D6: ROMANIA DEMONSTRATION VALIDATION REPORT

April 2024

Prepared for:

ESA/ESRIN

Frascati, Italy

Hatfield Consultants LLP

#200 - 850 Harbourside Drive
North Vancouver, British Columbia, Canada V7P 0A3
Tel: 1.604.926.3261 • Fax: 1.604.926.5389
www.hatfieldgroup.com

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

D6: ROMANIA DEMONSTRATION VALIDATION REPORT

Prepared for:

INCDS ROMANIA

Prepared by:

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
P.O. BOX 1000, FIN-02044 VTT
FINLAND
TEL: +358 20 722 111
HTTPS://WWW.VTTRESEARCH.COM/EN

APRIL 2024

ESA11339

VERSION 1

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AMENDMENT RECORD

This report has been issued and amended as follows:

Issue	Description	Date	Approved by
1	D6 – Romania Demonstration Validation Report	20240104	Andy Dean 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

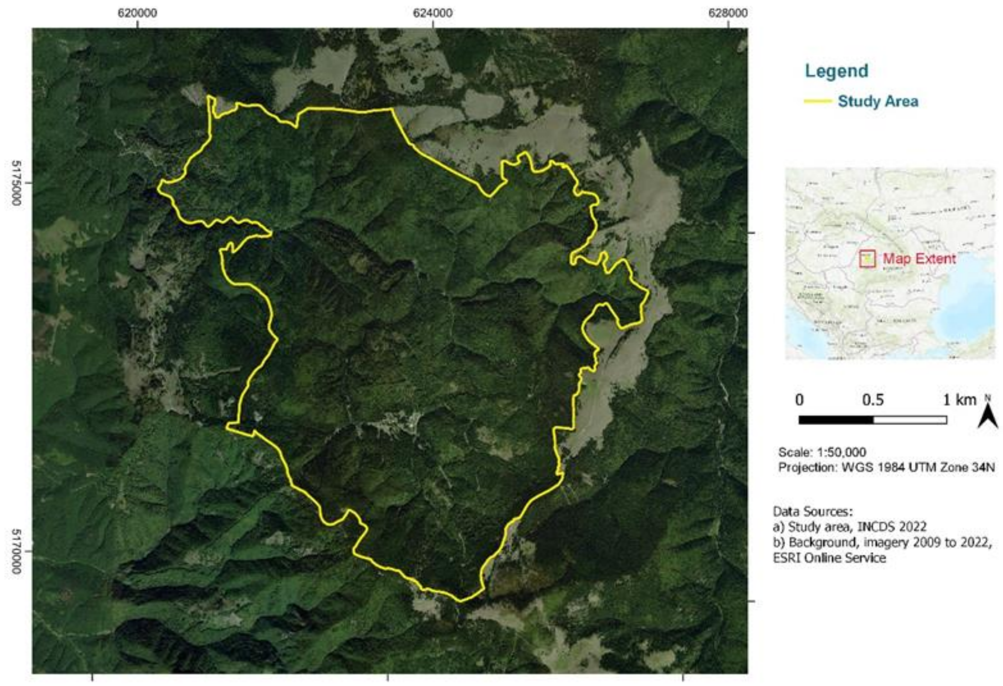
Deliverable 6 (D6) version 1 defined the validation methodology for the PEOPLE-ER methods and algorithms to be developed and the specific demonstrations with Early Adopters. This updated version of D6 is the Validation Final report, presenting the tools/algorithm applied in each demonstration and the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

2.0 INCDS – ROMANIA FOREST RESTORATION

2.1 DEMONSTRATION STUDY AREA AND OBJECTIVE

The demonstration site in West Carpathian Mountains (western Romania) covers 2800 hectares at 1200-1400 m altitude (Figure 1). The area is covered by forests with dominant tree species Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*), sometimes mixed with European fir (*Abies alba*).

Figure 1 Romania study area.



In 2017, over 180 ha were totally damaged and more than 1000 ha partially damaged in a storm. Since then, an infestation of European spruce bark beetle (*Ips typographus*) has affected the surviving forest stands, causing additional tree mortality. The local forest district is conducting ecosystem recovery actions by cutting the infected trees and planting new forest. The planting activities will continue until 2025.

