The Guadalupe Island Cypress Forest: On the Recovery track

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Summary

The introduction of goats in the 19th century to the Guadalupe Island seriously devastated its cypress forest. The island, located 260 km offshore the Baja California peninsula in the Pacific ocean, had a reduction of the forested area from 4,000 to 160 hectares. With the eradication of goats, the forest is no longer threatened, and its regeneration is already evident. New seedlings can be seen in patches in several parts within the forested area. With a QuickBird high resolution satellite image, an estimation of the remaining trees was performed segmenting NDVI images in combination with the average tree top areas measured in the field. The extent and percent of canopy cover of the three remaining patches was calculated. This is a base line study to measure in the near future the recovery of the cypress forest after the goat eradication program.

Introduction

The forests are some of the most treasurable natural resources and habitats. The Guadalupe Island cypress forest is not the exception. It's one of a kind. It grew up 250 Km away from the continent and it became exceptional. The endemic cypress used to share its space with another species, but after several catastrophes, it was left alone and decimated. Introduced goats, fires and diseases had terrible effects on it. Because of these, no recruitment occurred in the last 100 years. Only a bunch of old trees remained. It was just matter of time to lose them all. Fortunately, in 2003 a systematic restoration effort began. The goat eradication program was the first step. Now, after almost four years of continuous hard work, the goat eradication program has been completed (Alfonso Aguirre, personal communications). The cypress forest, and island itself, is entering into a recovery transformation without the goat's pressure, cypress seedlings can now be seen in different areas. Even though, the full recovery will be slow, conifers have long life cycles needing several years before they start to reproduce themselves. Until then, we will continue improving their condition. This study contributes to such effort.

During the last 20 years scientists have been using different approaches to map the Earth's surface (Weier and Herring 2001). Remote sensors onboard artificial satellites capture land cover images at different wavelengths enabling the study of vegetation cover through vegetation indexes (Didan and Yin 2002). The Normalized Difference Vegetation Index (NDVI) is one of them and it uses the absorption and reflective properties plants at different wavelengths. Chlorophyll absorbs visible light (from 0.4 to 0.7 μm) to produce glucose. The leave structure, in the other hand, reflects inferred light (from 0.7 to 1.1 μm). This contrast is exclusive of plants, and the NDVI uses it to make quantitative estimations about vegetation. It uses a differential formula to quantify the "greenness" of growing of plants. Mathematically:

$$NDVI = (NIR - VIS)/(NIR + VIS)$$

Where: NDVI = Normalized Difference Vegetation Index
NIR = Near Infrared Band
VIS = Red Visible Band

NDVI values range between −1 and +1. Dense green vegetation usually generates values near +1. Water, clouds and snow will produce negative values. Rocks and bare soil will be near to zero (Weier and Herring 2001). To calculate the NDVI image of the Island, we used a QuickBird Image of the Guadalupe Island captured on April 24th 2004 with a spatial resolution of 61 cm (2-ft) in the panchromatic band, and 2.44 m (8-ft) for the multispectral bands (Digital Globe, 2004). Our goal was to have a recent overall high spatial resolution perspective, to estimate the number of remaining adult trees. Also to measure the main forest patches and the empty spaces within them.

Study site

Guadalupe Island, of volcanic origin has a very abrupt terrain relief with peaks reaching 1,300m, in a mainly north-south elongated shape with main axes measuring 34 km long by 9 km wide. With an area of 250 Km^2, the island is located in the Pacific Ocean (Fig 1.), 250 km offshore the Baja California Peninsula (29° N, 118° 20'

W). It is well known for its vegetation richness: 171 native species of vascular plants, 21.8% of them endemic, including the Guadalupe cypress and a variety of the Monterey Pine (Moran 1996). It also possesses a unique combination of coastal scrub and an endemic palm forest. Its fauna is composed primarily by birds —marine and terrestrial—, terrestrial invertebrates and marine mammals (Aguirre *et al* 2003). The exotic fauna is also well represented: goats, dogs, cats and mice. All of them together are considered responsible for the disappearance of several native and endemic species.

