PEOPLE

Ecosystem Restoration

D6: CENTRAL AFRICAN REPUBLIC DEMONSTRATION VALIDATION REPORT

January 2024

Prepared for:

African Parks

South Africa

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PIONEER EARTH OBSERVATION APPLICATIONS FOR THE ENVIRONMENT – ECOSYSTEM RESTORATION (PEOPLE-ER)

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AMENDMENT RECORD

This report has been issued and amended as follows:

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1	D6 – CAR Demonstration Validation Final Report	20240104	(insert signature)	(insert signature)
			Andy Dean Project Manager	Marcos Kavlin Assistant Project Manager

1.0 INTRODUCTION

Ecosystem Restoration (ER) is important to reverse biodiversity loss and is a critical element of nature-based solutions (NBS) for climate change mitigation and adaptation, food security, and disaster risk reduction. ER is needed on a large scale to achieve the United Nations (UN) sustainable development agenda and as part of the UN Decade on Ecosystem Restoration (2021−2030). At the Convention on Biological Diversity (CBD) COP 15 in Montreal in December 2022, nations adopted a target to “Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity[1].

Effective planning, monitoring, and assessment of ER is required to evaluate ecosystem functions and to determine whether ER is having the desired impact. ER investments must be data-driven, requiring historical information on ecosystem disturbance and degradation, to enable planning of interventions, which are then monitored for their impact. There is a huge opportunity for satellite Earth Observation (EO) applications for ER, to meet the needs for regular, repeat measures of ER processes over long time periods covering large, often remote, areas.

To support ER investments, innovative methods are required to deliver high-quality EO-based products and indicators targeting high-priority forest, wetland, and biodiversity variables.

The Pioneer Earth Observation apPlications for the Environment (PEOPLE) ER project financed by the European Space Agency (ESA) is a trailblazer project to develop innovative high-quality EO-based application products, indicators, and methods, targeting ER research and development (R&D) priorities.

PEOPLE-ER is led by Hatfield Consultants – a science-driven service-oriented company that builds solutions to complex environmental challenges, with a depth of experience in ER projects in Canada and around the world. Hatfield is a trusted partner for the development of cutting-edge and practical EO technologies. The PEOPLE-ER consortium includes:

- VTT – the remote sensing team at VTT Technical Research Centre of Finland produces EO data processing chains for domestic and international users. The team is internationally known, particularly for its forest monitoring applications and the Forestry TEP cloud processing platform. VTT is ranked among the leading European Research and Technology Organisations (RTO).
- University of British Columbia, Faculty of Forestry – Dr. Nicholas Coops leads the Integrated Remote Sensing Studio (IRSS) and is a leading international research scientist in the application of EO technologies for forest ecosystem assessment and monitoring, including ER and the prioritization of methods and products for remote sensing essential biodiversity variables (RS-EBVs).

The Early Adopters are:

- **National Institute for Research and Development in Forestry (INCDS)** (Romania) – formally a member of the consortium, INCDS is the main organisation of research and development in forestry from Romania. INCDS is in charge for the forest resources assessment and monitoring

[1] HYPERLINK "https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022"https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022

in Romania through National Forest Inventory. INCDS has also secured the support of two Romanian NGOs as documented in letters of support: Forestry Society Association and Fundatia Grupul Verde Oradea.

- **IUCN** (Vietnam) – established in 1948, IUCN is an international authority working on a wide range of themes related to nature conservation, forests, ecosystem management, protected areas, global policy and governance and rights.
- **African Parks** – a leading non-profit conservation organisation that takes on the complete responsibility for the rehabilitation and long-term management of protected areas across Africa in partnership with governments and local communities.
- **Society for Ecosystem Restoration in northern British Columbia (SERNbc) (Canada)** – a key enabler for ER in forested ecosystems affected by cumulative disturbances from forest operations, energy exploration, wildfires, and forest pests/diseases.
- **Natural Resources Institute (Luke) (Finland)** – as one of the biggest clusters of bioeconomy expertise in Europe, Luke develops knowledge-based solution models and services for renewable natural resources management and supports decision-making in society.

The following PEOPLE-ER Tools are defined:

1. **Vegetation Spectral Recovery** – The PEOPLE-ER Vegetation Spectral Recovery tool provides a flexible, powerful set of EO data analytics solutions to support forest landscape ER assessment. The tool provides a method for high-resolution satellite EO data time series analysis to enable monitoring of vegetation recovery in forested ecosystems from boreal to tropical biomes.
2. **K Nearest Neighbour Tool** – The PEOPLE-ER k-NN tool enables wall-to-wall prediction of target variables of interest using field reference data and selected EO datasets.
3. **Wetland Function Trends** – The PEOPLE-ER Wetland Function Trends tool provides a flexible, powerful set of EO data analytics tools to support wetland ER assessment. The tool provides methods for high-resolution satellite EO data time series analysis to enable monitoring of inundation dynamics and trends in natural to heavily modified wetland ecosystems.

These tools were identified following assessment of the current State of the Art (Deliverable 2a), Policy and Stakeholder Analysis (D2b), and Early Adopter Value Proposition (D3). The Tools are fully defined in the Algorithm Theoretical Baseline Documents (D7).

