Pine Forest under alert in The Chaambi UNESCO Biosphere Reserve, Tunisia:
Tree-level impact assessment of long-term climate change and recent social troubles

Prepared by: Sameh Chaabani

Supervised by: Florent Mouillot
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Changes in forest cover are one of the most land cover change process globally, affecting biosphere, atmosphere interactions, and the sustainability of social-ecosystems at the local scale. Natural parks and reserves are created all over the globe to try and maintain natural vegetation as little affected by human pressure as possible. In Tunisia, the Chaambi national park has been created in 1967 and UNESCO Biosphere Reserve in 1977 at the southern boundary of the Mediterranean climate and susceptible to be highly affected by increasing drought or temperature, or human pressure wood fuel collection. In 2011 the Tunisia revolution highly affected the social equilibrium in the country and forest fires have drastically increased. We question here 1) how tree cover was impacted by the creation of the park and UNESCO Biosphere Reserve since the 1970's and 2) how recent fires have disturbed this park and the UNESCO Biosphere Reserve in order to propose potential management plans. We first estimated the present tree cover from various inventory data (national forest inventory, global remote sensing, land cover products) that we compared with tree cover estimates from google earth images for 2010. To identify tree cover change, we used aerial photos from 1963 that we scanned and georeferenced. We finally mapped the recently burned area from Landsat images to quantify the disturbance impact. We first concluded that global forest cover offer an unrefined representation of the reality, and that national forest inventory are also not refined enough to capture tree cover changes. Our google earth images analysis could produce the most accurate information to compare with ancient aerial photography. Then we observed an increasing tree cover in the park since the 1970's due to protection rules, but 6.200 ha of this forest was affected by fires in 2013 after the Tunisian revolution of 2011. Then we propose here to account for our analysis of the natural tree cover observed the fire before any replanting management plan to optimize tree cover according topoclimate and minimize costs.
**INTRODUCTION AND CONTEXT**

Mediterranean ecosystems are located at the boundary between temperate and arid ecosystems, the most susceptible to be affected by climate change (Lavorel et al., 1998, Giorgi and Lionello 2008). Within this bioclimate, the southern bound would be merely affected by increasing drought, impacting forest functioning, tree growth, tree dies back and disturbances. When considering that this southern band is located in North Africa, where local populations still significantly depend on ecosystem services as wood, pastures, and fruit/seeds/oil collection, understanding recent trends in forest functioning under climate changes and social change would underlie forthcoming forest management pathways. Global and continental scale studies have been carried out to provide a global picture of the ongoing and future trends of ecosystem changes and their impacts on social-ecosystem sustainability, but increasing evidence of local refuge from topoclimate heterogeneity could balance these views (Dobrowski 2011). Beside these fine scale functional adjustments across spatial and temporal scales, unpredictable disturbance might balance or enhance expected trends. The Chaambi biosphere reserve (UNESCO biosphere reserve since 1977) located in southern Tunisia happens to be the most southern (driest) location on the Mediterranean climate gradient with contrasted topographical situations (north vs south aspect, and high altitude from 300m to 1544m) worth of interest for studying contrasted responses to regional water deficit, to be a source of revenue for local rural population with pine seed collection used for traditional food and pasture, and where recent social troubles after the Tunisian revolution in 2011 lead to army intervention and subsequent large forest fires from bombing in 2013 and 2014. Based on these historical events, we question here i) how the creation of the UNESCO Biosphere Reserve actually impacted tree cover since 1977, ii) how the spatial pattern of tree cover naturally adjusted to topo-climatic conditions in these dry conditions, and iii) how the recent social events have affected the benefits of converting this area into a protected area.
Second Part

METHODOLOGY
1. Study site: the Chaambi Biosphere Reserve (Tunisia), UNESCO Biosphere Reserve since 1977

1.1. Site description

The choice of the Chaambi Biosphere Reserve has been done due to several reasons. Since 1977, this biosphere reserve was chosen by UNESCO as a Man and Biosphere Reserve. Its total area is about 43723 hectares, located 15 Kilometers west of Kasserine city, 35 kilometers north of Feriana and 50 Kilometers South of Thala (Figure 1).