The Guadalupe Island cypress (*Cupressus guadalupensis* S. Watson ssp*. guadalupensis)* is endemic. It provides a remarkable habitat to a wide number of bird species. It also provides fresh water to the local fishermen and their families. Historically it was widely disperse. It was easily seen in northern half of the island. Now it can only be seen near of the highest pick Monte Augusta, in the northern third. But there is evidence of its presence all over the area. Death trunks and root holes still remain. Through the years, the goats provoked a reduction of the forested area from 4,000 ha to only 160 ha (Fig 2). At the same time, the coastal scrub also considerable reduced its area, being replaced by introduced grasses and eroded soils (Moran 1996). Now the biggest concern is to know what is left and what can be done to improve its condition.

Methods

Fieldwork was conducted during a single visit in November of 2004. Three weeks on Guadalupe Island were spent traversing the three arboreal patches (Fig 3). 58 isolated individuals were measured (greater and smaller diameter, D1 and D2 respectively) and gps positioned, the criteria used for tree selection was: the individuals must to be adult trees fully developed, completely isolated of the rest and they must be complete individuals, i.e. without broken branches or apparent damages. In addition, 21 quadrants of about 2.500 m^2 each (25x25m) were made inside the wooded area, with an approximated separation of 200 meters between them. In them, live and dead trees were counted (Fig 4).

NDVI for the cypress forest

A subscene that contained the cypress forest was extracted from the island satellite image (Digital Globe 2004) and NDVI was calculated for this portion. To incorporate the higher spatial resolution of the panchromatic band, a variant of the original formula was used:

$$NDVI = \frac{NIR - VIS * PAN}{NIR + VIS * PAN}$$

Where:
- NDVI = Normalized Difference of Vegetation Index
- NIR = Near Infrared Band
- VIS = Red Visible Band
- PAN = Panchromatic Band

This change enabled a NDVI with the spatial resolution of the panchromatic band. For the analysis, the resulting NDVI image was segmented using a threshold. After experimentation and visual inspection, a threshold of 0.5 was used to detect most of the foliar area. For this task ER Mapper software (ver. 6.1) was used, the rest of the analysis was made in the ArcGIS 9.0 environment.

The segmented enhanced NDVI image was converted into vector applying masks to eliminate all undesirable polygons (Fig 5). After this, the polygons' areas were calculated and all polygons with an area less than 5 m^2 were eliminated, because they were considered too small to represent an adult tree. The final vector (FV) was used to calculate the potential number of trees and the pattern of space grouping. Finally, the total area found in the FV was divided into the three forest patches, in order to analyze each patch separately.

Potential number of remaining trees

With the trees' field measures, the elliptical area covered by each one was calculated. For this, the elliptical area formula was used. The GPS positions of the trees measured in field were used to identify them on the FV and to extract their area. The tree top area average was calculated using both measurements: the one from the field, and the one from the satellite image. These two area averages were defined as standard field tree (SFT) and standard remote sensed tree (SRST), respectively (Fig 6). Then, the total area of the FV was divided by each one of the standard trees to estimate the potential number of trees in each patch.

Space grouping

The contour of each wooded patch was digitized. For this, the boundary of each patch was considered and a buffer of 5 m was added to it (Fig. 7). This distance was considered to be a reasonable area of influence around

each tree. With the information of the FV and the total surface, the number of groups and trees in each patch were calculated using SFT and SRST values (Fig 8). Finally, to know the proportion of empty space within each patch, the area from the entire canopy was subtracted to the total area of the FV.