1.1 SCOPE OF DELIVERABLE D6 VERSION 2

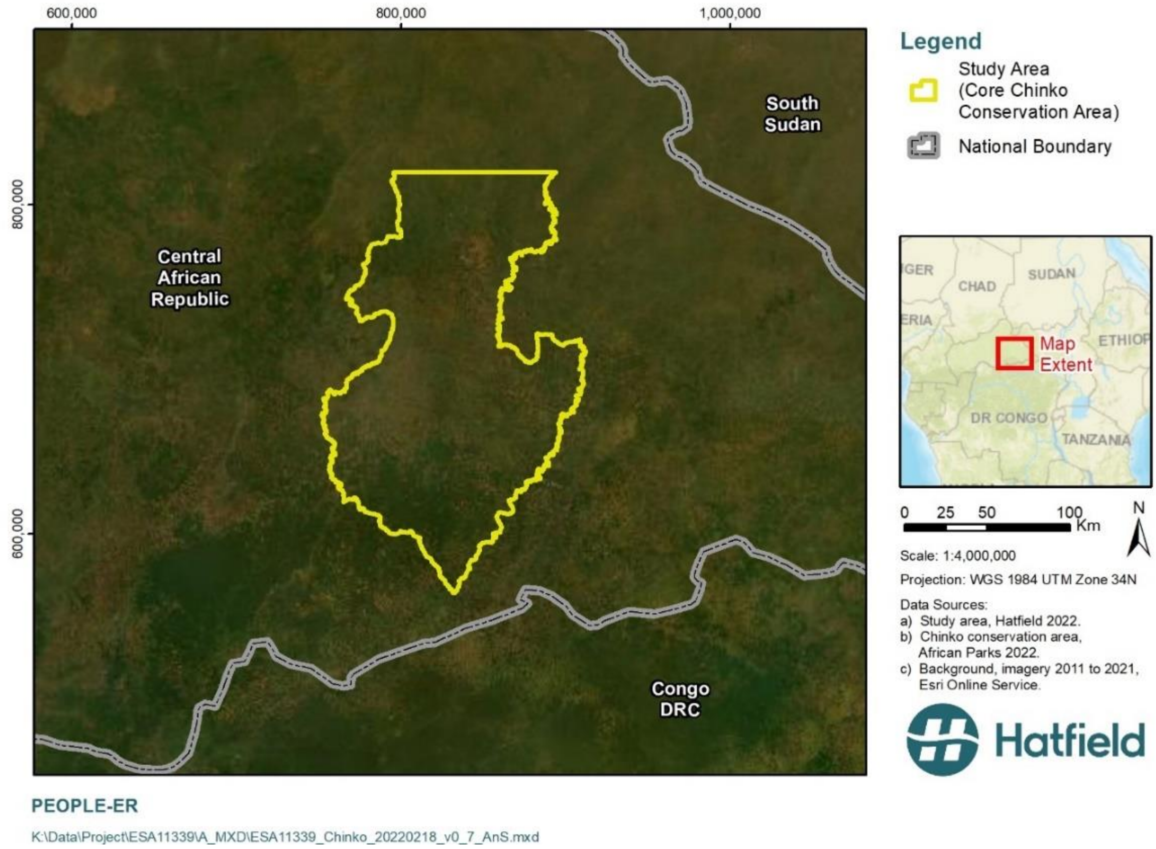
Deliverable 6 (D6) version 1 defined the validation methodology for the PEOPLE-ER methods and algorithms to be developed and the specific demonstrations with Early Adopters. This updated version of D6 is the Validation Final report, presenting the tools/algorithm applied in the demonstration and the full set of results and associated accuracy assessment.

2.0 AFRICAN PARKS – CHINKO CONSERVATION AREA RESTORATION

2.1 DEMONSTRATION STUDY AREA AND OBJECTIVE

The demonstration area with African Parks is the Chinko Conservation Area (CCA) in Central African Republic (CAR), which African Parks assumed responsibility for in 2014. The core protected area that African Parks actively manages is called “Aire de Conservation de Chinko”, CCA, and consists of five former hunting blocks of more than 24,300 km^2. The CCA is a mosaic of different woodland, savanna, and forested ecosystems with African Parks priority information needs related to recovery of degraded woodland savanna areas following their management interventions. African Parks has an active management plan for CCA with a range of data collected.

Figure 1 Chinko Conservation Area in Central African Republic.



Due to decades of political instability, population growth, and overgrazing, thousands of transhumance pastoralists are now forced to migrate south every year, mainly from South Darfur in Sudan, into the still intact savannas in eastern CAR where Chinko lies. Moving to avoid tribal conflict over ever-decreasing resources and in search of water and grazing for their livestock, the herders exert immense pressure on the landscape, burning grassland to create fresh grazing options, cutting trees, and allowing the spread of disease from cattle to wildlife. Armed and driven to ensure their own existence, the pastoralists often encounter resistance from sedentary communities, resulting in ongoing conflict and insecurity. This unregulated transhumance movement escalated to become the primary driver of degradation of the Chinko ecosystem (African Parks 2023).

African Parks developed the transhumance engagement programme to improve security in the region. Herders now adhere to the corridors, understanding the benefit for both themselves and their cattle, and the area free of cattle and habitat degradation has expanded from roughly 5,000 km^2 to over 26,000 km^2. Wildlife numbers are recovering with an increase of over 200% in herbivores and predators since 2017. Chinko's most recent 2023 aerial survey of cattle around the CCA revealed 35,000 cattle and over 650 nomadic tents, demonstrating the task to manage the effects of the transhumance movements is ongoing and enormous. To support the management of the level of human impact and the natural vegetation, it's vital to have information to support a land use strategy and community programmes (African Parks 2023).

