Quantifying Ancient Landscape Modifications using Machine Learning and Evolutionary Theory: A Case Study from Madagascar

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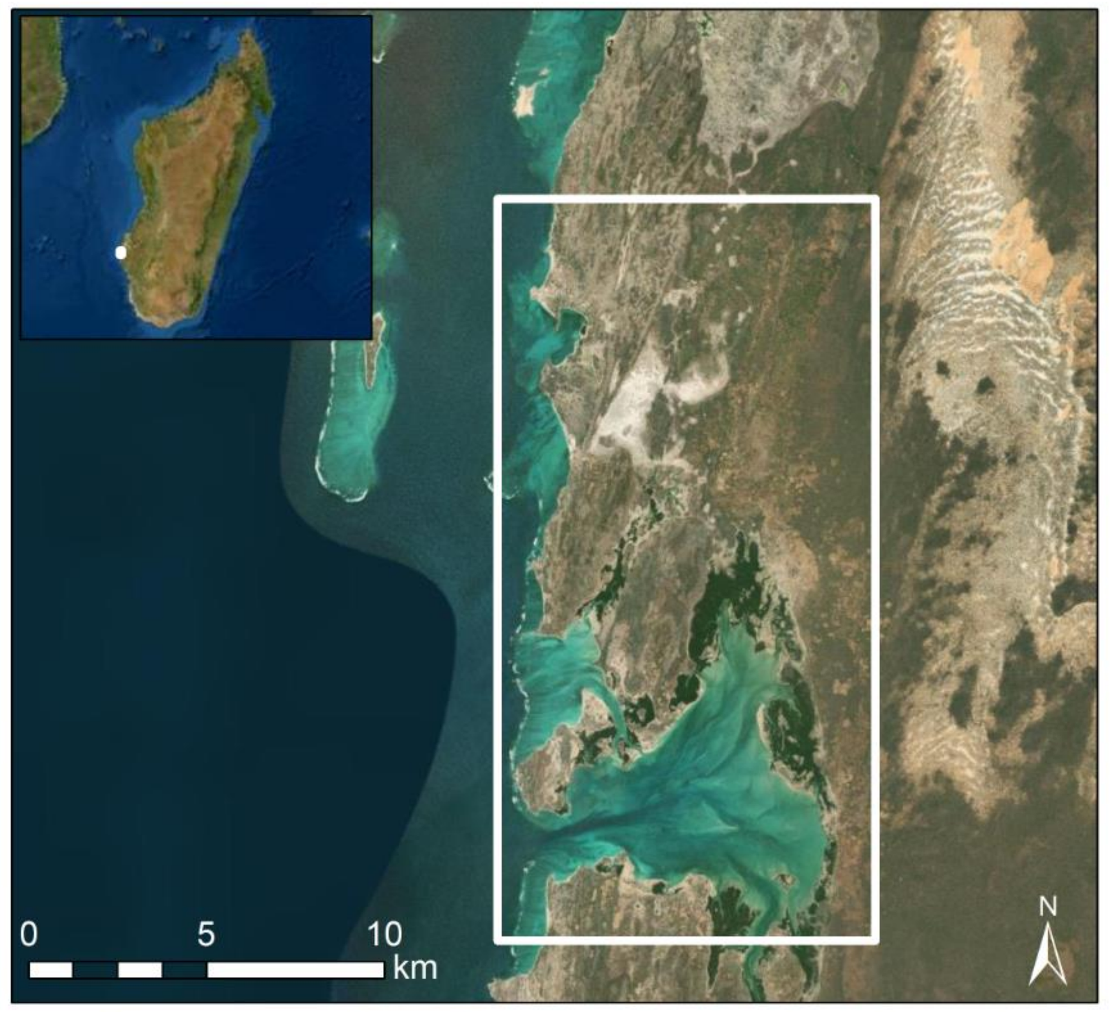
Introduction