Figure 1: Digital elevation model of Tunisia (A) and Chaambi Biosphere Reserve
This biosphere reserve has the specificity to represent all the physical conditions of the Tunisian Atlas; it belongs to the area of the central highlands of Tunisia and home to the highest mountain of Tunisia, namely Jebel Chaambi with an altitude of 1544 meters.

1.2. The Fauna

On the other hand, the Chaambi Biosphere Reserve hosts a fauna characteristic of the Tunisian Atlas mountain, adapted to the cold temperatures in winter and hot and dry summers. The most representative animals are the mountain gazelle, the wild boar which is a fairly common animal in the Aleppo pine forest and striped hyena, the largest carnivore of Tunisia (figure 2). The Chaambi Barbary sheep, disappeared since 1960 and was reintroduced in 1987. The wild-cat or gloved cat lives in trees and bushes. It represents the original wild form of our domestic cat, and is a predator of small birds, rodents and insects. Jackal and fox are common in the Biosphere reserve. They are nocturnal animals that often hunt in pairs or in groups.

Figure 2: wild boar and mountain gazelle in the Chaambi Biosphere Reserve.

1.3. The Flora

The Chaambi Biosphere Reserve is composed of over eighty species of plant whose density depend on the altitude, degree of exposure to sunlight and soil type. The most abundant species is the Aleppo pine. The understory of Aleppo pine forests is composed of Phoenician juniper, of Cistus spp, globular and rosemary. Seven plant communities compose the park and varying with altitude from bottom to top (MEDD, 2008):

- The Alfa steppes extend below the altitude of 900 m and is composed of Stipa tenacissima and Rosmarinus officinalis derived from the degradation of old dominated stands of Phoenician juniper.
• From 1000 to 1100 m lies the open Aleppo pine forest with an understory of Phoenician juniper and rosemary. Alfa becomes less abundant. This is the group of Phoenicia Juniperus and Pinus halepensis.
• The Pinewood diss (Pinus halepensis group and Ampelodesma Mauritania) gradually replaces Alfa and Juniperus Phoenicia dwindle rapidly, replaced by Juniperus oxycedrus.
• From 1100 to 1200 m, the pine forest is mixed with Quercus ilex.
• The mixed pine forest of sub-humid bioclimate with cool variant is accompanied by an understory of vigorous and dense holm oak (Pinus halepensis group, Quercus ilex and Staehelina dubia) whose action on the climate and soil favors shade-tolerant species humus. Alfa disappears completely.
• Upper in altitude, Pinus halepensis and Sorbus aria are not well represented on the North Slope of the Chaambi Biosphere Reserve. On the southern aspects, appears the sunny species composition: Pistacia Terebinthus Artemisia Atlantica, Rosa Sicula, Teucrium Flavum, Asphodeline Lutea Hypericum Ericoides, Anthemis Montana, Bupleurum Spinosum.
• At the ridge top, Quercus ilex and Prunus prostrate occur on the North facing slopes.
Figure 3: *Stipa Tenacissima*

Figure 4: *Rosmarinus Officinalis*
Figure 5: *Rosa Sicula*

Figure 6: *Teucrium Flavum*
Figure 7: Asphodeline Lutea

Figure 8: Hypericum Ericoides
Figure 9: *Anthémis Montana*

Figure 10: *Bupleurum Spinosum*
Figure 11: *Prunus Prostrata*
1.4. Physical description of the site

1.4.1. Topography

The Chaambi appears as a major mountain, the highest mountain in Tunisia with high, tight crests separated by deep valleys " (Bannour and Bouallegui., 1979). Figure 1 shows that altitudes higher than 1400 m represent only a small part of the total surface of the Biosphere Reserve. From West to the east of the park, a continuous decreasing altitude is observed. The Chaambi is connected to the chain of the anticlinal ones of Djebs Kesra, Bargou and Serj, upward to the Zaghouan city of the Tunisian ridge. The geologic substratum under the forest vegetation of the Biosphere Reserve is heterogeneous. The calcareous substrate belongs to diverse geologic times. Hard limestones and soft limestones, formed during the Cretaceous, appear on the sides of the Djebel. Marls are from the Cretaceous. On both sides of the Djebel Chaambi, the ponds of Foussana and Kasserine form depressions with quaternary alluviums. The torrents of water, which come down from the Djebel during heavy rain, can dig in these alluviums deep scratches and valleys.