Results

58 trees were measured in the field (averages D1 = 11.66 m and D2 = 10.11 m; SFT = 98.86 m^2 and SRST 132.48 m^2). The total wooded area estimated from the FV is 703,142.28 m^2. The divisions of the total forested area by the two tree top area averages were 7,112 trees and 5,307 trees respectively (difference = 1,805 trees); where 1,272 groups were identified. The number of trees and groups estimated for each patch is presented in table 1. The estimated density of live trees is 0.011 trees/m^2, while the density for death trees is 0.016 trees/m^2.

Table 1. Spatial grouping in the Guadalupe cypress forest.

Patch	Total Surface (ha)	Number of trees estimated using SFT	Number of trees estimated using SPRT	Identified groups	Dominant groups	Trees within the dominant groups	Trees present within the rest of the groups
North	4.47	452	337	32	1	300	From 1 to 6
Middle	29.09	2 942	2 196	252	1	1353	From 1 to 200
South	36.76	3 718	2 775	988	2	80 and 120	From 1 to 70
Total	70.31	7 112	5 307	1 272			

Table 2. Empty spaces in the Guadalupe cypress forest.

Patch	Total surface (ha)	Total top area (ha)	Difference (ha)	Total Top area (%)	Empty space (%)
North	7.46	4.47	2.99	59.91	40.09
Middle	50.27	29.09	21.18	57.86	42.14
South	101.83	36.76	65.07	36.10	63.90
Total	159.56	70.31	89.24	44.07	55.93

Discussion

There is a big difference between the numbers of trees estimated in both ways. In this sense, it is important to take into account the enormous natural tree top variation that exists within the species (Moran 1996). We envision two possible options to better calibrate the *standard tree* determination: a) to have stricter selection criteria of the trees to measure, or b) to have a bigger sample. Another important matter it to consider the high presence of damaged trees. During the fieldwork, many trees with harmed tops, a scarce foliage cover, or broken branches were detected. Also, the presence of what we called *twin trees* was noticed. This means, two trees that grew up side by side and with time their tops were merged as one. From the satellite image you would see them as one, but in the field you can clearly see there are two individuals. These two aspects, damaged and twin trees, must be considered for a better assessment. Even though, these estimations —the one made with field data and the one made through the NDVI— provide us with a range close to the real number of individuals within the cypress forest in the island.

We believe that the real number of trees must be closer to the conservative estimation (5,307 trees), because of a simple reason: the method used to estimate is more accurate. If it is true that field estimations are recognized worldwide, that does not necessary means that they are actually real (Figure 6). Instead, the polygon obtained with the NDVI provides us a better representation of the foliage cover because it comes from the luminous response of the tree itself, and therefore it is more similar to it. This makes it a better indicator.

But the real importance of this number is that it represents those individuals that survived all the catastrophes, and that they would be the ones giving life to a new generation of trees and leading the recovering of the entire forest.

We have no doubt that the best contribution of this work is for the island itself. This data is going to be used in others studies like the monitoring of the forest recovery and the resurgence of seedlings. Besides, they would be very useful during the preparation of a soil and fire management plan.

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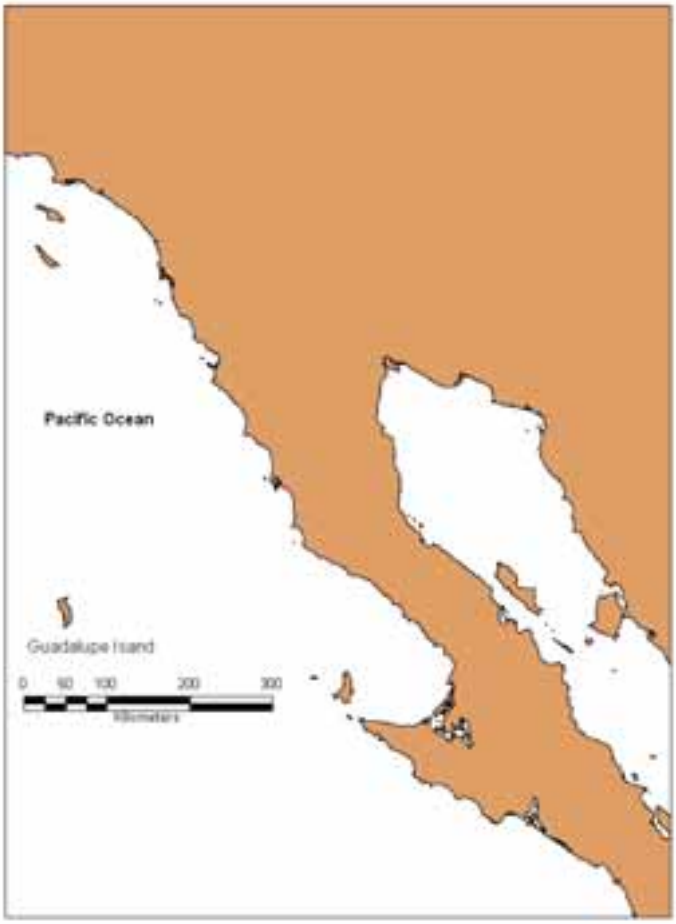