The early adopter INCDS works with two local NGOs in the area (Forestry Society Association and Fundatia Grupul Verde Oradea) to monitor the effect of ecosystem restoration activities. Monitoring of forest areas affected by windthrow requires a lot of field work. The objective is to reduce the amount of required field work and improve the spatio-temporal coverage of the monitoring activities with remote sensing.

2.2 DATA AND METHODS

2.2.1 EO Data

The ESA Sentinel-2 MSI Level 2 Surface Reflectance products were used in the Romanian demonstration area. Seven spectral bands were extracted from the L2 Surface Reflectance products (B02 Blue 0.49 µm, B03 Green 0.56 µm, B04 Red 0.67 µm, B05 Red Edge 1 0.71 µm, B08 NIR 0.84 µm, B11 SWIR 1.61 µm and SWIR 2.19 µm). These bands were selected to be used based on earlier results on optimal set of bands for forest variable prediction (Astola et al. 2019; Miettinen et al. 2021). All bands were resampled to 10 m spatial resolution using the nearest neighbor resampling. Images with minimum cloud cover were selected over a 5-year period from 2017-2022. The acquisition dates ranged between 29th August and 14th October.

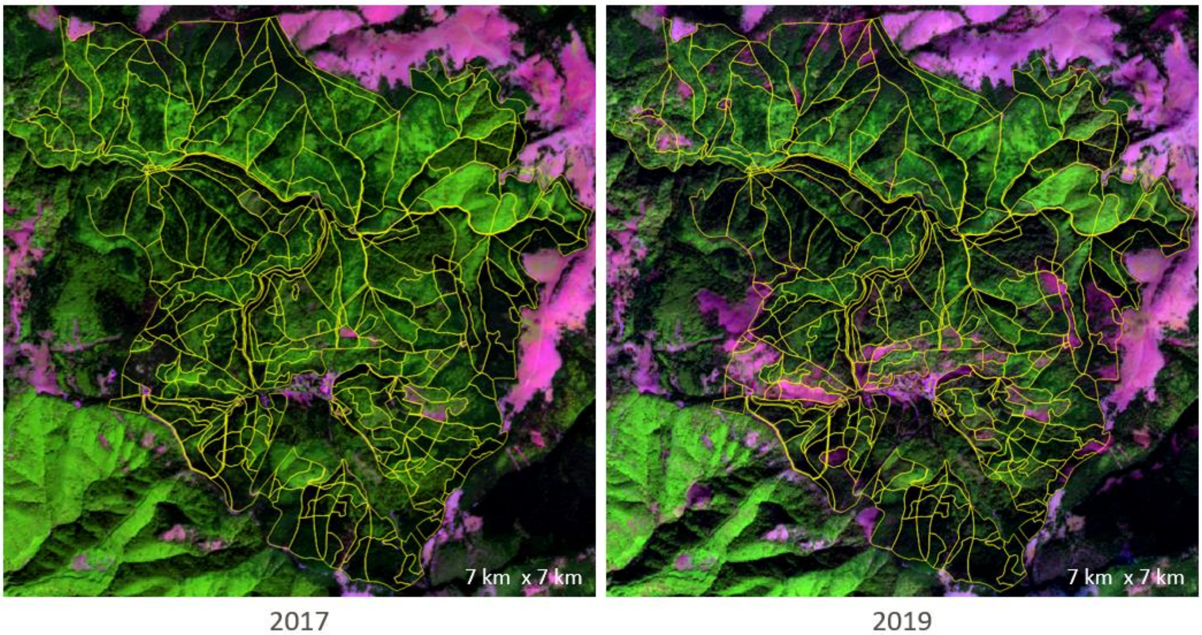
2.2.2 Reference Data

The reference data consisted of two key datasets:

1. Inventory of storm damage in forest stands 2017
2. Forest stand vegetation inventory 2019

The inventory of storm damage conducted after the October 2017 storm served as the main source of information to derive sample areas for the analyses. The analysis was conducted on the 291 forest stands in the Stana de Vale study area (Figure 2). The stands were classified into totally destroyed (31), partially destroyed (93) and unaffected (167).