Figure 12: Hypsometric map of Chambi Biosphere Reserve
1.4.2. Hydrology

The temporary rivers (called 'oued') in the National Park are represented by two big valleys in the region Wad Darb and Wad Htab. The two streams are occasional and show the mountainous character of the river system. According to Bannour and Bouallegui (1979) there are differences between the oueds which come down from the north side and those on the south side. The first ones have average slopes from 6 to 8 %. On the other hand, the others present steeper slopes with numerous breaks.

Figure 13: Map of the river system of the Chaambi Biosphere Reserve
2. Present forest status: Comparing data sources

In this chapter, I compared different sources of information regarding present forest cover characterization in the Chaambi Biosphere Reserve.

2.1. Data Source 1: National Forest Inventory (Tunisia)

Forest inventory has been delivered since 1995 by the Direction Général des Forêts (DGF) providing polygonal information on forest species and tree cover.

In this case the General Directorate of forestry and the National Center of Cartography and Remote Sensing have established the second forest and pastoral inventory between 1998 and 2008. The implementation of this national inventory was based on remote sensing techniques, geographical positioning system (GPS) and geographic information systems (GIS). The document used for the preparation of forest maps are:

- The photographic coverage of June 1998 for the governors of Béja, Bizerte and Jendouba
- The photographic coverage of September 2000 for the governors of Tunis, Ariana, Manouba, Ben Arous, Nabeul, Zaghouan, Siliana, Kef, Kasserine, Kairouan
- Satellite images of 2002 and 2003 for the other governors.

Field studies were performed in:

- From July 2003. June 2007, for the other governors (21 governors)

The establishment of this National Inventory, aimed at developing land use maps at a scale of 1/25 000 for Tunisia. The main theme is the analysis of major land use and the types of vegetation. The typology used is based mainly on the dominant plant species and on the distribution and importance of the wood or herbaceous cover. This typology adopted makes the results of the National Inventory compatible with results obtained previously on more limited areas.
Plant formations account in this National Inventory are:

- Forest land;
- Non-forest woodlands;
- Alfa;
- The steppes and lawns.
- Grazing areas.

The error rate is set between 2 and 3% for a probability of 0.68. The information collected in this inventory concerns:

- The areas of plant units;
- The main types of roads;
- Wood volumes;
- Increases of forest trees;
- The number of trees (density per hectare);
- Woody biomass;
- The perennial and annual herbaceous biomasses and those of the litter separately.
2.1.1. The method used for the establishment of the National Forest Inventory

1. Preliminary study: compendium of external data and the development of the nomenclatures and operating protocols of the inventory.

2. Mapping: This mapping phase includes:
   - The development of a system of classification
   - The photo-interpretation
   - Land use
   - Digitization of maps from visual observations

3. The field studies: to facilitate the task of the technician during the photo-interpretation.

A guide has been prepared.
4. Photo interpretation delimited homogeneous forest areas on the stereo pairs of aerial photographs, Infra-red, or black and white photos. The 1/20,000 scale of homogenous areas based on the classification system was adopted.

The study of aerial photographs and digital ortho photos allows for:
- identification of forest stands, the shrub and the garrigues of their contours.
- estimate of the surfaces of these stands.
- design a stratification;

Defining the tree, the forest, the species, the structure, the hedge, alignment, etc. The definitions adopted are inspired by the first national inventory of 1993, foreign inventories, international statistics and customs forest;

Field validation is carried out by a second visit to the field to confront the result of the photo-interpretation and make the necessary corrections.

2.1.2. Result of The National Forest Inventory:

The current surface of natural areas in Tunisia is 1 141 628 ha, composed of 672 985 ha (59\%) of forests, 336 788 ha (29\%) other forest formations as fire, rocky grounds, and 131 850 ha (12\%) with uncultivated lands (DGF. 2010).

The surfaces of the national territory inventoried according to the dominant forest species, the forest includes in particular 63.38\% of conifer, 25.59\% of broad-leaved trees, 4.41\% of diverse broad-leaved trees and 4.48\% of diverse conifer (DGF., 2010).

