LONG-TERM LAND RESTORATION ASSESSMENT USING REMOTE SENSING IN MEDITERRANEAN ECOSYSTEMS

Tom Avikasis Cohen // Ghadir Zbedat // Prof. Anna Brook
Spectroscopy and Remote Sensing Laboratory, School of Environmental Sciences, University of Haifa

ABSTRACT

The Mediterranean region's arid and semi-arid ecosystems are increasingly threatened by land degradation, desertification, and climate change. This study uses remote sensing indicators from Sentinel-2 satellite data to assess long-term land restoration efforts. Focusing on two case studies—the Heraklion Forest restoration and the transformation of agricultural land in Beit Lehem of Galilee into a food forest model—we analyzed six indicators: Normalized Difference Soil Index (NDSI), Soil-Adjusted Vegetation Index (SAVI), Plant Senescence Reflectance Index (PSRI), Structure-Insensitive Pigment Index (SIPI), Normalized Difference Infrared Index (NDII), and Normalized Difference Water Index (NDWI).
Our comparative analysis between restored areas and nearby non-restored control areas revealed significant improvements in vegetation health and water content in the restored areas. These findings underscore the effectiveness of restoration activities in enhancing ecosystem resilience to environmental stressors. This study demonstrates the critical role of remote sensing technologies in monitoring and managing land restoration, providing valuable data for sustainable land management in the Mediterranean region. Continuous monitoring and adaptive management, supported by robust scientific evidence, are essential for achieving long-term restoration success and resilience against climate change

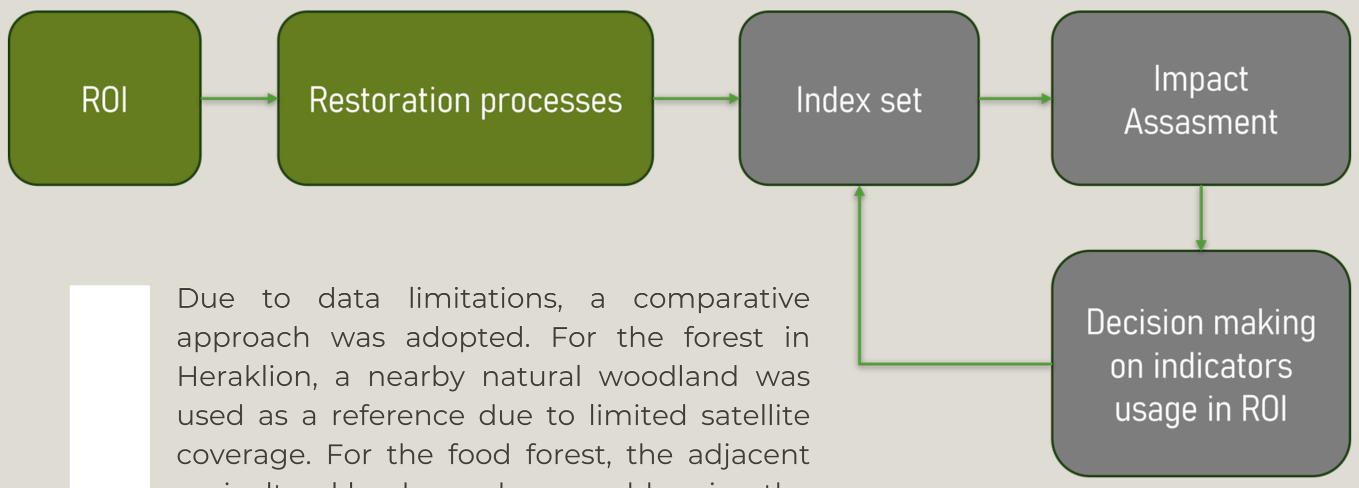
Satellite Remote Sensing - Soil Satellite remote sensing enables efficient, large-scale monitoring of soil properties, such as moisture, organic content, and degradation, by capturing spectral data across vast areas. Its effectiveness lies in its ability to provide consistent, long-term data, allowing for accurate tracking of soil health and changes over time, which is crucial for sustainable land management

