Earth Observation Tools for Ecosystem Restoration Monitoring

Ecosystem Restoration is important to reverse biodiversity loss and is a critical element of nature-based solutions for climate change mitigation and adaptation, food security, and disaster risk reduction.

We need ecosystem restoration 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).

COP 15 of the Convention on Biological Diversity (CBD) adopted a target to "Ensure that by 2030 at least 30 percent 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].

Satellite Earth Observation (EO) can play a major role in planning, monitoring, and assessment of ecosystem restoration at the scale required. The **Pioneer Earth Observation apPlications for the Environment (PEOPLE) Ecosystem Restoration (PEOPLE-ER)** project financed by the European Space Agency (ESA) has developed and demonstrated innovative ecosystem restoration applications.

Key PEOPLE-ER outputs

Forest Recovery

How can I track the recovery of forest conditions over large areas following a disturbance?

Spectral Recovery is an open source and multi-platform EO time series data analytics solution for restoration monitoring and assessment. It provides flexible methods for spectral recovery analysis by allowing users to select from a variety of spectral indices and recovery metrics as well as define reference or baseline conditions.

Wetland Flood Function Restoration

How can I assess the restoration of seasonal flooding over large areas following a restoration policy?

Satellite Wetland Inundation Flood Time-series Clustering (SWIFT-C) is an open methodology that provides a set of data analytics tools to support large scale landscape assessment, leveraging a radar EO time-series.

Forest Structural Variables

How can I estimate forest height, diameter, basal area, and volume over large areas?

K-NN is an open source tool for deriving forest structural variable maps by combining field reference data and EO datasets. It provides means to map ecosystem characteristics at any given timepoint before or during restoration.

Accessing the PEOPLE Ecosystem Restoration Tools

Findable, Accessible, Interoperable, Reproducible (FAIR) principles are followed to ensure that all algorithms and products are available to the community on publicly accessible environments with transparent access conditions. Embracing the FAIR principles enhances the knowledge sharing and open-science processes.

Spectral-Recovery

Provides automated analysis of Sentinel-2 and Landsat satellite EO data time series to enable monitoring of vegetation recovery in forested ecosystems from boreal to tropical biomes.

How to access:

- Codebase is available on GitHub: https://github.com/PEOPLE-ER/Spectral-Recovery
- Python Package Index (PyPI): https://pypi.org/project/spectral-recovery
- Documentation is available on GitHub Pages: https://people-er.github.io/Spectral-Recovery
- Hosted on the Forestry Thematic Exploitation Platform (Forestry TEP) for users who prefer a solution with graphic interface: https://f-tep.com

Satellite Wetland Inundation Flood Time-series Clustering (SWIFT-C)

Provides methods for analysis of Sentinel-1 radar EO data time series to detect changes in inundation dynamics in natural to heavily modified wetland ecosystems. A series of related methods that include: 1) landscape structure analysis; 2) visualize the similarity of temporal patterns in the radar time series; 3) clustering and classification of the time series to identify wetland inundation functions.

How to access:

- Codebase is available on GitHub: https://github.com/PEOPLE-ER/Wetland-Function-Assessment
- Documentation is available on GitHub Pages: https://people-er.github.io/Wetland-Function-Assessment

K-Nearest Neighbour

Enables wall-to-wall prediction of target variables of interest using field reference data and selected EO datasets.

How to access:

- Codebase is available on GitHub: https://github.com/PEOPLE-ER/k-NN
- Documentation is available on GitHub Pages: https://people-er.github.io/k-NN
- Hosted on the Forestry Thematic Exploitation Platform (Forestry TEP) for users who prefer a solution with graphic interface: https://f-tep.com

Support for Monitoring International Ecosystem Restoration Policies and Commitments

International action on ecosystem restoration is demonstrated through a range of strategic goals and targets. Tracking of progress requires transparent and repeatable methods to be available worldwide. PEOPLE-ER Tools can contribute to monitoring and assessment at national and regional levels.

