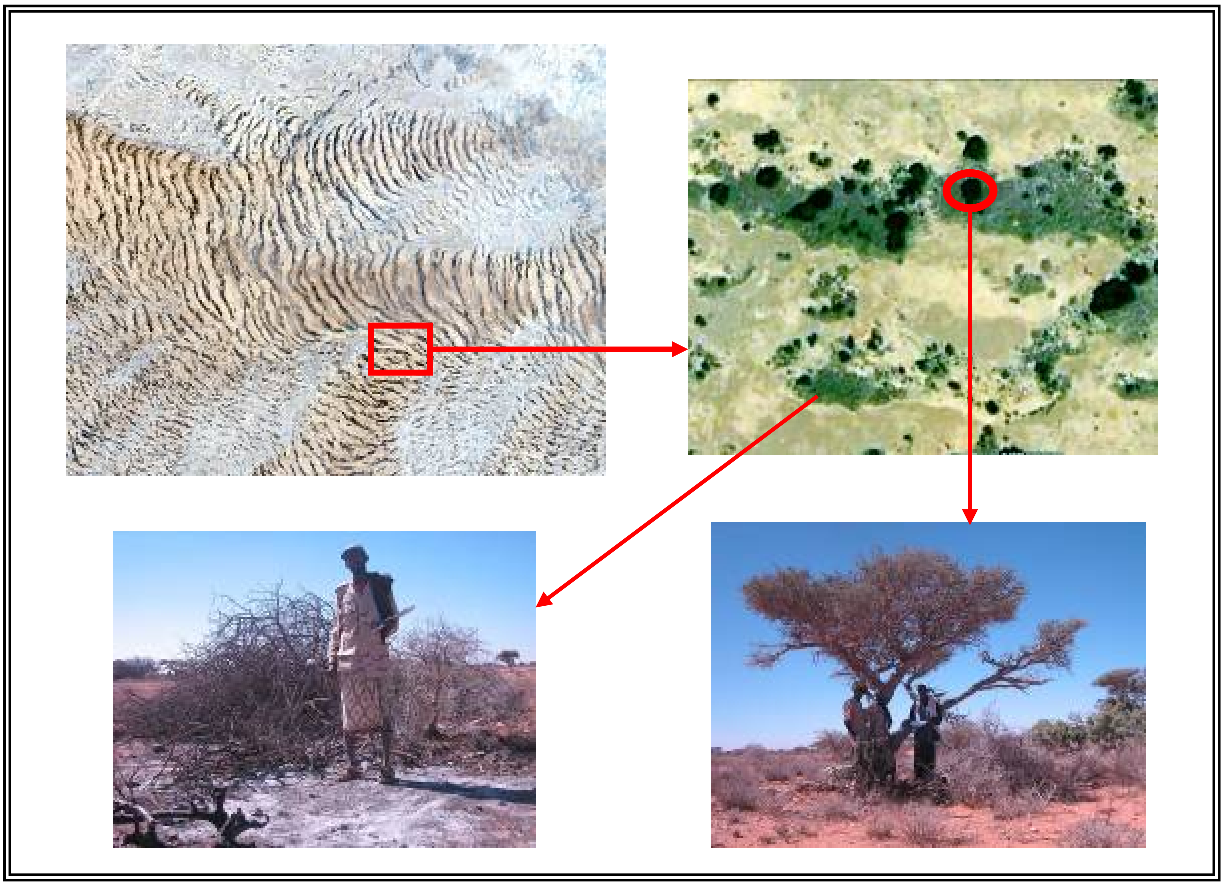
Detection of Tree Cutting in the Rangelands of North Eastern Somalia Using Remote Sensing



Project Report No L-15

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Somalia Water and Land Information Management
Ngecha Road, Lake View. P.O Box 30470-00100, Nairobi, Kenya.
Tel +254 020 4000300 - Fax +254 020 4000333,
Email: enquiries@faoswalim.org Website: http//www.faoswalim.org.

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* FAO-SWALIM, Nairobi, Kenya.

** EC–JRC, Ispra, Italy.

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Acknowledgments

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LIST OF ACRONYMS

AFS – Area Frame Sampling

EC – European Commission

FAO - Food and Agriculture Organisation

GIS – Geographic Information Systems

GPS – Global Positioning Satellite

JRC – Joint Research Centre

MOI – Materials of Interest

NGO – Non Governmental Organisation

NOAA – National Oceanic and Atmospheric Administration

SWALIM – Somalia Water and Water Information Management

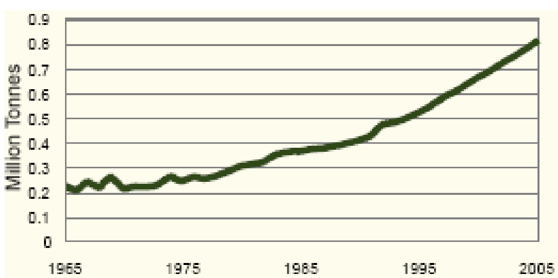
UNEP – United Nations Environment Programme

VHR – Very High Resolution

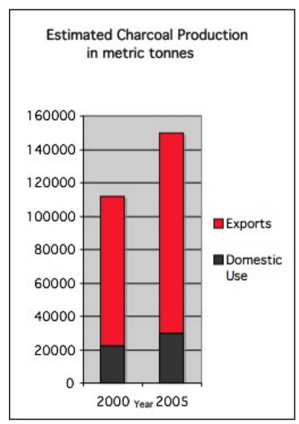
1 INTRODUCTION

Since the breakdown of governance in Somalia in 1991, natural resources management policies and strategies have been absent despite the fact that all livelihoods depends on them. The result has been poor management of the resources. Land degradation has been identified as a serious problem along the country, which definitely urges for actions to combat it (Omuto *et al*, 2009). Negative impacts on the productivity of resources in the country has also been identified by some authors (Bestman and Cassanelli, 2000; Mohamed and Viaconi, 2001).

The reduction of vegetation cover in time has been identified as one of the main types of land degradation in the country due to different activities like livestock grazing and wood collection (Omuto *et al*, 2009). The tree layer has been identified as the main vegetation type used for fuelwood collection, fencing and construction materials. Charcoal burning is a very vibrant activity in the woodlands of Somalia that has increased in time. There have been some attempts to quantify the production of charcoal (figure 1).



(a).



(b).

Figure 1: Charcoal production in Somalia (Source: a) FAOSTAT; b) Baxter, 2007)

Trade in charcoal, known to many as “black gold” has developed into a very lucrative line of business (Bakonyi and Abdullahi 2006). Charcoal, produced primarily from slow-growing acacia trees, is an important domestic energy source, although its production in Somalia is largely driven by foreign demand (UNEP, 2008). Every month, shiploads of charcoal are exported to the neighboring Arab states.

While there are some figures regarding charcoal production, very limited or no figures are available on the tree density dynamics. As a result, it becomes difficult to say if the trees are being utilized sustainably for the production of charcoal. As per figure 1, the demand for charcoal increases in time and has clearly accelerated during the last 20 years.

Using medium resolution remote sensing images and expert assessment, the trees of the tiger bush ecosystems of North Eastern Somalia were identified as areas in which tree cutting for charcoal burning is a common activity (Oroda *et al*. 2007). However, the real figures in terms of rate of trees cut per year were not calculated.

The recognition of single trees is one of the main tasks when deriving forest information from very high resolution (VHR) remote sensing data and many image analysis methodologies have been developed to tackle the issue. The detectability of single trees has been shown to depend on a variety of factors with the most significant being the spatial resolution of image data in comparison with the size of the tree to be detected and the distance between single trees (Hirschmugl et al. 2007).

Tiger bush (brousse tigrée) gives rise to a landscape formed by alternating vegetated (grass, shrubs or trees) and bare land, arranged in different patterns that can be classified as: banded, fuzzy, dashed or dotted, and spotted (Paron and Goudie, 2006). This depends on two main factors: slope gradient and mean annual rainfall (d'Herbes *et al*. 2001; Valentin, 1999). Tiger bush in Somalia (figure 2) (Paron and Goudie, 2006) and specifically in North Eastern Somalia (Oroda et al. 2007) have been identified as a very important type of vegetation that is currently under high pressure for wood collection, mainly for charcoal production.