These wood types are essentially localized in the Northern part of the country, and cover preferentially the mountainous zones (Abdelmoula., 1992)

Vegetation type and codes are presented in table 1:

<table>
<thead>
<tr>
<th>Type of vegetation types</th>
<th>Interval of classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense Broad-leaved trees</td>
<td>11 000000 - 11002000</td>
</tr>
<tr>
<td>Average Broad-leaved trees</td>
<td>11 002000 - 11003000</td>
</tr>
<tr>
<td>Opened Broad-leaved trees</td>
<td>11 003000 - 11006000</td>
</tr>
<tr>
<td>Dense Conifer</td>
<td>12001000 - 12002000</td>
</tr>
<tr>
<td>Average Conifer</td>
<td>12002000 - 12003000</td>
</tr>
<tr>
<td>Opened Conifer</td>
<td>12003000 - 12006000</td>
</tr>
<tr>
<td>Mixed</td>
<td>13001000 - 13006000</td>
</tr>
<tr>
<td>Shrubland</td>
<td>14000000 - 17000000</td>
</tr>
</tbody>
</table>
Increasing efforts have been devoted globally to deliver free-access land cover at 1 km down to 30m resolution. They include land cover types (forest, shrubland, grassland, crops and urban) (Gong et al., 2013, Tuanmu & Jetzt, 2014) and tree cover (Hansen et al., 2013).

### 2.2.1. Tree cover (Hansen et al., 2013)

Hansen et al., (2013) used Earth observation satellite data to map global forest loss (2.3 million square kilometers) and gain (0.8 million square kilometers) from 2000 to 2012 at a spatial resolution of 30 meters. This study, based on Landsat data, improves the existing knowledge of global forest extent and change by being spatially explicit. This global database quantifies gross forest loss and gain, provides annual loss information and quantifies trends in forest loss (figure 14). It was derived from an internal consistent approach that is exempt from the vagaries of different definitions, methods, and data inputs. Forest loss was defined as a stand-replacement disturbance or the complete removal of tree cover canopy at the Landsat pixel scale. Forest gain was defined as the inverse of loss, or the establishment of tree canopy from a non forest state. A total of 2.3 million km$^2$ of forest was lost due to disturbance over the study period and 0.8 million km$^2$ of new forest established.

![Figure 14](image-url)
Data Download
To download the individual 10° x 10° degree tile at 40N, 0E and 40N, 10E to cover the Tunisian extend we used this link http://earthenginepartners.appspot.com/science-2013-global-forest. Then we assembled two ‘tiff’ format images that cover Tunisia using th R Cran software ('Raster' package).

Figure 15: tree cover access and 10° x 10° tile representation for the Hansen et al. 2013 database.

2.2.2. Global 30m resolution land cover (Gong et al. 2013)
Gong et al 2013 have produced the first 30 m resolution global land-cover maps using Landsat thematic Mapper™ and enhanced Thematic Mapper Plus (ETM+) data. In this study...
6600 scenes of Landsat TM data were classified after 2006, and over 2300 scenes of Landsat TM and ETM+ data before 2006, selected from the green season. These images of the world’s land surface came from the United States Geological Survey in level L1T (orthorectified). Two software tools, Global Analyst and Global Mapper developed by extending the functionality of Google Earth and by referencing the Moderate Resolution Imaging Spectroradiometer enhanced vegetation index (MODIS EVI) time series for 2010 and high resolution images from Google EARTH.

2.2.3. Tuanmu et al., 2014

Four global land cover products were selected in this study: the GlobCover Land Cover product (GlobCover), the 2005 land-cover product from the Moderate Resolution Imaging Spectroradiometer (MODIS2005), the Global Land Cover 2000 product (GLC2000) (DISCover). To generate a consensus data set from the base products two-step approach was developed. In the first step resulted in an intermediate 500-m dataset from GlobCover and MODIS 2005 while in the second step a final data set was derived by integrating the intermediate dataset, DISCOVER and GLC200. To harmonize the different classification schemes, a generalized scheme developed by Herold et al. 2008 was adapted using the UN Land Cover Classification System (LCCS ; DI Gregorio, 2005).
2.2.3.1. Data Download

Figure 16: web portal for the global 1km consensus Land cover.