Madagascar is the subject of intense debate among archaeologists and holds important information pertaining to human-environmental interactions, particularly related to coping with extreme climate change. The archaeological record can elucidate these important dynamics, but archaeological deposits in this area generally bear ephemeral traces of past human activity and lack intensive landscape modifications that archaeologists typically look for as evidence of human impact or niche construction (e.g., agricultural development, monumental architecture, etc.). To remedy this issue, I use high-resolution satellite imagery and machine learning to reveal a history of human-induced landscape changes by comparing geophysical characteristics of archaeological sites to locations with no documented archaeological materials. Using a random forest probability algorithm, I quantify the extent of ancient human activity and contextualize modern-day landscape impacts in this region. The results of this analysis inform on the question of how we can develop successful machine learning models to understand dynamic systems. Our study thus expands the spatial- and temporal-scale at which we can evaluate human-environment dynamics, including during early periods of human history for which the archaeological record is comprised of very subtle traces that are otherwise difficult to detect.



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1: Map of study region in Velondriake, Madagascar

Theoretical Background

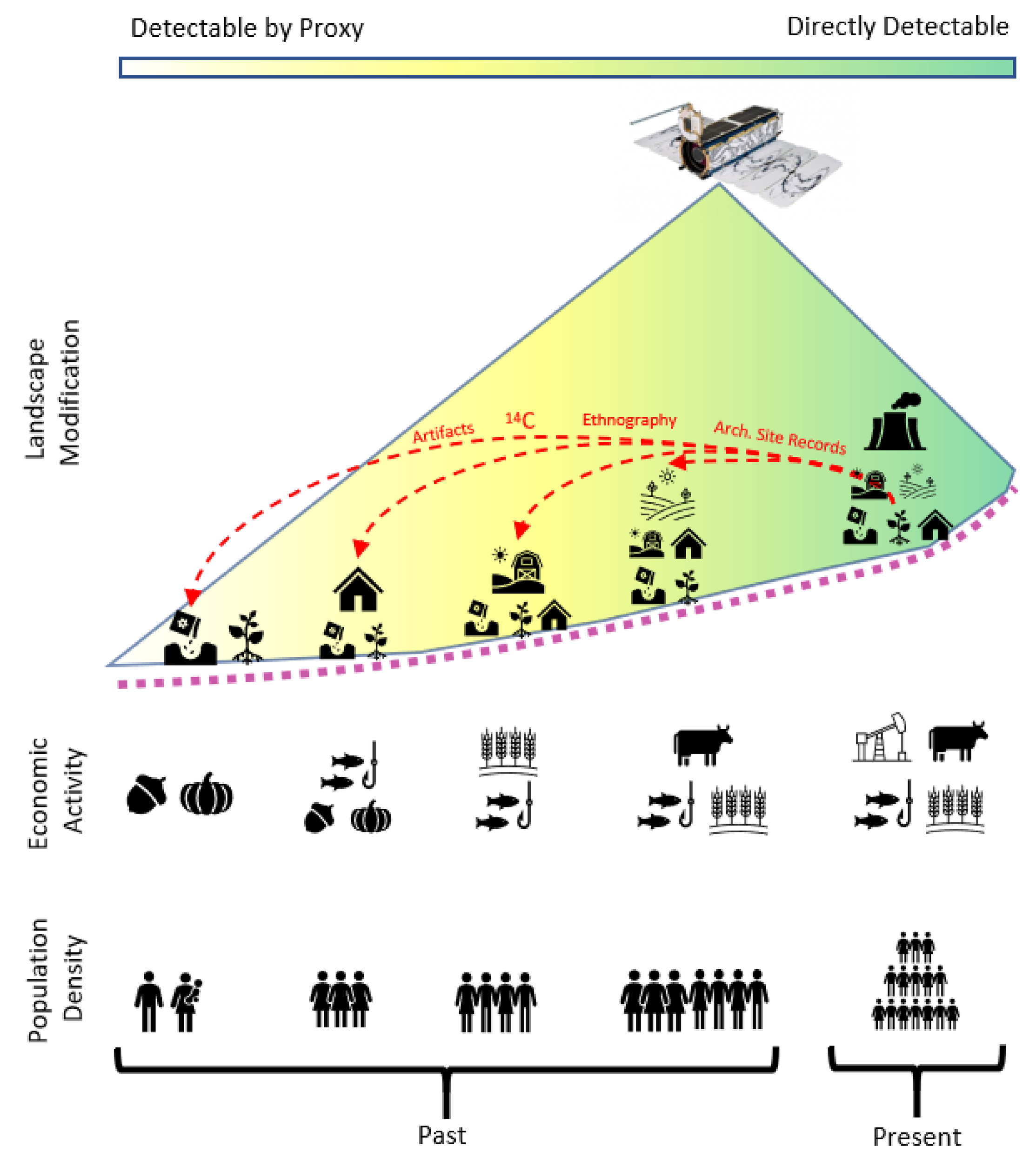


Figure 2: Over time, economic activities change, leaving a palimpsest of changing human activity on the modern landscape. These rate of landscape modification increases as the number and intensity of economic activities increases, ultimately leading to the present-day landscape. The modern landscape, which is detectable by satellite remote sensing represents a collective record of human actions, which are each detectable in different ways and to varying degrees. Modern modifications and some older landscape modifications can be