PEOPLE

Ecosystem Restoration

FINAL REPORT

May 2024

Prepared for:

ESA/ESRIN

Frascati, Italy

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

FINAL REPORT

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ACKNOWLEDGEMENTS

The **Pioneer Earth Observation apPlications for the Environment Ecosystem Restoration** (**PEOPLE-ER**) project was possible due to the financial support from the European Space Agency (ESA). Technical guidance and feedback from ESA were provided by Dr. Frank Martin Seifert.

The project required active participation with ecosystem restoration Early Adopters, and we appreciated the contribution of:

- **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) – An IUCN State member since 1993, IUCN Vietnam makes important contributions to biodiversity conservation and environmental protection in Vietnam.
- **African Parks** (South Africa) – 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 (Luke**) (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.

EXECUTIVE SUMMARY

The Pioneer Earth Observation apPlications for the Environment Ecosystem Restoration (PEOPLE-ER) project designed, implemented, and validated innovative high-quality EO-based applications and methods targeting European and international priorities for ecosystem restoration monitoring and assessment.

The PEOPLE-ER project was implemented between October 2022 and May 2024 with financial support from the European Space Agency (ESA). **Hatfield Consultants** (Canada) led the project with support from VTT Technical Research Centre of Finland (VTT) and the University of British Columbia (UBC) in Canada. The project involved active participation of five ecosystem restoration Early Adopters: National Institute for Research and Development in Forestry (Romania); IUCN Vietnam (Vietnam); African Parks (South Africa); Society for Ecosystem Restoration in northern British Columbia (Canada); and Natural Resources Institute (Finland).

Ecosystem Restoration tools and demonstrations were designed based on the requirements of the Early Adopters, European and international policy drivers, and the current state of the art in Earth observation. Three tools were developed to address broad ecosystem restoration requirements:

- **Spectral Recovery:** to 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.
- **Satellite Wetland Inundation Flood Time-series Clustering (SWIFT-C)**: to assess the restoration of seasonal flooding over large areas following a restoration policy, 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.
- **k-Nearest Neighbour (k-NN)**: to 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 a means to map ecosystem characteristics at any given timepoint before or during restoration.

The PEOPLE-ER tools are available under **Findable**, **Accessible**, **Interoperable**, **Reproducible** (**FAIR**) principles with the codebase available on GitHub (https://github.com/PEOPLE-ER) under an Apache 2.0 licence, along with documentation and tutorials including algorithm theoretical baseline definition (ATBD) documentation.

Demonstrations using the tools were completed with the Early Adopters in boreal and temperate forests in Canada, Finland, and Romania, the Mekong Delta in Vietnam, and the savanna woodland ecosystem of Chinko Conservation Area in Central African Republic. The demonstrations enabled verification of the tools and validation of the methods, using in-situ data, airborne laser scanning, aerial survey, and counterfactual study designs as appropriate to each demonstration.

Outreach and communications during PEOPLE-ER included the project website, presentations at GEO BON Global Conference: Monitoring Biodiversity for Action (2023), the European Geosciences Union (EGU) General Assembly (2024), and an online webinar. Scientific publications are in preparation in collaboration with Early Adopters.

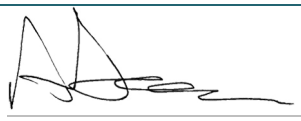
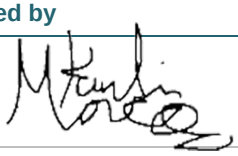
DISTRIBUTION LIST

The following individuals/firms have received this document:

Name	Firm	Email	SharePoint	Project Website
Frank Martin Seifert	ESA	✓	-	-

AMENDMENT RECORD

This report has been issued and amended as follows:

Issue	Description	Date	Approved by	
1	First version of Final Report	20240508		
			Andy Dean Project Manager, Hatfield	Marcos Kavlin Assistant Project Manager, Hatfield

1.0 NEED FOR ECOSYSTEM RESTORATION

Ecosystem Restoration 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.

Ecosystem restoration 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].

