

Forest Resilience and Ecosystem Service Value: Analysis of Changes and Interdependencies

Nwachukwu P.N.^{1*}, Berti-Equille L.^{2*}

¹UPVD IRD, ESPACE-DEV, Batiment B, 3ème étage ; 52 Av. Paul Alduy, 66860 Perpignan cedex 09, France

²IRD, ESPACE-DEV, 500, rue Jean-François Breton, 34093 MONTPELLIER cedex 05, France

*corresponding author: e-mail: laure.berthi@ird.fr

Ecosystem service value (ESV) is critical for understanding ecosystems' economic benefits and their responses to environmental change. This study uses Earth Observation (EO) data and machine learning methods to evaluate ESV trends across multiple continents from 2000 to 2024. Three key datasets were used: MODIS NDVI for vegetation monitoring, CHIRPS precipitation data, and the ESVD database. Data preprocessing includes data cleaning, feature engineering, and outlier detection. We used Random Forest, XGBoost, and ensemble stacking models to predict key variables and their relationships, such as kNDVI, as a proxy of forest resilience and ESV trends, precipitation patterns, and biome-specific variables. Our results show that kNDVI changes across continents reveal various patterns in vegetation dynamics that are in-line with precipitation patterns and are correlated with ESV changes. Our study emphasizes the significance of time interdependence and climate variability in ESV predictive modelling. Future efforts should focus on refining the time/space granularity of data collection and aggregation techniques and incorporating more environmental indicators to improve model robustness and application in policy-making.

Keywords: Forest, Landscape, Ecosystem, Service, Valuation.

1. Introduction

Ecosystem services valuation (ESV) is the monetary advantage that humans derive from ecosystems. The forest ecosystem covers approximately 30% of the land surface [1]. Forest ecosystems are essential in offering a wide range of benefits [2], such as soil preservation, carbon sequestration, habitat for biodiversity, flood control, etc. It absorbs over 33% of anthropogenic carbon emissions, playing a crucial part in the global carbon cycle and preventing further climate change. However, the forest ecosystem faces tremendous human and natural depletion, hampering its resilience. Regrettably, disruptions like wildfires, insect outbreaks, and extreme weather occurrences are

becoming more frequent threats to forest ecosystem resilience across the globe. Additionally, the frequency and severity of disturbances are increasing due to climate change, placing tremendous strain on the forest ecosystem across the globe. Forest resilience refers to its ability to endure, adjust, and recover from natural disasters like wildfires, insect outbreaks, and severe climate change-induced catastrophes.

Remote sensing technology has emerged as an indispensable tool for assessing forest resilience. Furthermore, vegetation indicators such as the NDVI and Kernel NDVI (kNDVI) can determine forest health and dynamism [1]. In this study, we aim to better understand the connection between kNDVI as a proxy of resilience of global forests (vegetated areas with a canopy ≥ 5 meters [3]) and global ESV.

2. Materials and Methods

We used three datasets: 1) [MOD13A3 V6.1](#) data product provided monthly at 1 km spatial resolution and processed the Summary Quality Assurance (*SummaryQA*) band of MODIS; 2) the [CHIRPS dataset \(Climate Hazards Group InfraRed Precipitation with Station data\)](#) with global monthly precipitation means from 2000-02-01 to 2024-04-30 at a 0.05° x 0.05° resolution. CHIRPS dataset combines satellite infrared and ground station data; 3) [Ecosystem Services Valuation data \(ESVD\)](#). We computed kNDVI from high-quality-filtered MODIS pixel data and analyzed the correlation between ESV and precipitation and resilience variables. Gradient Boosting, XGBoost, Stacking Ensemble and Random Forest were used to predict dynamic ecosystem service.

3. Results and Discussion

4. We consider 2,801 ESV sites only in forest areas, as illustrated in Fig. 1 and observed that ESV in Oceania and Europe increased significantly between 2015 and 2017, potentially due to policy changes (Fig. 2).