The objective of the PEOPLE-ER demonstration was to use the vegetation trends and recovery tool to assess the impact of management interventions in CCA woodland savanna between 2017-2023. Specifically, to demonstrate a method suitable for monitoring the vegetation recovery trend over the entire CCA, which can account for the subtle rate of change in vegetation conditions and account for seasonality of vegetation conditions.

2.2 DATA AND METHODS

2.2.1 EO Data

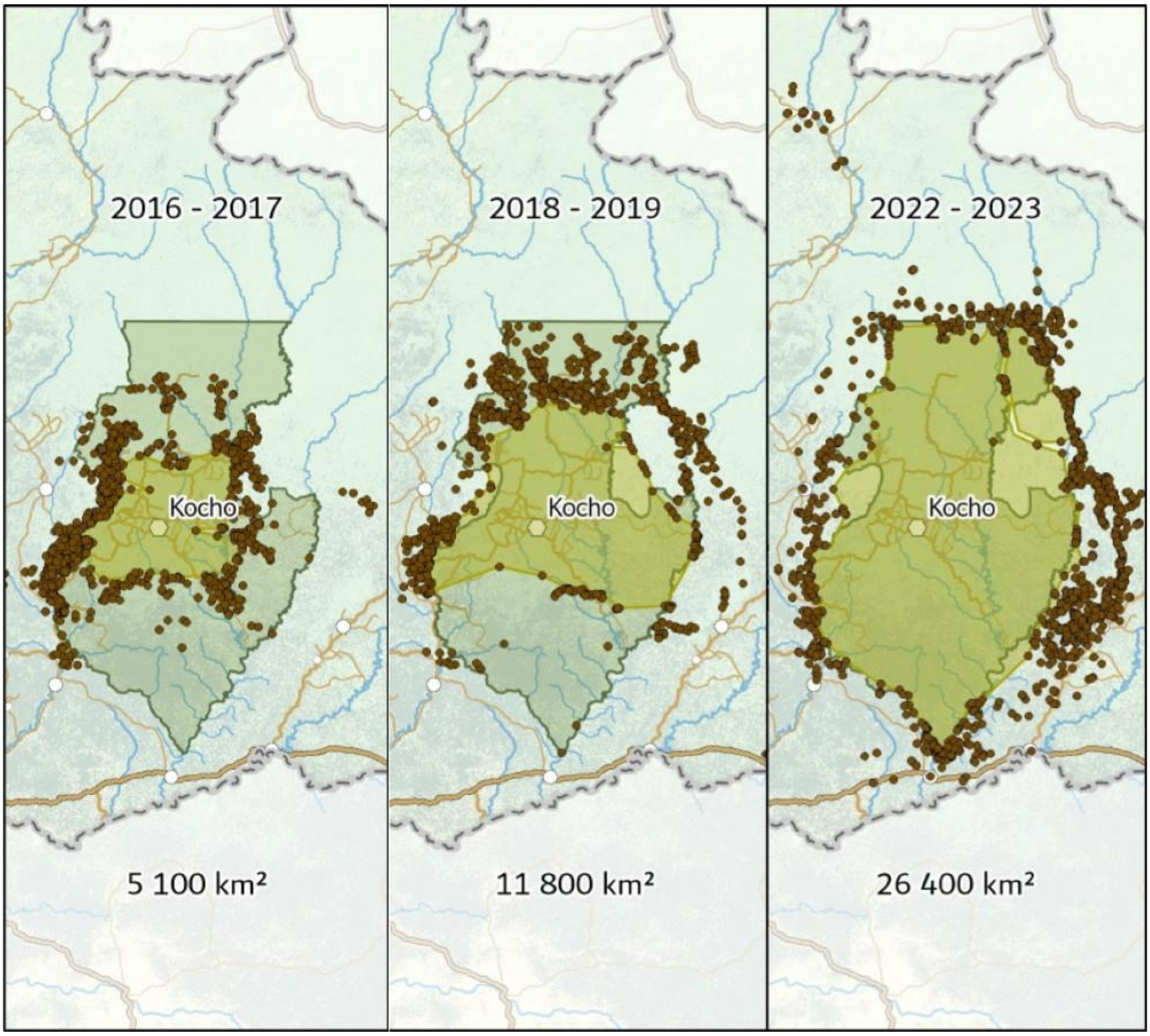
To implement the vegetation trend analysis, the full times series of Sentinel-2 data was used from August 2017 to August 2023. The Sentinel-2 surface reflectance data were obtained from the Microsoft Planetary Computer with scene classification layer (SLC) providing scene-based quality information and cloud and shadow masks.

Normalized Difference Vegetation Index (NDVI) serves as an established indicator of vegetation greenness and density and is widely employed for evaluating vegetation recovery. The collection of NDVI images was aggregated by month using median composition over the six-year period. These monthly image stacks consist of 72 layers, forming a monthly NDVI time series with 72 time steps at each pixel, facilitating further trend analysis.

2.2.2 Reference Data

African Parks maintains records of all management interventions, such as areas of habitat degradation that have been addressed through management actions, including construction of new roads, infrastructure, and fire management since 2010. The key reference data were georeferenced and timestamped data from livestock count data for 2016-2023 for 100,000 km^2 across the Greater Chinko area to provide an indication of current livestock areas in relation to management plans (Figure 2).

Figure 2 Expansion of Chinko's core protection area with transhumance movement along designated corridors.



