Identifying Intensively Managed Coffee Forests in Southwest Ethiopia using Satellite Imagery

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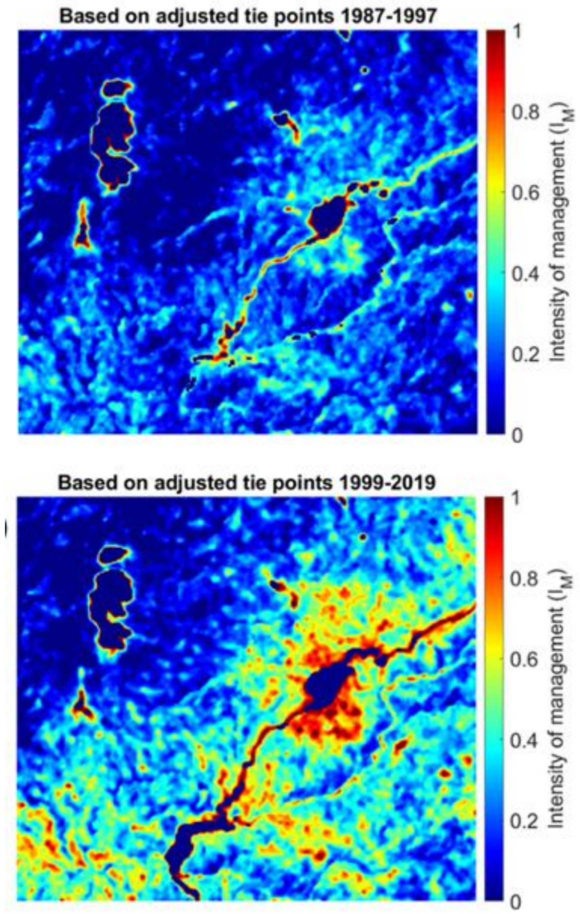
In collaboration with



Introduction

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- The natural high forest cover (EFAP, 1994) has been declining rapidly for many decades with only 4% of the country remaining forested at the end of the twentieth century (Eshetu and Högberg, 2000; Reusing, 2000; WBISPP, 2000).
- The remaining forest is suffering from various forms of degradation which threaten its survival.
- One of the two remaining blocks of Afromontane forests in Ethiopia is found in the southwest highlands of the country - a biodiversity hotspot and a genetic reservoir of wild coffee (Anthony et al., 2002; Gole, 2003; Senbeta, 2006), also known for producing one third of the country’s coffee production.

Introduction

- The coffee production under natural forest shade in the Afromontane forests (i.e., coffee forest) has been practiced since the 18th century when the coffee trade from Ethiopia developed (Aregay, 1988).
- The coffee forest can be beneficial as it creates an economically attractive land use which discourages farmers from expanding cereal cropping into natural forests.
- At the same time, farmers selectively fell canopy trees (to keep optimal shade) (Sutcliffe, 2010), and also remove competing understorey shrubs and tree saplings.
- This not only degrades the natural forest but also threatens its ability to regenerate (Aerts et al., 2011; Hundera et al., 2013).

Introduction

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- However, the extent of degradation within coffee forest is not well documented.
- Distinguishing between undisturbed natural forest and managed (disturbed) coffee forest is important so that the scale of this degradation is recognized and appropriate management responses developed.
- In this collaborative research, our objective is to examine if it is feasible to map the intensively managed coffee forest using satellite imagery (Landsat-8).
- To address the objective, we conducted field surveys in Gera to measure the in-situ canopy fraction and tree biodiversity, and then these ground-truth data were analysed with satellite imagery.