Restoration is crucial!
Restoration in agriculture, food forests, and natural forests is crucial for rebuilding biodiversity, enhancing ecosystem resilience, and combating climate change. By restoring degraded areas, we improve soil health, water retention, and carbon storage, creating healthier environments that support both human and ecological well-being

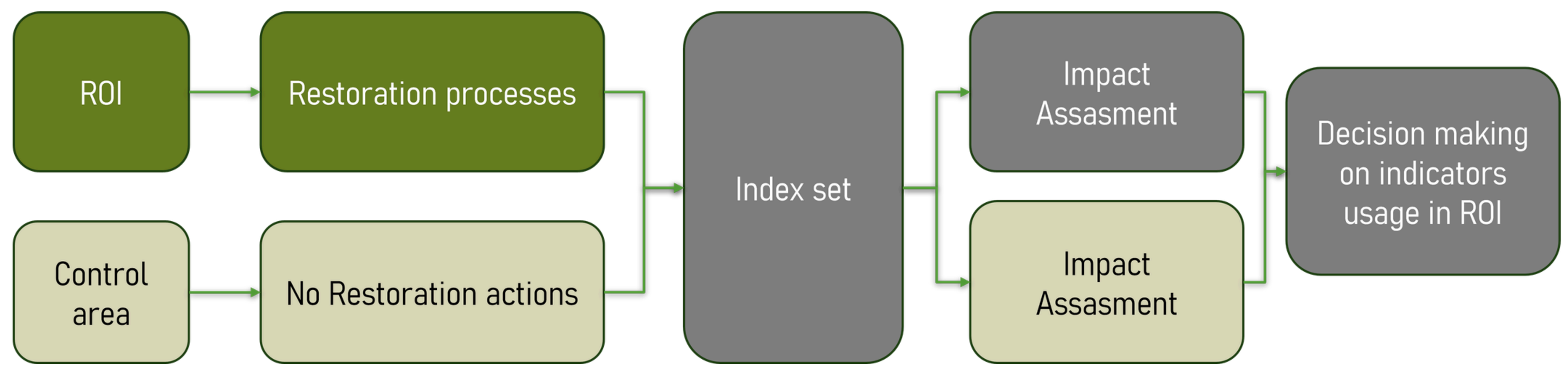
The soil is key!
Soil health is foundational in all restoration areas—agriculture, food forests, and natural forests—because it supports plant growth, stores carbon and maintains water cycles essential for ecosystem resilience. By improving soil structure and biodiversity, restoration efforts enhance nutrient availability and boost the ecosystem's ability to recover and sustain itself over time

METHODOLOGY

In this study, we conducted soil and vegetation analysis using remote sensing indicators derived from Sentinel-2 satellite data. Sentinel-2, a multispectral sensor launched in 2015, operates over the visible (VIS), near-infrared (NIR), and shortwave infrared (SWIR) ranges. It provides a spatial resolution of 10-20 meters and has a revisit time of approximately 10 days. Given our focus on long-term restoration processes rather than ongoing, short-term monitoring, this data is sufficiently detailed and temporally spaced for our analysis.
To explore the long-term impact of the restoration processes, we utilized the full timeframe available from the Sentinel-2 dataset, spanning from 2015 to the present. We divided each year into four seasons—winter, spring, summer, and autumn—to capture seasonal variations. Due to the dry climate of the eastern Mediterranean, we allocated a shorter period to winter and a longer one to summer. For each period, we averaged all available images to derive our indicators, ensuring a comprehensive temporal assessment



Due to data limitations, a comparative approach was adopted. For the forest in Heraklion, a nearby natural woodland was used as a reference due to limited satellite coverage. For the food forest, the adjacent agricultural land was chosen, addressing the challenge of its small study area



