Remote sensing monitoring of land restoration interventions in semi-arid environments

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Background info

- Restoration interventions
  > stop desertification/land degradation
  > improve land productivity
  > plantations, improved land management, run-off control infrastructures

- Evaluating the success of an intervention is challenging (lack of standardized and affordable methodologies)
  > success is rarely checked

Objective

Provide a first, standardized and objective assessment of the biophysical impact of an intervention, in terms of vegetation cover.
Method

• **NDVI as a proxy of vegetation cover (response to restoration)**

  changes in vegetation are natural
  (seasonal vegetation cycle, the inter-annual climate variability)

  success cannot be assessed focusing on the intervention only

• **Rely on comparative methods and use a state-of-art statistical design borrowed from the ecology domain:**
  **BACI (Before/After-Control/Impact) design**
Method

BACI (Before/After-Control/Impact) design

- to account for natural changes, the “impact” site is compared to another site, the control site
- it is the differential change (after vs. before) with respect to control that matters
Method

- Multiple controls extends this idea and avoids that the BACI results are due to a poor choice of control sites.

- Similarly, multiple temporal sampling before and after ensures that temporal fluctuations do not confound the detection of the impact.
Method

BACI: Linear mixed-effects model on NDVI site-level averages as in Schwarz, 2015. Fixed effects: period (before/after), class (impact/control), period x class. Random effect: site, sampling time.

- **BACI contrast** = \((\mu_{CA} - \mu_{CB}) - (\mu_{IA} - \mu_{IB})\)

Difference (control-impact) of the mean NDVI variation (after-before)

- **Significance \((P\text{-value})\) of BACI effect**

Used in testing the (null) hypothesis of no change (due to intervention)
Automatic selection of control areas

Requirements

1) relatively close in space to impact to experience the same weather variability
2) land cover before the intervention similar to impact
3) randomly selected
4) not subjected to anthropogenic changes
Automatic selection of control areas

1) close in space to experience the same weather variability

- search area/impact area = 600

* Striping due to the use of LS7 data affected by SLC-off
2) similar land cover before the intervention

- Unsupervised classification on the imagery before the intervention to find out areas similar to impact
2) similar land cover before the intervention

- Unsupervised classification on the imagery before the intervention to find out areas similar to impact
- Candidate controls: all possible square windows (area equal to impact) in the search area (other interventions masked out)
- Each of them characterized by a similarity ($s=1-\text{RMSE}$ in class composition) to impact area
3) randomly selected

- Among those similar \((s > 0.9)\), 20 controls are randomly selected using probability proportional to size.
3) randomly selected
• Among those similar (>0.9), 20 controls are randomly selected using probability proportional to size

4) not subjected to anthropogenic changes
• Controls are visually checked in the period analyzed

Avg NDVI (Impact/Controls Before/After) is used in BACI statistical framework
Matam region, Senegal
Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI), a pan-African project to combat desertification creating a green belt south of the Sahara

- Mainly tree plantations and rangeland restoration (fencing)
- Cash for work activities
Data

Remote sensing

Moderate spatial resolution

eMODIS NDVI
@ 250 m and 10-day frequency

Maximum NDVI during the growing season

High resolution

Landsat 7 and 8 NDVI
@ 30 m

Availability of cloud-free imagery VERY limited (exp. with LS7). One per season, not all the year of interest

NDVI at time of observation

BACI design:

- MODIS: Multiple controls and multiple time sampling (5 yrs B/A)
- Landsat: Multiple controls, single time
Data

Delineation of intervention areas
• Field missions

Consistency check of BACI results
• Qualitative evaluation of intervention success during field missions
• Very High Resolution imagery from Google Earth
Results, examples

- *Project 9, BACI significant, improvement*

  Landsat
  \[ P=0.007 \]
  RC= -18%

  MODIS
  \[ P=0.048 \]
  RC=-32%

- *Project 4, BACI non significant, degradation*

  Landsat
  \[ P=0.07 \]
  RC=18%

  MODIS
  \[ P=0.17 \]
  RC=6%
## Results, overview

### Qualitative information

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### BACI results

#### MODIS 5 years before/after

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<th>Relative contrast (%)</th>
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#### Landsat 1 year before/after

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- Good agreement with qualitative information
- Large agreement between MODIS and Landsat
- No biophysical impact detected for 10 out of 15 projects!
Conclusions

BACI applied to RS data

• cost-effective method to provide a first screening of restoration interventions
• agreement with VHR photointerpretation and field information
• with other RS-derived variables (e.g. soil moisture, surface roughness, fragmentation, VHR plant species mapping) may be applied to other impacts (soil conservation, habitat fragmentation, biodiversity)
• requires multiple undisturbed controls (no major and widespread changes)

Landsat vs. MODIS

• MODIS: high temporal frequency makes -> BACI multi-site-year, spatial resolutions may not be sufficient for small interventions
• LS: poor cloud-free availability (LS7). Positive prospects for more recent interventions using LS8 and Sentinel2