Figure 2 Stana de Vale (Romania) study area before (2017) and after (2019) the storm, with forest stand polygons visible.



In 2019, a forest field survey was conducted in the study area. The field inventories were conducted by local NGOs. Among the measured variables, the following were selected for the analysis:

1. Diameter (DBH, cm)
2. Height (H, m)
3. Fagus proportion = proportion (%) of Beech (*Fagus sylvatica*)
4. Spruce proportion = proportion (%) of Norway spruce (*Picea abies*)

The survey covered all of the 291 forest stands in the study area (Figure 2).

2.2.3 Methods

The analysis consisted of two main components:

1. Vegetation index times series analysis
2. Vegetation status mapping test

In the vegetation index time series analysis, the aim was to investigate the trajectory of vegetation indices following a storm event (to assess the potential of the Spectral Recovery tool). The analysis was based on visual evaluation of the times series following the storm event. To deepen the analysis, the correlation between vegetation indices and forest stand height was investigated, as forest height was considered to be a key attribute for forest recovery monitoring. The following vegetation indices were used:

- Normalized difference Vegetation Index (NDVI): (NIR-red)/(NIR+red)
- Normalized Burn Ration (NBR): (NIR-SWIR2.1)/(NIR+SWIR2.1)

In the vegetation status mapping test, the uncertainty of the k-NN tool was evaluated using the field inventory results. The training and testing feature banks were created using the forest stands unaffected by the storm. The uncertainty of the model was validated by comparing the k-NN produced estimates to the field inventory based stand information to calculate Root Mean Square Error (RMSE) and bias of the estimates as:

$$RMSE = \sqrt{\frac{\sum_i (y_i - \hat{y}_i)^2}{n}} \qquad BIAS = \frac{\sum_i (y_i - \hat{y}_i)}{n}$$

where y represents the observed reference values, yˆ represents the predicted values and n is the number of samples. Both RMSE and bias were provided in absolute terms and as % of the mean. All of the uncertainty statistics were calculated for each target variable.

The aim of the analysis was to assess the usability of the k-NN tool for provision of current ecosystem conditions in the interest areas. The analysis was based on a dataset provided by the Early Adopter, but similar model can be built with openly available field measurements (where available).

2.3 VALIDATION RESULTS AND DISCUSSION

2.3.1 Vegetation Index Times Series Analysis

The vegetation index time series analysis was conducted by visual examination of time series in the forest stands that had been classified as totally destroyed in the 2017 post storm inventory. NBR and NDVI were used in the analysis. The results (Figure 3 and Figure 4) reveal two key finding which later play an important role in defining the best solutions for the Early Adopter:

1. Both NBR and NDVI show a clear decrease following the storm event. However, it is important note that for some stands the drop is not immediate, but the decrease continues several years after the storm event. This issue was further investigated and is discussed in the following section.
2. By 2022, the NDVI values already overlap with the pre-storm values, while the NBR values are still consistently below the pre-storm level. Many NBR values show an increasing trend, but

some stands do not show any signs of recovery. The comparison between NBR and NDVI suggest that NBR would be a suitable index for recovery monitoring in the conditions of the study area, which is consistent with the research related to the Spectral Recovery tool (Pickell et al. 2016).

Figure 3 NBR and NDVI time series on storm damaged stands.