To provide an indication of the distribution of dense tree areas were determined based on the 10-meter tree cover and extent map produced by Brandt et al (2023).

To provide an indication of the impact of fire in the landscape, African Parks provided a fire frequency and fire occurrence analysis data derived from NASA FIRMS datasets[2]. This provided a raster product with 1 km grid resolution providing number of unique fires per year and months of fire occurrence over the period 2018-2022.

2.2.3 Vegetation Change Analysis Method

Technical details regarding the methods for vegetation change analysis can be found in the PEOPLE-ER Algorithm Theoretical Baseline Document (ATBD) (Hatfield Consultants 2023) and the notebooks and documentation on the PEOPLE-ER GitHub page[3]. However, the requirements of African Parks and the highly seasonal phenology of vegetation in the CCA, a modified analysis method was implemented.

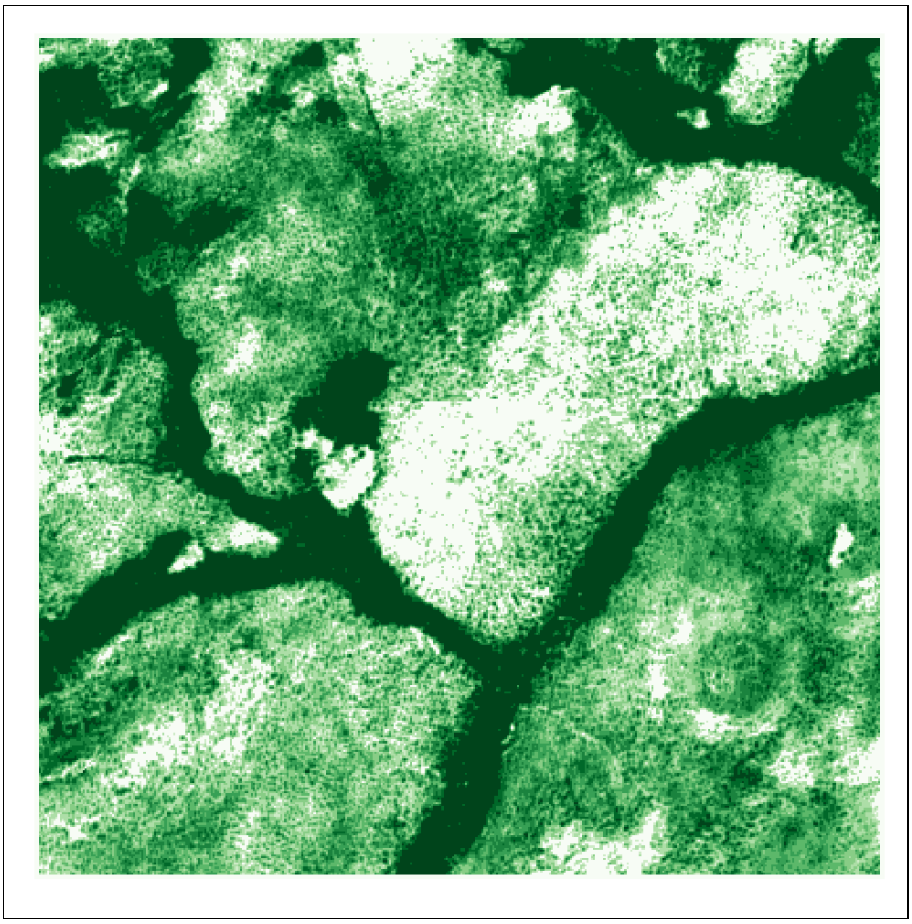
[2] https://firms.modaps.eosdis.nasa.gov/

[3] https://github.com/PEOPLE-ER/Spectral-Recovery

Using the monthly NDVI composites, a non-parametric Seasonal Sen's slope method (Hipel & McLeod, 1994) was employed for the pixel-based trend analysis that estimates the direction and magnitude of monotonic trend. This choice was informed by the evident seasonal pattern in CAR's vegetation due to phenology and the presence of data gaps due to the unavailability of cloud-free pixels in certain months. Seasonal Sen's slope is considered particularly suitable for this case due to its robustness to seasonal pattern and its ability to handle missing data (Hipel & McLeod, 1994). It calculates individual slopes for each pair by comparing values of the same month across different years, with the median of these slopes serving as the estimate of the overall trend over the entire observation period.

