged (km²)	Additions to stock (km²)	Reductions to stock (km²)	2020 extent (km²)	Net change in stock (km²)	Net change in stock (%)
Rainfed Cropland	965	751.4	184	214	935.26	-2.974	3.08%
Herbaceous Cropland	6	5.1	284	1	289.21	283.19	4,704.14%
Irrigated or Post-Flooding Cropland	2	1.4	0	0	1.60	-0.18	9.98%
Mostly Cropland in a Mosaic with Natural Vegetation	33	24.7	19	9	43.60	10.31	30.95%
Mostly Natural Vegetation in a Mosaic with Cropland	275	224.6	202	51	426.33	150.95	54.82%
Mostly Trees and Shrubs in a Mosaic with Herbaceous Cover	140	105.5	36	35	141.14	0.89	0.63%
Shrubland	363	270.2	77	93	347.63	-15.40	4.24%
Grassland	12,045	10,173.0	1,280	1,872	11,453.27	591.50	4.91%
Sparse Vegetation	10,105	9,174.9	7,287	930	16,461.47	6,356	62.91%
Sparse Shrubs	1.137	862.5	160	275	1,022.13	-115.37	-10.14%
Sparse Herbaceous Cover	10,275	5,832.3	754	4,443	6,586.03	-3,689	-35.90%
Bare Areas	47,668	44,676.9	632	2,991	45,309.38	-2.358	4.95%
Unconsolidated Bare Areas	7	54	2	2	6,95	-0.54	-7.18%
Consolidated Bare Areas	1	0.0	0	1	0	-1.12	-100.00%
TOTAL	**83,024**		**10,916**	**10,916**	**83,024**		

Source: World Bank

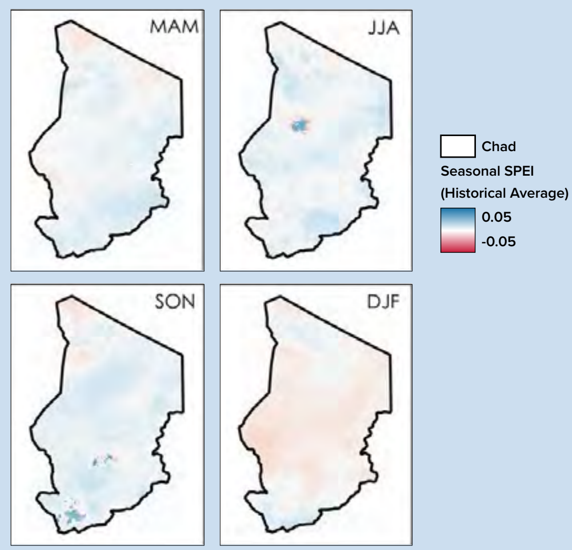
Table B.4. **Land cover accounts for the OROA Reserve and surroundings between 2002 and 2020**

Land cover	2002 extent (km²)	Unchanged (km²)	Additions to stock (km²)	Reductions to stock (km²)	2020 extent (km²)	Net change in stock (km²)	Net change in stock (%)
Rainfed Cropland	5,585.8	4997.9	866,3	588.0	5864.2	278.3	5,0%
Herbaceous Cropland	320,9	287.0	880,0	33.9	1167.0	846.1	263.7%
Irrigated or Post-Flooding Cropland	158.8	141.5	69.6	17.3	211.1	52.3	33.0%
Mostly Cropland in a Mosaic with Natural Vegetation	451.3	378.8	128.9	72.5	507.7	56.4	12.5%
Mostly Natural Vegetation in a Mosaic with Cropland	1,130.6	1,009.0	446,6	121,7	1,455.5	324.9	28.7%
Mostly Trees and Shrubs in a Mosaic with Herbaceous Cover	177.4	154.6	32.8	22.8	187.4	10.0	5.6%
Shrubland	1,016.8	886.1	145.7	130,7	1,031.8	15.0	1,5%
Grassland	57,525.2	52,387.8	2,717.8	5,137.4	55,105.6	-2,419.6	-4.2%
Sparse Vegetation	19,786.0	18,458.9	13,871.1	1,327.1	32,329.9	12,544.0	63.4%
Sparse Shrubs	1,229.3	982.6	120,3	246.7	1,102.9	-126.4	-10.3%
Sparse Herbaceous Cover	19,568.7	11,405.1	1,005,4	8,163,6	12,410,5	-7,158.2	-36.6%
Bare Areas	130,738.1	125,468.3	833,8	5,269.8	126,302.1	-4,436.1	-3.4%
Unconsolidated Bare Areas	81.5	73.4	8.6	7.9	82.0	0.7	0.9%
Consolidated Bare Areas	8.5	5.9	1.1	2.6	7.0	-1.5	-18.1%
Mostly Herbaceous Cover in a Mosalc with Trees and Shrubs	42.3	352	12.9	7,0	48.1	59	13.9%
Bodies of Water	5.2	4.7	2.6	0.5	7,3	2.1	39.8%
Urban Areas	12.5	124	6.1	0.1	18.5	6.0	48.0%
TOTAL	**237,838.7**	**216,689.2**	**21,149.5**	**21,149.5**	**237,838.7**		

Source: World Bank

Appendix C: Methods to Assess Drivers of Change and Identify Hotspots of Land Degradation

Table C.1. **Explanations of climate variables, methods used to process them into risk indices, and visualizations of the seasonal and spatial variability across these metrics**

Climate-related variables	Visualization (maps)
1. **Drought Index (5km-resolution): Standardized Precipitation Evaporation Index (SPEI)** one-month timescale. This SPEI combined precipitation from CHIRPS and Bristol Potential Evapotranspiration (hPET). **Explained:** SPEI greater than 2 are considered extremely wet, 1.5–2 is very wet, 1–1.5 moderately wet, minus 1 to 1 normal, minus 1.5 to minus 1 moderately dry, minus 2 to minus 1.5 severely dry, and values below minus 2 extremely dry. The 40-year mean seasonal SPEI indices (Figure C.1) reveal no persistent spatial patterns of drought relative to vegetative evapotranspiration. All values lie well within the normal range of -1 to 1 (the color bar scale in the figure is -0.05 to 0.05). Thus, any region or season cannot be interpreted as experiencing preternaturally heightened water stress based on SPEI. **Index aggregation techniques:** Monthly indexes covering 1981–2022 were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON). **Country context:** There is no significant spatial pattern in SPEI that indicates severe or persistent water stress in the country, at least at the 40-year seasonal average. **What does this mean for future climate change?** Without a SPEI-derived indication of water stress, we assume the following relationships indicate increased climate risk: **Water stress:** any deviation from current trend in seasonal precipitation (positive or negative) • **Flood risk:** any increase in short-period precipitation (1-day or 5-day maximums) • **Extreme heat:** any increase in the number of days over 35°C • **Climate shifts:** any increase in seasonal average temperature Data source: (Gebrechorkos et al., 2023) https://dx.doi.org/10.5285/ac43da11867243a1bb414e1637802dec	Figure C.1. **40-year mean seasonal SPEI indices**  Source: World Bank

2. **Precipitation anomaly (CMIP 6 ssp3–7.0 2040–2059, 50th percentile).**

   Explained: It is the increase or decrease in precipitation from current observed data.