2.2.4. Global Land cover ESA_CCI

Figure 17: web portal for the ESA_CCI land cover product.
To generate the global land cover maps the process chain adopted in this study. The Surface Reflectance (SR) products delivered by the CCI-LC project consist in MERIS global SR composite time series covering the period 2003-2001 that are the input for the classification process. The spectral content encompasses 13 of 15 MERIS spectral channels and the spatial resolution is about 300 m for the full Resolution and 1000 m from the Reduced resolution.

Figure 18: MERIS processing chain for the ESA land cover CCI product.
2.2.4.1. The Land Cover class

<table>
<thead>
<tr>
<th>Class</th>
<th>Label</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Cropland, rainfed</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Herbaceous cover</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Tree or shrub cover</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Cropland, irrigated or pass-fallowing</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Mosaic: permanent natural vegetation (tree, shrub, herbaceous cover) (&lt;50%)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Mosaic: natural vegetation (tree, shrub, herbaceous cover) (&lt;50%) / cropland (&lt;50%)</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Tree cover, broadleaved, evergreen, closed to open (&lt;25%)</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Tree cover, broadleaved, deciduous, closed (&lt;25%)</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>Tree cover, needleleaved, evergreen, closed (25–40%)</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>Tree cover, needleleaved, deciduous, closed (25–40%)</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>Tree cover, needleleaved, deciduous, closed (25–40%)</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Tree cover, mixed leaf type (broadleaved and needleleaved)</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>Mosaic: tree and shrub (&gt;50%) / herbaceous cover (&lt;50%)</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Herbaceous cover (&gt;50%) / tree and shrub (&lt;50%)</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>Shrubland</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>Evergreen shrubland</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>Deciduous shrubland</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>Lichens and mosses</td>
<td></td>
</tr>
<tr>
<td>170</td>
<td>Sparse vegetation (tree, shrub, herbaceous cover) (&lt;15%)</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>Sparse shrub (&lt;15%)</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>Sparse herbaceous cover (&lt;25%)</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>Tree cover, flooded, fresh or brackish water</td>
<td></td>
</tr>
<tr>
<td>210</td>
<td>Tree cover, flooded, saline water</td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>Shrub or herbaceous cover, flooded, fresh/saline/brackish water</td>
<td></td>
</tr>
<tr>
<td>230</td>
<td>Urban areas</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>Bare areas</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>Consolidated bare areas</td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>Unconsolidated bare areas</td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>Water bodies</td>
<td></td>
</tr>
</tbody>
</table>

Figure 19: Land cover classes of the Land Cover CCI

3. Individual tree cover from Google Earth images

We finally produced a tree cover map of the Chaambi Biosphere Reserve based on Google Earth images. Skurinhi and al., 2012 tested an automated multi-scale approach for detecting individual trees and estimated tree crown geometry using high spatial resolution satellite imagery. Individual tree crowns are identified as local extrema points in the Laplacian-of-Gaussian scale-space pyramid that is constructed based on linear scale-space theory. The approach simultaneously detects tree crown centers and estimates tree crown sizes (radiiues). They evaluated their method using two 0.6-m resolution QuickBird images of a forest site that underwent a large shift in tree density between image captures due to drought-associated mortality. The automated multi-scale approach produced a tree count estimates with an accuracy of 54% and 73%, corresponding to the dense and sparse forests, respectively. Estimated crown diameters were linearly correlated with field-measured crown diameters ($r = 0.73–0.86$). Tree count accuracies and size estimates were comparable with alternative methods (Skurinhi al., 2012).
We downloaded automatically google images with the 'RGooglemap' package over the study site at the finest resolution (0.5m). Images are true color 'tiff' format images. We chose a threshold of color (numerical value corresponding to the color displayed on the 'tiff' image) equal to 1200 to identify canopy cover, compared to lower values obtained for understory dry grassland highly contrasted to canopy in this region.

Then we aggregated the patches of pixels considered as canopy into individual trees. Canopy patches of more than 7 and less than 20 pixels were considered as isolated trees. Patches with more than 20 pixels are considered as aggregated trees.

We finally obtained a continuous forest surface on the massif of the Chaambi Biosphere Reserve, and a characterization of the isolated trees. The interest of this mapping is to offer a fine representation of the sometimes fuzzy outlines of the limit forest not forest based on a threshold of 10 % of cover by trees. Refining this border by a precise characterization of each of the individuals, In the zone of dense forest, we managed to characterize gaps in the dense forest.