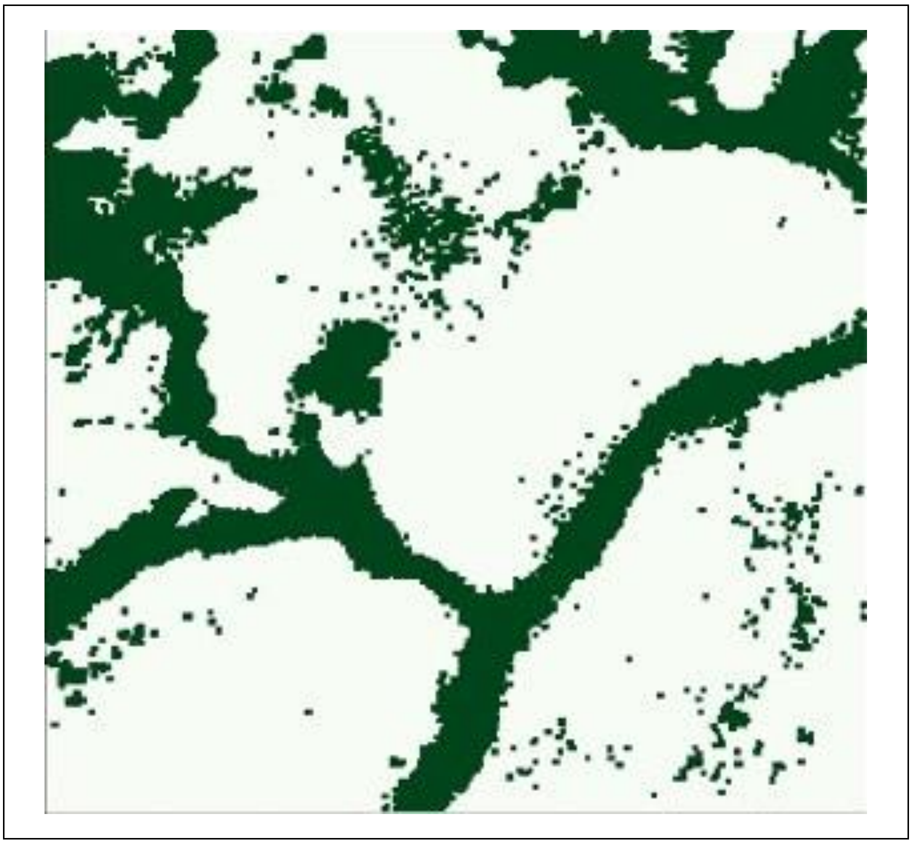
Since the analysis focuses on vegetation recovery in the savanna, pixels of dense trees were masked out from the image stacks. The dense tree areas were determined based on the 10-meter tree cover and extent map produced by Brandt et al (2023). The pixels with a probability of tree cover higher than 90% were considered as dense forest and excluded from trend analysis – an example is shown for a site in Figure 3.

Figure 3 Tree cover mask to limit analysis to savanna land cover.



Tree density (Brandt et al. 2023)

Figure 3 (Cont'd.)



Tree density (Brandt et al. 2023)

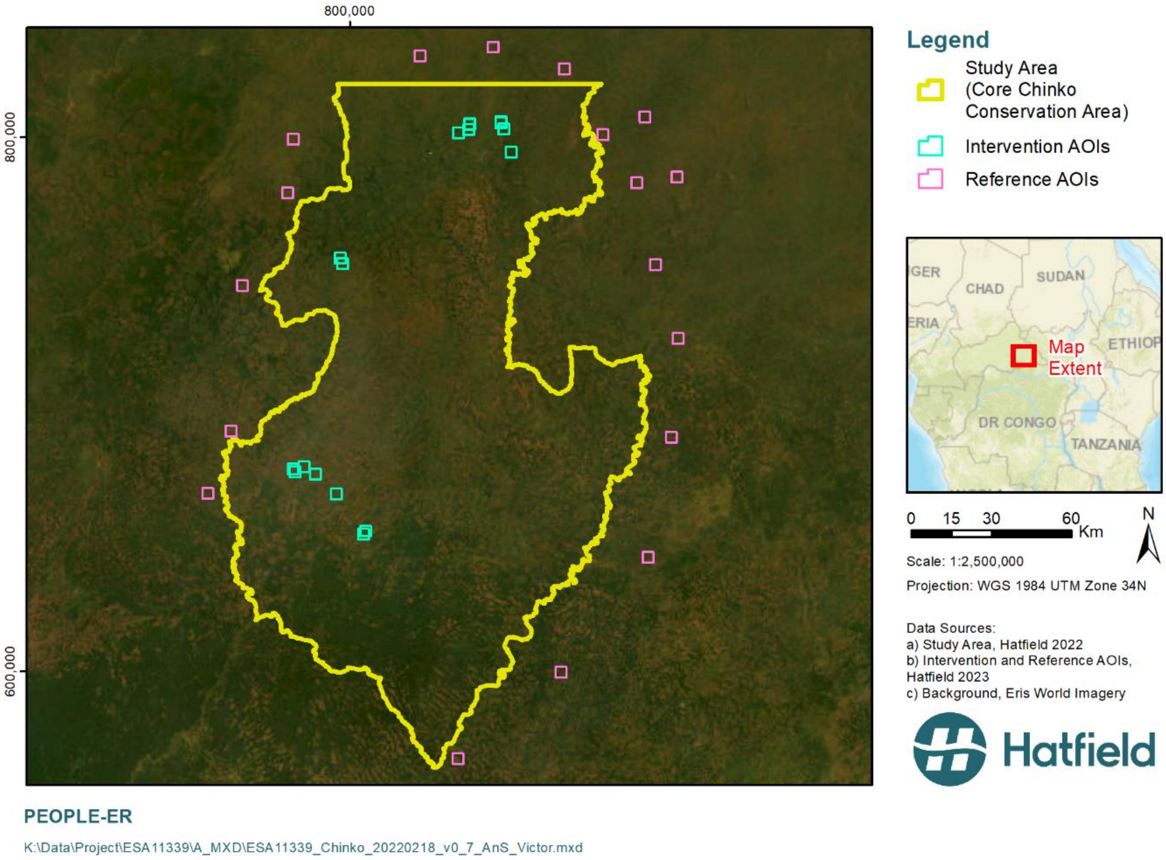
2.2.4 Impact Assessment Method

The impact assessment approach was based on evaluation of the difference between the NDVI trend for the management classes (i.e., intervention areas where natural regeneration is expected) and similar areas of habitat without the management intervention.