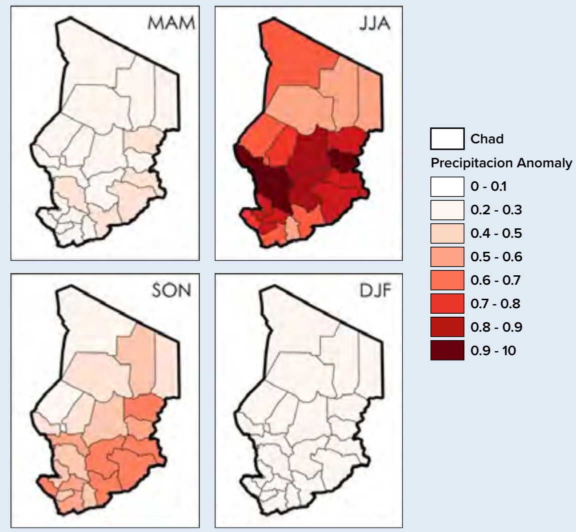
   Index aggregation techniques: Monthly indexes were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON).

   Country context: Precipitation increased primarily during the rainy season (JJA, SON). There was significant variability in that change across the country, but generally the Sahel region experienced the highest increases. There was no change in precipitation in DJF and only small increases during MAM.

   Risk ranking: Any change (increase, decrease) in precipitation was considered a risk, although Chad only experienced projected increases in precipitation.

   Data sources: WBCCKP (n.d.)

Figure C.2**. Precipitation anomaly across Chad, throughout the year**



Source: World Bank

3. **Monthly maximum 1-day precipitation (Rx1day) anomaly** (CMIP 6 ssp3–7.0, 2040–2059, 50th percentile).

   Explained: Very high 1-day precipitation totals could be the result of intense but short-lived precipitation events such as thunderstorms or may be due to precipitation occurring steadily over the course of the day. Short-duration, high-intensity precipitation events may lead to flash flooding, particularly in urban areas where storm drains may be overwhelmed (Adler et al., 2018).

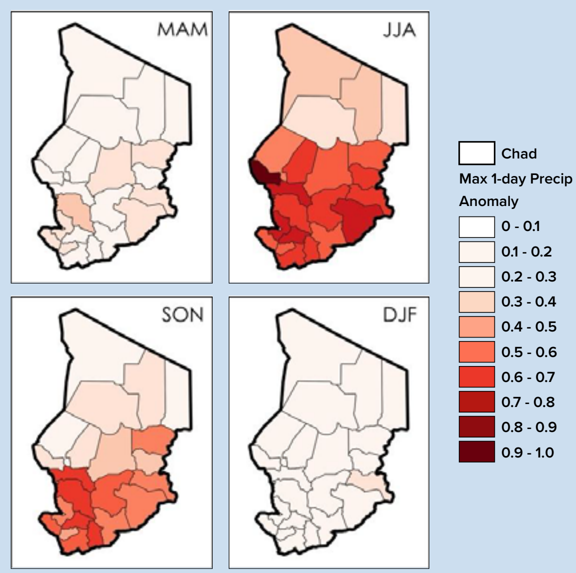
   Index aggregation techniques: Monthly indexes were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON).

   Country context: Extreme 1-day precipitation totals increased primarily in the rainy season (JJA, SON) and mostly in the southern half of the country. The southwestern portion of the country is at particular risk, posing a threat to denser population centers.

   Risk ranking: Any increase in extreme 1-day precipitation totals was considered risky.

   Data sources: WBCCKP (n.d.)

Figure C.3. **Monthly maximum 1-day precipitation anomaly across Chad, throughout the year**



Source: World Bank

4. **Monthly maximum consecutive 5-day precipitation (Rx5day) anomaly** (CMIP 6 ssp3–7.0, 2040–2059, 50th percentile).

   Explained: High precipitation totals can cause flooding in urban areas, damage to crops and roads, and erode topsoil. The index is relevant for water management, agriculture, and disaster risk assessment, particularly for assessing river flood, landslide, and erosion risks (Adler et al. 2018; EEA 2023).

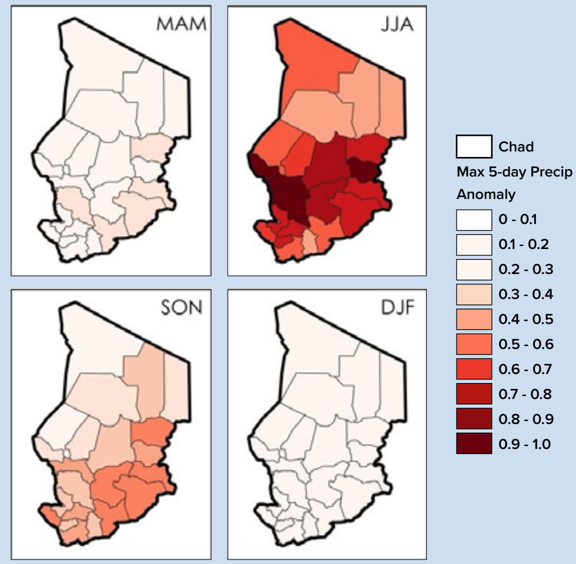
   Index aggregation techniques: Monthly indexes were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON).

   Country context: Extreme 5-day precipitation totals increased primarily in the rainy season (JJA, SON) and generally (but not exclusively) in the southern half of the country.

   Risk ranking: Any increase in extreme 5-day precipitation totals was considered risky.

   Data sources: WBCCKP (n.d.)

Figure C.4. **Monthly maximum consecutive 5-day precipitation anomaly across Chad, throughout the year**



Source: World Bank

5. **Monthly temperature anomaly** (CMIP 6 ssp3–7.0, 2040–2059, 50th percentile).

   Explained: A departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value.

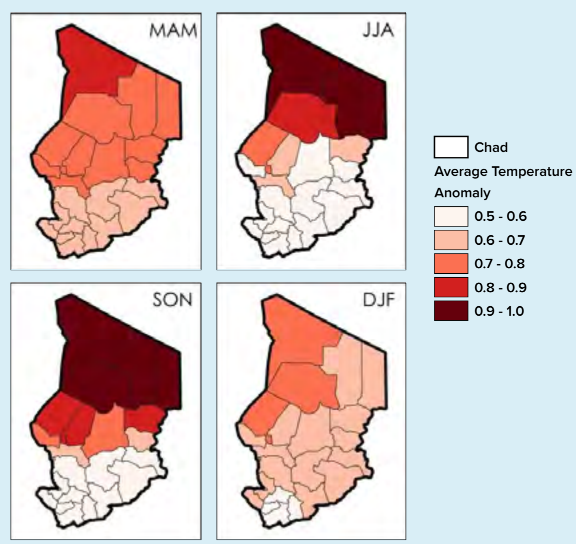
   Index aggregation techniques: Monthly indexes were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON).

   Country context: Temperatures increased significantly in all seasons. The northern half of the country is at particular risk, although there was no area deemed at "low risk" for temperature change.