The **European Union** (EU) aims to be a global leader in sustainable use of natural resources and mitigation of climate change effects. The **European Green Deal** is an ambitious programme aiming to make EU climate neutral in 2050. It contains a set of policy initiatives by the **European Commission** (EC) related to circular economy, sustainability, and climate change. Protection of biodiversity and ecosystems is among the key priorities of the Green Deal. Several strategies and initiatives under the umbrella of the Green Deal have links to ecosystem restoration. These include:

- *Biodiversity Strategy for 2030*, aiming to put Europe's biodiversity on the path to recovery by 2030 for the benefit of people, climate and the planet.
- *EU Nature Restoration Plan*, for EU countries to put in place effective restoration measures to restore degraded ecosystems.
- *EU Forest Strategy for 2030*, setting a vision and concrete actions to improve the quantity and quality of EU forests and strengthen their protection, restoration and resilience.
- Proposal for a Regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals Nov 30.2022.

Effective planning, monitoring, and assessment of ecosystem restoration is required to evaluate ecosystem functions and to determine whether restoration is having the desired impact. Ecosystem restoration 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 ecosystem restoration, to meet the needs for regular, repeat measures of processes over long time periods covering large, often remote, areas.

To support ecosystem restoration investments, innovative methods are required to deliver high-quality EO-based products and indicators targeting high-priority forest, wetland, and biodiversity variables. Potential users are any entity with an interest or stake in the ecosystem restoration assessment and monitoring. Stakeholders include international organizations, governments at all levels, non-government organizations, and the private sector.

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

2.0 PROJECT OBJECTIVE

In response to the policy drivers and requirements organization implementing ecosystem restoration, the objective of the **Pioneer Earth Observation apPlications for the Environment Ecosystem Restoration** (**PEOPLE-ER**) project was to develop innovative high-quality EO-based application products, indicators, and methods, targeting ecosystem restoration research and development priorities.

3.0 APPROACH

3.1 PROJECT TEAM

The PEOPLE-ER project was led by **Hatfield Consultants** – a Canadian 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 Hatfield-led PEOPLE-ER consortium included:

- 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).

3.2 EARLY ADOPTERS

The 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 (INCDS)** (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)** – an IUCN State member since 1993, IUCN Vietnam makes important contributions to biodiversity conservation and environmental protection in Vietnam.
- **African Parks (South Africa)** – 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 (SERNbc) (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 (Luke) (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.

4.0 ACTIVITIES AND OUTPUTS

The PEOPLE-ER project was implemented between October 2022 and May 2024 in three consecutive tasks, described in the follow sections.

4.1 TASK A VALUE-PROPOSITION CONSOLIDATION

The PEOPLE-ER project team assessed the current state of the art, policy agendas, and the requirements of stakeholders and Early Adopters, which led to our rationale for demonstrations and proposed EO tools focused on ecosystem restoration.

The outputs were:

- D1 – Collaboration description with the Early Adopters.
- D2 – Report on: a) state-of-the-art review on the relevant EO algorithms, methods, models, non-EO data and information technology; b) review of relevant major ongoing projects/initiatives and broad stakeholder groups analysis; c) policy analysis and traceability matrix.
- D3 – Specific Value Proposition Analysis report for the selected Early Adopters.
- D4 – Agile Development Plan (ADP)
- D6 – Validation Methodology (VM), presenting the initial algorithm/method trade-off analysis.

4.2 TASK B AGILE DEVELOPMENT AND VALIDATION

The PEOPLE-ER project team implemented iterative Agile methods that are responsive to changing user needs. The key parts of our agile development approach include: creating and maintaining the product backlog; conducting sprint planning meetings to prepare for an upcoming sprint; executing a sprint; and conducting sprint review and retrospective meetings.

Findable, Accessible, Interoperable, Reproducible (FAIR) principles were 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.

The outputs were:

- D5 – Agile Development Progress Review report.
- D7 – Algorithm Theoretical Baseline Documents (ATBDs) and achieved products specifications.
- D8 – Documentation associated to the developed software.
- D9 – Early Adopters Demonstrator assessment report.
- D10 – Report on the successful integration into a platform environment.

4.3 TASK C OUTREACH AND ROADMAP DEFINITION

The PEOPLE-ER project team's overarching strategy was to promote the awareness, interest, and direct engagement and interactions of the Early Adopters, stakeholders, and other potential users of the PEOPLE-ER tools.

The outputs were:

- D11 Communication website
- D12 Webinar and Workshop
- D13 User Handbook
- D14 Policy Highlights
- D19 Evolution roadmap
- D22 Two scientific publications

5.0 TOOLS & DOCUMENTATION

5.1 SPECTRAL RECOVERY

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.