Using African Parks' timestamped livestock count data and inputs from African Parks management team, we selected 17 intervention sites with the CCA that were impacted and degraded by nomadic livestock grazing but that were protected by the African Parks management intervention. Vegetation was expected to recover in these areas. African Parks also supported the identification of 18 reference sites in the periphery of the CCA that are of comparable climate conditions but are exposed to pastoralism and fire pressure. Because they are on the peripheries of the CCA it's possible that there is higher pressure compared to other areas further away from the CCA.

This pixel-based trend analysis was conducted for 18 reference and 17 intervention sites in the CCA. A 4x4 km square site area of interest (AOI) was created for each of the sites (Figure 4).

Figure 4 Distribution of reference and intervention sites in the CCA.



In evaluating vegetation recovery between reference and intervention sites, two statistical tests were employed to compare the trends within the AOIs. Based on the direction of Sen's slope and p-value from Mann-Kendall test, pixels were classified into four categories: significantly positive, non-significantly positive, significantly negative, and non-significantly negative trends. Subsequently, the Mann-Whitney-Wilcoxon test, a non-parametric statistical analysis, was employed to ascertain if intervention sites exhibited a more substantial presence of significantly positive trends, indicative of increased greenness, compared to the reference sites. Additionally, the Student's t-test was utilized to determine if the Sen's slope at intervention site pixels significantly surpassed that of the reference sites.

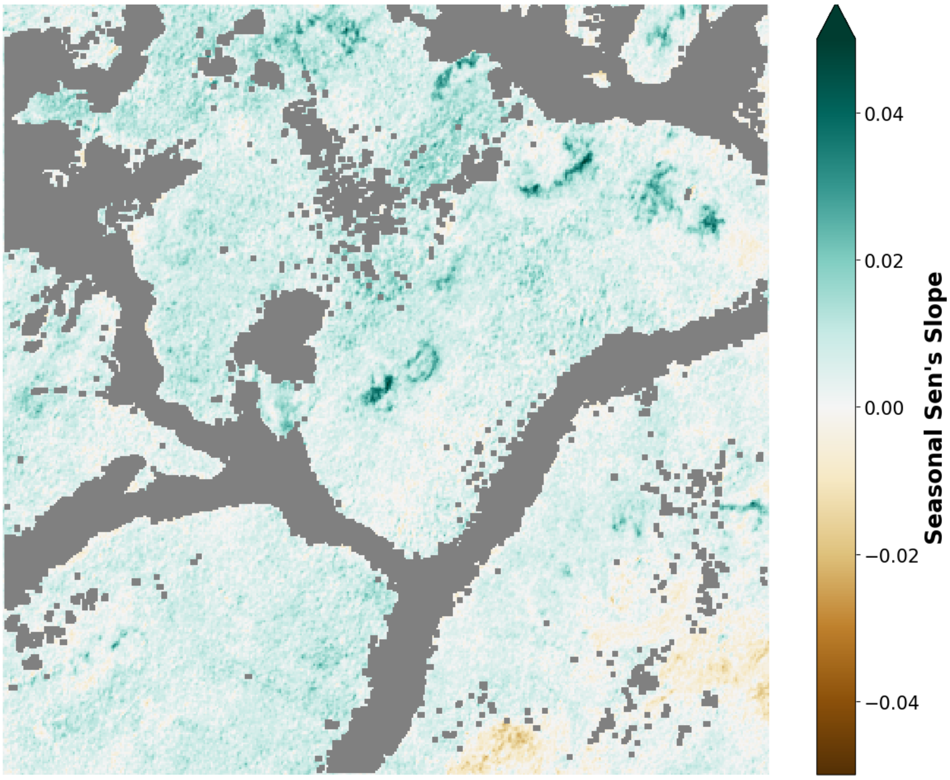
Furthermore, pixels within both reference and intervention sites were categorized into three levels based on their initial NDVI values in 2017 (the baseline year for the analysis). These levels delineate low vegetation (NDVI < 0.3), medium-level vegetation (NDVI between 0.3 and 0.6), and high vegetation (NDVI > 0.6). Student's t-tests were performed for each level of pixels separately, aiming to identify any potential dependencies of vegetation recovery processes on the baseline vegetation status.

To assess the potential impact of fire on the recovery performance in reference and intervention sites, we categorized pixels into three fire regimes based on their fire number in 2017 (baseline year). These regimes include no fire (fire number = 0), low fire (fire number between 1 and 2), and high fire (fire number > 2). Student's t-test were conducted for pixels of each fire regime between reference and intervention sites.

2.3 RESULTS, VALIDATION AND DISCUSSION

The Seasonal Sen's slope for each site AOI was visually investigated to indicate trends of greening between 2017-2023. An example Sen's slope product is visualized in Figure 5 for the same 4x4 km intervention AOI with the CCA as shown in Figure 3 – the slope shows a generally increasing greenness trend for most of the savanna land cover, with grey pixels indicating the dense tree cover mask.

Figure 5 Seasonal Sen's slope for an intervention site AOI within the CCA.



Statistical analysis reveals that African Parks' management interventions effectively improve vegetation recovery process in the CCA. In general, intervention sites exhibit a notably higher proportion of significant positive greening trends compared to the reference sites (Figure 6). Implementation of a Mann-Whitney-Wilcoxon test confirms a significantly larger presence (p-value < 0.01) of significant positive trends within intervention sites.