   Risk ranking: Any positive anomaly was considered a risk due to increased risk of heightened evapotranspiration and water scarcity, alongside other high-temperature risks.

   Data sources: WBCCKP (n.d.)

Figure C.5. **Monthly temperature anomaly across Chad, throughout the year**



Source: World Bank

6. **Hot days above 35° Celsius anomalies** (CMIP 6 ssp3–7.0, 2040–2059, 50th percentile).

   Explained: An approximation of the number of extreme heat events that can increase human and animal health risks, crop failure, etc.

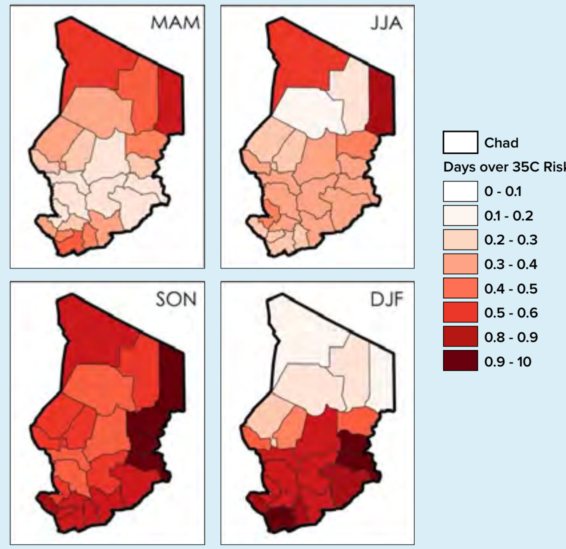
   Index aggregation techniques: Monthly indexes were combined into seasonal mean: Dec, Jan and Feb (DJF); Mar, Apr, May (MAM); Jun, Jul, Aug (JJA); Sept, Oct, Nov (SON).

   Country context: The spatial patterns of extreme heat risk varied by season, although most parts of the country experienced significant risk during at least one season. The SON and DJF periods in particular show high risk to areas of denser human populations.

   Risk ranking: Any increase above 35 degrees Celsius could potentially threaten the lives of livestock and people and cause disease outbreaks.

   Data sources: WBCCKP (n.d.)

Figure C.6. **Hot days above 35° Celsius anomalies across Chad, throughout the year**



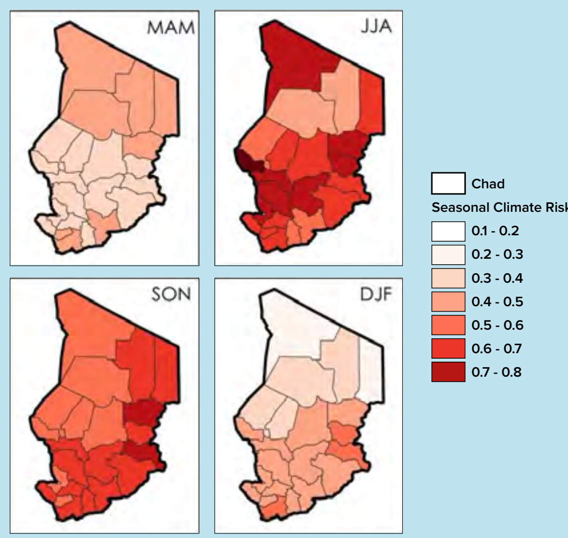
Source: World Bank

Climate risk summary level 1: The averaged CMIP6 ensemble (ssp3–7.0, 2040–2059, 50th percentile)

Explained: Seasonal average of each of the five component CMIP6 sub-indicators were used. Each sub-indicator had first been processed into 0–1 indices of risk based on the annual maximum and minimum values for each indicator.

Country context: Most of the climate risk accrues during the rainy season (JJA, SON) and is distributed relatively evenly across the country, although some areas experience higher risk of certain sub-indicators than others (e.g. precipitation vs temperature).

Figure C.7. **Climate risk across Chad, throughout the year**



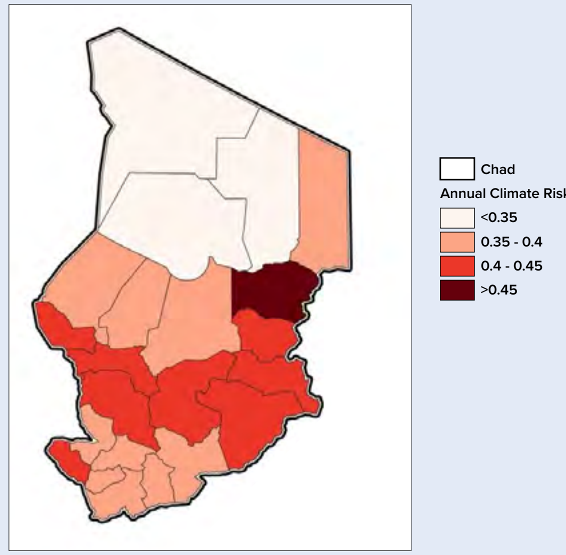
Source: World Bank

Climate risk summary level 2: Overall climate change risk map by region by 2050 on an annual average using the 50th percentile of CMIP6 ensemble.

Explained: Seasonal risks (climate risk summary level 1) were averaged into a single annual score.

Country context: The greatest climate risk occurs in a band just south of the Sahel region. This poses a threat to local ecosystems and the services they provide to the populations living within that band.

Figure C.8. **Climate risk across Chad, annual average**



Source: World Bank

Appendix D: Methodology for the Estimation of the Cost of Inaction on Land Degradation in Chad

Foregone Ecosystem Services, Crop and Livestock Production

The economic values of foregone ecosystem services, crop and livestock production due to inaction on land degradation in Chad are estimated by using the loss of net primary productivity (NPP) of biomass (Table D.1), different ratios of conversion from NPP to respective products and services in different land cover types, unit market prices and values, and as appropriate, yield of these products and services.

Table D.1. NPP loss in degraded lands in Chad

Land cover type	NPP loss in degraded land*		
	Baseline (2025) (A)	Additional NPP loss due to degradation in 2050** (B)	BaU (2050) (A+B)
Forests	71.00%	17.70%	88.70%
Croplands	71.00%	2.00%	73.00%
Pastures	71.00%	1.92%	72.92%
Shrublands	71.00%	5.54%	76.54%
Wetlands	71.00%	12.77%	83.77%

*In comparison to the NPP of healthy land in the respective land cover type;
**In comparison to the baseline (2025).

Source: Natural Capital Insights

Additional NPP loss due to land degradation in 2050 for a land cover type is calculated by multiplying the predicted soil loss (that is, sediment export) with a soil loss to NPP loss ratio of 0.55 as reported by Zika and Erb (2009). The predicted soil loss data for each land cover type is generated by Natural Capital Insights as a part of the degradation analysis for this report.

The NPP loss for every year between 2025 and 2050 is estimated by following a linear trend of the corresponding loss values in these two terminal years. The share of product or service loss due to land degradation each year between 2025 and 2050 is estimated by multiplying the respective NPP loss value by an appropriate conversion factor as given in Table D.2.

