Abstract— Restoration interventions to combat desertification and land degradation are carried out in arid and semi-arid areas to improve vegetation cover and land productivity. Evaluating the success of an intervention is challenging due to various data constraints and the lack of standardized and affordable methodologies. We propose a semi-automatic methodology to provide a first, standardised and objective assessment of the biophysical impact, in terms of vegetation cover, of restoration interventions using remote sensing data. The normalized difference vegetation index (NDVI) is used as a proxy of vegetation cover. Recognizing that changes in the environment are natural (e.g., due to the seasonal vegetation development cycle and the inter-annual climate variability), conclusions about the success of the intervention cannot be drawn by focussing on the intervention area only. We thus use a comparative method that analyses the temporal (before/after the intervention) variations of the NDVI of the impacted area with respect to multiple control sites that are automatically selected. The method provides an estimate of the magnitude of the differential change of the intervention area and the statistical significance of the no-change hypothesis test. Controls are randomly drawn from a set of candidates that are similar to the intervention area. As an example, the methodology is applied to restoration interventions carried out within the framework of the Great Green Wall for the Sahara and the Sahel Initiative in Senegal. The impact of the interventions is analysed using data at two different resolutions: 250 m of the Moderate Resolution Imaging Spectroradiometer and 30 m of the Landsat mission.

I. INTRODUCTION

Desertification, defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities, represents a major threat to population and ecosystems [1]. Restoration interventions are among the several strategies that can be put in place to combat land degradation and often involve the improvement of vegetation cover [2], through plantations of appropriate species or through improved land management.

Independent assessment of the success of restoration projects is often challenging because interventions may be located in areas that are difficult to access and have poor infrastructure. Additional challenges refer to the lack of affordable and standardized methodologies/criteria and the difficulty of obtaining long-term data to monitor the effect of an intervention outside the project’s timespan. Verification performed by the implementing agent is also frequently not available.

Remote sensing (RS) can help cope with the widespread lack of timely, long-term, reliable, and homogeneous ground information, especially in African drylands. Few examples of the use of RS data to assess restoration interventions are available [2]–[4].
Vegetation indices such as the Normalized Difference Vegetation Index (NDVI; [5]) can be used as proxies to monitor the fraction of vegetation cover, i.e. the fraction of ground covered by green vegetation [6]. However, evaluating the “greening” of a restoration intervention presents a challenge, because the direct comparison of the NDVI of the area before and after the intervention would not be informative. In fact, vegetation cover will change over time independently of the restoration project. Two main sources drive the temporal variability of vegetation status: the annual seasonal development cycle (one or more) and the inter-annual climate variability. Both fluctuations hamper the possibility of making a direct comparison.

In this study we make use of the BACI design to develop a method to assess the impact of a restoration intervention on vegetation fractional cover solely based on RS information (i.e. NDVI). The method is intended to perform a cost-effective verification of the effectiveness of the restoration intervention that may be used as a first screening, usable to plan additional field verification campaigns, and as a medium- to long-term impact monitoring tool when applied repeatedly over time.

To illustrate the approach we apply it to a case study in Senegal, where a number of restoration interventions were performed in the context of the Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI), a pan-African initiative to combat desertification [7]. The biophysical impact was assessed using RS data at two different spatial resolutions, namely the Moderate Resolution Imaging Spectroradiometer (MODIS) at 250 m and Landsat at 30 m, and compared with qualitative information from field observations and photointerpretation of VHR imagery.

II. STUDY AREA AND DATA

The test case-study encompasses several interventions conducted in the Matam region in the northern Senegal, in a relatively flat area belonging to the Sahelian acacia savannah ecoregion characterized by a hot arid desert climate. In the area, several restoration projects including reforestation and improved forage production have been implemented in the context of the GGWSSI.

The analysis was performed on freely available satellite imagery at two different scales: 250 m eMODIS NDVI product and 30 m surface reflectances from the Landsat missions, both provided by the United States Geological Survey (USGS). The eMODIS NDVI is delivered as temporally smoothed 10-day maximum value NDVI composites [8].

Inspection of MODIS multi-annual temporal profiles for the intervention areas permitted to determine the period of vegetation growth, roughly ranging from July to September with maximum development reached in late August. Largely cloud-free Landsat imagery was selected during this period. Landsat 8 OLI data are available since 2013, before that time we had to rely on Landsat 7 ETM+ data (since 1999), affected by data gaps due to the Scan Line Corrector failure (SLC-off). Landsat-based NDVI was computed with the red and near infrared bands of surface reflectance products. Although not strictly required, the BACI design benefits from having multiple time observations before and after the time of intervention. Whereas gathering multiple MODIS observations is straightforward, it is very challenging for Landsat 7 in this geographical settings, therefore, when analysing Landsat data, we opted to select a single image before and after the intervention.

Additional very high resolution (VHR) imagery from Google Earth was used for the qualitative evaluation of the restoration interventions.

The outline of the project polygons and main project information (type and year of intervention, responsible institution) were obtained during field campaigns (June – August 2014, October 2015). Restoration interventions mainly regarded tree plantations (Acacia nilotica, Acacia senegal, Acacia seyal and Balanites aegyptiaca), fencing of plots to enhance natural regeneration of woody species and restore rangeland grasses, and the combination of the two.