Pixels within site AOIs were categorized based on reference and intervention sites. Note that in some cases the site AOIs overlapped due to the proximity of sites, and in these cases duplicated pixels in overlapping AOIs were excluded from statistical analysis. The occurrence of positive trends comprises over 70% of the pixels in intervention AOIs, while in reference sites, it accounts for less than 50% (Figure 7). Also, the incidence of statistically significant positive trends is twice as frequent at intervention sites as that observed at reference sites. On the other hand, meaningful vegetation degradation (i.e., significant negative trends) was scarcely observed within intervention AOIs, whereas it is not uncommon in reference AOIs.

Overall, pixels in intervention sites demonstrate noticeably higher values of Seasonal Sen's slope compared to the reference AOIs (Figure 8). The Student's t-test yielded a p-value < 0.01, indicating statistically significant faster vegetation growth in intervention areas. While all the three initial NDVI levels present a faster vegetation recovery at intervention sites, the disparity is most pronounced in sites where the baseline vegetation conditions were low and medium based on NDVI, suggesting greater potential for vegetation recovery in areas initially with lower vegetation coverage. Figure 9 shows that across all the three fire occurrence regimes, vegetation recovery was consistently stronger at intervention sites compared to reference sites. We also noticed that among intervention sites, the average Seasonal Sen's slopes of pixels decline with the baseline fire occurrence. This negative relationship indicated that areas with lower fire occurrence in 2017 likely exhibited faster vegetation recovery over the observation period.

Figure 6 Percentage of site area showing a positive and negative greening trend for reference and intervention sites.

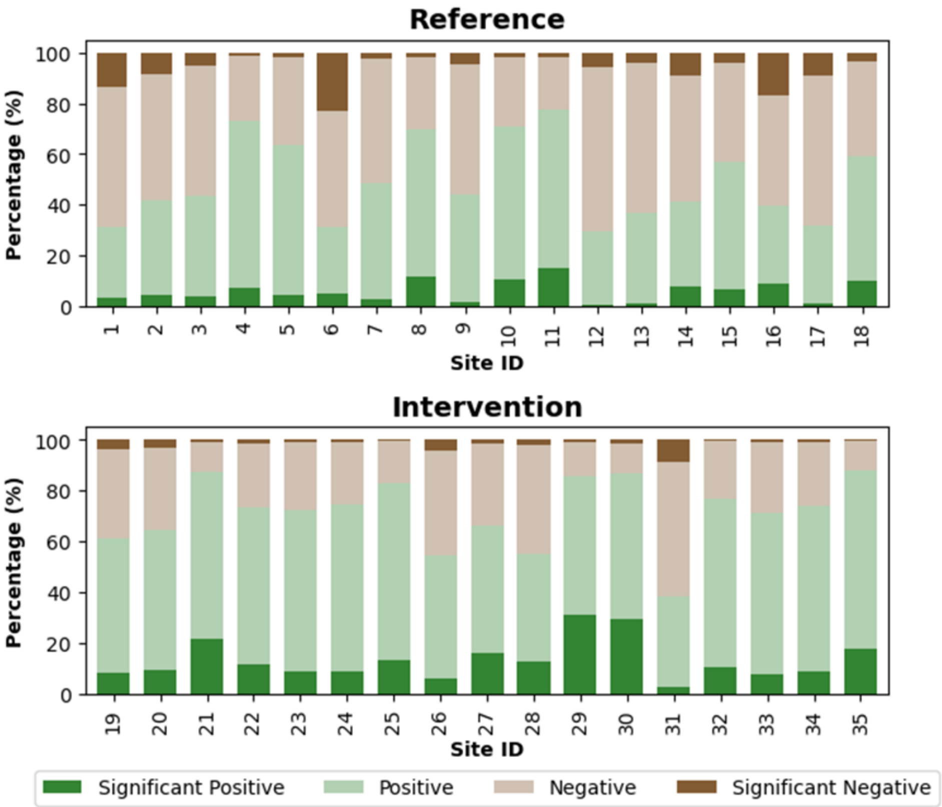


Figure 7 Overall percentage of reference and intervention site area showing a positive or negative greening trend.

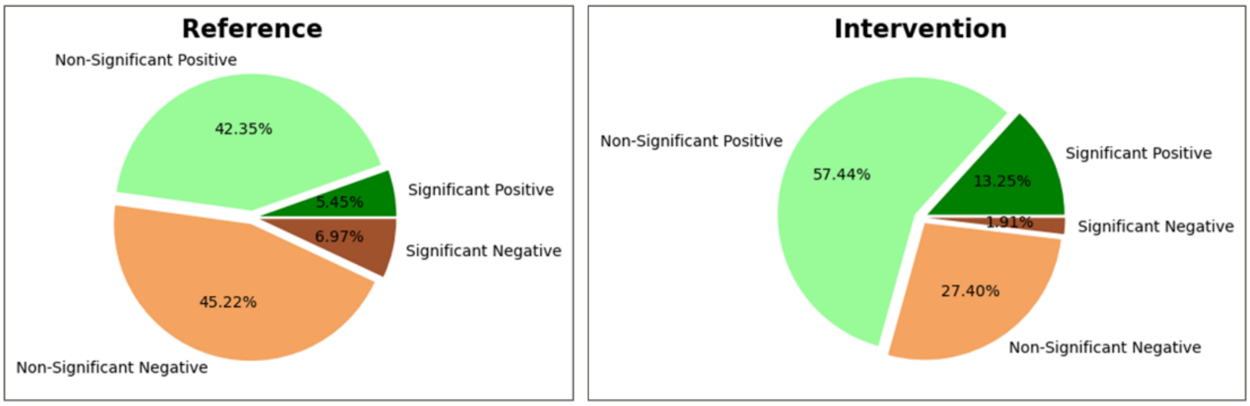


Figure 8 Vegetation greening trends in reference and intervention sites based on baseline vegetation condition.