The critical need is the computation of forest ecosystem recovery metrics using satellite EO data in a reproducible, scalable manner. More specifically, there is a need for an accessible solution that provides standardized metrics and information pertaining to change in vegetation conditions following ecosystem disturbances or restoration interventions, based on the calculation of spectral indices from an EO time series (annual cloud-free composite). Potential use cases include ecosystem restoration monitoring efforts for forested ecosystems or remote sensing research of forest recovery responses.

Users include:

- Ecosystem restoration practitioners interested in monitoring restoration success or ecosystem recovery;
- Remote sensing or GIS specialists studying ecosystem recovery responses;
- NGOs involved in ecosystem restoration and biodiversity conservation;
- Levels of government that aim to assess landscape-scale or site-level conditions of vegetation; and
- International Finance Institutions (IFIs) that wish to have a reproducible tool and methodology with which to efficiently monitor their programs.

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/

5.2 SATELLITE WETLAND INUNDATION FLOOD TIME-SERIES CLUSTERING (SWIFT-C)

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 the radar EO time-series.

The critical need is to be able to identify the areas of seasonal flooding/inundation in wetlands, especially to identify the impact of restoration efforts by reconnection of wetlands to the natural hydrological system. The use case is catchments / river systems where natural, irregular inundation is a restoration priority. The users are restoration practitioners, NGOs, levels of government and IFIs working to implement and monitor policy changes and implementation of interventions or restoration activities.

The biological effects of irregular inundation is known to be a high-priority remote sensing biodiversity product, related to the "ecosystem disturbance and habitat structure" Remote Sensing Essential Biodiversity Variable (RS-EBV) (Skidmore et al., 2021). This is in part due to biological diversity and ecosystem services in seasonally flooded landscapes depending on the location and persistence of surface water (be it inland or coastal) and the nutrient exchange that occurs during these flood events.

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/

5.3 K NEAREST NEIGHBOUR (K-NN)

K Nearest Neighbour (k-NN) is a 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.

The critical need is to acquire information on ecosystem characteristics by efficient and reliable means at regular intervals to monitor and evaluate the ecological and climate effects of ecosystem development. In the forestry context, regulatory and voluntary reporting requirements for stakeholders are rapidly increasing due to the growing number of national and international regulations and initiatives related to forest restoration, biodiversity, and climate effects. Forestry stakeholders are required to either report, or alternatively verify reports, on the status and changes of forest characteristics. EO based monitoring approaches such as the k-NN tool support forestry stakeholders to meet their reporting and monitoring requirements.

Potential users include:

- Private large scale forest owners who need to respond to reporting requirements on the status and changes of the forest, e.g., during restoration efforts following a disturbance event;

- National and international administrative organizations who need to either produce or verify reports on the development of forest ecosystems;
- NGOs interested in ecosystem restoration, biodiversity or climate; and
- Academics working on various aspects of ecosystem monitoring;

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 TEP for users who prefer a solution with graphic interface: https://f-tep.com/

5.4 PLATFORM INTEGRATION

The objective of PEOPLE-ER tool integration was to maximize the usability of the tools, considering the varying levels of EO and information technology expertise among current and future users. People with limited expertise should be able to benefit from the tools with a simple graphical user interface, while people with deeper expertise often want to have access to underlying code and use the tools in their preferred processing environment.

To maximize synergies with existing IT infrastructure, the tools were made available on existing platforms and online environments, namely:

1. Forestry TEP (https://f-tep.com/)
2. GitHub repository (https://github.com/) – providing access under the FAIR principles allowing utilization in a local environment or on suitable platforms, such as Microsoft Planetary Computer or Creodias.

6.0 DEMONSTRATIONS

The PEOPLE-ER Project involved five demonstrations with early adopters in Canada, Romania, Finland, Central African Republic, and Vietnam.

6.1 FOREST RESTORATION – CANADA

In North Central BC, forest ecosystems are impacted by the cumulative effects of mountain pine beetle, wildfire, forest harvesting, and energy operations. Monitoring forest recovery following disturbance is a critical information need.

The objective was 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.

The demonstration assessed 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 k-NN tool was also assessed as a complementary tool to estimate biophysical parameters at restoration sites.

The analysis successfully allowed for the visualization of recovery progress relative to both historic and reference target conditions across multiple disturbance types and ecosystems. Users were able to identify areas where recovery is proceeding as expected and those that may need further restoration or management intervention.

6.2 FOREST RESTORATION – ROMANIA

INCDS in Romania conducts research to improve understanding about the impact of restoration activities for both the forest restoration sites and the surrounding areas.