---

6 CLEAN WATER AND SANITATION

15 LIFE ON LAND

Monitor wetland inundation to assess *Change in the extent of water-related ecosystems over time.*

Monitor forest recovery to assess *Progress towards sustainable forest management.*

UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030

Monitor forest and wetland inundation to assess the impact of efforts aiming to *halt the degradation of ecosystems, and restore them to achieve global goals.*

BONN CHALLENGE

Monitor forest recovery to assess contribution to the Bonn *Challenge to restore* ***150 million hectares*** *of deforested and degraded land by 2020 and* ***350 million hectares*** *by 2030.*

Forest Declaration Assessment

Monitor forest recovery to assess contribution to the *UN New York Declaration on Forests for 3****50 million ha under restoration*** *activities by 2030.*

Convention on Biological Diversity

Monitor forest recovery and wetland inundation change to assess contribution to ***COP 15 Target 2.***

30 percent of areas of degraded terrestrial, inland water, and coastal marine ecosystems, under effective restoration.

Convention on Wetlands
Convention sur les zones humides
Convención sobre los Humedales
Ramsar

Monitor wetland inundation change to assess contribution to ***Strategic Plan for 2016-2024 Goal 3.***

Wisely Using All Wetlands – restoration is in progress in degraded wetlands, with priority to wetlands that are relevant for biodiversity conservation, disaster risk reduction, livelihoods and/or climate change mitigation and adaptation.

European Commission

Monitor forest recovery change to assess contribution to

EU Biodiversity Strategy for 2030 *where 30% of the budget dedicated to climate action is planned for investment in biodiversity and nature-based solutions.*

EU Forest Strategy *that calls for adaptive forest restoration and ecosystem-based management to achieve EU policy targets.*

PEOPLE Ecosystem Restoration Partners

Consortium Members

A consortium of leading companies and research institutions came together in a collaborative, user-focused, and knowledge-sharing approach to deliver the PEOPLE-ER project.

Hatfield is 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 Integrated Remote Sensing Studio (IRSS) in the Faculty of Forestry is a leading international research group 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 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).

Early Adopters

"Early Adopters" are the Civil Society Organizations (CSOs) and Non-Governmental Organisations (NGOs) active in ecosystems restoration with an interest in the novel EO solutions developed by the project for use in their work. The Early Adopters participated in the design and development and evaluation of the EO solutions.

- **National Institute for Research and Development in Forestry (Romania)** – the main organisation of research and development in forestry from Romania. In charge of forest resources assessment and monitoring in Romania through National Forest Inventory.
- **IUCN Vietnam** – Vietnam became an IUCN State member in 1993 and has made important contribution to biodiversity conservation and environmental protection in Vietnam.
- **African Parks** – a leading non-profit conservation organisation that takes on the complete responsibility for the rehabilitation and long-term management of national parks across Africa in partnership with governments and local communities.
- **Society for Ecosystem Restoration in northern British Columbia (Canada)** – a key enabler for ecosystem restoration in forested ecosystems affected by cumulative disturbances from forest operations, energy exploration, wildfires, and forest pests/diseases.
- **Natural Resources Institute (Finland)** – one of the biggest clusters of bioeconomy expertise in Europe, develops knowledge-based solution models and services for renewable natural resources management and supports decision-making in society.

Wetland Restoration Case Study – Mekong Delta

IUCN Vietnam works with the Government of Vietnam and partners including the World Bank, the Embassy of the Netherlands, and GIZ to develop alternative economic, social, and environmental strategies for land use in the Mekong Delta, balancing food production with environmental values. This culminated in Resolution 120 in 2017, which provided the political basis for a **transition to flood-based agriculture** such as lotus and the traditional long-stem flood-adapted rice varieties. The shift toward a more natural hydrology allows for restoration of the Mekong floodplain has major biodiversity and climate change adaptation benefits [2]. While the area of natural wetlands in protected areas is very small, large areas of restored semi-natural wetlands could be considered "other effective area-based conservation measures" (OECMs) [3].