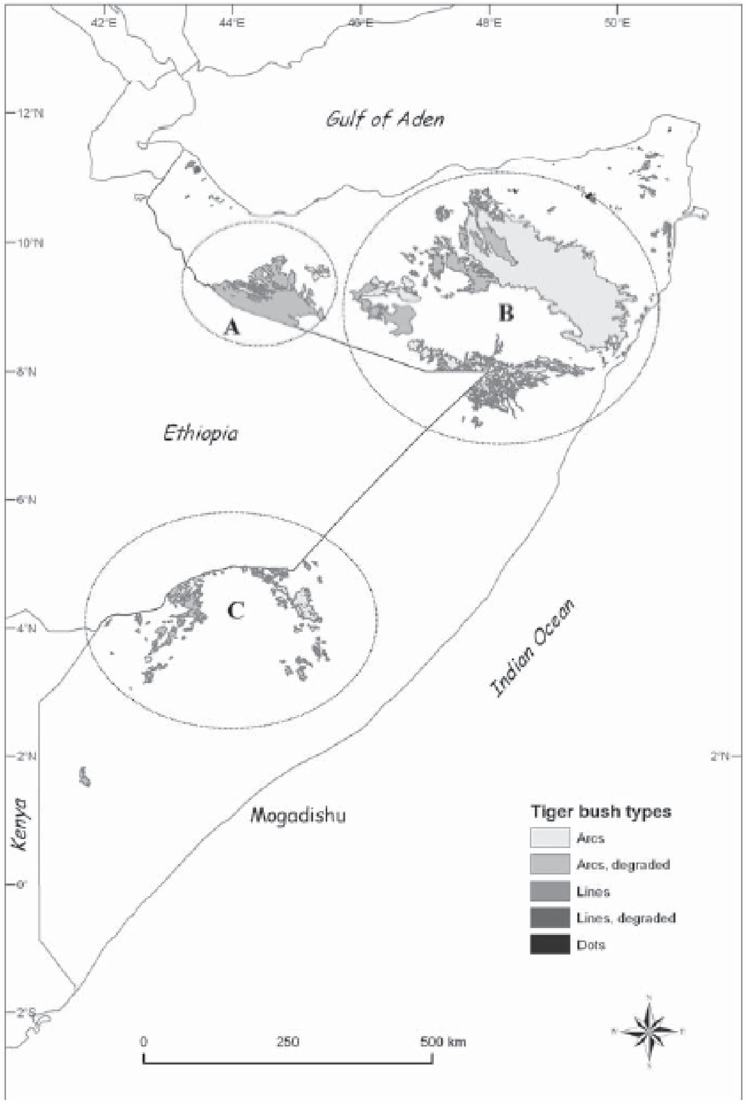


Figure 2: Tiger bush map for Somalia. (Source: Paron and Goudie, 2006). The grey colours identify the five different types of tiger bush. The capital letters A, B and C identify the main areas of presence of tiger bush.

In this study, SWALIM has made the attempt to continue the assessment in terms of quantifying the tree cutting activity in the above study area in which this activity is the main source of income. The use of very high resolution satellite images combined with fieldwork was the main tools for the detection and quantification of tree population for two different dates, with a five year difference (the earlier images are either from 2001 or 2002 while the second date is either in 2005 or 2006). Based on that, it was possible to estimate the yearly rates of tree cutting in the study area and also provide the real figures in terms of resource availability (tree density). The findings will definitely contribute in understanding the dimensions of charcoal burning in the study area and will call the attention regarding the impacts on the environment.

Objectives

The objectives of this study are:

- to generate baseline data on tree density in the study area in Puntland over two different periods 2001 or 2002 and 2005 or 2006 using very high resolution satellite imagery (IKONOS and QUICKBIRD);
- to detect changes in tree composition for both periods and calculate the rate of tree cutting for the period 2001-2006;
- to develop a simple procedure for tree density change detection to be applied in other woodlands in Somalia

2 MATERIALS AND METHODS

2.1 Study Area

The study area is located to the north of Garowe (Figure 3). It covers parts of Sool Region with an area of approximately 190 km^2. It lies between longitude 48^o and 48^{o}48’ East and latitude 8^{o}36’ and 9^{o}55’ North. The area is covered by the tiger bush vegetation and formed part of the study area during SWALIM Phase II.

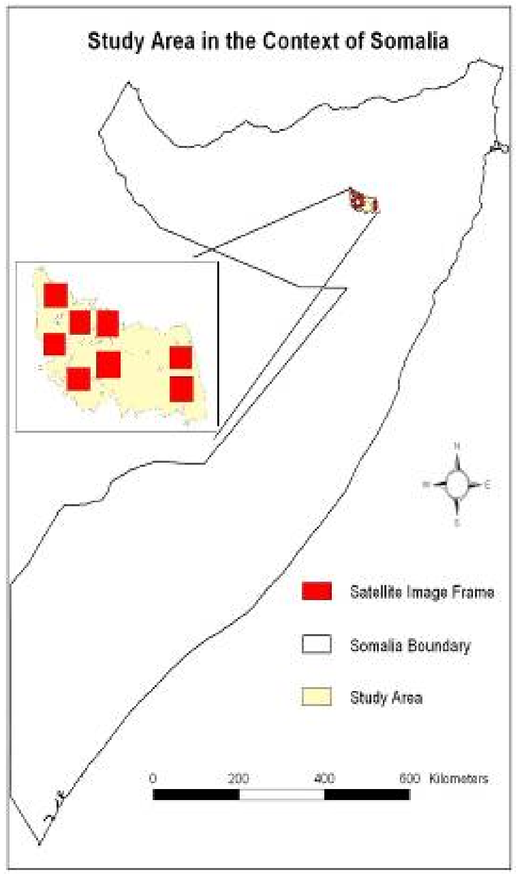


Figure 3: The study area

Climate

The climate of the study area is classified as arid. Rainfall ranges between 100 to 200 mm per year while mean annual relative humidity is between 60% and 70%. The study area falls within the inter-tropical zone and generally has four seasons with bimodal rainfall distribution. The first rainy season is called ***Gu*** and occurs between April and June. The dry season that follows the first rains is called ***Xagaa*** and lasts between July and September followed by the second rains called ***Dayr*** (October – November and sometimes December). The period between December and March is dry and is known as ***Jilaal***. Rainfall is highly variable temporally and spatially and can be described as erratic (typical of all rangelands). Mean annual potential evapotranspiration stands at 2054mm with mean monthly potential evapotranspiration of 174 mm. PET values derived from NOAA Satellite are given in the results section of this study. The mean annual temperatures vary between 24^{o}C and 28^{o}C.

Land cover-vegetation

The land cover of the study area is made up, principally, of a terrestrial ecosystem of natural vegetation that is typically called the Tiger Bush (see figure 4). The Tiger bush vegetation in this study area is patterned vegetation community consisting of alternating bands of trees or shrubs, separated by bare ground and low herbaceous cover, that runs roughly parallel to contour lines of equal elevation. The Tiger Bush pattern occurs on the low slopes in this arid environment of Somalia.

The woody plants comprising the tiger bush are used for fire wood and as a source of foliage for grazers. This class is made of open shrubs covering 15 – 65% with sparse trees (1 – 15%). The woody plants here include *Acacia bussei, Acacia tortilisl, Acacia nubica, Boscia minimifolia* and *Acacia melifera* while the herbaceous species include *Andropogon kelleri,* and *Sporobolus spicatus.*

Land use

In terms of land use, the study area is mainly pastoral, principally nomadic pastoral system. The main livestock species are camels, goats, sheep and to a lesser extent cattle in the northern study area. Charcoal burning is carried out in the area of study as an economic activity. It greatly affects land cover. Several urban settlements have developed and commercial activities are thriving.