INCDS 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.

The objective was to assess the Spectral Recovery and k-NN tools to address the need for a landscape-scale monitoring solution and to provide estimates of structural parameters before and after disturbances, and during recovery.

The Spectral Recovery tool was used to produce recovery metrics using Sentinel-2 for impacted sites. 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.

6.3 WOODLAND SAVANNA RESTORATION – CENTRAL AFRICAN REPUBLIC

Chinko Conservation Area in Central African Republic is a mosaic of different ecosystems, incredibly rich with a unique composition of biodiversity and opportunities for ecological and evolutionary processes. Key threats include regional insecurity, weak governance, cross border infringement and high levels of poverty among both local sedentary and nomadic populations.

African Parks ecosystem restoration and protection interventions in Chinko include expanding the area free of cattle to reverse habitat degradation.

The objective was to assess vegetation recovery in Chinko's woodland savanna between 2017-2023 using a spectral recovery method suitable for monitoring in a highly seasonal landscape.

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. This method addresses the challenge of the evident seasonality of vegetation and the presence of data gaps due to clouds in certain months.

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%. 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. Satellite EO data provided a powerful independent line of evidence to other datasets, such as African Parks' aerial surveys of livestock counts.

6.4 WETLAND RESTORATION – MEKONG DELTA, VIETNAM

Vietnam's upper Mekong Delta is susceptible to extreme floods and droughts. IUCN is supporting an initiative to transition away from a third annual rice crop into nature-based solutions (NBS) of flood-based agriculture. This includes ending investment in high dikes, which prevent flooding from the Mekong River, and enabling floodplain reconnection.

To contribute to policy implementation, IUCN requires information on flood extent, floodplain connectivity, and flood-based crop extent.

The objective was 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 from 2018 to 2022. The analysis showed a 22% decrease in the total area of triple rice, which helped IUCN Vietnam and their partners to understand the progress in the transition to flood-based agriculture.

6.5 PEATLAND RESTORATION – FINLAND

North Ostrobothnia and southern Lapland regions in Finland contains active and abandoned peat extraction sites. Drainage ditches were designed to reduce the wetness and regulate the water table levels to promote wood production. The objective was to reduce the amount of field work and increase the spatio-temporal detail of restoration site monitoring with the help of remote sensing. The aim is to be able to follow the development of the restoration process annually in a spatially explicit manner.

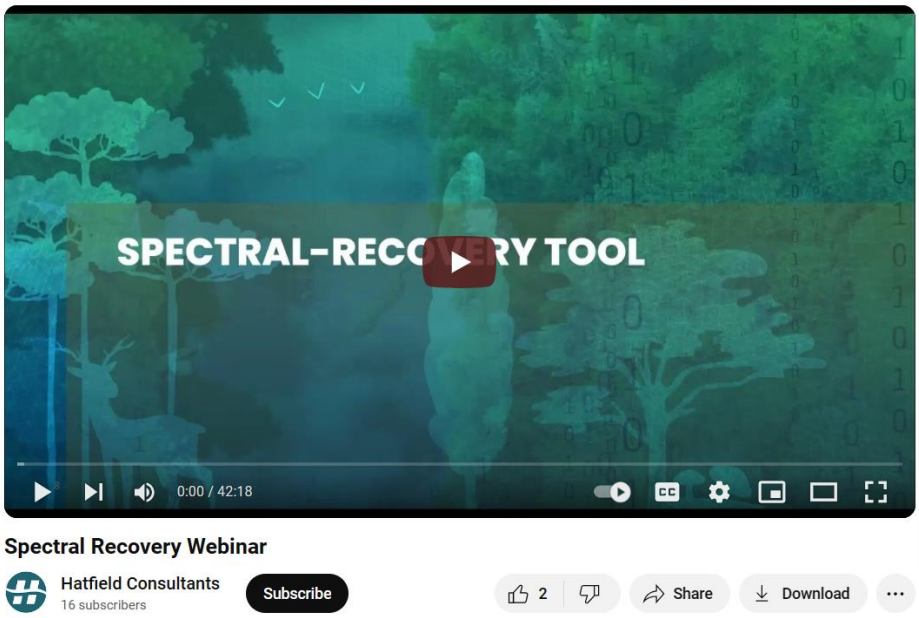
The analyses consisted of vegetation index times series analysis (analogous to the Spectral Recovery tool) and vegetation status mapping. Overall, the analysis on the vegetation index time series suggests that vegetation index time series monitoring will be a useful tool (1) for abandoned peat extraction area surveillance and (2) for alerting of drastic changes in restoration areas. However, with the current datasets and approaches, it may not be useful for monitoring annual trends in peat restoration sites in the study area.