Figure 1. Guadalupe Island location in the Pacific Ocean, 250 km offshore the Baja California Peninsula.

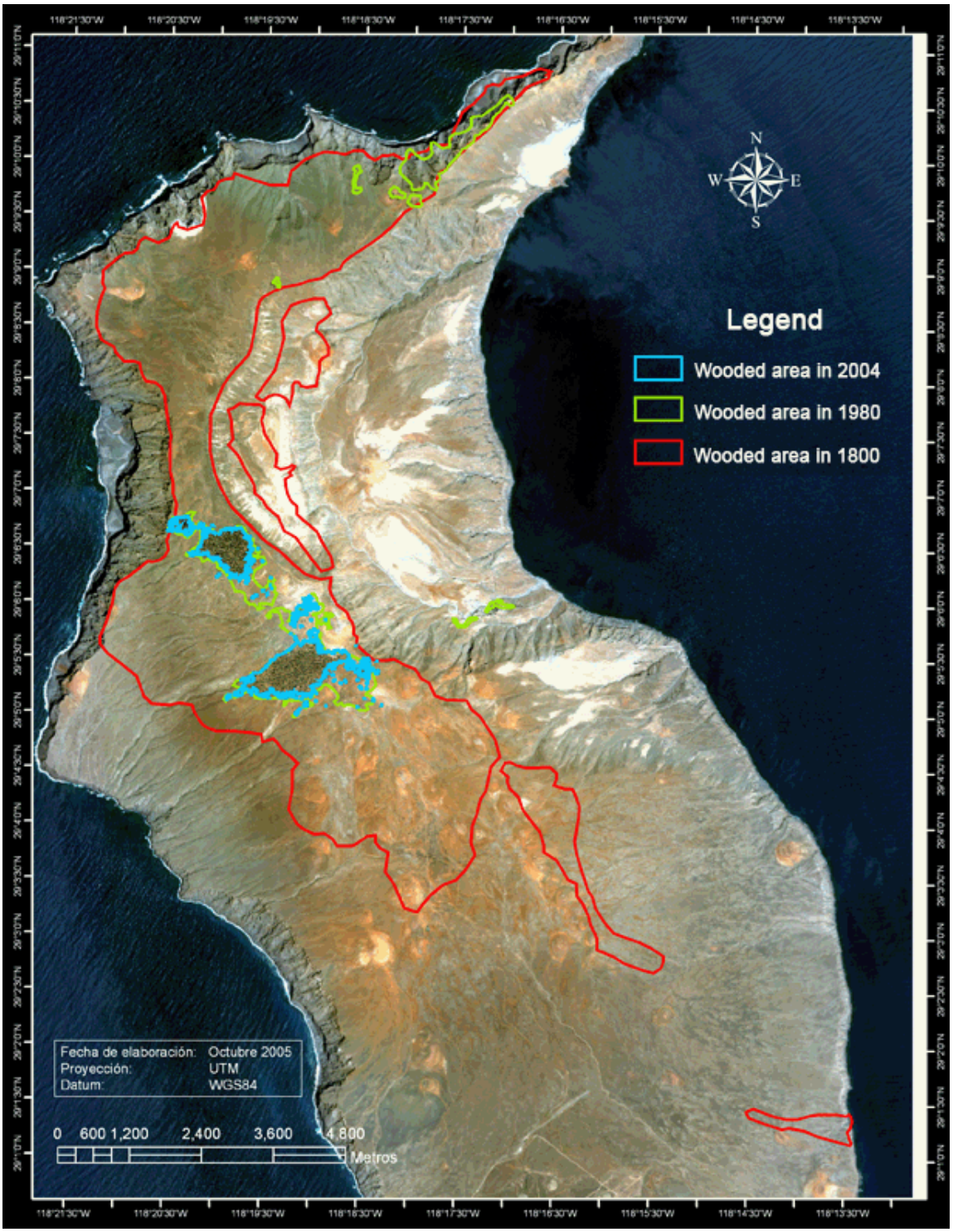

Figure 2. Satellite image of Guadalupe Island.