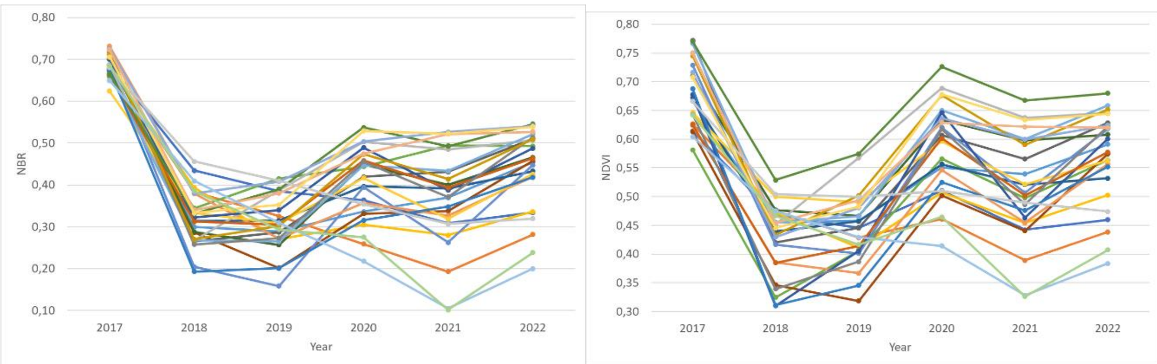
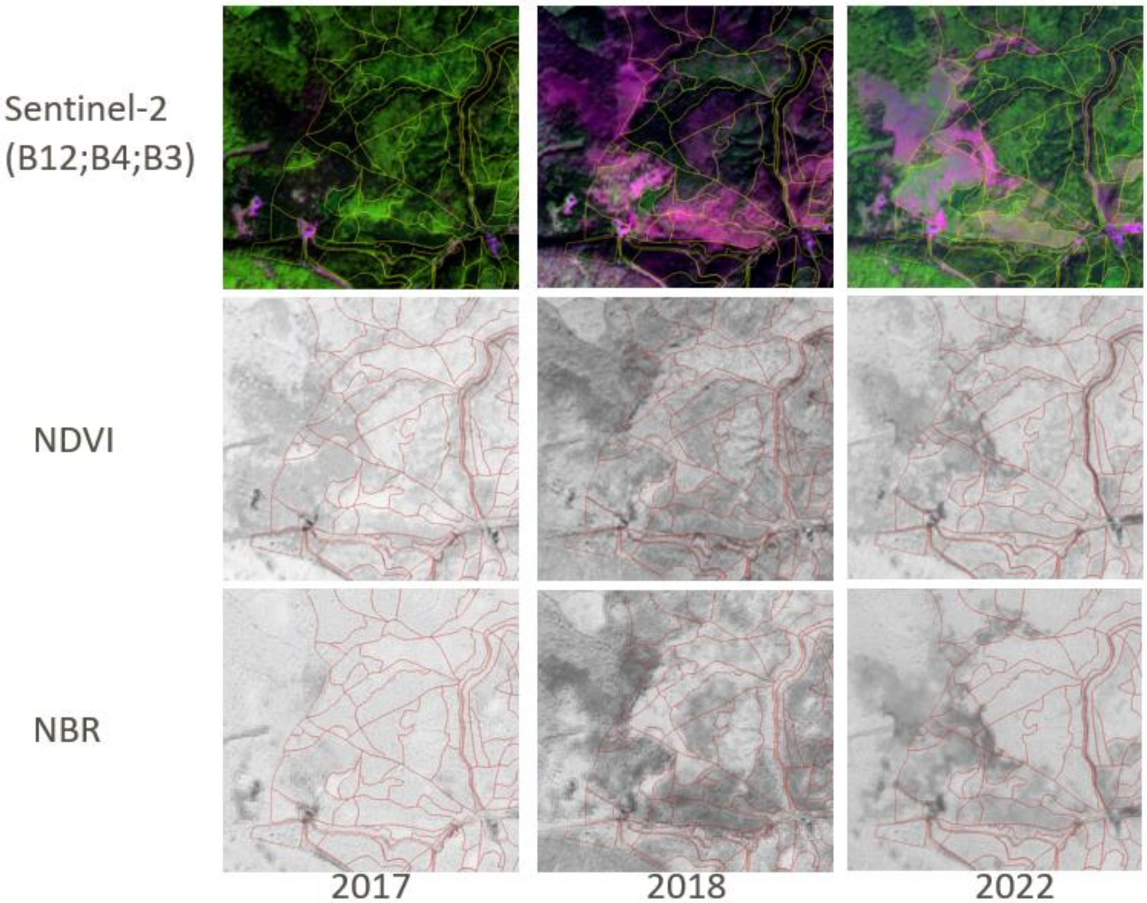