7.0 COMMUNICATION AND USER ENGAGEMENT

The objective for communication and user engagement around the PEOPLE-ER tools was to raise awareness of the tools, use cases, and to expand the number and type of users to include ER and EO researchers and practitioners. Key tools included the project website (Figure 1), webinar (Figure 2), and presentations at international events.

Figure 1 PEOPLE-ER website (www.people-er.info)

Figure 2 PEOPLE-ER webinar (https://youtu.be/2pGToi2kirM)



7.1 PRESENTATIONS

GEO BON Global Conference: Monitoring Biodiversity for Action

A presentation was given in Montreal at the conference (Oct 9-13th 2023). The presentation was titled "Open EO tools for terrestrial vegetation and wetland function recovery analysis to support ecosystem and biodiversity restoration projects."

European Geosciences Union (EGU) General Assembly 2024

A workshop and presentation at the EGU (April 15-19th 2024) promoted the PEOPLE-ER project outputs, focusing on the Spectral Recovery tool for forest restoration monitoring. The presentation was titled "Monitoring Forest disturbance recovery using metrics derived from multi-spectral satellite time-series: introducing the spectral recovery open-source package with European and Canadian use cases."

7.2 SCIENTIFIC PUBLICATIONS

Four scientific publications are in preparation for submission as summarized in Figure 3.

Figure 3 Graphical summary of the PEOPLE-ER publications.

Supporting ecosystem management and restoration through spectral indices and recovery metrics: a remote sensing approach in Saik'uz traditional territory, British Columbia, Canada

Remote Sensing in Ecology and Conservation Open Access ZSL

Evaluating Savanna Vegetation Recovery following management interventions in Chinko Conservation Area, Central African Republic, through Sentinel-2 NDVI Trend Analysis

LDD Land Degradation & Development

Spectral recovery: an open tool for forest recovery monitoring and assessment using Earth observation time series

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

Mapping Reduction in Intensity of Rice Agriculture in the Vietnamese Mekong Delta using t-SNE and Dynamic Time Warping with Sentinel-1 Time Series