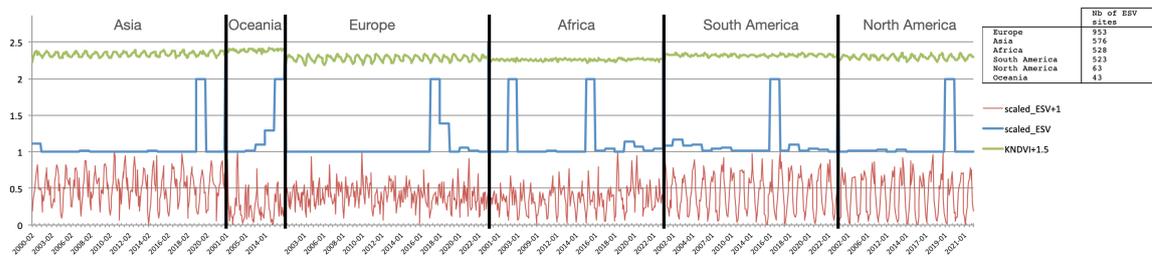


Figure 2. Precipitation, ESV and kNDVI Changes for ESV sites

Asia and North America saw peaks in 2019, whilst Africa has 2 peaks in 2002 and 2015 and South America in 2016.

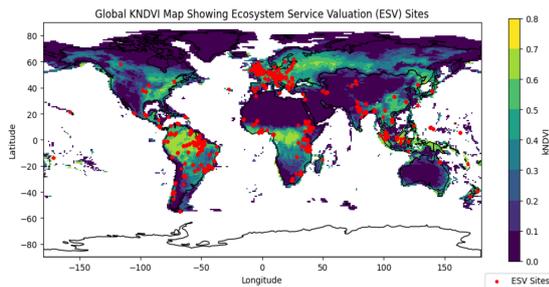


Figure 1. Map of kNDVI and ESV sites

In Fig. 3, kNDVI and precipitation show a positive correlation in Asia (+0.76) and North America (+0.70), indicating vegetation cover increased with rainfall. ESV has weak correlations with both kNDVI and precipitation across continents suggesting other factors drive ecosystem service valuation. Precipitation significantly impacts vegetation but minimally influences ESV trends. Other variables likely affect ESV dynamics.



Figure 2. Pearson correlation and p-values between ESV, precipitation, and kNDVI per continent.

Across the continents, ESV correlation with kNDVI is very weak, with negative relationships in Americas and Africa, indicating minimal impact. Precipitation-ESV shows mixed effects: weakly negative in all continents except Oceania. kNDVI and precipitation in Oceania (-0.41) show negative correlations. Surprisingly, precipitation and kNDVI do not significantly increase overall ESV, indicating that other factors affect the valuation of ecosystem services. When comparing the correlations between kNDVI, precipitation and ESV for forest biomes in Fig. 3, we observe strong correlations between precipitation and kNDVI in Asia, North and South America but other values remain weak, indicating ESV is influenced by additional factors beyond kNDVI and precipitation. Overall, no strong direct

and linear relationship of ESV is observed, highlighting the complexity of ecosystem valuation.

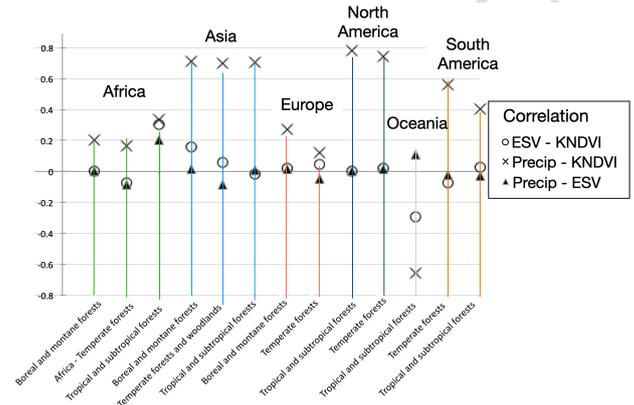


Figure 3. Pearson correlation of between different ESV forest biomes and precipitation and kNDVI.

For ESV prediction, random forest outperformed XGBoost, gradient boosting, and ensemble with the lowest MAE (0.644), RMSE (11.029), and R² score (0.99), making it the best model for ESV prediction as illustrated in Fig 4.

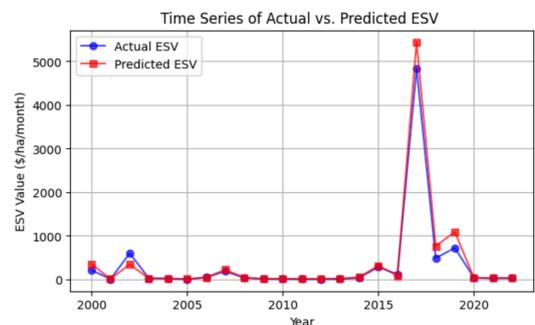


Figure 4. Random forest Performance for ESV prediction.

5. References

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