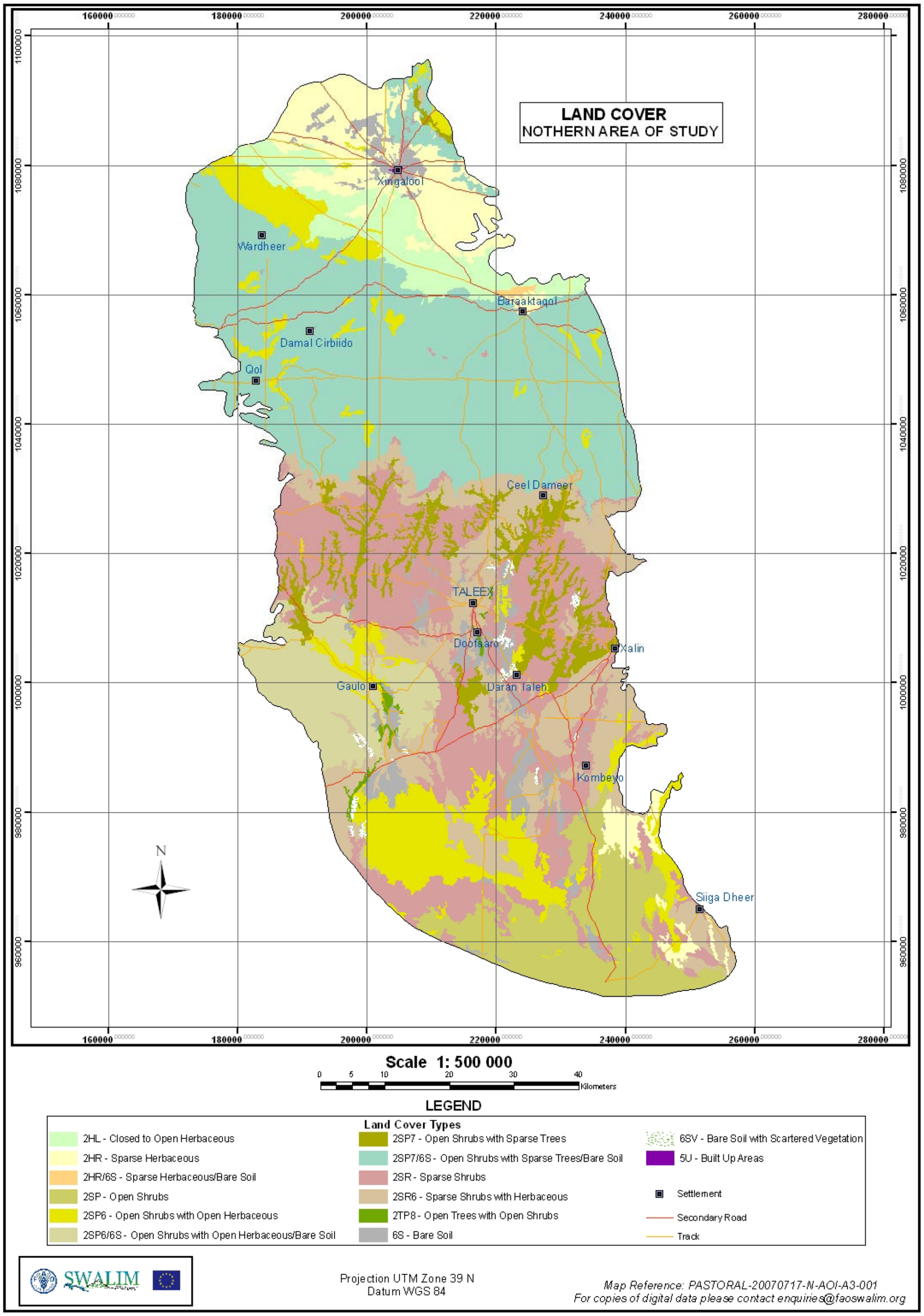


Figure 4: Land cover map of the study area

2.2 Materials

The materials used in this study included the following:

- The vegetation map of the study area and surrounding areas produced by *Oduori et al* during SWALIM Phase II.
- 8 Panchromatic Ikonos very high resolution satellite images at 1meter resolution.
- 8 Panchromatic Quick bird very high resolution satellite images at 0.6 meter resolution.
- Etrex GPS for locating trees in the field.
- Digital camera for taking photographs during the field work

2.3 Methods

In figure 5 the methodological framework is presented.

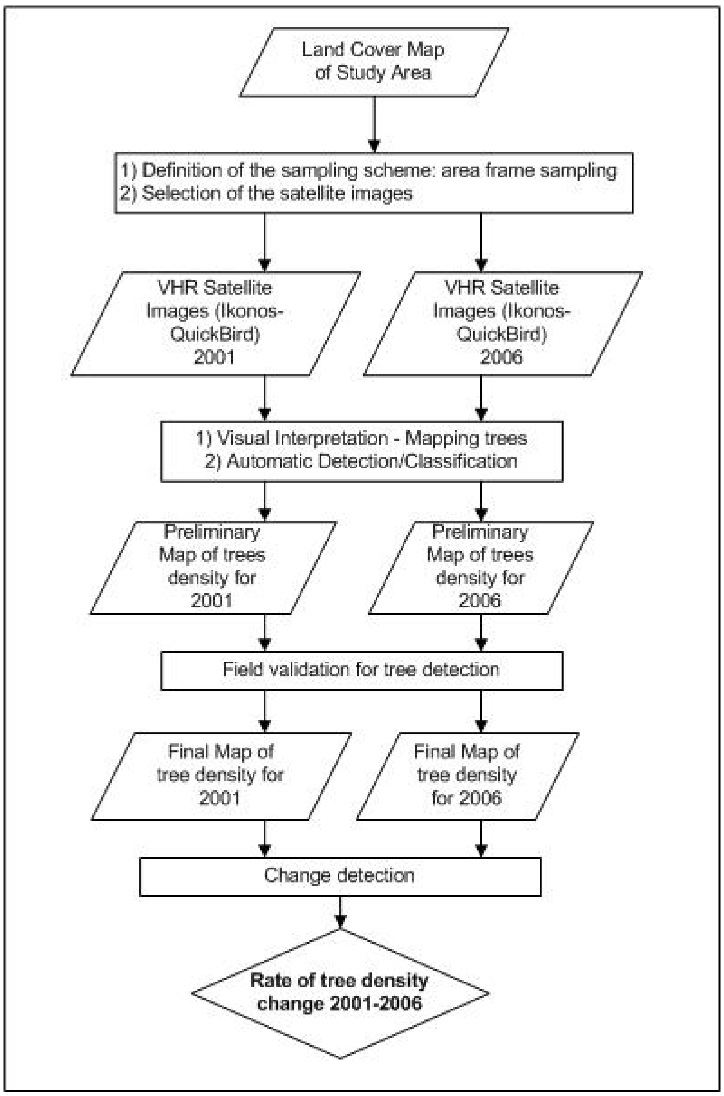


Figure 5: Methodological framework

2.3.1 Definition of the sampling scheme: area frame sampling

The land cover map produced in SWALIM Phase II was the basis for defining the sampling scheme. In order to define a proper sampling scheme for mapping representative trees sites some criteria were followed: the variability of trees should be representative of the whole study area; the sites shall be accessible for field verification. Considering these criteria, area-frame sampling was selected as the prominent method. Area Frame Sampling (AFS) is a statistical procedure to measure the quantity of materials of interest (MOIs) to a surveyor (the user) in a geographic region of interest. The “area frame” bounds the region of interest, or study area. It may be specified by an arbitrary boundary (like a rectangle), a natural boundary (like an ecosystem), or an administrative unit (like a state). Area frame sampling aided by remote sensing is also very instrumental in areas like Somalia where field work is limited due to the prevailing socio political situation or insecurity, to be precise (Gallego and Delince, 2001).

At an initial stage, sampling frames of roughly 8km*8km size were selected within the study area. These then formed the basis for the acquisition of the satellite images.

In every selected satellite image frame, sampling was done along systematic quadrats placed 2 km along transects spaced 2km apart (Ottichilo et al 1985). Each quadrat had a size of 5.3 ha. These quadrats were used for counting trees. All the trees within these 5 .3 hectare quadrats were counted. Figure 6 is an illustration of the area frame sampling method that was used in the study. A total of nine 5.3 ha area quadrats were used in every image (see figure 7). The coding of these quadrats was done according to the settlement closest to them. The image frames were given codes that ranged from 01 to 08 (see figure 7). The images were 8 km by 8 km in size.

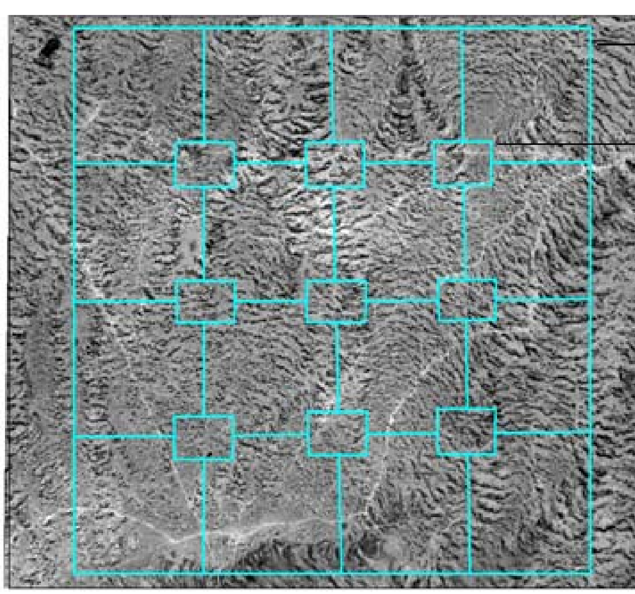


Figure 6: Area frame sampling (systematic sampling)