According to Guettat 2013, we validated the results of automatic classification of visual validation, to obtain the rates of commission and omission on zones tests, between the individual trees identified by the automatic classification and the individuals located visually on the images from Google Earth. The table 2 represents the rates of commission, omission and the exact estimation of the individuals. This analysis was used as a basis for the adjustment of the parameters of the method of classification to obtain the lowest rates of commission and omission and we present here only the final result.

Table 2: validation, cross validation test between visual and automated tree detection

<table>
<thead>
<tr>
<th>Detected spot Extract Bing</th>
<th>No tree</th>
<th>tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tree</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>tree</td>
<td>15</td>
<td>72</td>
</tr>
</tbody>
</table>

- Total: 72+15=87
- Errors of commission: 15/87 17 %

The quality of Guetat 2013 results is in the margin of error obtained with other more complex methods using commercial images, as for example (Skurikhin, Garrity, McDowell, and Cai.,
which obtain an identification with a rate of 54\% accuracy in dense forest and 73\% in forest opened in similar forest zones of forests of the New Mexico (USA).

4. **Historical forest composition from ancient aerial photographs**

To assess the forest dynamic in the Chaambi Biosphere Reserve since the Unesco Biosphere reserve creation, we compared the present forest cover map to the forest cover observed in the 1960's. Tunisia was first covered by aerial photography at the end of the 1960’s and images are stored at OTC (Office de Topographie et de Cartographie Tunisie). We aimed at building a GIS mapping of individual trees from ancient aerial photographs from the 1963. Our first goal was to georeference the ancient 1963 scanned aerial photographs, to accurately overlap with modern day satellite imagery and to define its existence in physical space, on a cartographically accurate reference system. The aerial photography scanned were saved as a '.tiff' format file. To execute the georeferencing process, we activate the toolbars in ArcGIS, we check effects, georeferencing. Then web ring the satellite imagery that will be used as the basis of georeferencing our aerial photographs. Go to File ->Add Data->Add Basemap and we select a satellite imagery basemap. In this step we used Basemap+Vivid Service named DigitalGlobeImageryTile Service. Then we added the raster image to the project and apply control points to match the raster image to the underlying geography based on common features as road, rocks, or houses. For best results, we tried to find features that are easy to identify, such as: Main street intersections, piers, Bridges, Peninsulas and Rivers.

Finally, after adding 4 control points, the aerial photography get shifted to find the « best » fit possible. Once we achieved this step we click the view link Table button in the Georeferencing toolbar. This opens a table which contains all control points. We select all the control points and save them in the project folder. The RMS Error should be <2. All aerial photos were projected to the WGS84 geographic coordinate system and were analyzed using the free RCran.
Figure 20: Mosaic of the aerial photos of 1963 over the Chaambi Biosphere Reserve
Third Part

RESULTS AND DISCUSSION
Figure 21: tree cover of Chaambi Biosphere Reserve from the National Forest inventory

We compared the results of tree cover with the information from the national forest inventory of Tunisia (DGF) (Figure 21), built on the basis of an information of remote detection and campaigns of ground. The figure 22 represents the map of the density stemming from Google earth analysis, automated and resampled at 30m resolution so as to obtain a density from continuous between 0 and 100 %.
The figure 22 shows the good fit between the highest densities identified in the forest inventory and google Earth tree cover estimation, as well as the good delimitation of outlines up to the open forest. We can, however, notice that the tree cover approach from google earth allows a characterization of the heterogeneity of the density tree cover inside the polygons of dense and average forest, a not insignificant information for a long-term monitoring observatory of potential damages of the forest in this natural reserve.
Figure 23: Tree Cover from Hansen 2013 and Google Earth
Figure 24: Comparing Gong et al 2013 and tree Cover Google Earth
Figure 25: Comparing ESA Land cover CCI and tree cover from Google Earth
Figures 22 to 25 present the comparisons between the tree cover assessment from google images and the global tree cover from global remote sensing. The global forest cover offers an unrefined representation of the reality. This information is insufficient for local approaches. Hansen et al., 2013 product is the finest resolution and it represents the best product to monitor the tree cover.