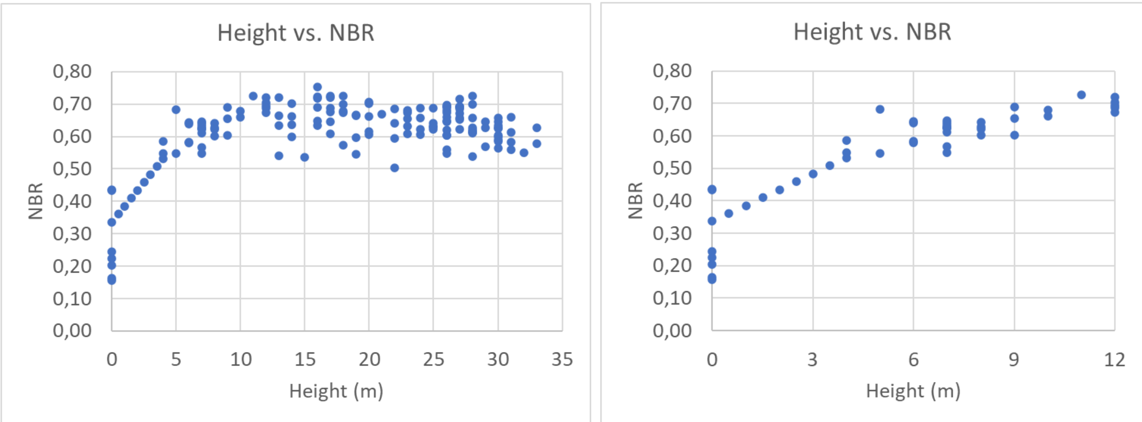
Figure 4 NBR and NDVI response to storm damage.



To further investigate the suitability of the NBR index to monitor the recovery of storm damaged areas, correlation between NBR and the tree height was investigated. This investigation was conducted using the 2019 forest inventory data. Only forest stands undamaged by the storm were used in the analysis, as many discrepancies were noticed in the 2019 measurements of the stands affected by the storm. These discrepancies are expected to be caused by partial or continued destruction of the forest within the stands.

The investigation revealed a clear correlation between NBR and the tree height in the early development phases up to around 7 m of height, with potential usability up to 12 m of height (Figure 5). Beyond that, NBR does not seem to provide any information on the height. Note that the field survey results did not have any values in the range of 1-4 m. Linear interpolation was used within this range in Figure 5.

Figure 5 Relationship between height and NBR, with a zoom (1-12 m) on the right.



Overall, the investigation into the usability of vegetation indices indicates that NBR is a useful index for monitoring storm recovery in the study area. This is important as NBR is one of the indices available in the Spectral Recovery tool. However, slow degradation processes following the storm may complicate the recovery monitoring. This issue was further investigated in the vegetation status mapping test.

2.3.2 Vegetation Status Mapping Test

The vegetation status mapping test was conducted with the k-NN tool. This tool allows mapping of vegetation characteristics in the areas of interest, which could be used to monitor both degradation and recovery of vegetation in storm affected areas and elsewhere.

The feature bank was created with the 2019 forest inventory, using only forest stands unaffected by the 2017 storm in the feature banks. The average spectral vector within the stand was recorded and combined with the forest inventory field survey results. Altogether 103 training stands and 52 testing stands were available for the analysis.

The k-NN tool uncertainty was evaluated with the 2019 datasets. The error metrics show relatively good RMSE values, but significant biases (Table 1). Further investigation on the scatter plots (Figure 6) show that the height is consistently overestimated until 23 m height. This explains the positive bias of nearly 90 cm in the height estimation. But overall, the scatter plot for height show a good correlation between the estimated and reference values. For the Fagus proportion, the correlation is similarly very clear in the scatter plot.