The economic value of foregone ecosystem services in a year for a land cover type is calculated by multiplying the share of foregone ecosystem services value in that year for that land cover by the unit value of ecosystem services for that land cover type. In Chad, the value of ecosystem services provided by forests is US$136.45/ha/year, by shrublands US$68.22/ha/year and by wetlands US$50.16/ha/year, as well as by croplands

Table D.2: Conversion factors used to estimate product and service loss from NPP loss

Product/ Service	Conversion factor*	Applicable land cover type	Comment, justification, and source
Ecosystem services	1.00	All	The amount of ecosystem services supplied is exactly proportional to the biomass stock in a particular ecosystem. Therefore, the NPP loss share is equal to the share of the foregone ecosystem services value.
Crop production	0.50	Cropland	For example, a 50% NPP loss in cropland results in a 25% crop production loss. Major et al. (1986)
Livestock product	0.17	Grassland	In Chad, livestock production is entirely pasture-based. Therefore, for 1% NPP loss due to degradation in pasture, 0.17% of livestock product (that is, meat, milk and wool) is foregone (A Well-Fed World, n.d.)

*NPP loss to product/service
Source: World Bank

US$16.64/ha/year and by grasslands US$5.54/ha/year (FAO Stat n.d.; FEWS NET n.d.; Wamucii n.d.)[14]

The economic value of foregone crop production in a year is calculated by multiplying the share of foregone crop production in that year by the average annual crop production revenue in Chad. According to the USDA Foreign Agricultural Service (2025), the average crop yield in the last five years in Chad – including all major crops: rice, millet, maize, sorghum, peanut and cotton - is over 761 kg/ha/year. The average revenue from this crop production in the country is estimated to be US$ 525/ha/year (based on data from FEWS NET (n.d.).

The economic value of foregone livestock production in a year is calculated by multiplying the share of foregone livestock production in that year by the average annual livestock product revenue in Chad. The average revenue from livestock products in the country is estimated to be US$189/ha/year (FAO Stat n.d.; FEWS NET n.d.; Wamucii n.d.). Meat, milk, offal, and wool are included in livestock product revenue calculation.

GHG emissions

Based on the carbon stock data provided by Natural Capital Insights as part of the degradation analysis for this report, the rates of GHG emissions due to degradation in Chad between 2025 and 2050 are 1.35 CO_2e/ha/year in forests, 0.16 CO_2e/ha/year in croplands, 0.18 CO_2e/ha/year in grasslands, 0.31 CO_2e/ha/year in pastures and 0.71 CO_2e/ha/year in wetlands. To monetarily value GHG emissions, a shadow price of carbon of US$108/t$CO_2$e, as per the World Bank's Greenhouse Gas Accounting Guidance (see World Bank, 2017) for FY 2024, is used for the first year of analysis (2025). According to the Guidance, the price increases gradually to reach US$190/t$CO_2$e in 2050. The total economic value of GHG emissions due to land degradation in a land cover type in a year is calculated by multiplying GHG emissions rate and the shadow price of carbon and the area of degraded land (in ha) in that land cover type in that year.

14 The ecosystem services included in this estimation are non-wood forest products (NWFPs), recreation, habitat and species protection, and hydrological services. For wetlands, all of the above except NWFPs. For croplands: pollination, biological control, and waste treatment; grasslands: recreation (Siikamäki et al. 2021, Mirzabaev et al. 2022).

Infrastructure Damage

The costs of infrastructure damage caused by each hectare of degraded land are calculated by using the average cost of infrastructure damage in Sub-Saharan Africa and the Infrastructure Development Index (Statista 2025) that represents the level of infrastructure development. According to the Global Centre on Adaptation (2021), the average costs of infrastructure damage due to inaction on cropland degradation in the Sub-Saharan Africa region are US$92.82 per ha. According to the Infrastructure Development Index, wide disparity exists in the region—from the highly developed South Africa to the highly underdeveloped Chad and Mali. So, the regional average does not represent the individual country situations. Therefore, the annual costs of infrastructure damage by inaction on cropland degradation in Chad are estimated to be US$7.9 per ha by multiplying the regional average with the Infrastructure Development Index for Chad, (that is, 8.49 out of 100 or 8.49 percent). Due to a lack of data, it is assumed that the costs of infrastructure damage by degraded land in other land cover types are the same as those of croplands.

Sensitivity Analysis with Carbon Prices for the Share of GHG Emissions in the Total Costs of Inaction

Table D.3. **Share of total costs of inactions on land degradation**

Shadow price of carbon, US$/t$CO_2$e	Share of total costs of inactions on land degradation	
	GHG emissions	Other impacts
Base (115)	37.73%	62.27%
5	12.26%	87.74%
10	13.87%	86.13%
100	35.19%	64.81%
200	49.17%	50.83%
300	58.19%	41.81%
400	64.50%	35.50%

Source: World Bank

Estimation of the Costs of Land Restoration

Cost definition

The restoration costs are defined as the additional costs of chosen actions in comparison to the costs of the current practices in the degraded land that will be restored. The costs are the sum of direct costs (e.g., crop cultivation and tree planting) as well as opportunity costs (e.g., foregone livestock production).

Croplands

Conservation Agriculture

Conservation agriculture includes cover cropping, minimum tillage, and applying organic fertilizers instead of chemical ones. Cover cropping is done purely for conservation purposes, not for crop production. Conservation agriculture is not commonly practiced in Chad (Degrand and Benoudji 2017). Naturally, relevant cost data is not available for the country. The conservation agriculture costs for this report are estimated based on Mirzabaev et al. (2022). According to this study, the average costs of this practice in the Sahel Region are US$366 per ha per year (in 2022 constant US$). Assuming a 25 percent lower cost level in Chad than in the Sahel due to lower labor and input costs when compared to the cost level in other countries of the region, the conservation agriculture costs are estimated to be US$304 per ha per year in 2024 constant US$ (by adjusting for inflation).

Crop Diversification

Crop diversification is assumed to involve rotating all major crops currently produced in Chad such as rice, maize, millet, sorghum, peanut, and cotton in a certain period on the same piece of land. Like conservation agriculture, crop diversification is also not a common practice in Chad at present, and no relevant cost data is available, and therefore a value-transfer method is used. The average annual costs of crop diversification in Tajikistan with a similar set of crops are estimated to be US$12 per ha in 2024 constant US$ (World Bank 2024b). Assuming a 25 percent lower cost in Chad than in Tajikistan due to lower labor and input costs when compared to the cost level in Tajikistan, the crop diversification costs in Chad are estimated to be US$9 per ha (in 2024 constant US$).

Pastures

Rotational Grazing

Rotational grazing is assumed to involve resting 10 percent of the pastures from grazing every year. A total of 125,641 ha of degraded pastureland is targeted to be brought under restoration through rotational grazing and thus 12,564 ha of it will be rested each year (Table 5.1) This means in 10 years all pastures under restoration would have rested for one year. It is assumed that the rested pastures will be excluded from grazing through fencing, as this is a conventional practice throughout the world. Therefore, the costs of rotational grazing are the foregone livestock production due to the unavailability of fodder from rested pastures (i.e., opportunity costs) and the cost of fencing.