On the other hand, by combining various products, we can approach a realistic representation of the forest surfaces in Tunisia. This combination validated on Tunisia could be used in a representation of the Mediterranean forests on the zone the Maghreb where the homogeneous information is missed.

In conclusion for this first part, global land cover products are of good quality of major forest contours, but bring poor information for open forest like the Chaambi Biosphere Reserve to capture forest dynamic. Tree cover below 20% is not captured. However, we have provided a simple analysis of true color freely accessible google images, and we could obtain a precise information, particularly efficient on tree cover below 20%. This method could be easily used for forest inventories with precise tree cover detection.

**TREE COVER DISTRIBUTION IN 2010: AN ADJUSTMENT TO MICROCLIMATIC CONDITIONS**

From the tree cover density obtained from the google image analysis, we tested if the spatial variability of tree cover in the Biosphere Reserve was correlated to drought. We hypothesized that tree cover, since 1963 without human impact, adjusted to soil water availability so that tree cover would be higher on the wettest areas, and lowest on the drier areas. As the rainfall in the Biosphere Reserve is somehow homogeneous with a little more rainfall on the upper altitudes, we quantified the dryness of microsites by the total annual solar radiation influencing potential evapotranspiration. We calculated on an hourly basis, the received solar radiation on each pixel of the digital elevation model at 30m by using the R cran package 'SolAr' and 'insol'. From a digital elevation model and latitude, the packages calculates the solar azimuthal angle and orientation, its angle with any given slope and aspect, and the subsequent solar radiation. The hourly solar radiations have been added to get the annual
value. Figure 26 represent the digital elevation model (altitude) in the Biosphere Reserve and the subsequent annual solar radiation.

**Figure 26**: A: digital elevation of the Chaambi Biosphere Reserve (Red: high altitudes 1500m, blue: low altitudes 300m), B: Annual clearsky global solar radiation (W.m-2) over the Chaambi Biosphere Reserve calculated from geophysical processes (R cran package 'Solar' and 'insol').

When crosstabulating tree cover classes with solar annual radiation (figure 27), we observed that dense forests were located in the less sunny areas, and the open forests were mostly located on the sunniest areas with the highest potential evapotranspiration. This result, then sustained our hypothesis that tree cover in the Chaambi Biosphere Reserve was naturally adjusted to drought conditions, a natural hydroecological equilibrium of tree cover with drought.
Figure 27: Frequency distribution of tree density classes (from 90% in green to 10% in yellow) along an annual solar radiation gradient (low solar radiation corresponds to the less drying sites, and high radiation corresponds to the driest sites).

Tree cover change between 1963 and 2010

Figure 28 illustrates representative snapshots of tree cover from the 1960's (from aerial photos) and from the 2010 (from google images). We observe here a significant tree cover increase. This pattern is actually a generic pattern observed in the Biosphere Reserve from visual interpretation (figure 20). Unfortunately, we could not finalize a full tree cover assessment in the same format as the google images to fully cross tabulate the two maps. Color thresholds in the black and white maps are unstable between images and within an image. We are in the process of analyzing each of the 40 photos covering the park to fully convert to individual trees, but early visual results can already conclude on tree encroachment in the region and all over the biosphere reserve.
Figure 28: Tree cover from aerial photography from 1963 (A) and from google image analysis from 2010 (B)
THE LARGE FIRE OF 2013 IN CHAAMBI BIOSPHERE RESERVE

Forest fires are one of the most important sources of land degradation that lead to deforestation and desertification processes (P.A Hernandez-Leal., 2004). One of the most important causes of fires that threaten our forest every year are anthropogenic ones. Sometimes this makes especially difficult the generation of risk maps that provide timely information about areas that are vulnerable to fire (P.A Hernandez-Leal., 2004). Indeed Fires are an integral part of the natural cycle of Mediterranean ecosystems (BelHaj., 2012). Fires are a chronic problem, the environmental consequences obliged the governments of the countries concerned to make intensive efforts aimed at both prevention and control. The case of the Tunisian forest, due to climatic, ecological and socio-economic contexts is favorable to wildfires, subjected each year to important fires for the country. Although the yearly areas burned in Tunisia (around 1500 ha) may appear to be low compared to other countries, these fires are detrimental because the protection functions provided by the Tunisian forest areas are essential in the bioclimatic context of this country (Abdelmoula, 1992).