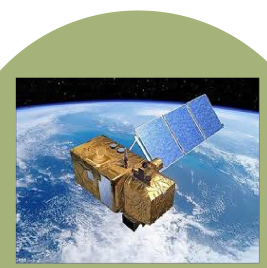
CASE STUDIES

Bethlehem of Galilee Food Forest
A food forest is a sustainable agricultural system designed to mimic a natural forest ecosystem, where diverse layers of plants, including trees, shrubs, herbs, and ground cover, work together to produce food. By promoting biodiversity and natural soil health, food forests create resilient environments that support a variety of crops and require minimal human intervention

Heraklion Forest
The Heraklion forest restoration project demonstrates the power of long-term ecological recovery, where reforestation efforts have successfully revived native species and improved biodiversity. Through sustainable management and conservation practices, the forest now serves as a model for resilience and habitat restoration in Mediterranean ecosystems

Major Differences in Pilot Areas

Purpose: Food forest // Natural forest
Size: ~3 acres // Hundreds of acres
Time of Restoration: Less than 10 years // Several decades
Plant Composition: Mostly edible plants // Native Mediterranean flora, with a focus on trees
Management Approach: Active (polyculture, permaculture) // Minimal human intervention
Biodiversity Goals: Increase while producing food // Restore and maintain native biodiversity



SENTINEL 2 Multispectral

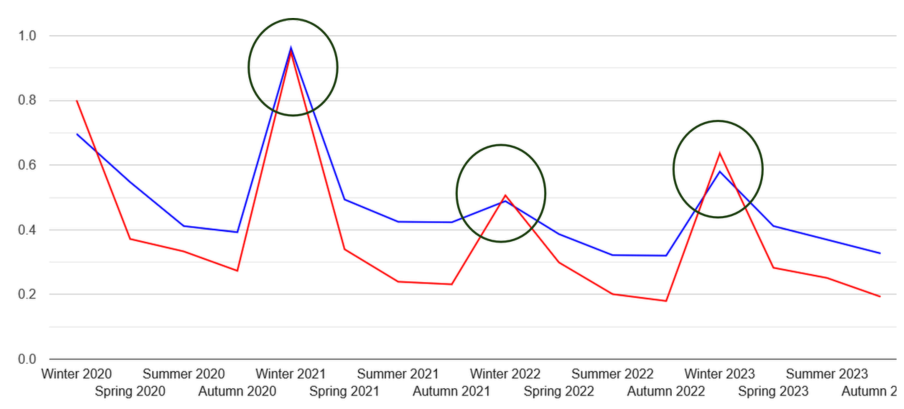
To identify and evaluate relevant changes in vegetation and soil conditions, several spectral indices were selected for initial testing. These indices, derived from satellite imagery, provide insights into vegetation health, water content, and soil properties. Each index was chosen for its ability to highlight specific biophysical and biochemical attributes, ensuring a comprehensive analysis of the study areas

Index	Index Data			
	Purpose		Range	Notes
NSDI	Normalized Shortwave Infrared Difference index	*NSDI = (SWIR1-SWIR2)/(SWIR1+SWIR2)*	(-1) - (1)	SWIR1 - Band11, SWIR2 = Band12
SAVI	Soil Adjusted Vegetation Index	*SAVI = ((NIR - Red) / (NIR + Red + L)) * (1 + L)*	(-1) - (1)	L = 0.5
PSRI	Plant Senescing Reflectance Inde	*PSRI = (Red - Blue) / Red Edge2*	(-1) - (1)	RED EDGE2 = Band5
SIPI	Structure Insensitive Pigment Index	*SIPI = (NIR - AER) / (NIR - Red)*	(0) - (2)	
NDII	Normalized Difference Infrared Index	*NDII = (NIR - SWIR) / (NIR + SWIR)*	(-1) - (1)	SWIR1 = Band11
NDWI	Normalized Difference Water Index	*NDWI = (NIR - MIR) / (NIR + MIR)*	(-1) - (1)	MIR = Band12