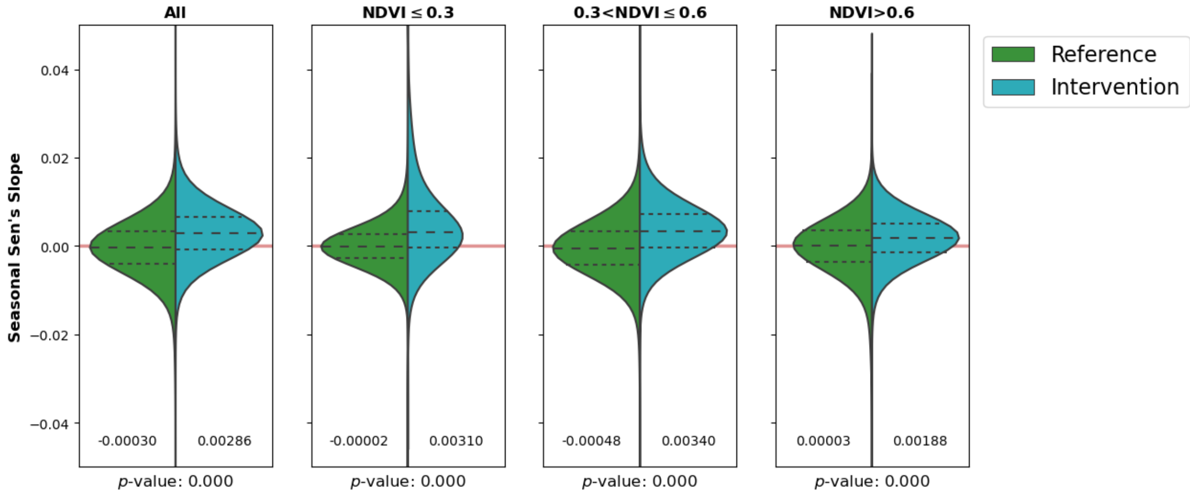
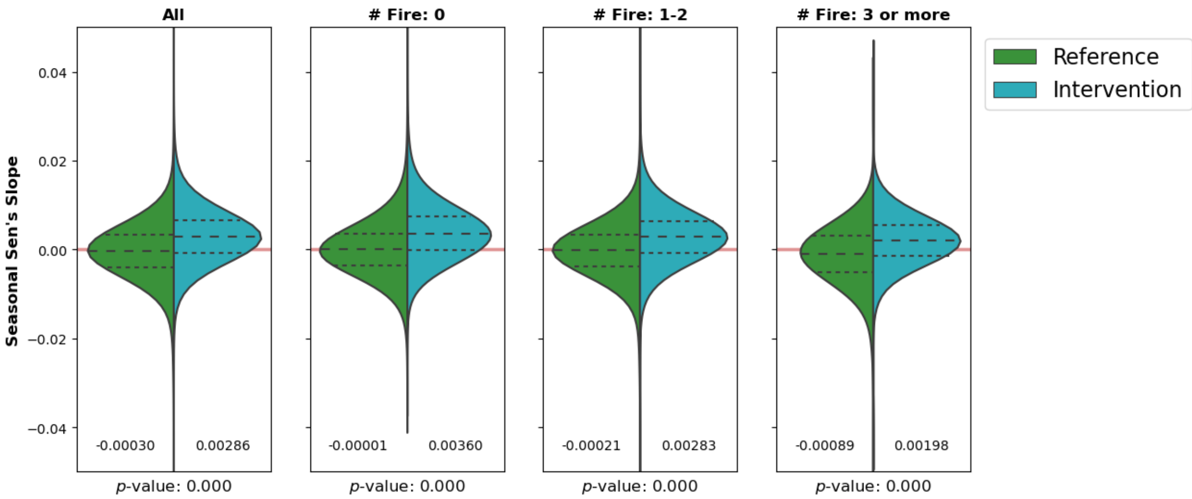


Figure 9 Vegetation greening trends in reference and intervention sites based on baseline fire regimes.



2.3.1 Main Conclusions on the CAR Demonstration Area

The main conclusions in respect to the Early Adopter needs and the demonstration objectives can be summarized as follows:

- The PEOPLE-ER spectral recovery analysis methods and customized analysis for the African Parks use case demonstrate the strong potential for satellite EO methods and tools to provide valuable information for ecosystem restoration management in this type of landscape. The key benefits are:
    - Independence of the EO data to provide an additional line of evidence to other datasets, such as aerial surveys of livestock counts.

    - Synoptic nature of EO data, with the potential to complete the analysis over large areas including the entire CCA if leveraging cloud resources.
    - Ability of Seasonal Sen's slope to mitigate the effects of strong vegetation phenology in this landscape.

- Vegetation recovery within the CCA intervention area was significantly improved compared to the reference locations. The recovery was strongest in degraded areas with lower vegetation density at the beginning of the monitoring period.
- Vegetation recovery within the intervention areas showed a negative relationship with fire frequency. The recovery was strongest in areas with low fire occurrence at the beginning of the observation period, suggesting that reducing fire occurrence is an important recovery strategy for African Parks.

3.0 REFERENCES

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