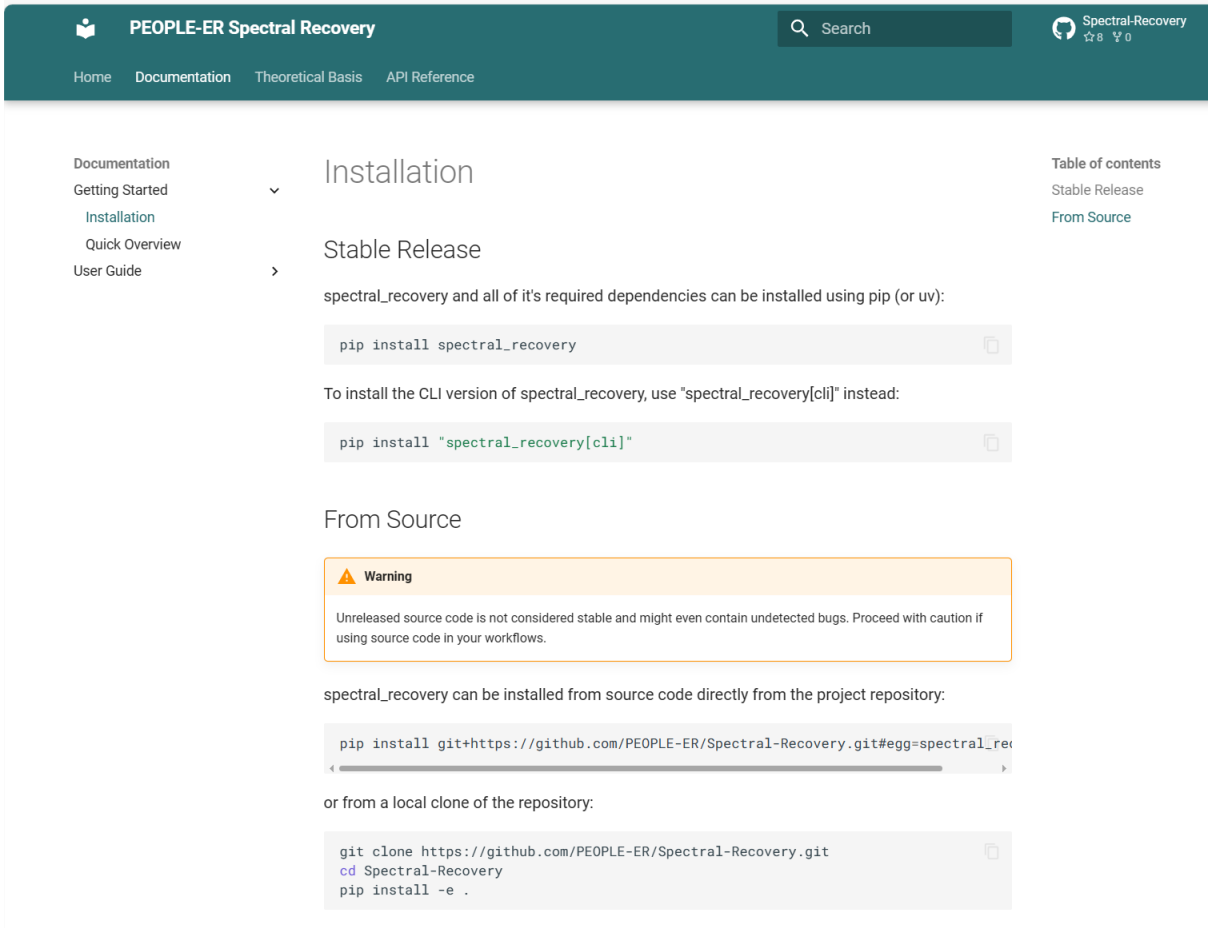
remote sensing

7.3 USER GUIDELINES AND TRAINING

The PEOPLE-ER tools and documentation produced are available to Early Adopters and the wider potential user community under FAIR principles. Documentation including sample data and example notebooks is available on GitHub Pages:

- Spectral Recovery: https://people-er.github.io/Spectral-Recovery/ (see Figure 4)
- SWIFT-C: https://people-er.github.io/Wetland-Function-Assessment/
- K-Nearest Neighbour:: https://people-er.github.io/k-NN/https://people-er.github.io/Spectral-Recovery/

Figure 4 Example of GitHub Pages documentation (Spectral-Recovery).



8.0 DEVELOPMENT PRIORITIES FOR USER ADOPTION

8.1 USER ENGAGEMENT

The PEOPLE-ER Project outreach was successful in its goal of generating interest in the project tools. Early adopters and other users have shown interest in the capabilities of the tools. For example, we have recorded **more than 4,000 downloads of the Spectral Recovery tool from Github**.

To promote awareness and adoption of the tools, future attendance and presentation at the following events is recommended:

- United Nations Biodiversity Conference of the Parties (COP) to the UN Convention on Biological Diversity – COP 16 will take place in Cali, Colombia in Q4 2024. COP16 could provide the opportunity to further interact with conservation and restoration practitioners to communicate the availability of the tools. The next GEO-BON meeting may be a better forum, however, the timing and location is currently unknown.
- SER World Conference 2024 – The Society of Ecological Restoration will host it's 2024 World Conference in Denver, Colorado, United States, in October 2024. This would provide another valuable opportunity to interact with the target user community and would aid in the generation of further development ideas and improvements for the tools.

8.2 ADDITIONAL DEMONSTRATIONS

The PEOPLE-ER Project completed five demonstrations of using the tools in different landscapes in support of ecosystem restoration projects. Following the workshop, to promote awareness and adoption of the tools, additional demonstrations are recommended, with interest expressed for collaboration.

Intertidal habitat restoration

The Horizon Europe REWRITE Project (https://rewriteproject.eu/) promotes the adaptation of the innovative conservation approach of 'rewilding' as a nature-based solution to restore intertidal areas in Europe and beyond. The REWRITE project has expressed interest in using the SWIFT-C tool to assess the return of a naturalized intertidal flood typology on these landscapes.

Spectral Recovery validation in European or tropical forests

Spectral Recovery was demonstrated and validated in Canada and Romania, but there is an opportunity to complete further demonstrations in Europe to consolidate the benefits of the tool to support monitoring of implementation of *EU Nature Restoration Plan* and *EU Forest Strategy for 2030*.