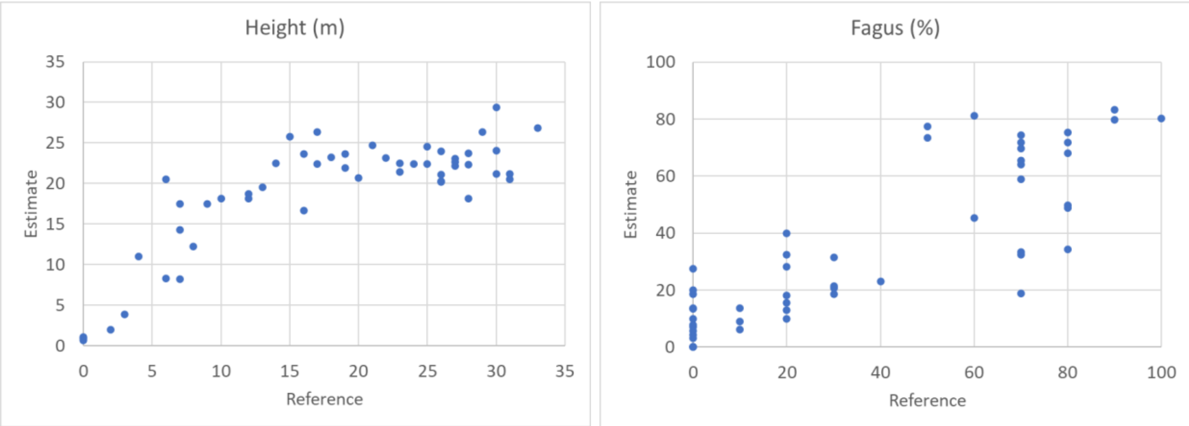
The height scatter plot reveals the trend of overestimation in the lower ranges and the saturation in the higher ranges. These are typical features for the k-NN (and many other) empirical methods for satellite based vegetation structure estimation, as noticed already in the Finland study area. In the case of

Romania, the creation of the feature bank using stand-wise averages may have further emphasized the effect.

Table 1 Error metrics of the k-NN tool in the Romania study site.

Variable	RMSE	RMSE%	Bias	Bias%
DBH	12,2	48,3	1,95	7,67
HGT	6,0	33,1	0,88	4,85
FA	17,6	46,3	-2,93	-7,70
MO	24,6	50,5	2,44	5,01

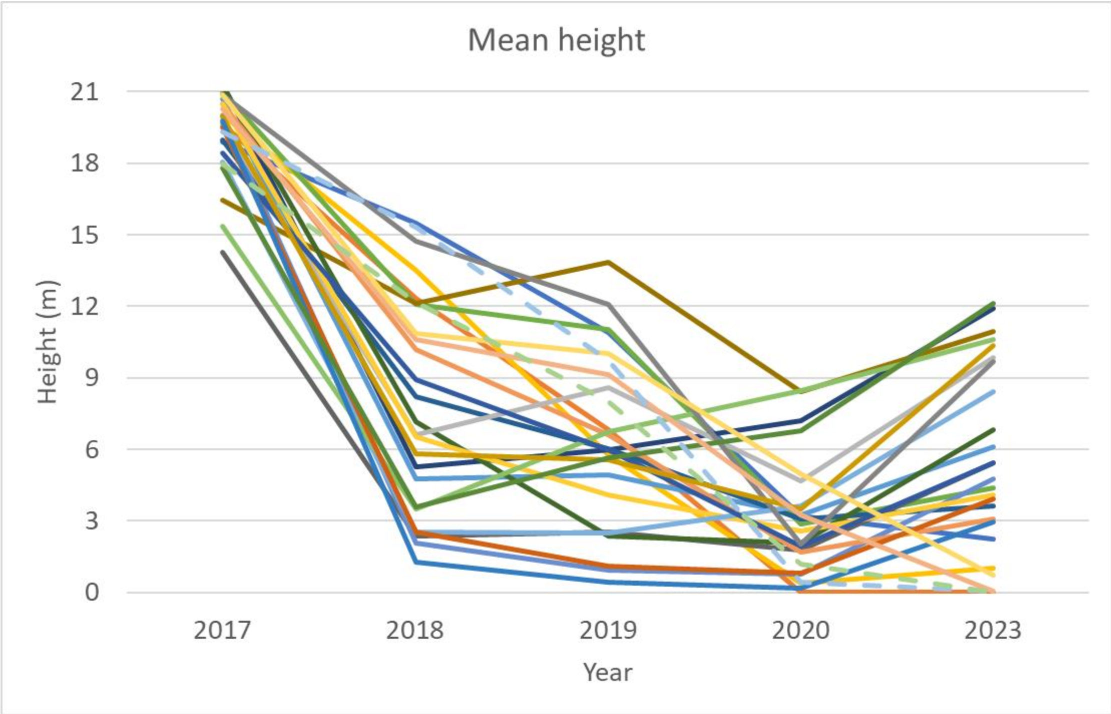
Figure 6 Scatter plots of stand level height and estimation with k-NN.