Methods - Study Area

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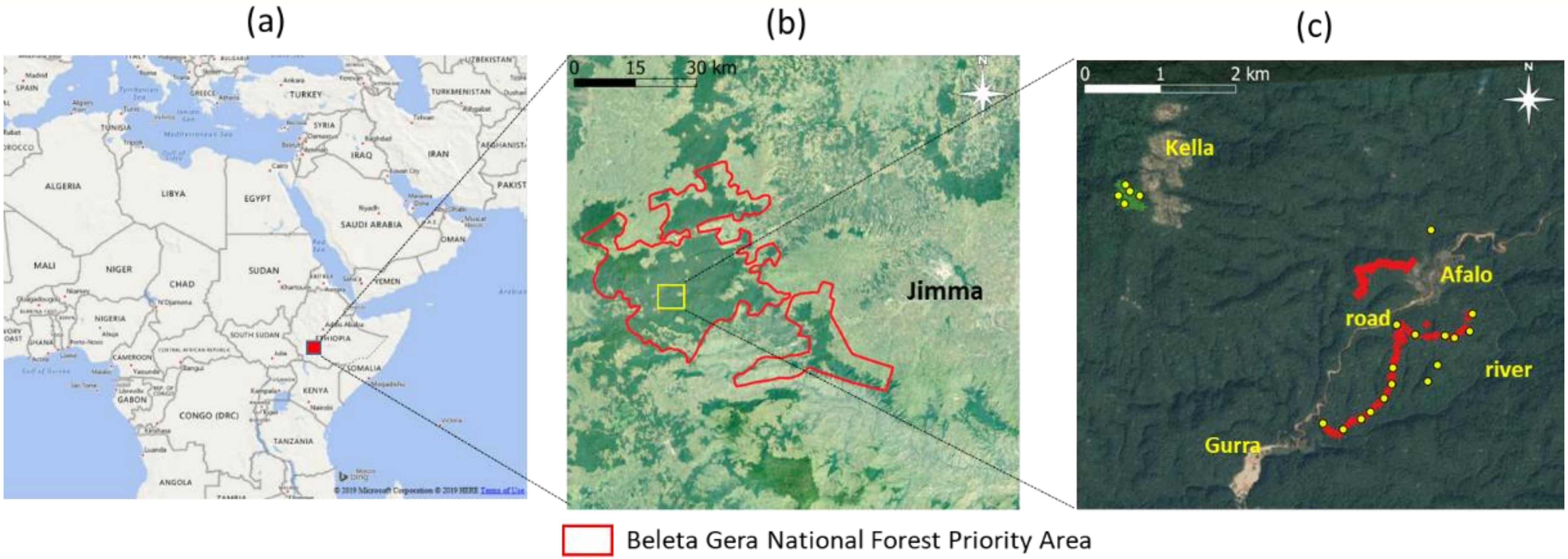

Green crosses: natural forest survey sites

Red dots: intensively managed coffee forest survey sites

Yellow dots: tree survey sites

Methods - Field Survey

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Date	Activity
19 February 2019	Canopy photos and tree surveys in natural forest
21-25 February 2019	Canopy photos and tree surveys in intensively coffee forest

- **Canopy photo survey – obtaining canopy fraction**
- **Tree survey – # tree, # species, basal area for the trees with DHB > 5 cm**

Methods - Canopy cover photography

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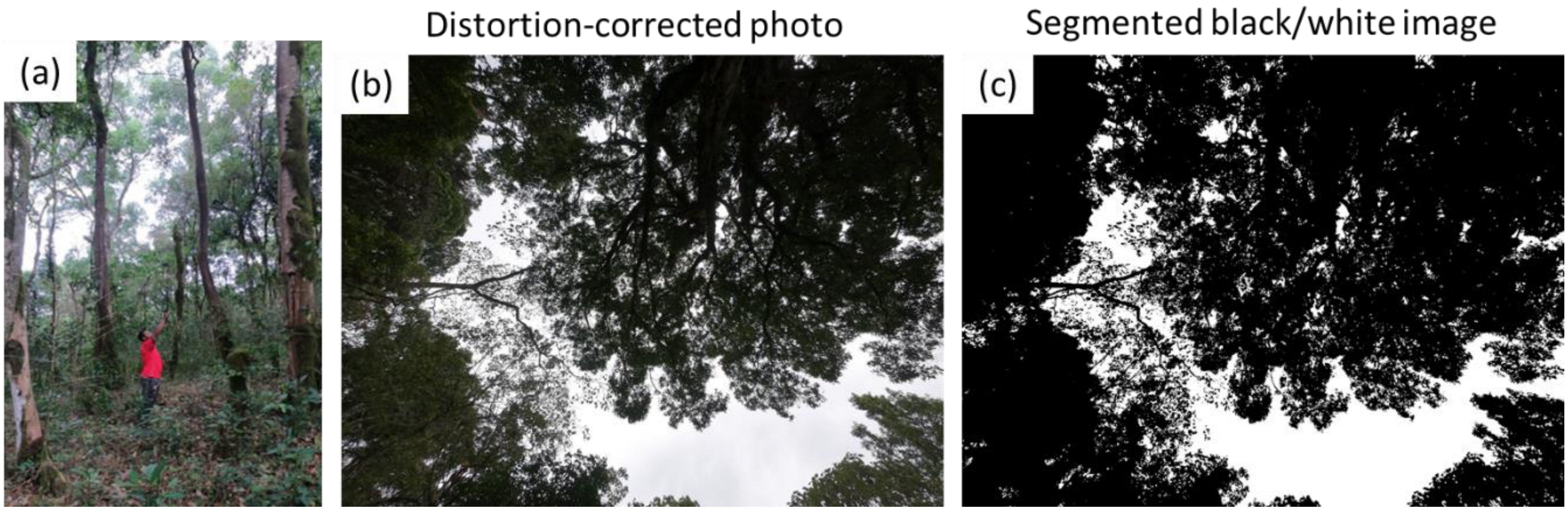