III. METHODS

A. BACI sampling design

The evaluation of impact involves comparative methods. Direct comparison of the area before and after the supposed impact is not a viable option as changes could not be causally attributed to the intervention because of the natural (i.e. climate and seasonal-driven) temporal variation of NDVI. In BACI design, to account for natural changes, the restoration intervention area (i.e. the “impact” site) is compared to another site, which is referred to as the control site [9]. In this way, it is the differential change (after vs. before the intervention) with respect to control that matters (Fig. 1).

![Fig. 1. Principle of BACI assumption, modified after [10]](image)

The use of multiple control sites and time of observation (i.e. BACI with multiple sites and times) extends this idea and avoids the criticism that the results of the BACI experiment are solely due to a poor choice of control sites or observation time. While the use of multiple sites was achievable using both remote sensing data (Landsat and Modis), the use of multiple times was possible with MODIS only due to the describe scarcity of cloud-free Landsat imagery.

A linear mixed-effects model on NDVI site-level averages was used to test the impact of the restoration intervention as in [10]. In this context, the period (before/after), the site class (impact/control) and the interaction of site class and period are fixed effects while the site and the sampling time, being non-exhaustive samples of the potential sites and sampling times, are considered to be random effects.
The BACI analysis provides two important statistics (among others): the significance (i.e. P-value) of the BACI effect test and the so-called BACI contrast. The BACI contrast is calculated as the difference (controls vs. impact) of the mean differences (after vs. before). The percent relative contrast is then computed as 100 * contrast/mean of the RS variable before the intervention.

**B. Control selection**

With respect to the impact, a control area should possess the following characteristics: i) similar land cover before the intervention, ii) relatively close in space to experience the same weather variability, iii) not subjected to anthropogenic changes in the whole before-after period being analysed, and iv) randomly selected. In addition, even if not strictly required by the BACI design, we opted for selecting control areas with a size similar to that of the impact area to ensure a balanced sampling size.

In order to fulfil such requirements we proceeded as follows for each of the impact sites. First, we restricted the area where controls are searched for to a circular area centred on the centroid of the impact site. The extent of such area was defined as a multiple of the impact area size (search area / impact area = 600). Second, we used the images acquired in the period before the intervention to perform an ISODATA classification with 5 classes spatially restricted to the search area. Third, we defined a generic control as a square spatial window with the same area of the impact site. The population of potential controls is thus formed by all the possible and overlapping windows centred on each of the pixels belonging to the search areas. Then, the fractional class composition is computed for each potential control using the map produced by the ISODATA classification. Fourth, the land cover similarity between each potential control and the impact is defined as the complement of the root mean square error between the fractional compositions and one, i.e. similarity = 1 – RMSE. Values close to one thus indicate nearly identical overall class composition between a potential control and the impact. Fifth, we subsample the population of potential controls by discarding those with a similarity smaller than 0.9. From this sample we randomly extract 20 control sites. Random extraction is executed using probability proportional to size sampling [11] in which the selection probability for each element is set to be proportional to its similarity to the impact site.

Once the location of the controls is established, the RS variable of interest is extracted for all valid pixels belonging to the impact and control areas for the period before and after the intervention.

**IV. RESULTS AND DISCUSSION**

As reported in Table I, a significant and negative BACI contrast (i.e. improvement in NDVI with respect to controls after the intervention) was detected in five and four out of 15 sites using MODIS and Landsat, respectively.

**TABLE I. BACI RESULTS FOR THE 15 TEST SITES ANALYSED. R.C. STAND FOR RELATIVE CONTRAST (BACI CONTRAST / MEAN OF RS VARIABLE).**

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<td>I1</td>
<td>0.0032</td>
<td>-19.94</td>
<td>0.3384</td>
<td>-12.25</td>
<td>0.0166</td>
<td>-16.25</td>
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<td>-12.67</td>
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<td>-17.58</td>
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<tr>
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<td>0.0530</td>
<td>-12.67</td>
<td>0.4235</td>
<td>-13.84</td>
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<tr>
<td>I4</td>
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<td>I5</td>
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<td>I6</td>
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Despite the fact that only a minority of the interventions were found to have had an impact, focussing on the sites for which a significant BACI effect was detected, the average relative contrast is -20% and -27% for MODIS and Landsat, respectively. With the rough approximation of considering NDVI equal to the fractional vegetation cover, these numbers translate into a significant improvement of the vegetation cover with respect to the controls.

Finally, large agreement about detection of a significant greening of the intervention exists with field observations and VHR imagery inspection (data not shown).

**V. CONCLUSIONS**

A before/after control/impact design, was applied for the first time to RS data to evaluate the biophysical impact of restoration projects. In the absence of standardized methodologies to assess the success of an intervention project, the proposed approach can be considered a largely objective and cost-effective method to provide a first screening of restoration interventions that may drive further and complementary in situ analyses, thus increasing the cost-efficiency and feasibility of restoration interventions’ evaluation also in remote areas and over large geographic regions.

Applicability of the proposed method is however limited to the verification of a biophysical impact in terms of variation in vegetation cover. Therefore, interventions that do not affect the greenness cannot be treated. In addition, one should bear in mind that the row biophysical impact on biomass amount is the only scrutinized. Other impacts, ranging from improvement of the quality of vegetation (e.g. nutritional value, biodiversity) to the socioeconomic outcomes (e.g. involvement of local communities in cash or food for work projects) of the intervention, are beyond the scope of the method but may be relevant in other perspectives.

The proposed approach can be considered a largely objective and cost-effective method to provide a first screening of restoration interventions that may drive further and complementary in situ analyses, thus increasing the cost-efficiency and feasibility of restoration interventions’
evaluation also in remote areas and over large geographic regions.

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