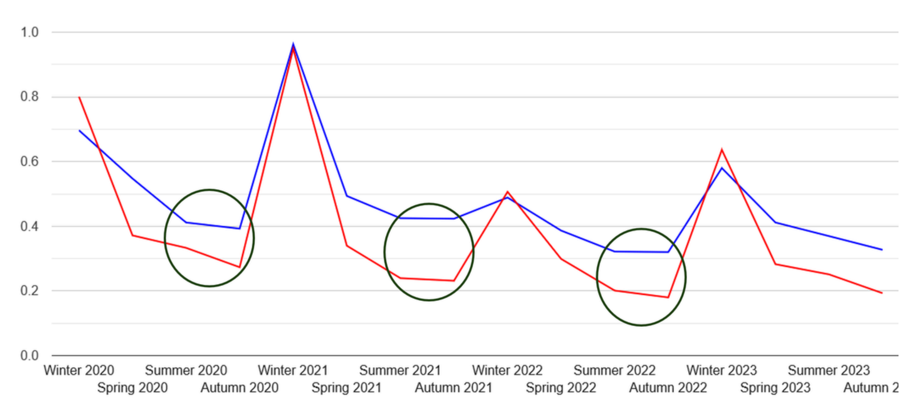
RESULTS

Presentation of examples from the findings in our analysis of soil and vegetation health using remote sensing indicators derived from Sentinel-2 satellite data, over two indicators out of all the ones tested. The data spans from winter 2020 to autumn 2023, capturing seasonal variations and long-term trends in both restored and control areas. This comparative approach allows us to evaluate the effectiveness of restoration efforts and identify improvements in vegetation resilience to environmental stressors. The subsequent sections detail the seasonal and temporal patterns observed in the chosen indicators, providing insights into the success and challenges of the restoration projects

SAVI Index // Food Forest, Spring 2021 // Blue = Restores area, Red = Control area