directly identified. Older and subtler activities (i.e. soil changes, foraging, etc.) can be identified by proxy, wherein we can infer the timing of different changes seen in the present by linking visible differences to known areas of historic/archaeological human presence. Here, I trace niche construction (habitat modification) of foraging societies, using geophysical properties (which are associated with vegetative and soil characteristics.

Methods

1. Download PlanetScope imagery (1) over the course of three years in the study region
2. Compiled 3-year averages for the dry and wet seasons between 2018 and 2020. Seasonal differences are extreme in this region.
3. Conducted a pixel-by-pixel comparison in R (2) between the two images to highlight the difference between the wet and dry seasons
4. Assessed the spectral characteristics of a sample of known archaeological (n = 330) and non-archaeological (n = 80) deposits throughout the study area to determine their geophysical separability.
5. Use Google Earth Engine (GEE) to train a random forest (RF) probability algorithm to identify archaeological deposits in southwest Madagascar. To evaluate accuracy of this model, we withheld 40 archaeological points and 17 non-archaeological points (~12% of the training data) for validation
6. RF model uses 128 trees and three iterations (following 3)
7. Results of RF algorithm are converted to polygons and I calculate the area of these polygons to quantify the extent of archaeological landscape modifications within the study region.

Results

- Spectral differences between archaeological and non-archaeological locations are statistically significant ($p<0.01$; Fig. 3).
- RF classifier trained using 300 archaeological points and 63 non-archaeological points and produced accurate results (Table 1; Fig 4).
- Approximately 38.6 km^2 (~17%) of this region has been significantly modified by human activity in the study region (Fig. 5).
- The density of anthropogenic areas appear highest 3-5km inland where pastoralism has been predominant for the past several hundred years (Fig. 5).