By applying the methodology given in Appendix D of this report, but considering only livestock products, the lost livestock production at present due to pastureland degradation is estimated to be US$23 per ha. Considering 71 percent NPP is lost due to the degradation of pastures in comparison to a normal healthy pasture in Chad and the rest 29 percent of NPP is retained (based on the data provided by Natural Capital Insights), the market value of livestock production from degraded pasture in the country is US$9 per ha. This value is foregone in year 1 and hence is the opportunity cost of resting pastures in rotational grazing.

It is assumed that due to rotational grazing the degraded land will be restored gradually to reach the full productivity of a healthy land in 20 years (Ferwerda 2016). Therefore, the livestock production associated with the degraded pastures that are brought under restoration through rotational grazing will increase gradually to reach a maximum of 100 percent in 20 years from a 0 percent increase in year 1. Therefore, the opportunity costs of rotational grazing will also increase gradually to reach US$18 per ha in year 20 and then remain the same.

According to the World Bank (2023), in rotational grazing, fencing needs to be changed every six years. The same study estimates that the fencing cost is US$25 per ha (in 2023 constant US$) in Tajikistan. Assuming a 25 percent lower cost in Chad than in Tajikistan due to lower labor and input costs when compared to the cost level in Tajikistan, the fencing cost in Chad is estimated to be US$20 per ha (in 2024 constant US$).

Silvopastoral System

The costs of the silvopastoral system include the costs of establishing and maintaining the tree and grass-covered areas and foregone livestock production because of fodder volume reduction for converting a part of the grassland to a tree-covered area. Due to a lack of any relevant estimates from Chad, the establishment and maintenance costs are estimated based on Mirzabaev et al. (2022). According to this study, in the Sahel Region, in a silvopastoral system, the average costs of establishment (in the 1st year) and maintenance (from 2nd year onward) are US$297 per ha and US$69 per ha, respectively, in 2022 constant US$. Assuming a 25 percent lower cost in Chad than in the Sahel due to lower labor and input costs when compared to the cost level in other countries in the region and the establishment and maintenance costs are estimated to be US$247 per ha and US$57 per ha, respectively in 2024 constant US$.

Following Rios-Diaz et al. (2006), it is assumed that in the silvopastoral system, 20 percent of all degraded pastures will be covered with trees and the rest with grass. By combining this assumption with the opportunity costs of resting pastures under rotational grazing (see the preceding section), the opportunity costs of tree cover in the silvopastoral system are estimated to increase from US$2 per ha in year 1 to US$4 per ha in year 20 in 2024 constant US$.

A total of 502,536 ha of degraded grassland is targeted to be brought under restoration through the silvopastoral system and 100,513 ha of it (20 percent) will be under tree cover and the rest will be under grass cover (Table 5.1).

Forests and Shrublands

Protection and Vegetation Management

It is assumed that all targeted degraded forests and shrublands will be brought under protection and vegetation management in 10 years, with 10 percent being restored each year. This means the area under these actions increases gradually to reach the target level of 68,004 ha for forests and 83,644 ha for shrublands in 10 years. This staged approach will give the Chad government sufficient resources each year to implement the actions effectively. Moreover, it will allow the government to improve implementation by correcting any mistakes made in previous years.

The cost estimate for protection and vegetation management in Chad is not available. Therefore, a benefit transfer from the relevant Armenian data is used for cost estimation. Based on A-Tree-For-You (2023), annual protection and subsequent management costs in Armenia are US$0.8 per tree (in 2023 constant US$). Because of lower labor and input costs and an overall lower biomass stock per ha to manage and protect, a 33 percent cost reduction is assumed for Chad in comparison to the cost level in Armenia. This means the costs of protection and vegetation management in Chad are US$0.56 per tree/plant (in 2024 constant US$). Assuming that fully stocked and fertile forests or shrublands have 1,000 trees and other plants, and due to degradation, only 29 percent NPP remains in these land cover classes (Natural Capital Insights), the protection and vegetation management costs for Chad are estimated to be US$162 per ha in year 1. As the degraded forests and shrublands are restored and NPP is regained due to protection and vegetation management (see Ferwerda 2016), the associated costs are reduced. Considering this, it is assumed that the costs are reduced gradually to reach 58 percent (that is, twice the rate of remaining NPP at present) in year 20 in comparison to that of Year 1.

Reforestation/Afforestation

It is assumed that all targeted degraded forests and shrublands will be brought under reforestation/afforestation in 10 years, with 10 percent of the land restored each year. This means the area under these actions increases gradually to reach the target level, i.e., 4,534 ha for forests and 5,576 ha for shrublands in 10 years. This staged approach is justified with the same reasons given for protection and vegetation management above.

Reforestation/afforestation in Chad will include costs of establishment (that is, land preparation, planting materials, and planting), seedling replacement due to mortality and management (that is silvicultural practices). Since forests and shrublands in Chad are under public ownership and/or management, no land purchase or rental will be needed for reforestation/afforestation.

The cost estimate for protection and vegetation management in Chad is not available. Therefore, a benefit transfer of relevant data from Central Asia is used for cost estimation. Based on A-Tree-For-You (2023), land preparation and tree planting costs in Armenia are US$0.57 per seedling (in 2023 constant US$). Because of lower labor and machinery costs and less clearing required in land preparation due to an overall lower biomass stock per ha, a 30 percent cost reduction is applied for Chad in comparison to the cost level in Armenia. Therefore, the costs of land preparation and planting in Chad are estimated to be US$0.45 per seedling (in 2024 constant US$).

Based on World Bank (2023), planting material costs in Tajikistan are US$0.9 per seedling (in 2022 constant US$). Because of lower labor and nursery costs and the use of local seeds, which are site-suited but much cheaper than the imported ones, a 45 percent cost reduction is applied for Chad in comparison to the cost level in Tajikistan. Therefore, the costs of planting materials in Chad are estimated to be US$0.55 per seedling (in 2024 constant US$). This means the establishment costs in Chad are US$1.00 per seedling.

Following conventional practices in tree plantation management globally, it is assumed that the seedling mortality rate is 10 percent of the initial planting density and replanting to replace the dead seedlings will occur during year 2–4. Therefore, the replanting costs in reforestation/afforestation in Chad are US$0.1 per seedling (in 2024 constant US$). It is also assumed that silvicultural practices to manage the plantations start from year 1 and incur 10 percent of the establishment costs, i.e., US$0.1 per seedling/tree (in 2024 constant US$).

The initial planting intensity is assumed to be 1,000 seedlings per ha. This means the establishment costs (only in year 1) are US$1,000 per ha, replanting costs US$100 per ha per year (in year 2–4) and management costs US$100 per ha per year (from year 1 onward) in Chad.

Agroforestry

It is assumed that all targeted degraded forests and shrublands will be brought under agroforestry in 10 years, with 10 percent of land restored each year. This means the area under these actions increases gradually to reach the target level, i.e., 18,135 ha for forests and 22,305 ha for shrublands in 10 years. This staged approach is justified with the same reasons given for protection and vegetation management.