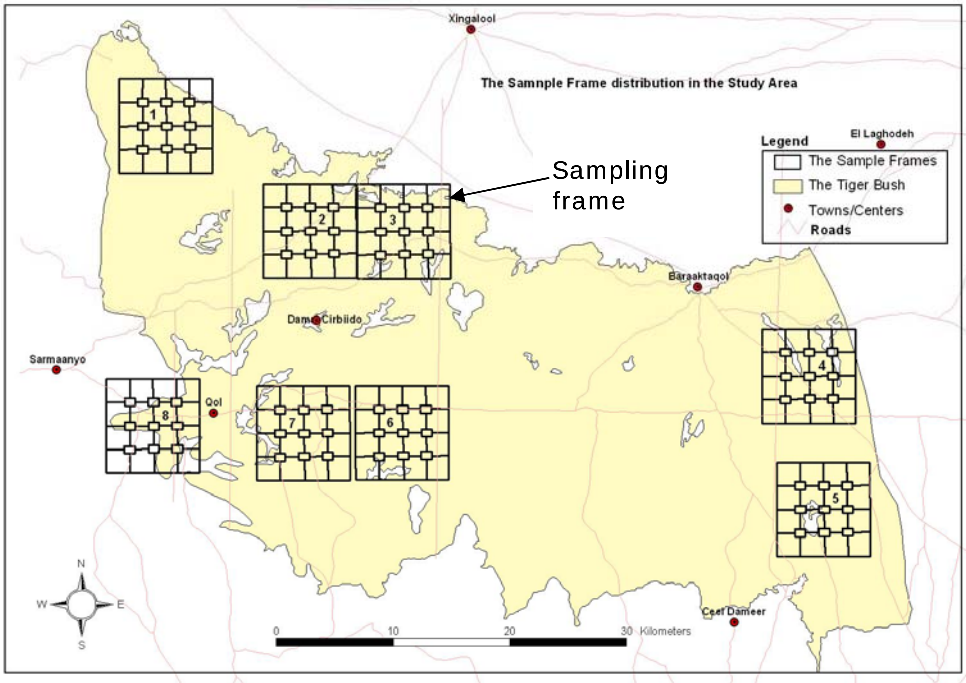


Figure 7: The Tree Counting sampling Frames

2.3.2 Selection of the satellite images

The selection of the satellite images to be used in this study was based on the location of the selected frames that were generated previously. To compute change in tree density, it was decided that multi-year images would be used in this study. Three time periods were decided upon, 2000, 2005 and 2008. However, after exhaustive checks with the very high resolution satellite image providers, only two time periods could be acquired, 2001/2002 and 2005/2006. It must also be mentioned here that to satisfy these two time periods, it was unavoidable that two different very high resolution satellite image data sources would be used, Ikonos and Quick Bird, with spatial resolution of 1 meter and 0.6 meters, respectively in the panchromatic band.

In total, 8 high resolution satellite images were selected in the study area as shown in Figure 3, based on the sample frames. These images were for two years, mainly 2001 and 2006 and sometimes 2002 and 2005. Consequently, a total of 16 very high resolution satellite images were used. It will also be mentioned here that the images were acquired by the Joint Research Centre (JRC) of the European Commission (EC) in the framework of their Technical

Support to Food Security Information Systems in the Horn of Africa project (Administrative Arrangement AIDCO ref CRIS (Ref. CRIS/FOOD/2005/0114-046).

2.3.3 Mapping trees using visual image interpretation

The multi-year (2001/2002 and 2005/2006) high resolution satellite imagery (Ikonos and Quick Bird) were used in the exercise. Photographic elements of tone, hue, texture, shape, size, pattern, shadow and geographic context were used to identify the trees.

A photo-interpretation key in (figure 8) was developed to precede the visual interpretation of the satellite images. The photo interpretation was done on-screen, with the computer aiding in brightness and contrast enhancements to facilitate robust visual identification of the trees. Every identified tree was digitized as a point feature in ArcView software and saved as a shape file. The interpretation of the 2001 images was done first.

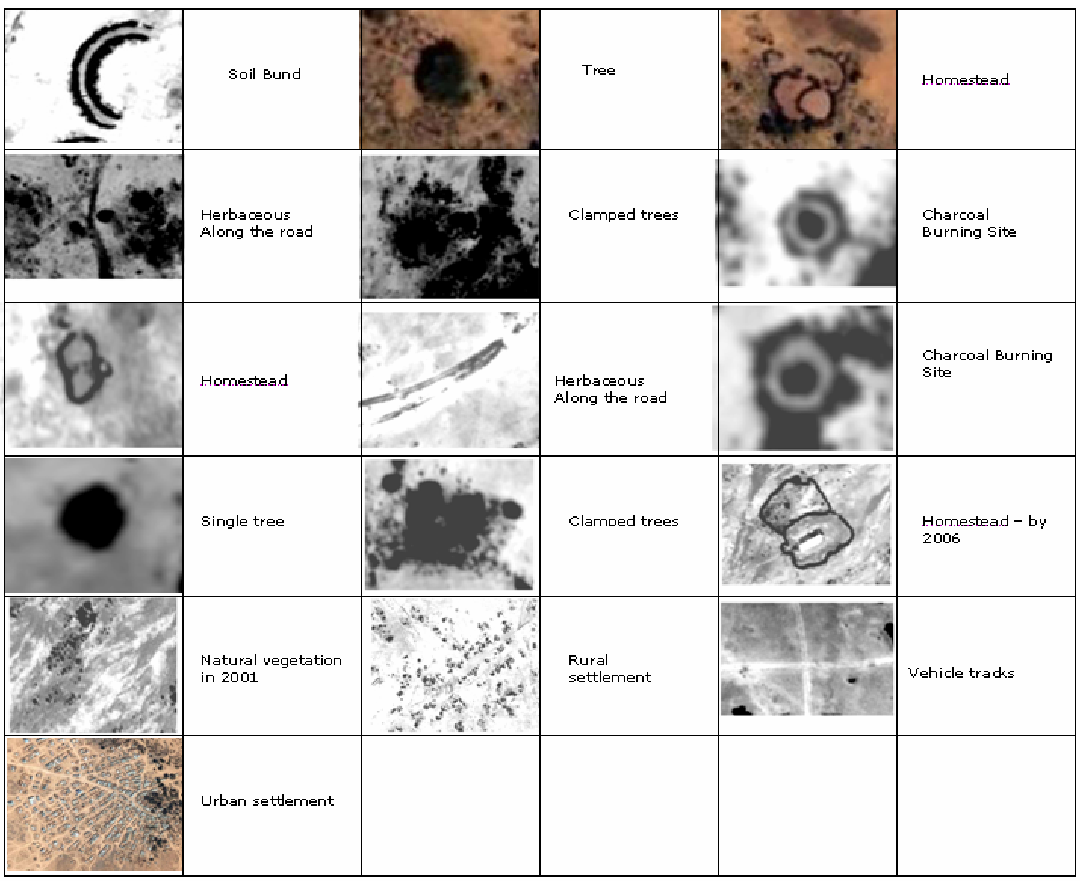


Figure 8: The Photo interpretation key

The photo-interpretation key did not include a quantitative definition of the tree size or height ranges but was rather relying on the experience of the photo interpreter. This means that tree identification was mainly based on the dark colour and rather round shape, depicting the distinguishing characteristics of trees. The characteristic tiger bush pattern of the vegetation in the study area also aided in the identification of the trees. However, while single trees were easily recognized, clamped trees were rather difficult to identify. In this case a rough approximation of the location of the tree was done based on the shape of the individual constituent trees.

The interpretation of the 2005/2006 images was done by first superimposing the 2001/2002 interpretation on the Quick Bird images. Then by subtraction or addition of trees, the interpretation of the 2006 images was done. The result was a set of shape files containing points representing trees in the year 2005/2006.

2.3.4 Mapping trees using automatic detection/classification

2.3.4.1 Background

The visual tree identification described in the previous paragraphs is a classical area frame sampling approach derived from aerial photo-interpretation (Ottichilo 1985). However, the method is really labor intensive and the total area of the sampling frames remains below 1% of the area covered by the VHR imagery. It is therefore of great interest to use image processing methodologies for automatic object detection in parallel to the visual interpretation, in order to run the change detection on the full images. Several object detection methodologies based mainly on morphological analysis are available in literature (Hirschmugl et al. 2007, Karantzalos and Argialas 2004), but none of them was directly applicable to the specific environmental conditions of the study area, since most of them are specific to single trees.

By looking at the very high resolution images acquired for the specific area in Northern Somalia, it is evident that the spectral information contained in these images is relatively poor. Vegetation is composed mainly by shrubs, trees typical for very dry environments (*Acacia* species) and sparse grass. Vegetated areas assume the typical tiger bush design of long parallel strips of vegetation intervalled by large areas of bare or very sparsely covered ground. In the vegetation belts, multilayer vegetation is present and in the denser vegetation clusters tree crowns are often continguous or partially overlapping. This makes it difficult to use classical tree detection algorithms as for example those developed by JRC for Olive tree counting and represents at the same time a limitation for visual interpretation.

The images include no concrete built-up structures, nor any other larger features which would simplify orientation. There are no large water bodies within the images for calibration purposes. These 2 characteristics make it very difficult to perform a properly validated radiometric calibration and an automatic calibration based on image metadata was used to convert the original digital values to reflectances (Baraldi et al., 2003).

Unfortunately from a first visual analysis of the reflectances from the 2 sensors it turned out that the Ikonos calibration was quite far from the one done on Quickbird and was not in line with a database of spectral signatures for bare soil and vegetation available at JRC (Baraldi et al., 2003). Therefore a manual so called “dark substraction” was done to intercalibrate the images from the 2 sensors. Considering the difficulties in intercalibrating the multitemporal images it was decided to use only one pair of Ikonos and Quickbird images for methodological development.