(a) The canopy cover photography was conducted by using GoPro® Hero7 Black camera (wide angle) attached to a one-meter expandable camera pole.

(b) Wide-angle distortion was corrected by MATLAB® Fisheye calibration procedure.

(c) Segmentation to black (canopy) and white (sky) image was done by using Kernel Graph Cut algorithm.

Methods - Tree Survey

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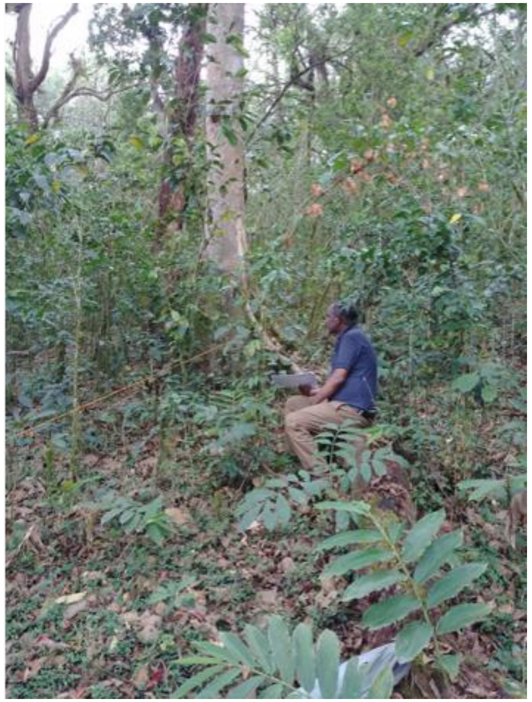
- Tree surveys were conducted in both NF and HMCF.
- Each plot - 20 by 20 meters
- At each plot, trees with more 5 cm in diameter at breast height (DBH) were identified and recorded
- Total 21 plots: 5 plots in natural forest and 16 plots in intensively managed coffee forest



Methods - Satellite Imagery

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Satellite Sensor and Data Product	Acquisition Date (yyyymmdd)	Comments
Lansat-5/TM Level 2 Surface Reflectance	19870106 19910202 19910218 19920120 19940125 19960131 19970202 19990208 20000126 20010128 20020131	Used for time-series analysis
Landsat-8/OLI Level 2 Surface Reflectance	20150204 20170108 20170124 20180127 20180212	
	20190130	Used for comparison with field data

- Total of 17 Landsat images were acquired, including 11 Landsat-5 (L5) Thematic Mapper (TM) and 7 Landsat-8 (L8) Operational Land Imager (OLI) data
- Landsat data used in this study are Level 2 surface reflectance products (LEDAPS product for L5 TM and LaSRC product for L8 OLI)
- The normalized difference vegetation index (NDVI) and the normalized burned ratio (NBR) were calculated

$$NDVI = \frac{R_{nir} - R_{red}}{R_{nir} + R_{red}} \qquad NBR = \frac{R_{nir} - R_{swir2}}{R_{nir} + R_{swir2}}$$