In agroforestry areas, a 30 percent tree cover with 400 seedlings per ha, and 70 percent crop cover with crop diversification are assumed, which is a standard practice. By using the same cost figures for reforestation/afforestation, the tree related costs of each ha of land under agroforestry in Chad are: US$400 per ha for tree-cover establishment costs (only in year 1), US$40 per ha for tree replanting costs per year (in year 2–4), and US$40 per ha per year for tree-cover management costs (from year 1 onward). The annual crop-related costs in Chad are US$9 per ha (in 2024 constant US$), which is the same as the crop diversification cost (see Section on Crop Diversification).

Wetlands

The recommended action for restoring degraded wetlands is rehabilitation. It is assumed that the wetland restoration costs per ha are 10 percent of the costs of reforestation/afforestation per ha.

Water Resources Management

According to the World Bank (2022) water erosion is a significant cause of environmental degradation in Chad. Therefore, to make land restoration sustainable and long-lasting, it is necessary to stabilize the banks of the water courses. Therefore, the costs of this action are incurred in the form of constructing the relevant infrastructure (notably, gabion walls) and maintaining them afterwards.

Based on You (2008), 2.5 meters of banks should be stabilized for each ha of land restored. This means 2.46 million meters of banks need to be stabilized with gabion walls to restore 0.98 million ha of degraded land in Chad.

The global average cost of gabion wall construction is US$35 per meter (Gabion Review 2023). Assuming a 25 percent lower cost in Chad due to lower labor and input costs when compared to the global level, the gabion wall establishment costs are estimated to be US$26.25 per meter in 2024 constant US$. It is assumed that the construction of the above infrastructure starts in year 4 and finishes in year 10, and the construction is paced evenly every year. The gabion walls require regular maintenance in the subsequent years after the completion of the construction. The maintenance costs are assumed to be 1 percent of the construction costs.

Management Costs of Implementing the Actions

The management of the implementation of the restoration actions incurs costs to the Government of Chad. These may include administrative costs and resources needed for management and relevant policy and regulatory reforms. It is assumed that implementation costs will be 1 percent of the combined costs of restoring all degraded lands. This is a standard figure used for the implementation of restoration projects.

Estimation of the Benefits of Restoration

Definition of Benefits

The benefits of land restoration in this report are defined as the 'incremental impacts' of the restoration actions and quantified by comparing the total outputs of the 'with action' scenario with the BaU scenario.

Enhancement in Ecosystem Services Value

As explained in the methodology for the costs of inaction, in Chad the value of ecosystem services provided by forests is US$136.45/ha/year, by shrublands US$68.22/ha/year and by wetlands US$50.16/ha/year as well as by croplands US$16.64/ha/year and by grasslands US$5.54/ha/year (Siikamäki et al. 2021 and Mirzabaev et al. 2022). According to the same methodology, 71 percent of the ecosystem services value is foregone due to land degradation in the country. This means that when the degraded land is fully restored, the ecosystem services value will increase by 71 percent. Moreover, as the specially targeted actions are taken with dedicated management for their implementation, it is assumed that the land under restoration will have a 150 percent efficiency gain in ecosystem services value in comparison to normal lands in Chad.

It is assumed that the benefit of enhanced ecosystem services value is realized in a gradual schedule starting from 0 percent in year 1 to reaching 100 percent in year 20 and remains at that level for the rest of the analysis period. This is justified by the fact that it takes about 20 years after taking actions for the degraded land to be fully restored (see Ferwerda 2016).

GHG Emissions Reductions

As mentioned in the methodology for the costs of inaction, the rates of GHG emissions due to degradation in Chad between 2025 and 2050 are 1.35 CO_2e/ha/year in forests, 0.16 CO_2e/ha/year in croplands, 0.18 CO_2e/ha/year in grasslands, 0.31 CO_2e/ha/year in grasslands and 0.71 CO_2e/ha/year in wetlands. Land restoration will not only stop these emissions but also enhance the GHG removal rate due to sustainable land management. As the specially targeted actions are taken with dedicated management for their implementation, it is assumed that the land under restoration will have a 75 percent efficiency gain in GHG removal rate in comparison to normal land in Chad. A shadow price of US$108/t$CO_2$eq, as per the World Bank's Greenhouse Gas Accounting Guidance (2017) for FY 2024, is used for the first year of analysis. The price increases gradually to reach US$190/t$CO_2$e in year 2050.

It is assumed that the GHG removal benefit is realized in a gradual schedule starting from 0 percent in year 1 to reaching 100 percent in year 15 and remains at that level for the rest of the analysis period. The GHG removal estimation is adjusted for the risks of damage to vegetation and lands by natural factors such as pests, diseases, floods, drought, and fire. It is assumed that 10 percent of the potential GHG removal by lands under restoration is not realized in year 1. It is also assumed that the non-realization share will be gradually reduced to 5 percent in year 10 and will remain so for the rest of the analysis period as land management improves due to the restoration.

Crop Production Increase

In Chad, the average revenue from crop production is US$525/ha/year, as explained in the methodology for the costs of inaction. According to the same methodology, over 35 percent of crop yield is foregone due to degradation of croplands. This means that when the degraded cropland is fully restored, crop production will increase by 35 percent. Moreover, as the specially targeted actions are taken with dedicated management for their implementation, it is assumed that the cropland under restoration will have a 150 percent efficiency gain in crop production in comparison to normal agricultural land in Chad.

Based on UNDP (2025), crop yield in Chad will be lost due to climate change by 20 percent per decade through to the end of the 21st century. Thus, it is assumed that 45 percent additional crop loss due to climate change will be avoided by restoring degraded croplands in year 25 (2050) after starting the restoration.

It is assumed that the benefit of increased crop production is realized in a gradual schedule starting from 0 percent in the first year to reaching 100 percent in year 20 and remains at that level for the rest of the analysis period. This is justified by the fact that it takes about 20 years after taking action for the degraded land to be fully restored.

Livestock Production Increase

As explained in the methodology for costs of inaction, the average revenue from livestock production in Chad—that is entirely based on pastures—is nearly US$189/ha/year. According to the same methodology, nearly 12 percent of livestock production is lost due to degradation in pastures in the country. This means that when the degraded pastures are fully restored, livestock production will increase by 12 percent. Moreover, as the specially targeted actions are taken with dedicated management for their implementation, it is assumed that the grasslands under restoration will have a 150 percent efficiency gain in terms of livestock production in comparison to normal pastures in Chad.

Based on You (2008), 25 percent of the livestock yield in Chad will be foregone due to climate change by 2050. Thus, it is assumed that 25 percent additional livestock production loss due to climate change will be avoided by restoring degraded pastures in year 25 after starting the restoration.

It is assumed that the benefit of increased livestock production is realized in a gradual schedule starting from 0 percent in the first year to reaching 100 percent in year 20 and remains at that level for the rest of the analysis period, with the same justification as given for croplands.