The deferent changes in the cypress forest distribution are shown.

Figure 3. The three remaining wooded patches on Guadalupe Island.

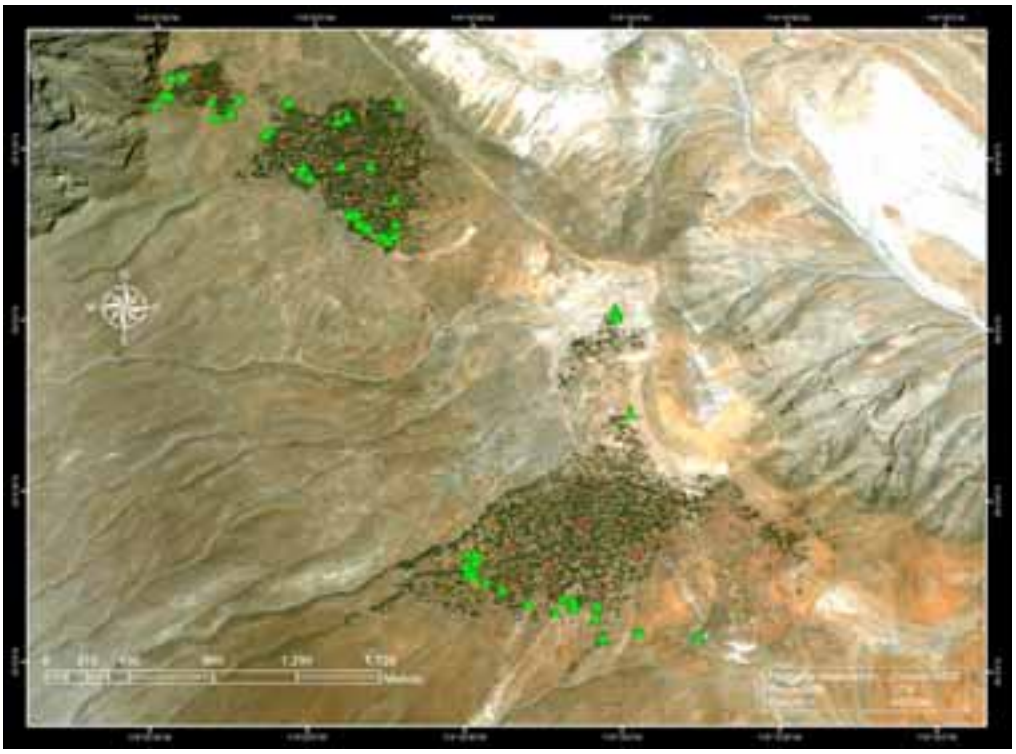

Figure 4. Location of the measured trees and the quadrants made on the field.