Methods - Algorithm

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$$NDVI = I_{ndvi} \times NDVI_{HMCF} + (1 - I_{ndvi} \times NDVI_{NF}) \quad (1)$$

$$NBR = I_{nbr} \times NBR_{HMCF} + (1 - I_{nbr} \times NBR_{NF}) \quad (2)$$

$$I_{ndvi} = \frac{NDVI - NDVI_{NF}}{NDVI_{HMCF} - NDVI_{NF}}, \qquad I_{ndvi} = 0\ to\ 1 \quad (3)$$

$$I_{nbr} = \frac{NBR - NBR_{NF}}{NBR_{HMCF} - NBR_{NF}}, \qquad I_{nbr} = 0\ to\ 1 \quad (4)$$

$$I_m = W \times I_{ndvi} + (1 - W) \times I_{nbr}, \qquad I_m = 0\ to\ 1 \quad (5)$$

- To estimate the level of degradation (I_m) caused by intensive management practices in the coffee forest, our proposed algorithm utilizes the tie points in the NDVI and NBR domains.
- With known tie points for Natural Forest (NF) and Highly Managed Coffee Forest (HMCF), satellite-derived NDVI and NBR can be expressed as in Eqs (1) and (2).
- The Eqs (1) and (2) can be rearranged for measuring the intensity of degradation (I_m) using NDVI and NBR - Eqs (3) and (4).
- Then, we can consider the intensity of degradation (I_m) as a weighted sum of I_{ndvi} and I_{nbr} – Eq (5).

Results – Canopy cover fraction

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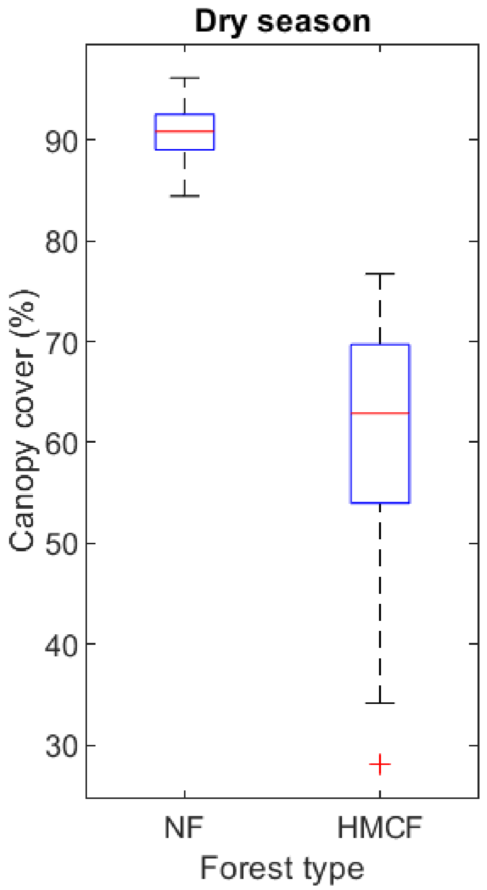

- Clear distinction in in-situ canopy cover between HMCF and NF
- The standard deviation (SD) of canopy cover in HMCF is higher than SD in NF

Figure 1: Tree canopy cover fraction from undisturbed natural forest (NF) and heavily managed coffee forest (HMCF).

Results – Tree survey

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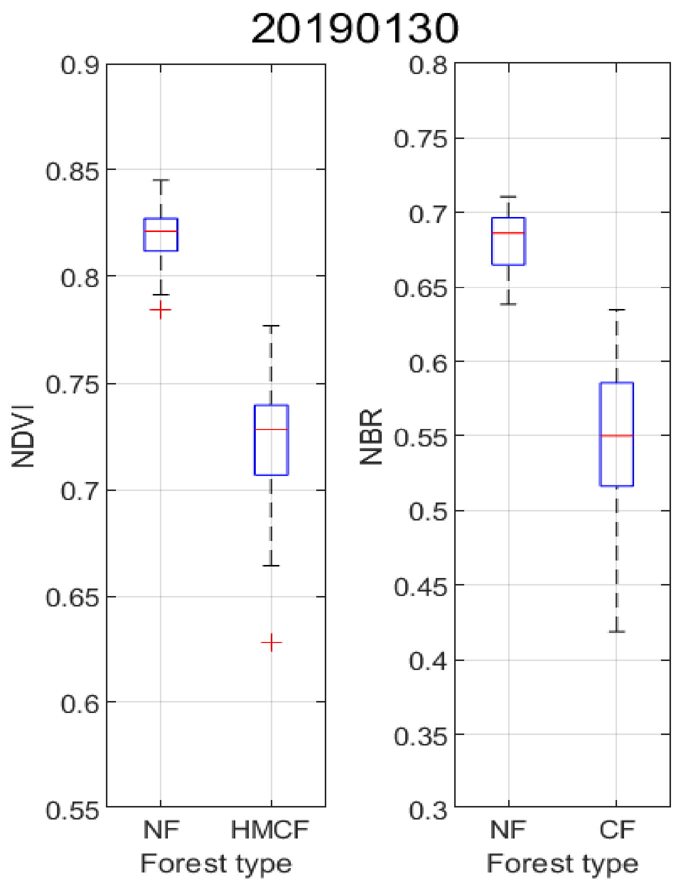
Table 1: Summary of tree biodiversity survey results. The trees with DHB larger than 5 cm were only selected for the survey.