Infrastructure Damage Reduction and Avoidance

As estimated in the methodology for the cost of inaction on land degradation, the average costs of infrastructure damage due to land degradation in Chad are nearly US$8/ha/year. This means that when the degraded lands are fully restored, these costs will be avoided. Moreover, as the specially targeted actions are taken with dedicated management for their implementation, the incremental impacts of flooding and landslides induced by land degradation that are causing infrastructure damage will be mitigated as the land is gradually restored. This will reduce maintenance and repair frequencies and thus costs and lengthen the service life of infrastructure. To capture this, a 150 percent efficiency gain in terms of infrastructure damage avoidance and reduction due to land restoration in Chad is assumed.

It is assumed that the benefit of infrastructure damage avoidance and reduction is realized in a gradual schedule starting from 0 percent in the first year to reaching 100 percent in year 20 and remains at that level for the rest of the analysis period. This is justified by the fact that it takes about 20 years for the degraded land to be fully restored (see Ferwerda 2016).

Economic Sensitivity Analysis of Land Restoration

Table D.4. **Economic sensitivity analysis of land restoration**

Parameters	Parameter values in the base case	Change	IRR		BCR		NPV (million US$)	
			Without GHG ERs*	With GHG ERs	Without GHG ERs	With GHG ERs	Without GHG ERs	With GHG ERs
Base case	32.36%	39.33%	3.03	3.78	1,158	1,586		
Discount rate	6%	4%	32.36%	39.33%	3.91	4.89	2,742	3,671
		15%	32.36%	39.33%	2.35	2.91	523	745
Shadow price of carbon	US$115 /$tCO_2e$	10	32.36%	34.01%	3.03	3.29	1,158	1,306
		400	32.36%	53.36%	3.03	5.12	1,158	2,347
Croplands restored	140,603 ha	-50%	29.71%	37.70%	2.83	3.68	862	1,267
		50%	34.23%	40.49%	3.17	3.85	1,453	1,904
Pastures restored	628,204 ha	-50%	36.14%	41.68%	3.32	3.92	1,887	2,372
		50%	40.68%	44.55%	3.68	4.09	4,530	5,217
Forests restored	90,675 ha	-50%	33.39%	40.17%	3.16	3.89	1,125	1,503
		50%	31.44%	38.58%	2.92	3.69	1,190	1,669
Shrubland restored	111,525 ha	-50%	33.14%	39.97%	3.13	3.86	1,132	1,522
		50%	30.86%	38.11%	2.85	3.63	1,213	1,727
Wetland restored	12,088 ha	-50%	32.49%	39.36%	3.03	3.77	1,155	1,574
		50%	32.24%	39.31%	3.03	3.79	1,160	1,597
Management costs	1%	0%	32.36%	39.33%	3.03	3.78	1,158	1,586
		30%	26.50%	32.79%	2.31	2.89	980	1,409
Crop price	US$0.69/kg	-50%	26.38%	33.64%	2.50	3.26	858	1,286
		50%	38.26%	45.02%	3.56	4.31	1,457	1,886
Livestock product price	US$4.9/kg	-50%	29.43%	36.59%	2.79	3.55	1,158	1,586
		50%	35.23%	42.03%	3.26	4.00	1,311	1,739

* Emissions reductions

Source: World Bank

Appendix E: Methods to Model Ecosystem Services and Identify Hotspots of Restoration Opportunity

This appendix provides additional information on the methodology used to identify hotspots of restoration opportunity across Chad, i.e., areas where restoration can show the greatest improvement in controlling erosion and reducing soil loss, thereby preventing further losses in the productivity of croplands, pastures, and forests; improving rainfall-runoff dynamics, thereby reducing peak flows; and increasing carbon storage.

To this end, spatially explicit ecosystem services models were applied to estimate the potential improvement that could be achieved through implementing landscape restoration in Chad's landscapes. Restoration potential was estimated using the InVEST Sediment Delivery Ratio (SDR), Seasonal Water Yield (SWY), and Carbon models. We also estimated biomass forage potential from Net Primary Productivity on grasslands. Each of these ecosystem service models are described briefly in the following sections.

To reflect changes in land condition due to restoration actions, the approach taken assumed that land restoration would have the effect of improving a land parcel's condition class from "poor" to "good" or from "fair" to "good". Note that this assumes that restoration actions taken in poor-quality agricultural land are more "remediation" than "restoration", as cropland is not taken out of production and replaced with natural landscapes but instead assumed to be better-managed cropland with less degradation. Model parameters reflecting this change in land condition for each scenario were developed (based on a percentage reduction in parameter quality depending on the severity of degradation) and used as input to each ecosystem service models. Historical climate conditions were used to drive the ecosystem service models.

Benefits of restoration were calculated for each district as the percent change in the total sediment export, total storm surface runoff, and the total land-based carbon storage between the BAU/No-action scenario and the scenario where restoration practices are implemented.

Carbon

The InVEST carbon model (Natural Capital Project 2025) was used to estimate the total amount of carbon stored in four carbon pools: aboveground biomass, belowground biomass, soils, and dead matter. The model requires input carbon pool estimates by land use and vegetation condition class. Values of carbon stored in different land types were taken from published carbon density generated by Spawn et al (2020) Pixel-level model results for carbon storage were totaled for each administrative region.

Erosion Control

Soil erosion is the movement or displacement of the upper layer of soil, and it is a naturally occurring process that affects all landforms. Certain human activities greatly enhance this process and contribute to a substantial soil loss. This is significant because topsoil contains the highest amount of organic matter and is best suited for agricultural activities.

In this study, the InVEST Sediment Delivery Ratio (SDR) model (Natural Capital Project 2025) was utilized to estimate the baseline impacts of land degradation on erosion and sedimentation. The spatially explicit SDR model estimates for each pixel the average amount of erosion per year, then integrates information on the landscape context (land cover and land use upslope and downslope of the pixel) to estimate the amount of sediment thereafter retained on the landscape or washed away in streams. The model is based on an implementation of the Revised Universal Soil Loss Equation [RUSLE1; (Renard 1997)] for the calculation of annual soil loss, and includes a sediment delivery function as a function of the hydrological connectivity of each pixel in the landscape. Data for the SDR model includes biophysical parameters for the calculation of erosion dynamics, sediment export and retention across the landscape, including data on elevation (Lehner, Verdin, and

Jarvis 2008), land use land cover (Zanaga et al. 2022), rainfall erosivity (Panagos et al. 2023), watershed boundaries (Lehner and Grill 2013), and soil erodibility as derived from SoilGrids data (Poggio et al. 2021).

Water regulation: baseflow and flood control

Water regulation ecosystem services considered include the infiltration of water and flow through the sub-surface, contributing to baseflow, and surface runoff, which can contribute to flood risk. The InVEST Seasonal Water Yield (SWY) model (Natural Capital Project 2025) was utilized to estimate the potential impacts of land degradation and restoration on these water regulation services. The model estimates the amount of water produced by a watershed that arrives in streams over the course of a year. The two primary outputs of the model are quickflow and baseflow - quickflow represents the amount of precipitation that runs off the land directly, during and soon after a rain event, and baseflow is the amount of precipitation that enters streams more gradually through sub-surface flow, including during the dry season. Soil and land cover properties determine how much of the rain runs off the land surface quickly (producing quickflow) versus infiltrating into the soil (producing local recharge). Data inputs to the Seasonal Water Yield model include rainfall, potential evapotranspiration, topography, soil properties, and land cover.