The k-NN was then applied to the time series of Sentinel-2 imagery 2017-2023. The investigation of the stand mean height development in those stands which were classified as totally destroyed by the storm revealed a very diverse set of results (Figure 7). While some of the stands present a clear drop in the mean height, in some stands it takes many years to decrease to the lowest point. Some of the stands have their lowest height estimate in the latest image in 2023, while other stands already show clear growth trend by 2023. While looking at the absolute height measurements, it needs to be remembered that the method tends to overestimate height in the shorter range.

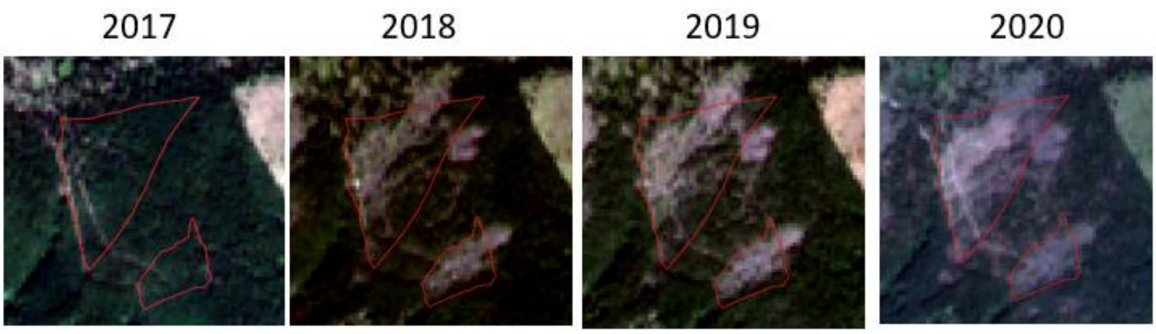
Closer investigation into the stands revealed high variation in tree heights within the stand. The mean height of the stand is strongly affected by the variation caused by varying amount of remnant standing trees. As already mentioned earlier many of the totally damaged stands had very high height also in the 2019 field inventory. This was the main reason why these stands were not used in the feature bank creation. In that sense, the k-NN test supports the field measurements.

Figure 7 Mean stand height in forest stands totally destroyed by the storm.



Visual analysis of the development of the forest stands classified as totally destroyed explained the noticed decreasing trends. Many stands have gradually lost their tree cover or they been totally cleared only in later stages. Partially damaged (e.g., top damage) trees may live on several years after the storm without showing significant changes in the spectral signature. These areas are also very vulnerable for bark beetle attacks which may lead to salvage logging of the areas. Figure 8 shows a typical example of the post-storm development of two stands classified as totally destroyed. The tree cover is slowly decreasing until 2020, showing a decreasing trend in height estimations, rather than recovery (dashed lines in Figure 7).

Figure 8 Development of a totally destroyed forest stand.



2.3.3 Main Conclusions on the Romania Demonstration Area

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

- The Spectral recovery tool may not be useful in all aspects due to the slow degradation processes in many forest stands following a storm and the small forest stand size. However, it will be useful in creating vegetation index times series of interest areas for initial evaluation of the development trends.
- k-NN can be used to estimate forest heigh and other forest attributes in the study area. It is useful for monitoring overall forest development in the area or monitoring degradation following storm events. But it is not optimal for recovery monitoring as it is not accurate in detecting early development of forests.
- The combination of vegetation index trend analysis (e.g., with the Spectral Recovery tool) and k-NN vegetation structure mapping may be useful for:
    - Alerting of degradation trends in forest stands.
    - Alerting of drastic changes in vegetation attributes in any of the interest or nearby areas.
    - Monitoring the progress of regeneration on planted areas, as NBR correlates well with forest height in the study area.