Demonstrating the tool in managed European Forests, particularly in forests where multiple management interventions are underway, would display the potential of the tool for monitoring multiple different intervention types and comparing them based on reproducible metrics. Opportunities for collaboration on demonstrations include:

- Laboratory of Dr. Cornelius Senf (Technical University of Munich), which has completed research on spectral recovery metrics.
- Finnish Geospatial Research Institute is interested in spectral recovery validation based on the availability of multi-date LiDAR surveys in Finland's forests, which makes the testing and

validation of the tool in this landscape optimal, as one would be able to measure the tool's accuracy at different stages of the recovery process.

Tropical forests present another use case for demonstrating the tool. For example, restoration events in tropical forest regions will demonstrate the tool's use in highly productive and dynamic environments, with challenges such as cloud cover.

8.3 TECHNOLOGY DEVELOPMENT

The PEOPLE-ER project team completed development of the first versions of three tools. Following the workshop and based on user requirements, additional technical development is identified.

Spectral Recovery

1. **New recovery metrics** – should be integrated into the tool to ensure current, relevant research can be utilized by practitioners and researchers. Suggestions for new metrics by users or researchers should be facilitated through the GitHub Issues page.

2. **Integration for openEO** – making the tool available as a pre-packaged algorithm on openEO could be extremely helpful to users of the tool that wish to use the tool on different cloud-based backends without having to go through the challenge of ingesting the tool themselves into platforms like openEO. This would most likely increase the user base of the tool as well as provide further interest for platforms such as openEO by the conservation and restoration practitioner communities.

SWIFT-C

- **Improvements in the packaging of the tool** – in line with the packaging of the Spectral Recovery tool (Python package shared in PyPI) would be recommended or developing a simple application with a GUI to simplify the process for non-coding users.

- **Testing the methodology with other SAR sensors** – including VHR SAR sensors. These include TerraSAR-X and newspace sensors such as IceEye and Capella Space.

k-NN

The current version of the tool is fully functional in the sense that it can be used operationally. Further developments will be based on identified needs and/or requests arising from the user community. Continued communication and support to the current users is foreseen, while also trying to grow the number of users by promoting the tool towards a wider user community. Potential technical developments to consider in the future include:

- **Facilitation of feature bank creation within the Forestry TEP**, thus removing the necessity for the user to create the feature bank offline using auxiliary software (e.g., QGIS). This would remove the need to download any image data from Forestry TEP to the user's own computer.

- **Provision of pre-made feature banks for key satellite data products** (e.g., Sentinel-2 L2A imagery) and specific ecoregions. To create such feature banks, extensive publicly available ground reference datasets from the ecoregions of interest would need to be available.

9.0 CONCLUSION

The PEOPLE-ER project designed, implemented, and validated innovative high-quality EO-based applications and methods targeting European and international priorities for ecosystem restoration monitoring and assessment.

The PEOPLE-ER project was implemented in a collaborative approach by **Hatfield Consultants**, VTT, and UBC with active participation of five ecosystem restoration Early Adopters: INCDS (Romaina), IUCN Vietnam (Vietnam), African Parks (South Africa), SERNbc (Canada), and Luke (Finland).

Ecosystem Restoration tools and demonstrations were designed based **on the requirements of the Early Adopters, European and international policy drivers, and the current state of the art in Earth observation. Three tools were developed to address broad ecosystem restoration requirements: Spectral Recovery, SWIFT-C, and k-NN. The PEOPLE-ER tools are available** under FAIR principles with the codebase available on GitHub (https://github.com/PEOPLE-ER) under an Apache 2.0 licence, along with documentation and tutorials.

Demonstrations using the tools were completed with the Early Adopters in boreal and temperate forests in Canada, Finland, and Romania, the Mekong Delta in Vietnam, and the savanna woodland ecosystem of Chinko Conservation Area in Central African Republic. The demonstrations enabled verification of the tools and validation of the methods, using in-situ data, airborne laser scanning, aerial survey, and counterfactual study designs as appropriate to each demonstration.

Outreach and communications during PEOPLE-ER included the project website, presentations at GEO BON Global Conference: Monitoring Biodiversity for Action (2023), the European Geosciences Union (EGU) General Assembly (2024), and an online webinar. Scientific publications are in preparation in collaboration with Early Adopters.

The PEOPLE-ER project generated interest in the ecosystem restoration community and several opportunities to further develop the tools and complete additional demonstrations are identified.