2.3.4.2 Image processing

Multispectral information from Ikonos and Quickbird is available at a 4 m and 1 m resolution respectively. It was decided that considering the objective of individual tree detection, this resolution is not sufficient and the analysis should be carried out on pansharpened images. Pansharpening was therefore performed by using the Gram Schmidt method included in ENVI and by manually entering the wavelengths for the 4 channels of the two sensors used (IKONOS and QUICKBIRD) by bringing the final resolution to 1m for Ikonos and 0,6 m for Quickbird. The pansharpened images were compared with the multispectral ones for radiometric consistency with satisfactory results.

To use the spectral information of the images an automatic spectral rule based mapping for identifying main vegetation patterns on the images was performed by using the software developed by Baraldi (Baraldi et al. 2003). The objective was to produce a classification which would help to eliminate from the tree detection the non interesting vegetation classes like bare soil and sparse grass. The outputs of this classification show that spectral information alone is not sufficient for a satisfactory identification of trees in an arid environment as expected. Trees cannot reliably be distinguished from underlying vegetation such as grass and shrubs, nor are they comparable to green trees of temperate climates in terms of greenness. Especially in the dry season, the chlorophyll content of acacia like trees can be extremely low (Rembold et al, 2001).

For this reason it was decided to combine the spectral rule based classifier results with morphological object detection methods. The main assumptions of this are that trees are generally round objects of a certain size and with a strong brightness contrast compared with the background.

To detect such objects without knowing exactly the size of the trees and working with different resolutions (Ikonos and Quickbird) it was decided to apply a DMP (derivative of the morphological profile) method (Benediktsson et al., 2003). This is using a morphological filter known as “closing” which has the following effects on the image: smooth the contours, fuse narrow breaks and long thin gulfs, eliminate small holes, and fill gaps in the contours of an image. The closing of an image is defined as the dilation of the image followed by subsequent erosion using the same structural element. The result shows higher values for large dark objects. The DMP methodology is carrying out the closing at 5 different scales (kernel sizes of 3, 5, 13 and 19), then the difference is calculated between the closings at different scales and finally the maximum of the differences is retained. This ensures that the closing scale which provides the maximum contribution to object identification is retained. High values correspond to large objects.

This analysis is further refined by computing the spatial autocorrelation for all pixels in the image i.e. in practical terms the likeliness to have another dark pixel next to a dark one. In the images of the study area this is expected to be high within the vegetation stripes and low between them and for isolated objects. In this case autocorrelation was computed for the closing images at all the 5 spatial scales used for the DMP procedure and then summed together. In this way we retained the autocorrelation information from the different spatial scales. The final value is then combined with the DMP analysis by an AND operator.

Both the DMP and autocorrelation images had to be thresholded to produce a Boolean mask for final comparison with the spectral classifier results. This was done empirically by comparing the size of identified objects with what would be identified as a tree visually on the pansharpened images by using the interpretation keys described before (Figure 9).

The spectral and morphological analyses are finally combined into one single equation:

Treememership = (b1 + 10b2) * (b3 AND b4) [Equation 1]

where,

b1 = low biomass vegetation (background mask) from spectral rule based classifier
b2 = high biomass vegetation (vegmask) from spectral rule based classifier
b3 = DMP morphological analysis (threshold > 3)
b4 = Autocorrelation analysis (threshold > 3)

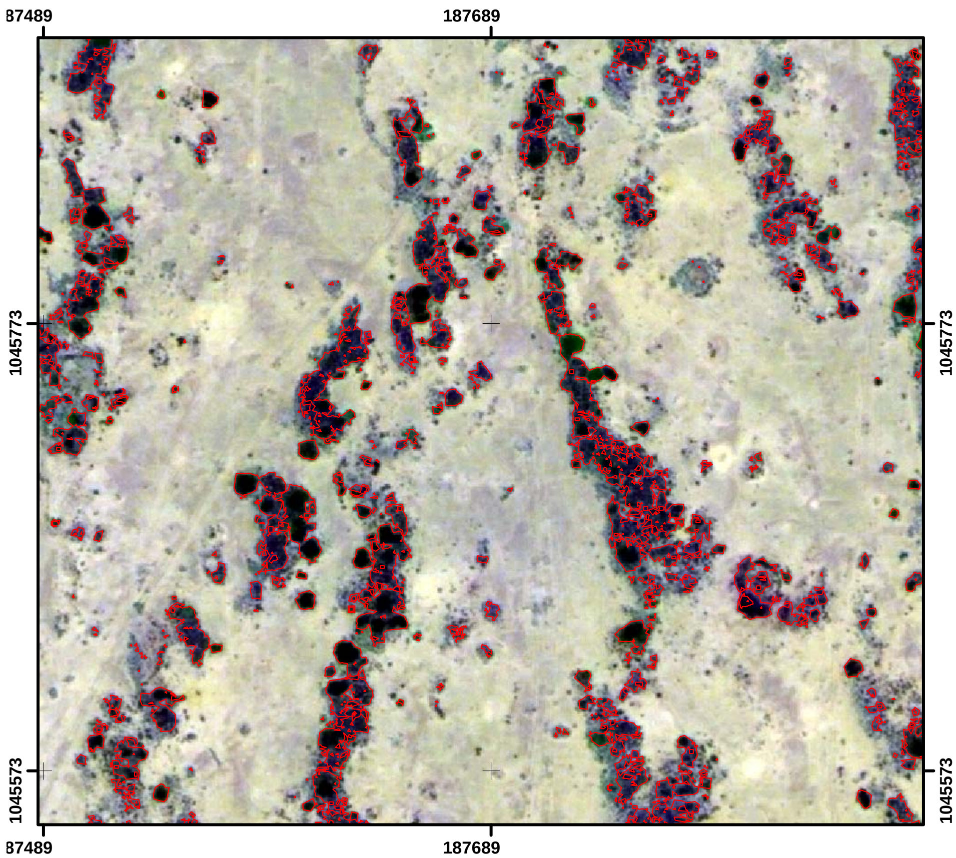


Figure 9: Results of the tree detection analysis shown as contours on a small subset of the pansharpened Quickbird image

2.3.4.3 Multitemporal analysis

To make a multitemporal comparison between the 2 image acquisition dates (2001 for Ikonos and 2005 for Quickbird) and in order to detect possible changes in tree cover, the resolution of the Ikonos images was increased by re-sampling it from 1m to 0,6m. Then the 2 images with 0.6 m resolution were co-registered by manually identifying 15 ground control points (RSME < 1 pixel) on the image pair and using the ENVI image to image warp function. The ENVI layer stacking function was used to extract only the overlaying areas from the 2 scenes. The images correspond to scene 7 of the visual interpretation, next to the Damal Cirrbido settlement.

Then the automatic spectral classifier and the morphological analysis were run for each of the images. Similar thresholds were applied to the DMP and autocorrelation images for obtaining Boolean masks to be used in equation 1.

Finally an image difference was produced in order to obtain the following 3 classes:

1. no change
2. areas identified as trees at T1 and not at T2 (decrease)
3. areas not identified at T1 and identified as trees at T2 (increase)

As can be seen in the figure below, the resulting images are quite similar, where the one derived from Quickbird looks slightly smoother due to the originally higher resolution (0,6 m compared with 1 m of Ikonos).

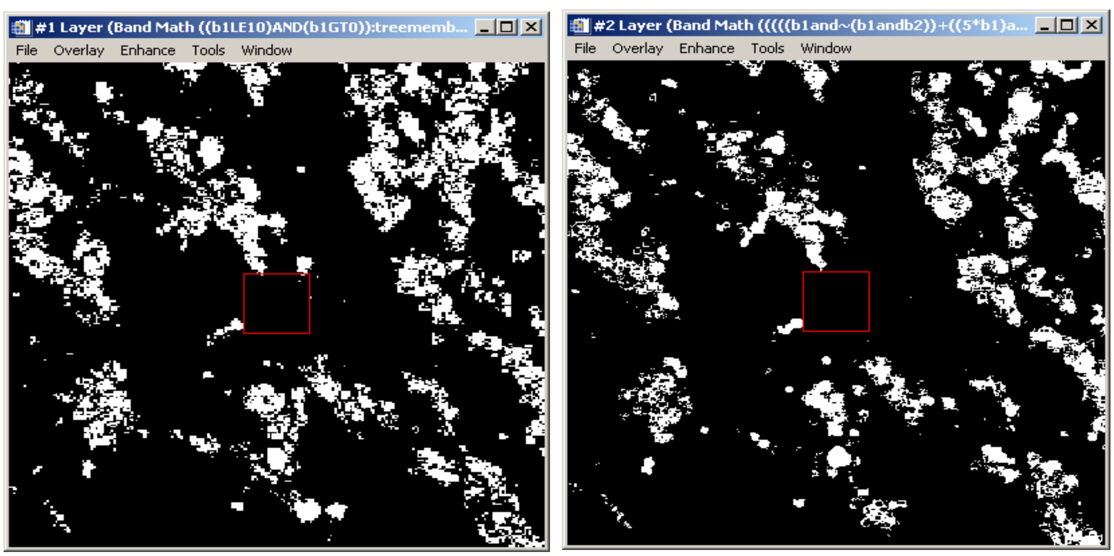


Figure 10: Results of the tree detection analysis on the Ikonos image of 2001 (left) and the corresponding image of 2005 (right)

2.3.5 Field validation of preliminary tree densities

In this activity, the objective was to verify whether what was identified as a tree on the image was indeed a tree on the ground. To do this, a total of one hundred and twenty nine selected features identified as trees, in different sampling frames were used. The main criteria used for selecting these features included proximity to roads and settlements. The x and y coordinates of these point features were put in the Etrex GPS and later tracked down in the field to establish if they really were trees. The results of the field verification by help of a GPS were tabulated in a matrix.