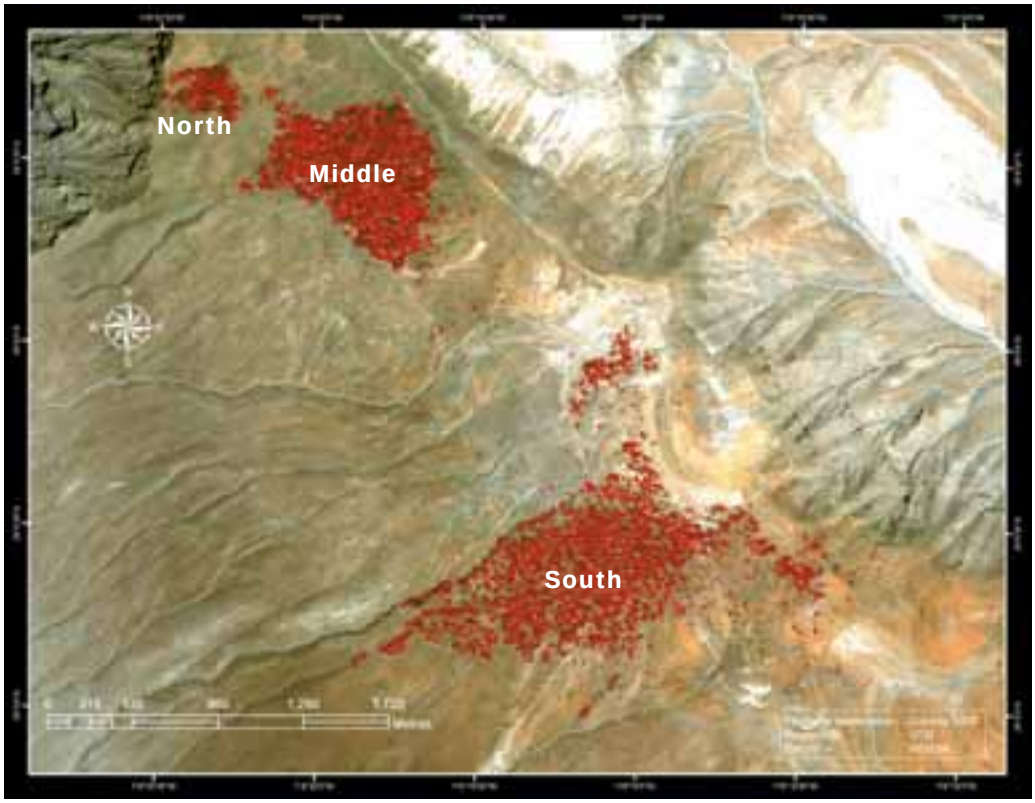

Figure 5. NDVI obtained. The final vector (FV) is shown after the masks were applied.

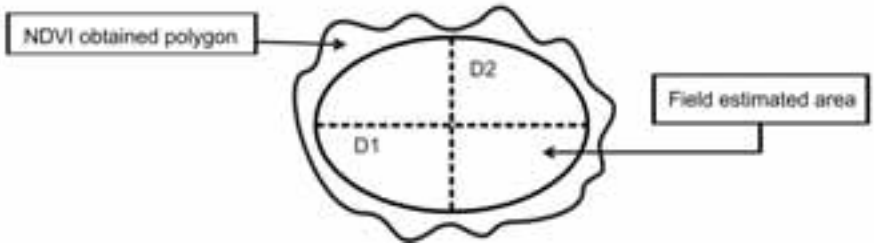

Figure 6. Comparative diagram of field estimated tree top area and the polygon obtained through the satellite image.