Objective: to assess the change in flood patterns from 2018 to 2022 to identify restoration areas that are open to the natural "flood pulse" and areas still protected by high dikes.

The radar-based SWIFT-C workflow was used to assess the transition to re-naturalized flooding in An Giang Province in the Upper Mekong Delta. The workflow allows us to address: (1) persistent cloud cover during the rainy season; (2) timing of the flood pulse can change be several weeks from year-to-year; (3) lack of available landscape parcel/unit geospatial data and complexity of land use within land parcels.

First, we created landscape units as the basis for the analysis using an image segmentation method. We then used a state-of-the-art embedding technique to visualize the similarity of temporal patterns. Next, we clustered the time series to identify those with a distinctive temporal pattern that can then be attributed with a specific land cover or land use. Finally, using reference data, we were able to accurately classify fields from 2018 to 2022 to determine if they are connected or isolated from the natural flood pulse (double rice or triple rice) (Figure 1).

Results: the analysis showed a 22% decrease in the total area of triple rice between 2019 and 2022, which helped IUCN Vietnam and their partners to understand the progress in the transition to flood-based agriculture.

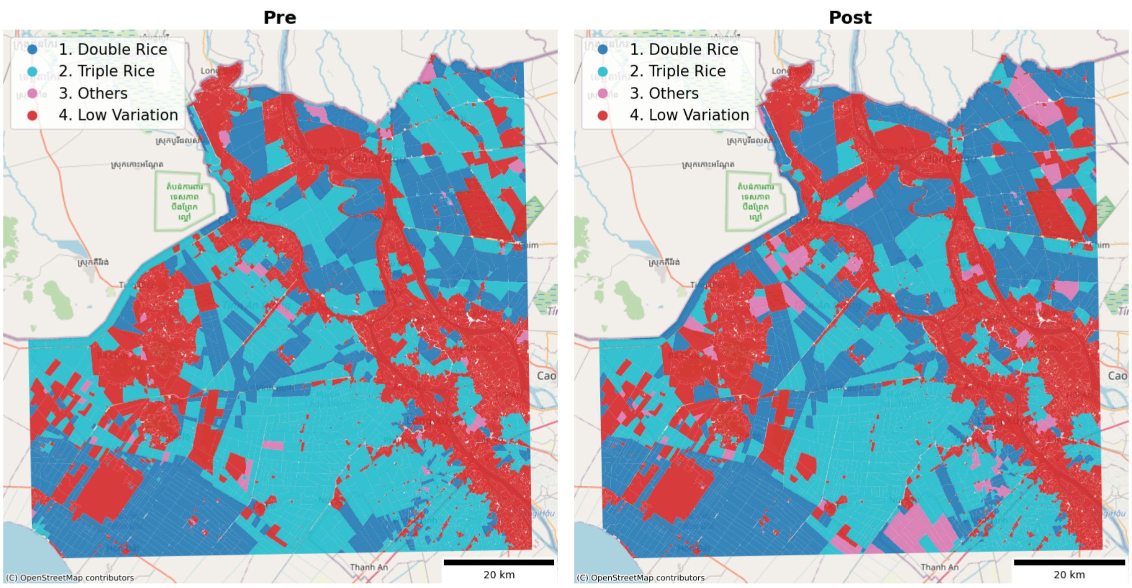

Figure 1. **Classification of land use in An Giang Province, Vietnam, using SWIFT-C to identify fields connected to the natural flood pulse.**

Forest Restoration Case Studies – Canada and Romania

The Spectral Recovery and K-NN tools were tested in northern British Columbia and Romania, where forest disturbance over the past few decades from wildfires, harvesting, resource exploration, and windstorms have impacted the quality of habitat and the provisioning of ecosystem services.