The field validation activity was done by a trained Somali surveyor. However, one big limitation in this exercise was that the field work was carried out about 3 years after the images were taken by the satellite. Nonetheless, field work went on pretty well except in one area where 15 points could not be visited because the field surveyor was chased away by the charcoal burners.

To solve the problem of field-checking out-dated satellite images, it was decided that other indicators of tree presence at the time the images were taken would be used. For example, the presence of a tree stamp would confirm that there was once a tree in a given point.

While at the point, the field surveyor described the point using the form provided in the Annex 1 of this report. The X and Y coordinates of the point were recorded. Other attributes recorded in the form included, whether tree or shrub, the height of the tree, single or tree clamp, other, etc. The surveyor was mandated to confirm the presence of a tree at the point at least dating back in time when the images were taken.

2.3.6 Change detection of trees (2001-2006)

The field results were used to prepare the final maps of tree densities in 2001 and 2006 in the study area.

Using the results of the attribute table, and using the Africover extension in ArcView, the tree counts were generated for every shape file. The Dbase IV spread sheet tree count results for every shape file were exported to Excel software. In Excel, the tree densities were computed for every year. Tables and graphs were generated to show the tree counts in every year and the difference in tree counts for the two time periods. Percentages of loss or gain in trees between 2001 and 2006 were also computed in Excel. These tables and graphs are shown in the results chapter of this report. To do this, the results of 2006 were subtracted from those of 2001. Tree count maps for 2001 and 2006 for a few sampling frames were also generated to show loss or gain of trees between 2001 and 2006. The standard deviations of estimation and the means were also calculated.

Finally, the overall percentage rate of change in tree density was calculated by subtracting the tree density results of 2006 from those of 2001 and dividing the results by the tree density results in 2001 and multiplying the final result by 100.

The emanating data was then analyzed to establish the change in tree density in the study area. The tree density from the different years was compared to show either increase or decrease in trend. The rate of tree density change (positive or negative) over time (2001 to 2006) was calculated. The loss or gain of trees was extrapolated for the whole study area based on the results from the area frames. Statistics (standard deviation, variance) were also generated on tree density estimation in the area.

3 RESULTS

3.1 Tree density maps from visual interpretation

The following maps (figure 11), tables and graphs show the different tree densities in the studied time periods 2001/2002 and 2005/2006 in the various sampling image frames, and subsequently the various quadrats, sampled in the study area. The quadrat results have been identified according to the settlement closest to them, besides the image frame user Identification code that ranges from 01 to 08. The overall average identification success for trees sited on the images, and validated in the field, is also given in this section.

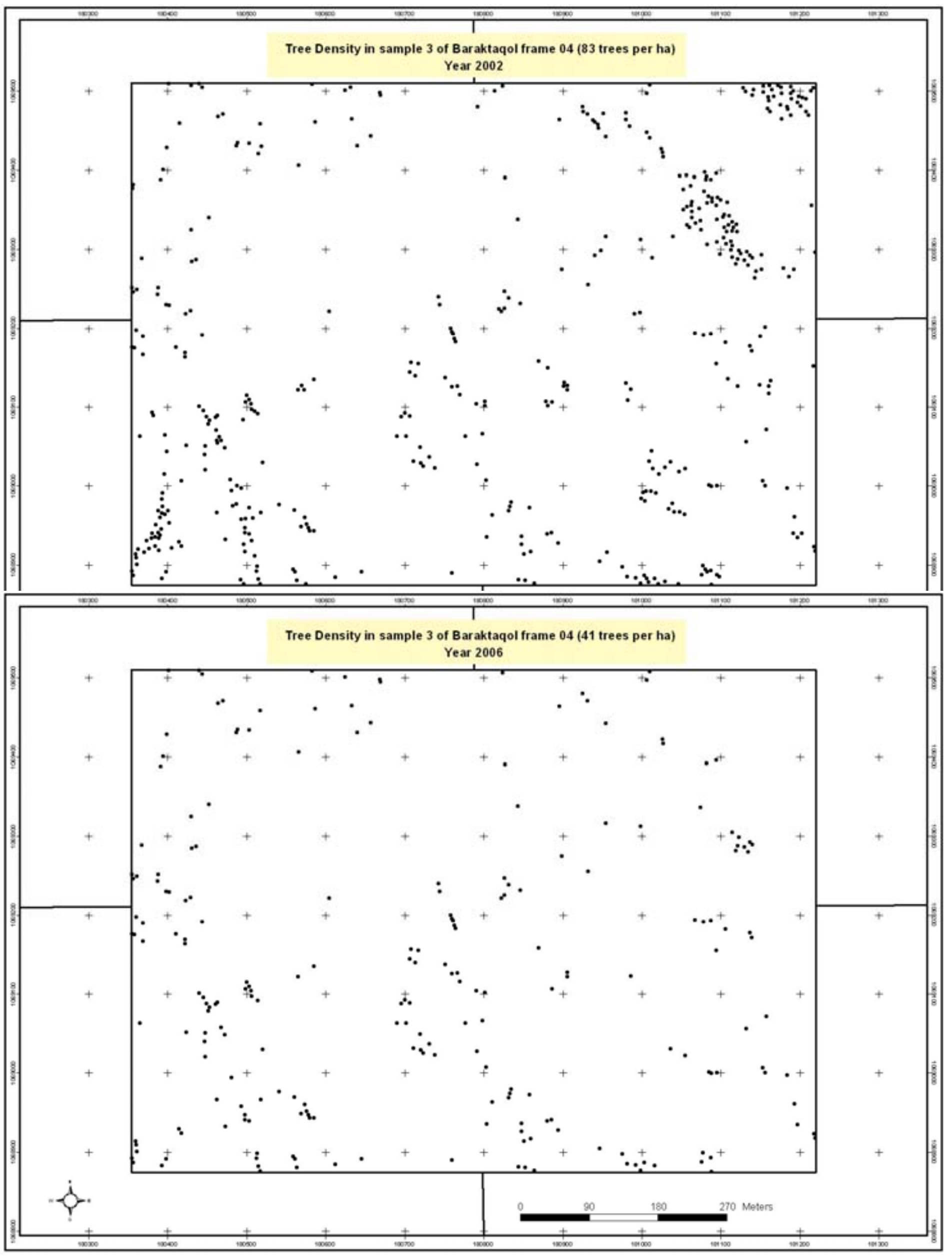


Figure 11: Map of tree densities for Baraktaqol

3.1.1 Tree density by sampling image frames

Wardheer 01

In this image sampling frame (Table 1), a positive increase in tree counts between 2001 and 2006 was recorded. The number of trees counted increased from 6453 in the year 2001 to about 7979 trees in the year 2006, about 21% increase. The tree count in each 5ha quadrat is shown in the table. The increase in tree count can be attributed to the environmental conservation efforts by NGOs and the community. Soil bunds (figure 13a and 13b), built by Horn Relief, characterise the landscape in this area. The soil bunds appear in 2006 according to the Quick Bird satellite image in figure 13b. Figure 12 gives a bar chart pictorial presentation of the tree count results of table 1.