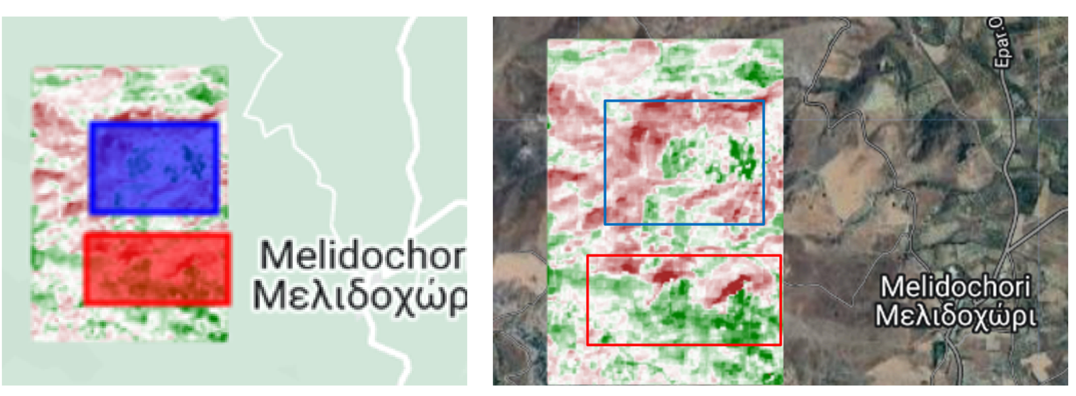


SAVI Index // Food Forest, Timeline, **Winters: Almost no difference**

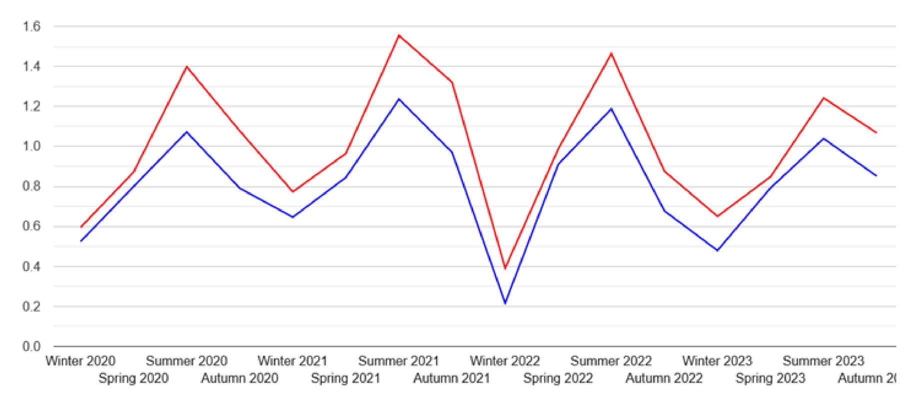


SAVI Index // Food Forest, Timeline, **Summers: Noticed differences**

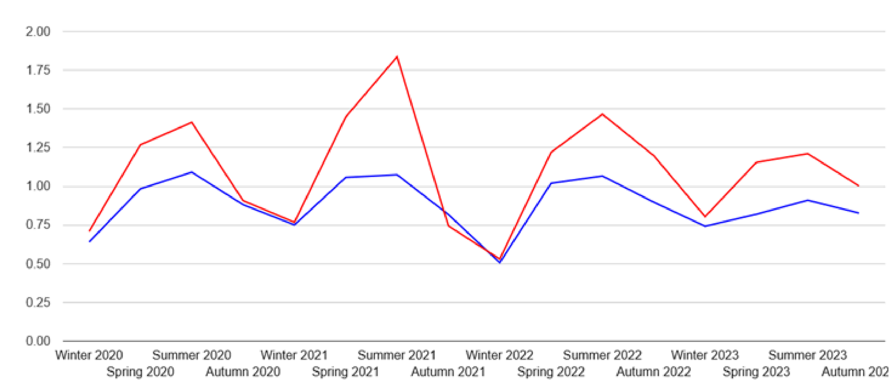
The analysis of SAVI from winter 2020 to autumn 2023 shows seasonal vegetation patterns in both restored and control areas. Higher SAVI values during wet seasons indicate healthier vegetation, while lower values in dry seasons reflect reduced health. Over time, restored areas exhibit higher SAVI values, greater stability, and resilience compared to control areas. These findings highlight the positive impact of restoration efforts and the value of SAVI in guiding sustainable land management



SIPI Index // Heraklion Forest, Spring 2021 // Blue = Restores area, Red = Control area



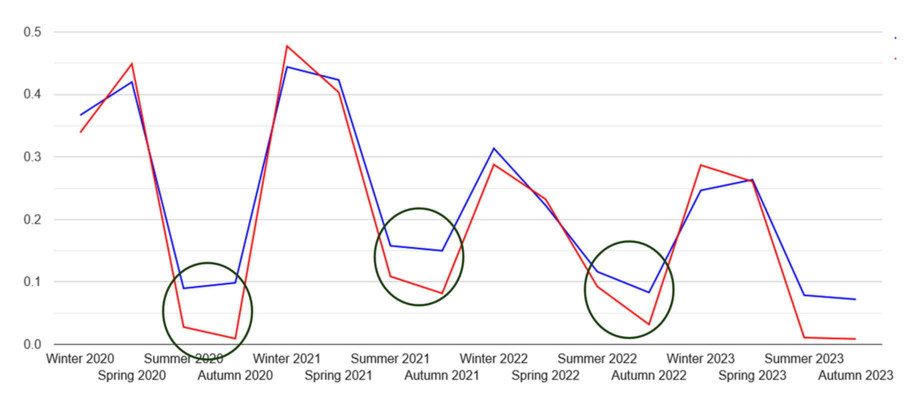
SIPI Index // Heraklion Forest, Timeline, Parallel trend lines