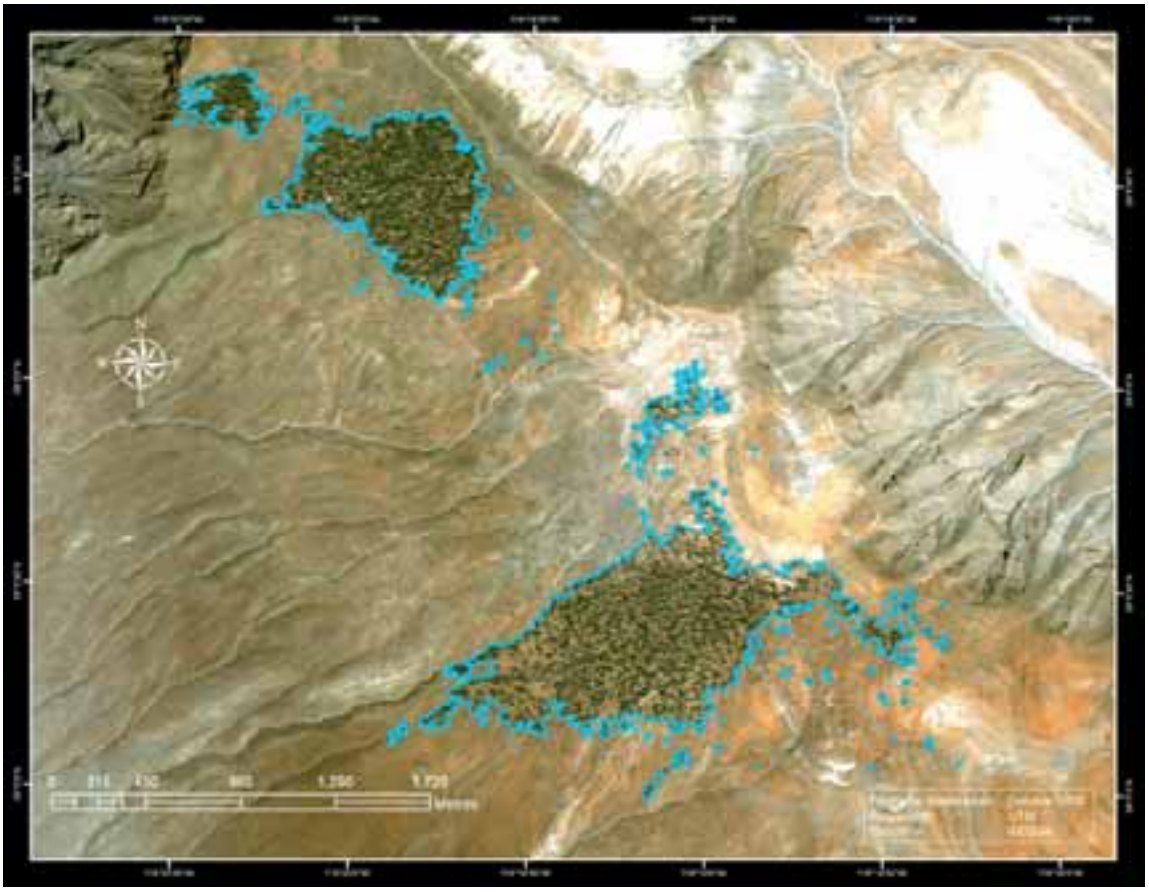

Figure 7. Forested area outline (160 ha).

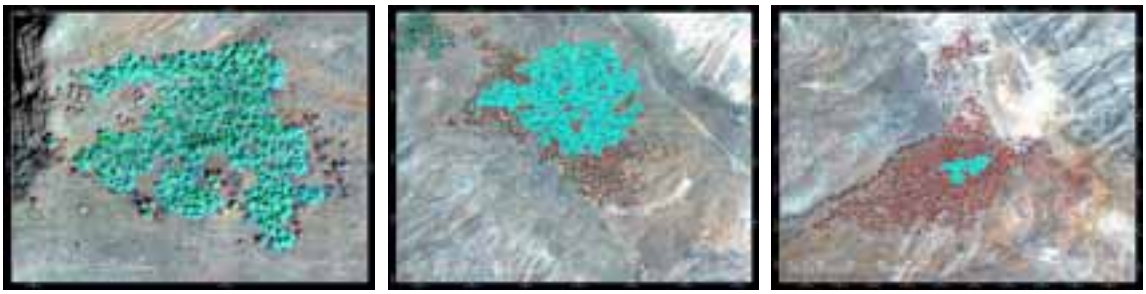

Figure 8. Dominant groups of each wooded patch: North, Middle and South, respectively.