The Biosphere Reserve has been transformed from 2011-2012 into an ideal refuge for the Salafists who occupied a large part of this territory and in a cowardly and risky way while being riddled with antipersonnel mines and whose disastrous results were reported several times over the last two years. In 2013, large fires affected the park due to bombing and intentional forest clearing. Since then, visiting the park is forbidden, neither for recreation nor scientific purpose. In addition to our quantification of tree cover dynamic since the creation of the park, we present here how all the efforts for increasing tree cover in the last decades have been destroyed. In this case to monitor the impact of this large fire we use recent remote sensing techniques (Bastarrika et al., 2011; Koustias et al., 2013) from free access 30m Landsat images from the site (www.glovis.usgs.gov) to assess the burned area in the Biosphere Reserve, by comparing surface reflectances before and after the fire. In order to estimate the burned areas in the Biosphere Reserve we used spatial images of the free access site Landsat. We were therefore able to compare forest cover on Tunisia between 2010 and 2013. We have 3 fires triggered in 2013 in Kasserine, 2 covering 1186 and 102 Ha. Then the fires were digitized on ArcGis. The figure above shows the large fire and the inventory forest forest area burned on an aerial photo taken from a Landsat photo. Once the polygons are exported under Arc GIS, we can calculate their area. We can also estimate the burned areas...
using Google earth image (BelHaj., 2012). We estimated the burned area in the Chaambi Biosphere Reserve in 2013 to reach 6200ha, where no fire had been observed since the 1960's, affecting both the southern slopes of the Biosphere Reserve with low tree density and the also the northern part with high tree density.

![Figure 29: The large Fire of 2013 in Chaambi Biosphere Reserve](image)

The Chaambi Biosphere Reserve is located in the most southern boundary of the Mediterranean biome. We wonder how the forest will recover from this exceptional disturbance. The tree cover adjustment to drought conditions in the park that we observed from aerial photography before the fire might not be reached again by a lack of post fire regeneration. It's now not authorized to go to the park for scientific work, so we have no information on this natural regeneration process. Whatever the actual regeneration is, we might expect management plans to restore the forest by potentially planting pine trees. Our work on the tree density before the fire, and our findings that tree cover was adjusted to microclimate and drought should help the managers to adapt the planted tree density to these microclimates and the tree density we observed. Overplanting could lead to mortality due to enter individual competition, and thus a waste of money.
CONCLUSION AND RECOMMENDATIONS

We studied the individual tree dynamic in the Aleppo Pine forest of the UNESCO Biosphere Reserve Chaambi in Tunisia. Our aim was to assess the impact of the creation of the Biosphere Reserve in 1977 on tree cover, the state of present tree cover and its ecological adjustment to environmental conditions, and finally to quantify the impact of the 2013 fire after the 2011 Tunisian revolution. We could digitize and georeference aerial photos from the 1963 where individual tree could be visible, and propose a high resolution tree cover by analyzing the present true color google images. We showed that high resolution images are the only source of data to be used for long term forest change analysis mostly driven by tree cover change, compared to highly visible deforestation where all sources of land over data can be used. In turn, we illustrated the increasing tree cover over the last 40 years in Chaambi despite increasing temperatures and drought in the region. We could conclude then on a positive impact of the Biosphere Reserve creation on the forest dynamic. However, the detection of the burned area from Landsat images in 2013 provided a burned area of 6200ha (92%), covering most of the Core area. In turn, all the efforts from the last 40 years have been lost during this event. We wonder how post fire regeneration will actually recover the tree density from the period before the fire due the high water scarcity in the region potentially limiting seedling survival. In case management plans to replant trees would be decided, we suggest to adapt tree density plantation to the observed tree density before the fire, to prevent tree mortality and reduce useless and costly high density plantations. Following tree regeneration from Lidar information and tree cover analysis would indicate how natural regeneration could maintain the prefire tree density or if tree plantation is needed. Tree location from both aerial photos and google images should be further studied to identify tree by tree mortality and regeneration and figure the tree replacement dynamic according to topographical position, as a major source of information for the ecology of *pinus halenpensis* in dry environment. The fire of 2013 also offers a unique opportunity to further study post fire regeneration under dry conditions in this region.
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