Forest type	Number of species	Number of trees	Basal area (m^2/ha)
NF	7.4 ±0.5	**35.8 ±13.7**	**135**
HMCF	6.8 ±2.2	**14.8 ±7.7**	**58**

- The number of trees per hectare in the NF area is significantly higher than in the HMCF area.
- The basal area in the NF area is much larger than in the HMCF area.
- In NF, most of the tree species are evergreen trees with some pockets of deciduous tree species.
- HMCF are dominated with deciduous species such as *Albizia gummifera* and *Millettia ferruginea*, due to the selective removal of broad- leaved evergreen trees by the farmers during their selective management and retention of species.

Results - Algorithm



- Both NDVI and NBR values are significantly distinctive between HMCF and NF.

Figure 2: NDVI and NBR derived from the 2019 Landsat-8 OLI imagery.

Results – Temporal evolution of NDVI and NBR

- Both NDVI and NBR values vary from image to image, yet there is a consistent trend that the separation between NF and HMCF values increase over time.

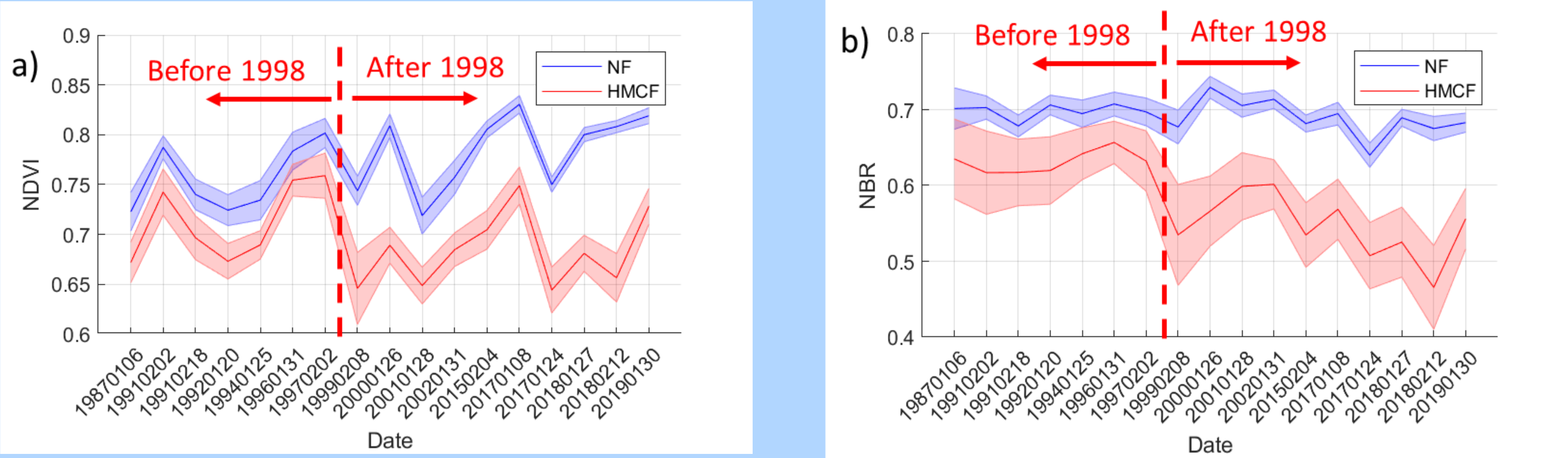


Figure 3: Temporal evolution of a) NDVI and b) NBR derived at the NF and HMCF sites. Dates are shown in year, month and day for the Landsat imagery used to derive NDVI and NBR. Thick blue line is the mean NDVI or NBR at the NF site, and the shaded area bounded by thin blue lines marks the upper and lower bounds of a SD of NDVI or NBR at the NF site. Thick red line is the mean NDVI or NBR at the HMCF site, and the shaded area bounded by thin red lines marks the upper and lower bounds of a SD of NDVI or NBR at the HMCF site.