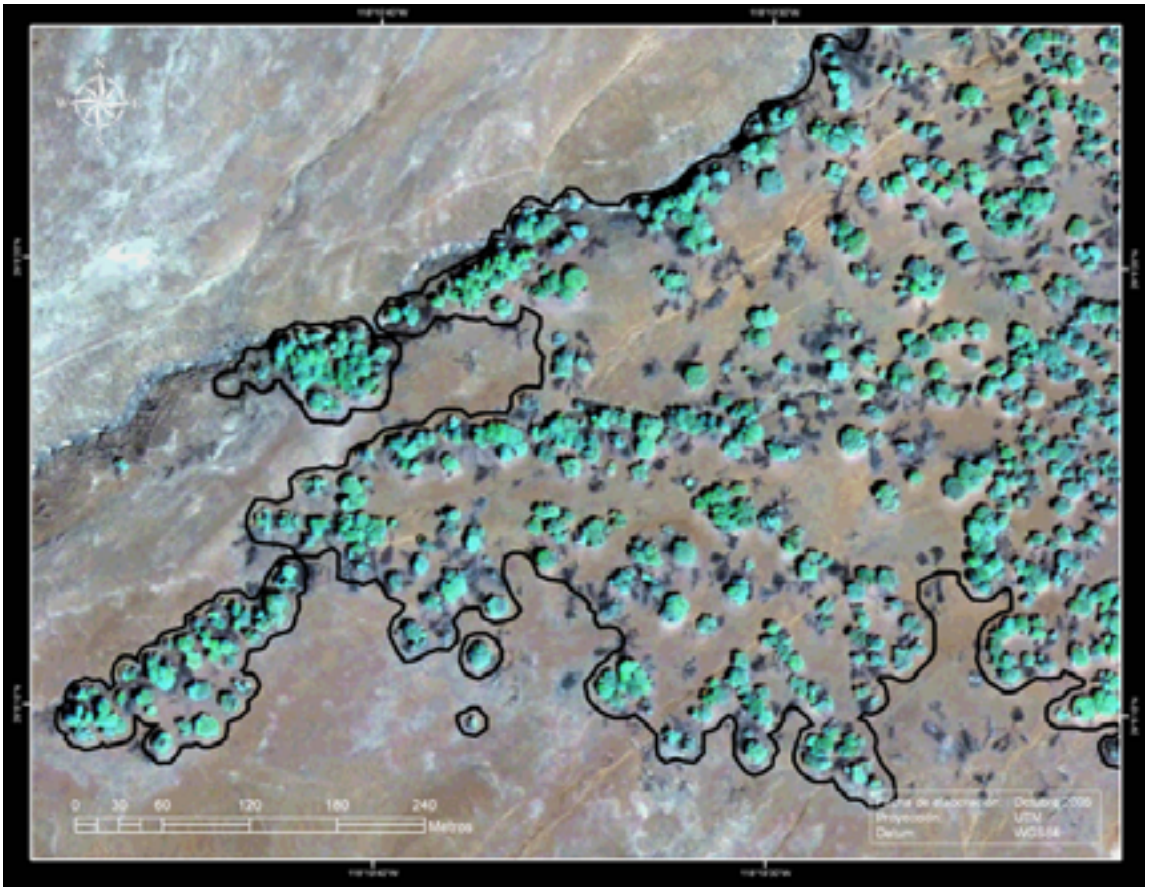

Figure 9. A closer look of the southern patch. It can be seen the distance between the trees. This is the most disperse patch of the island.