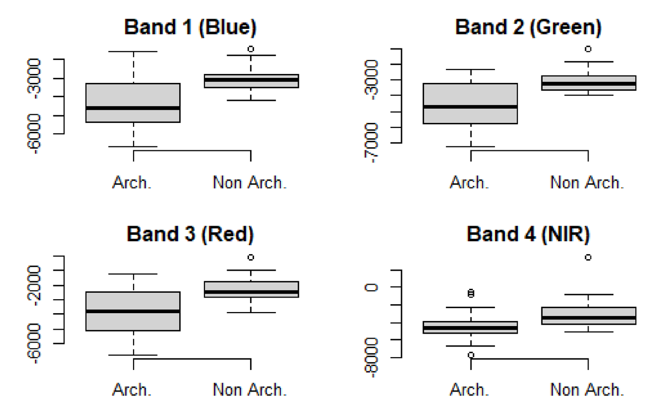


Figure 3

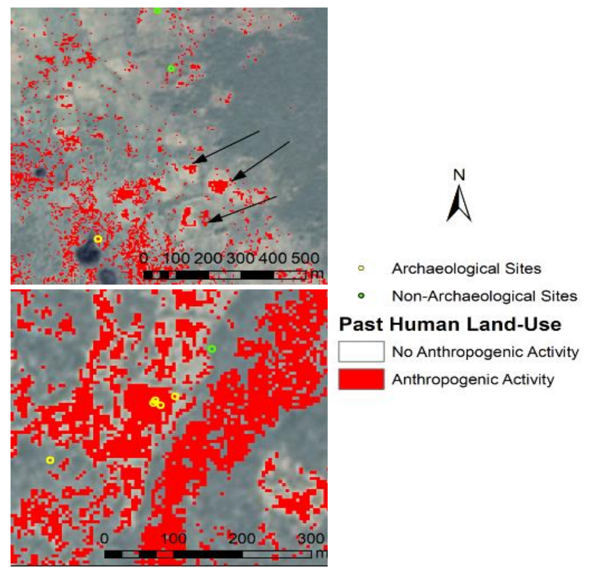


Figure 4

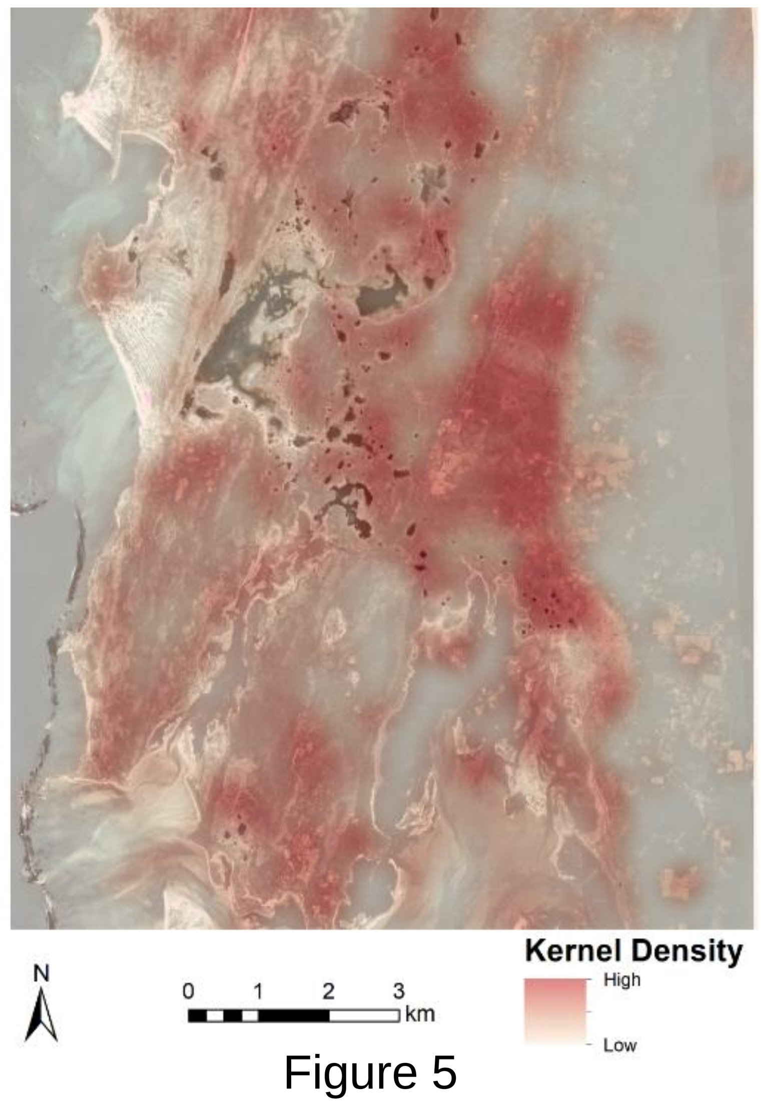


Figure 5

Table 1: Accuracy Metrics

Threshold	Precision (Validation)	Recall (Validation)	F1 (Validation)	Precision (Training)	Recall (Training)	F1 (Training)
0.7	0.972	0.875	0.921	0.976	0.963	0.969
0.65	0.973	0.900	0.935	0.977	0.973	0.975
0.6	0.947	0.900	0.922	0.964	0.977	0.970

Conclusion

This study demonstrates how machine learning can aid archaeologists in locating and quantifying human activity at a landscape scale. This is of major significance for Madagascar, where the island's human history has remained largely obscure because of the ephemeral nature of early archaeological deposits and a lack of context surrounding early human-environmental dynamics. This research further demonstrates how machine learning can help to advance evolutionary research focused on human-environmental systems dynamics. Furthermore, this research shows how machine learning permits for time and cost-effective data collection, which is for further work on coupled human-natural systems.

References

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Acknowledgements

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