Results – Temporal evolution of NDVI and NBR

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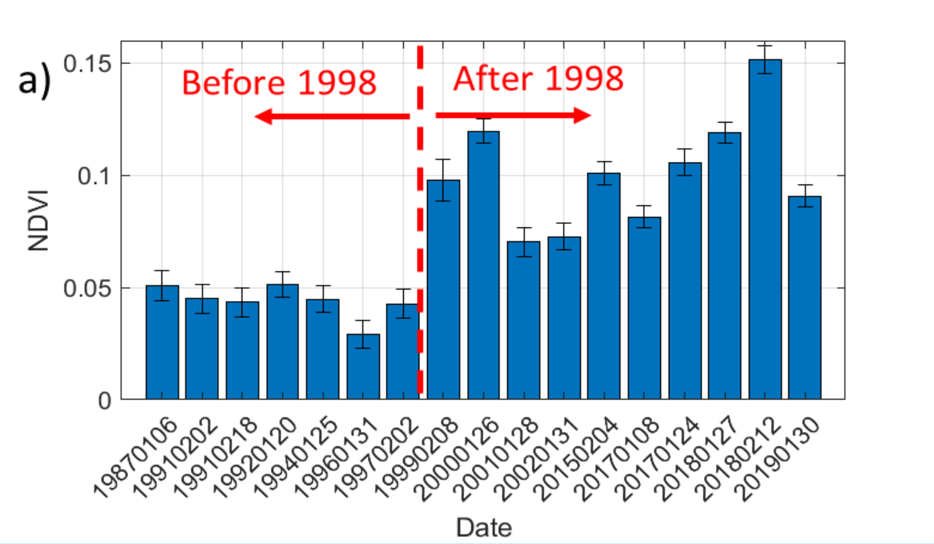
- The difference in mean NDVI or NBR between NF and HMCF is significantly larger after 1998.



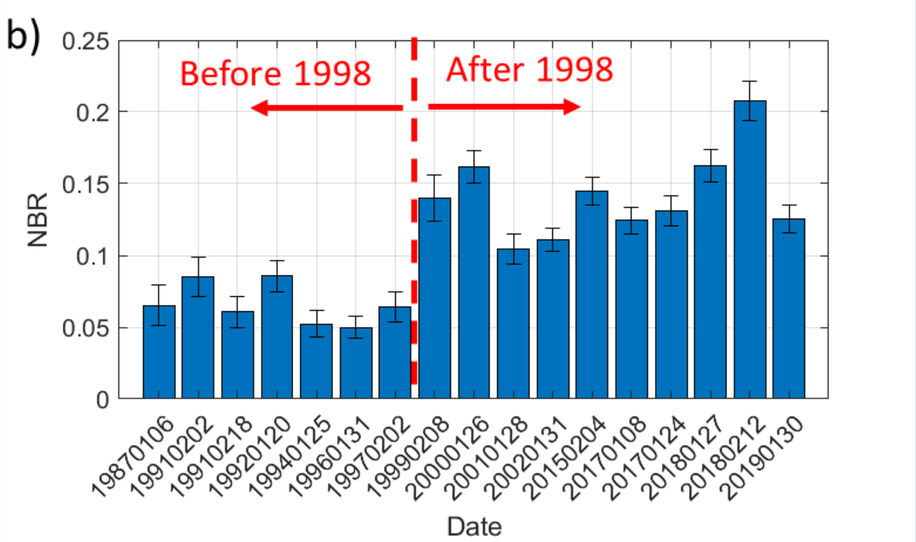


Figure 4: Temporal evolution of the difference in mean between NF and HMCF sites for a) NDVI and b) NBR. The error bars in the graph were estimated from the standard deviations from NF and HMCF sites. Dates are shown in year, month and day for the Landsat imagery used to derive NDVI and NBR.