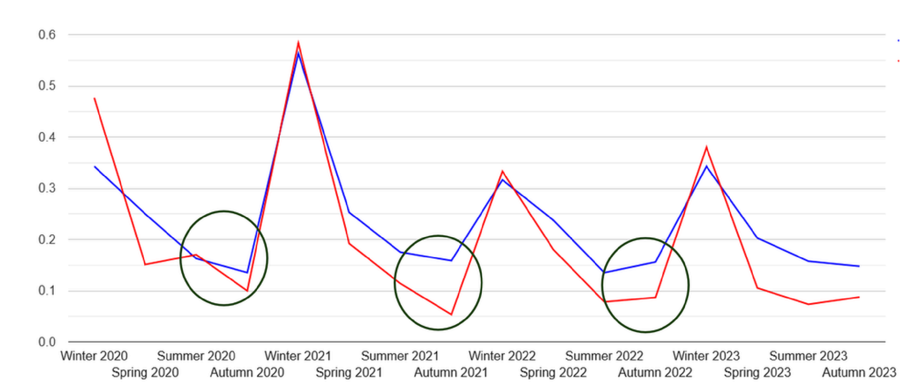
SIPI Index // Food Forest, Timeline, **Noticed differences only during summers**

The SIPI index trends for the Heraklion Forest show parallel patterns between the restored and control areas across all seasons, indicating consistent vegetation responses. In contrast, the Food Forest reveals notable differences during the summer seasons, where the restored area exhibits lower SIPI values compared to the control area. This suggests that restoration efforts in the Food Forest might mitigate vegetation stress during dry periods, whereas in Heraklion Forest, both areas respond similarly throughout the year

The analysis of Normalized Difference Water Index (NDWI) reveals seasonal patterns in both the Food Forest and Heraklion Forest, providing insights into vegetation water content and moisture dynamics. In the Food Forest, higher NDWI values during winter and spring indicate increased water content, while lower values in summer and autumn reflect reduced moisture. Over time, the restored area shows improved water retention, with slightly higher NDWI values during wet seasons and greater stability compared to the control area. Similarly, in the Heraklion Forest, pronounced seasonal trends highlight improved water content in restored areas, particularly during wetter periods, with fewer sharp declines in NDWI values. These findings demonstrate the positive impact of restoration activities on water retention and vegetation resilience, emphasizing the importance of NDWI as a tool for monitoring restoration success and guiding sustainable land management



NDWI Index // Heraklion Forest, Timeline, **Noticed differences only during summers**



NDWI Index // Food Forest, Timeline, **Noticed differences only during summers**

DISCUSSION

The results emphasize the importance of comparative analysis in understanding the impact of restoration efforts. The significant differences observed between restored and control areas highlight the effectiveness of restoration in enhancing vegetation health and resilience. By leveraging nearby control areas, this approach effectively compensates for data limitations, enabling the detection of changes and restoration impacts even in small and complex regions. Seasonal trends, as reflected in the indices, provide a deeper understanding of ecosystem responses to climatic variations, offering the ability to forecast vegetation health over time. The stability and resilience observed in restored areas underscore the long-term benefits of restoration efforts, particularly in mitigating environmental stressors. Furthermore, the ability to analyze large areas over extended timescales offers a comprehensive understanding of ecosystem dynamics and the broader impacts of restoration activities. These findings reinforce the value of using remote sensing indicators to monitor restoration progress and guide sustainable management practices

Next Steps
Building on these findings, the analysis process will be extended to additional pilot areas across the Mediterranean, enabling broader regional insights. A user-friendly platform will be developed to allow stakeholders to access and utilize the data. Integrating machine learning techniques will enhance the detection of temporal and spatial patterns, supporting adaptive restoration strategies. Ultimately, the project aims to create a decision-making system to guide restoration efforts, ensuring sustainable land management and ecosystem recovery