Table 1: Tree counts in image sampling frame 01

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
1.1	Wardheer	651	729	78	12.0
1.2	Wardheer	93	122	29	31.2
1.3	Wardheer	0	0	0	0.0
1.4	Wardheer	622	554	-68	-10.9
1.5	Wardheer	1230	1980	750	61.0
1.6	Wardheer	1428	1476	48	3.4
1.7	Wardheer	713	1076	363	50.9
1.8	Wardheer	718	895	177	24.7
1.9	Wardheer	998	1147	149	14.9
	Mean	717	886.6		
	STDEV	469.6	627.8		
	Sum	6453	7979	1526	20.8

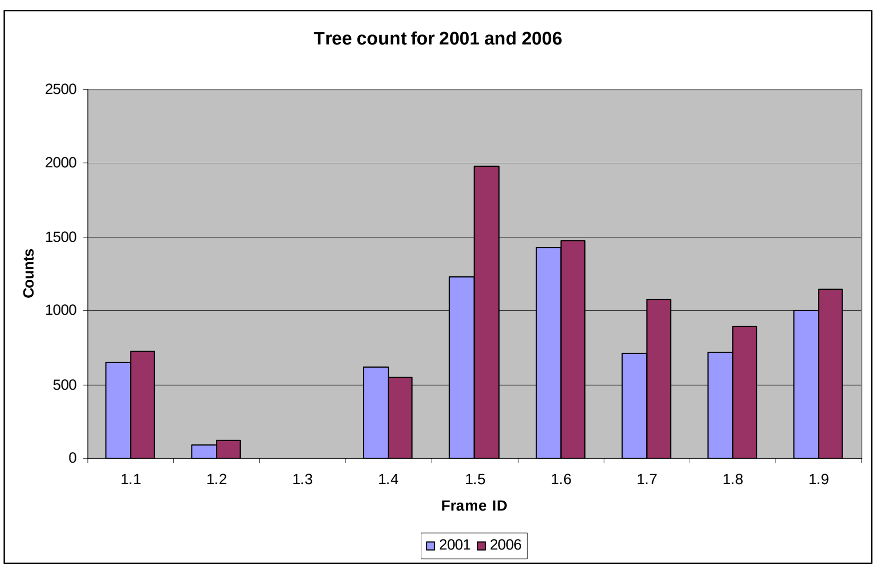


Figure 12: Tree counts in image sampling frame 1

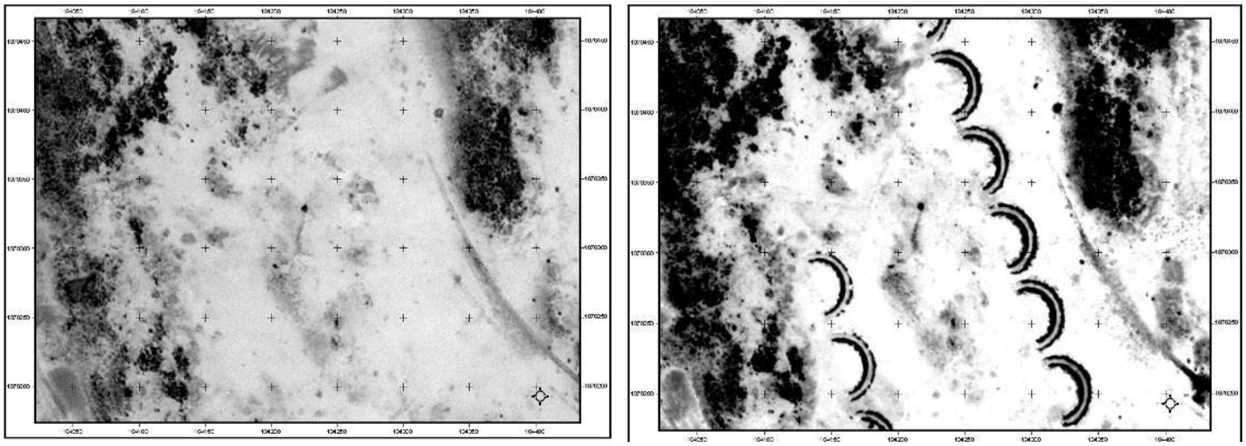


Figure 13: a) Wardheer area in December 2001, b) Soil Bunds in Wardheer Area in September 2006 (Vegetation around bunds includes Andropogon kellery, Chrysopogon aucheri and others).

Wardheer 02

This image sampling frame, (Table 2) recorded a decrease in tree density. The results showed a 19% decrease in tree density, with 1417 trees having been lost between 2001 and 2006. The tree density means stood at 1047 and 889 trees per 5ha in 2001 and 2006, respectively.

Table 2: Tree counts in image sampling frame 02

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
2.1	Wardheer	1452	1234	-218	-15.0
2.2	Wardheer	2511	2345	-166	-6.6
2.3	Wardheer	816	505	-311	-38.1
2.4	Wardheer	210	124	-86	-41.0
2.5	Wardheer	666	576	-90	-13.5
2.6	Wardheer	1047	806	-241	-23.0
2.7	Wardheer	1011	928	-83	-8.2
2.8	Wardheer	1075	889	-186	-17.3
2.9	Wardheer	631	595	-36	-5.7
	Mean	1047	889		
	STDEV	650	629		
	Sum	9419	8002	-1417	-18.7

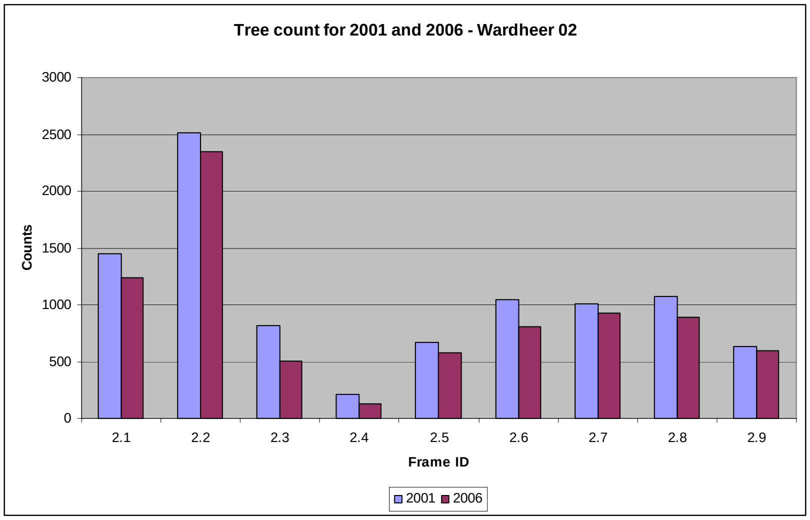


Figure 14: Tree counts in image sampling frame 2

The chart in figure 14 is a pictorial presentation of the tree density in the 2nd image sampling frame as established by the visual count from the Quick Bird very high resolution images. The change in tree density has remained low with the figures shown in the chart, the table 2 and figure 15. Figure 15 is a clip of the steps in multi-year satellite image interpretation to count trees around an area in Wardheer settlement neighbourhood. Notice that there were fewer trees counted in the 2001 satellite image interpretation as compared to those counted in the interpretation of 2006.

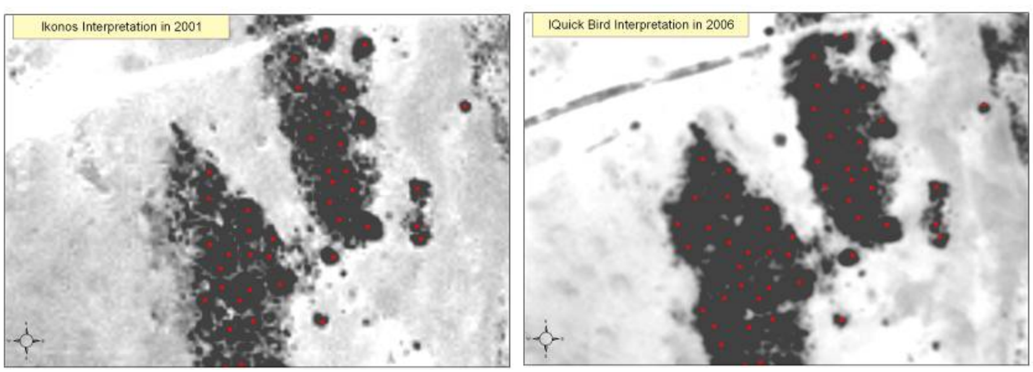


Figure 15: Increase in trees

Damal Cirbiido 03

This image sampling frame (Table 3) recorded a decrease in tree density that was more than 60% of within the two years 2001 and 2005. Out of a total of 17841 trees counted for the year 2001, 10211 trees were lost by the year 2005. The tree density means stood at 1,982 and 848 trees per 5ha in 2001 and 2005, respectively. Figure 16 gives a pictorial presentation of the results.