The SWY model requires monthly rasters from multiyear averages of rainfall depth, potential evapotranspiration, and number of rain events. Daily time series of precipitation, potential evapotranspiration and actual evapotranspiration from 2001 to 2020 were taken from CHIRPS (Funk et al. 2015) and Global Aridity Index and PET Database (Zomer, Xu, and Trabucco 2022) databases. Using these data, a series of monthly averages were derived for each pixel in the model domain: average monthly rainfall, number of rain events per month, average monthly potential evapotranspiration and average monthly actual evapotranspiration. Vegetation water use coefficients (KC) for the SWY model were derived by taking the ratio of actual to potential evapotranspiration by month over the same period. Soil physical properties were based on SoilGrids and reclassified into Hydrologic Soil Groups (Ross et al. 2018). Curve Numbers for each LULC classification were assigned following the USDA Soil Conservation Service (SCS) procedures (USDA-NRCS 2004).

The SWY model was run for the BAU and the landscape restoration scenarios, by changing the land use and vegetation condition input to the model (to reflect land degradation or restoration). As with the sediment data, no field-based observation data on water flows were available for model calibration, so results should be interpreted in terms of relative, rather than absolute, flow values. Pixel-level model results for quickflow (representing surface runoff) were totaled for each micro-watershed and the difference between the BAU scenario and the restoration scenario were used as indicators of the benefit of landscape restoration for flood mitigation

Forage Biomass

Vegetative biomass available for foraging provides grazing herds of domesticated animals requisite caloric intake, sustaining livelihoods across provinces in which shepherding is commonplace. To estimate forage biomass for all land cover types (including degradation status), we analyzed MODIS Net Primary Productivity (NPP) data for our reference year, 2021 (Running and Zhao 2021). We calculated the average NPP for each land cover type to create a parameter lookup table that could be applied to future land cover maps. Pixel-level results for forage biomass were totaled for each administrative region under current, future, and restored future scenarios.

Appendix F: Normalized Difference Vegetation Index Results

Table F.1: National summary of land cover changes in land degradation Unit: ha

Land cover and scenario	Poor	Fair	Good
Cropland 2021	8,095	33,149	10,380
Cropland 2050 BaU	17,366	28,015	6,241
Cropland 2050 restored	16,508	27,918	7,196
Forest 2021	18,945	14,600	8
Forest 2050 BaU	13,071	18,732	1,742
Forest 2050 restored	12,607	18,712	2,226
Grassland 2021	85,809	226,405	56,538
Grassland 2050 BaU	70,953	223,432	74,343
Grassland 2050 restored	66,833	222,328	79,568
Shrubland 2021	22,905	111,223	1,483
Shrubland 2050 BaU	18,549	106,291	10,776
Shrubland 2050 restored	17,721	106,010	11,886
Wetland 2021	1,624	7,626	1,381
Wetland 2050 BaU	1,539	6,437	2,655
Wetland 2050 restored	1,539	6,437	2,655

Source: World Bank

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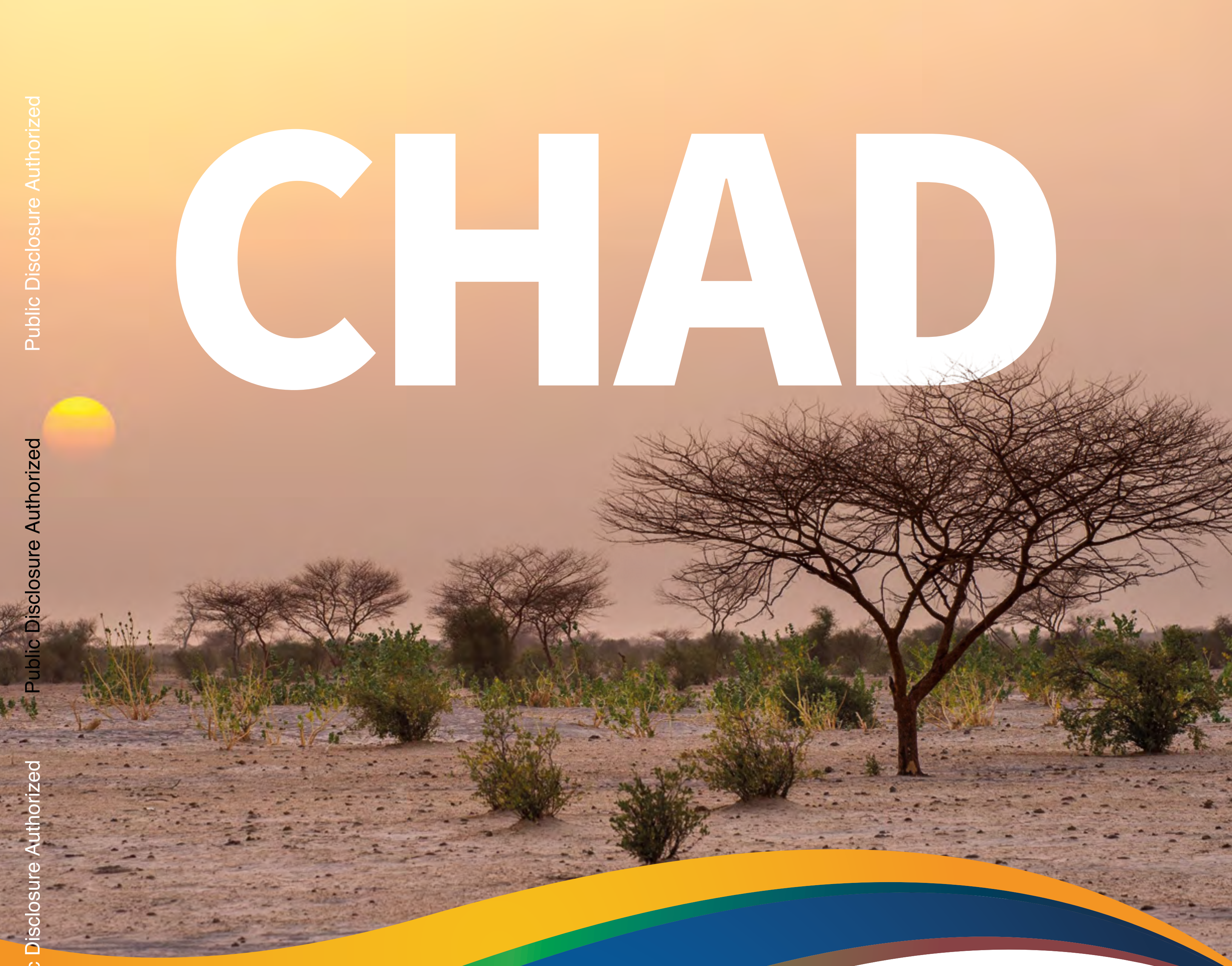
CHAD



Strategic Landscape Restoration for Resilience: **Leveraging Ecosystem Services to Secure Livelihoods in Chad**

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