The Society for Ecosystem Restoration in Northern BC and the National Institute for Research and Development in Forestry in Romania urgently need tools to enable efficient monitoring of the progress of forest restoration activities and quantification of ecological and climate effects of forest disturbances and subsequent recovery.

Objective: to assess forest recovery across a landscape using standard recovery metrics derived from Landsat and Sentinel-2 time series, to identify areas that are recovered, recovering as expected, or potentially need management intervention. Further, to assess novel functionality provided by the Spectral Recovery tool to compare 1) setting recovery targets using historical value or reference sites; 2) Sentinel-2 compared to Landsat time series; and 3) single pixel-, multi-pixel-, and polygon-based analysis.

The Spectral Recovery tools allowed us to address the need for a landscape-scale monitoring solution that supports various restoration programs and their historical or reference ecosystem goals; support the use of both Sentinel-2 and Landsat imagery; and provide consistent measures of recovery progress through recovery metrics, important for monitoring and reporting purposes. The tools enabled the assessment of ecosystem recovery following wildfire, harvest, and windthrow disturbances in two study sites (Canada and Romania) and at multiple spatial scales.

The k-NN tool was used to support the analysis by providing additional information on the state of the forest before and during the restoration activities. Time series of height, species and biomass maps were created over the interest areas to monitor the development of forest characteristics.

Results: the analysis successfully allowed for the visualization of recovery progress relative to both historic and reference target conditions across multiple disturbance types and ecosystems. These results were explored at multiple spatial scales: the pixel-level, the disturbance-level, and the landscape-level. Users were able to identify areas where recovery is proceeding as expected and those that may need further restoration or management intervention (Figure 2).

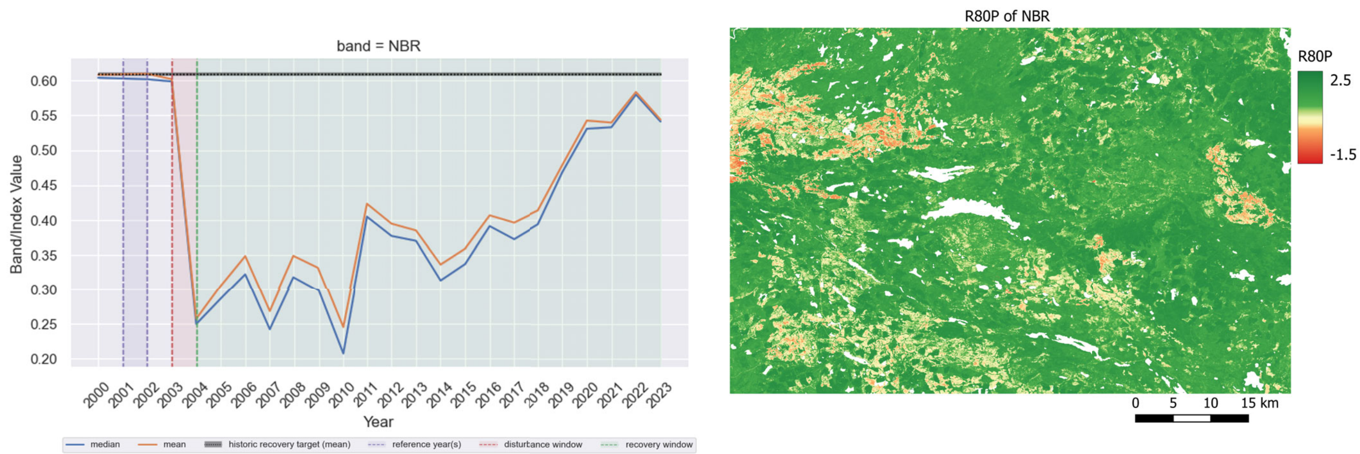

Figure 2. **Example output spectral trend produced by the tool (Left). Landscape level R80P metric produced by the tool (Right). A value of 1 indicates the pixel as having reached 80 percent of its pre-disturbance value. Higher values indicate higher degrees of recovery.**

Woodland Savanna Restoration Case Study – Central African Republic

African Parks assumed management responsibility for the Chinko Conservation Area (Chinko) in 2014. The core protected area consists of five former hunting blocks and is a mosaic of woodland, savanna, and forested ecosystems of more than 24,300 km^2.