Results – Estimating the intensity of degradation using tie-points

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- A set of tie-points were used to characterise typical condition of NF for the 1987-1997 period (T_{N87a}) and the 1999-2019 period (T_{N99a}) and HMCF for the 1987-1997 period (T_{H87a}) and the 1999-2019 period (T_{H99a}).
- The results show that significant intensification of the level of forest degradation (I_M) in the areas near villages (red – severe degradation and blue – low degradation).

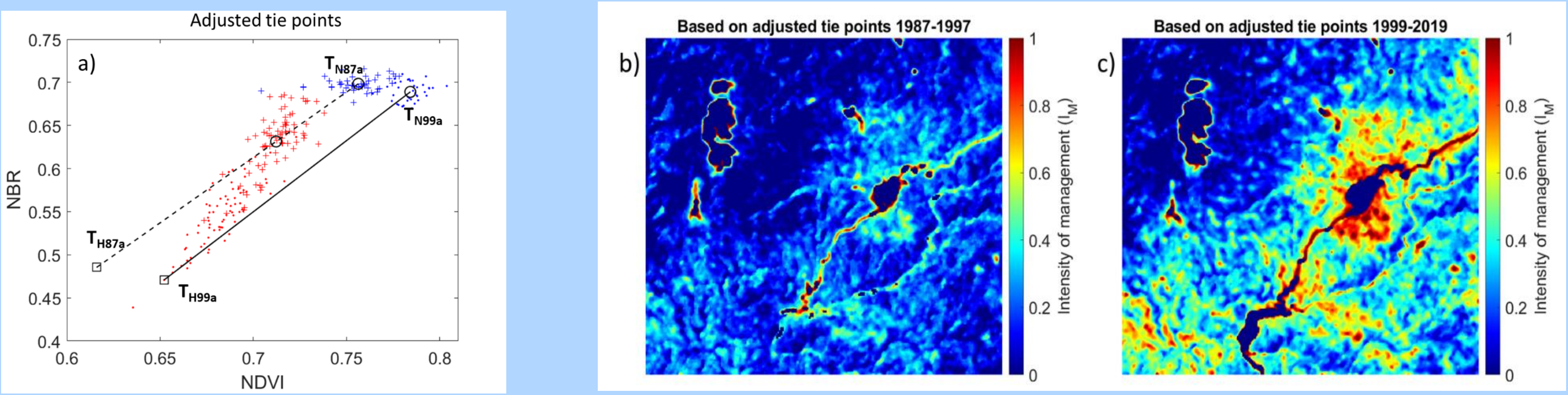

Figure : a) Adjusted tie points for NF (T_N) and HMCF (T_H), and the intensity of management (I_m) estimated using the new tie points for b) the 1987-1997 and c) 1999-2019 periods. In a), for the 1987-1997 period, the data points for NF and HMCF sites are shown in small blue and red crosses and in a dotted line connecting the tie points T_{N99a} and T_{H99a}. For the 1999-2019 period, the data points for NF and HMCF sites are shown in blue and red dots and in a solid line connecting the tie points T_{N87a} and T_{H87a}.

Summary & Conclusions

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- Intensively managed coffee forests have distinctively different canopy cover and Landsat-derived vegetation indices (NDVI and NBR) from natural forests.
- The time-series analysis of 32 years of Landsat data reveal a clear trend in the level of degradation in the coffee forests due to intensive management.
- Our proposed tie-point method provides a way to estimate long-term changes in the intensity of degradation in coffee forests.
- The results from the tie-point method suggest the expansion of areas of intensive management of the coffee forest and the intensification of the consequent degradation of that forest occurred in the study area following the change of government in 1991 and the introduction of new economic policies, changed arrangements for access to government forest, as well as economic situation, i.e., rising coffee prices.

References

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For the references and detailed information, refer to the recently published paper below:

Hwang, B., Hundera, K., Mekuria, B., Wood, A., and A. Asfaw (2020) Intensified Management of Coffee Forest in Southwest Ethiopia Detected by Landsat Imagery. Forests, 11, 422, DOI:10.3390/f11040422.

https://www.mdpi.com/1999-4907/11/4/422