Due to decades of political instability, population growth, and overgrazing, thousands of transhumance pastoralists migrate into eastern CAR where Chinko lies. This unregulated transhumance movement escalated to become the primary driver of degradation of the Chinko ecosystem [4]. In response, African Parks developed a programme to improve security where herders adhere to corridors, understanding the benefit for both them 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. To support the management of the, it's to support a land use strategy and community programmes [4].

Objective: to provide vital information on the natural vegetation by using a spectral recovery method to assess the impact of management interventions in Chinko's woodland savanna between 2017-2023. Specifically, to demonstrate a method suitable for monitoring the vegetation recovery trend over the entire core protected area.

We created monthly NDVI images using the full Sentinel-2 times series from August 2017 to August 2023 and the non-parametric Seasonal Sen's slope method [5]. This method addresses the challenge of the evident seasonality of vegetation and the presence of data gaps due to clouds in certain months. Dense trees were masked from the image stacks using the tree cover extent produced by [6]. A counterfactual analysis method was used to compare areas within the core protected area with reference areas.

Results: The occurrence of positive vegetation trends comprises over 70% of the pixels in intervention AOIs, while in reference sites, it accounts for less than 50% (Figure 3). 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 areas, whereas it is not uncommon in reference areas. The initial vegetation conditions or the frequency of fire did not affect the conclusion that African Parks' management intervention supported savanna vegetation recovery. Satellite EO data provided a powerful independent line of evidence to other datasets, such as African Parks' aerial surveys of livestock counts.

Figure 3. Occurrence of positive and negative vegetation trends in reference and intervention sites.

References

[1] Secretariat of the Convention on Biological Diversity, "COP15: Nations adopt four goals, 23 targets for 2023 in landmark UN biodiversity agreement." [Online]. Available: https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022

[2] IUCN, "Transboundary dialogue on wetlands and agriculture in the Mekong Delta." Accessed: Nov. 23, 2023. [Online]. Available: https://www.iucn.org/story/202302/transboundary-dialogue-wetlands-and-agriculture-mekong-delta

[3] IUCN, "IUCN WCPA Other Effective Area-based Conservation Measures Specialist Group." Accessed: Nov. 23, 2023. [Online]. Available: https://www.iucn.org/our-union/commissions/group/iucn-wcpa-other-effective-area-based-conservation-measures-specialist

[4] African Parks, "Chinko: Creating a Solution for Coexistence." [Online]. Available: https://www.africanparks.org/chinko-creating-solution-coexistence#

[5] K. W. Hipel and A. I. McLeod, Time series modelling of water resources and environmental systems. Elsevier, 1994.

[6] J. Brandt, J. Ertel, J. Spore, and F. Stolle, "Wall-to-wall mapping of tree extent in the tropics with Sentinel-1 and Sentinel-2," Remote Sensing of Environment, vol. 292, p. 113574, 2023.

For More Information

Dr. Andy Dean

Vice President

Hatfield Consultants

E-mail: adean@hatfieldgroup.com

Hatfield Consultants

#200 – 850 Harbourside Drive

North Vancouver, BC V7P 0A3

Tel: +1 604-926-3261

www.hatfieldgroup.com

Dr. Frank Martin Seifert

Earth Observation Programme - Climate Action, Sustainability and Science Department

E-mail: frank.martin.seifert@esa.int

ESA / ESRIN

Via Galileo Galilei

00044 Frascati (RM), Italy

Tel: +39-337-141-3955

https://www.esa.int/Applications