Table 3: Tree counts in image sampling frame 03

Quadrat	Settlement	Tree Count 2001	Tree Count 2005	Change in tree counts	% Change in tree counts
3.1	Damal Cirbiido	2550	1087	-1463	-57.4
3.2	Damal Cirbiido	2326	1259	-1067	-45.9
3.3	Damal Cirbiido	291	55	-236	-81.1
3.4	Damal Cirbiido	2395	663	-1732	-72.3
3.5	Damal Cirbiido	1686	343	-1343	-79.7
3.6	Damal Cirbiido	1525	71	-1454	-95.3
3.7	Damal Cirbiido	1589	938	-651	-41.0
3.8	Damal Cirbiido	3270	1975	-1295	-39.6
3.9	Damal Cirbiido	2209	1239	-970	-43.9
	Sum	17841	7630	-10211	-61.8
	Mean	1982.3	847.8		
	STDEV	839.1	630.4		

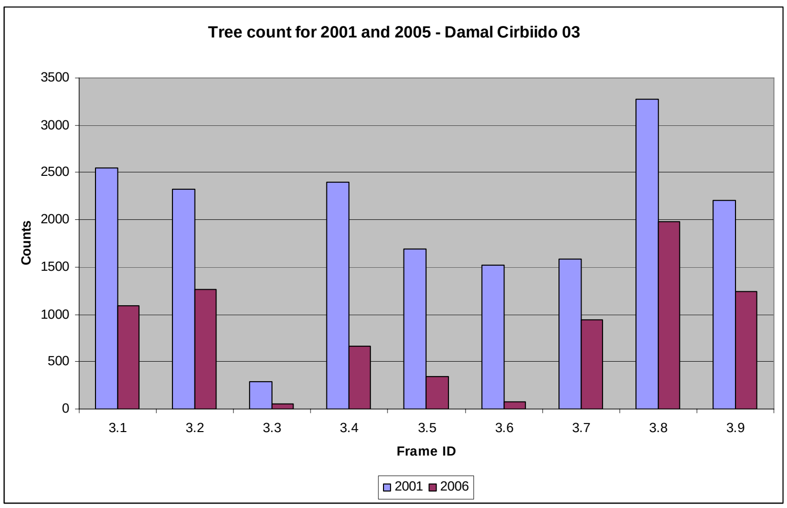


Figure 16: Tree counts in image sampling frame 3

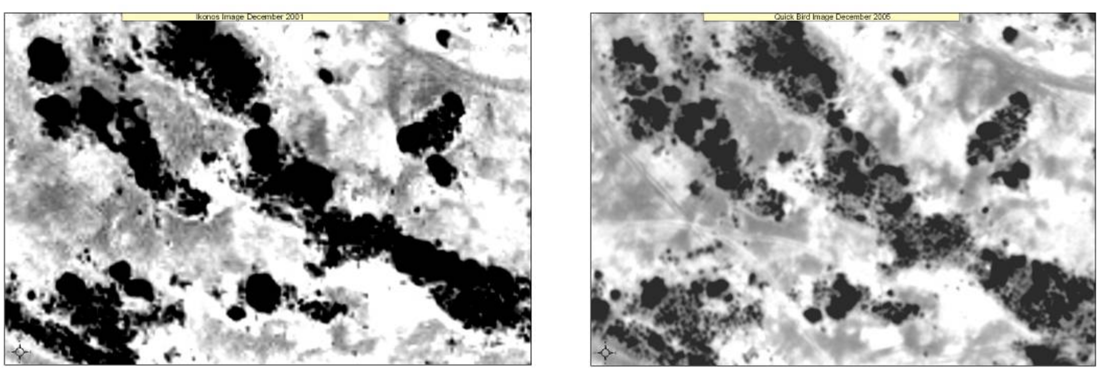


Figure 17: Tree counts in frame 3

Figure 17 show the same area in 2001 and 2005. This is in frame 3 and you can notice the difference in tree density in the two images. Notice that several trees have disappeared between 2001 and 2005. Several roads also criss-cross the landscape in the Quick Bird image of 2005 as compared to that one of 2001.

Baraagtaqol 04

These image sampling frame (Table 4) ws close to Baraagtaqol settlement, with a low number of trees counted in both the years. The mean value for the trees counted was also low. In all about 34% trees were lost within the two years (2001 and 2006). The mean value for the trees counted stood at about 750 and 497 in the year 2001 and 2006, respectively.

Table 4: Tree counts in image sampling frame 04

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
4.1	Baraagtaqol	1519	877	-642	-42.3
4.2	Baraagtaqol	531	388	-143	-26.9
4.3	Baraagtaqol	439	219	-220	-50.1
4.4	Baraagtaqol	734	419	-315	-42.9
4.5	Baraagtaqol	689	465	-224	-32.5
4.6	Baraagtaqol	600	453	-147	-24.5
4.7	Baraagtaqol	356	240	-116	-32.6
4.8	Baraagtaqol	609	414	-195	-32.0
4.9	Baraagtaqol	1281	1003	-278	-21.7
	Sum	6758	4478	-2280	-33.9
	Mean	750.9	497.6		
	STDEV	390.4	267.3		

Figure 18 shows that the loss in tree density over the two year periods is significant.

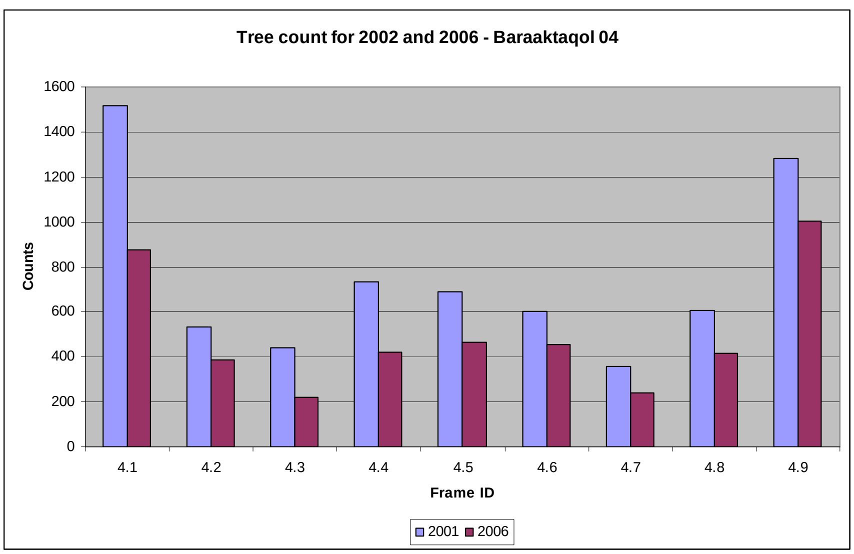


Figure 18: Tree counts in image sampling frame 4

Baraagtaqol 05

Also close to Baraagtaqol, this image sampling frame (Table 5 and figure 18) recorded low averages for the trees counted and also had a more than 60% decrease in tree density for the two years that were investigated. The trees decreased by 5,262 from 8,457 in 2001 to 3,195 in 2006. The area close to Baraagtaqol is facing intense clearing (figure 19).

Table 5: Tree counts in image sampling frame 05

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
5.1	Baraagtaqol	1284	532	-752	-58.6
5.2	Baraagtaqol	864	301	-563	-65.2
5.3	Baraagtaqol	1569	704	-865	-55.1
5.4	Baraagtaqol	1223	499	-724	-59.2
5.5	Baraagtaqol	815	173	-642	-78.8
5.6	Baraagtaqol	427	131	-296	-69.3
5.7	Baraagtaqol	572	365	-207	-36.2
5.8	Baraagtaqol	710	208	-502	-70.7
5.9	Baraagtaqol	993	282	-711	-71.6
	Sum	8457	3195		
	Mean	939.7	355	-5262	-62.7
	STDEV	365.7	189.4		

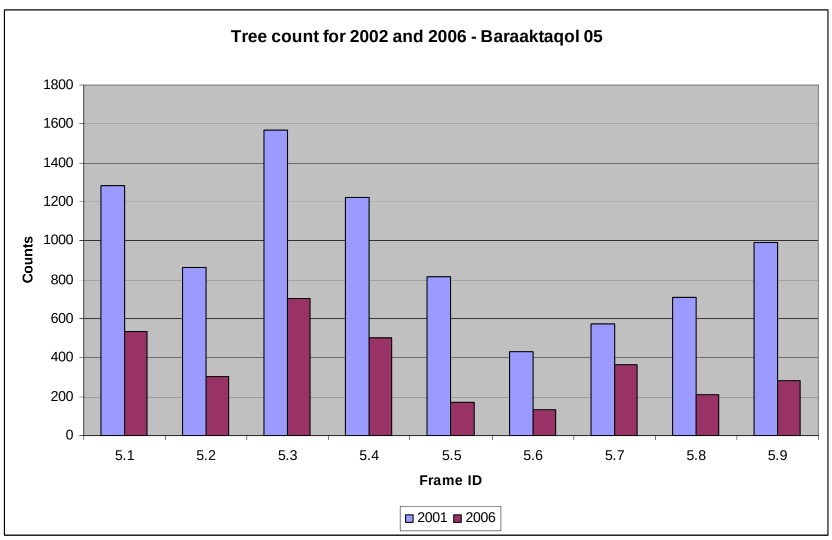


Figure 19: Tree counts in image sampling frame 5

Baraagtaqol 06

This image sampling frame (Table 6) was further from the Baraagtaqol settlement and recorded a 17% decrease in tree density between the two years 2001 and 2005. In total, 3106 trees were lost, i.e., from 19,011 trees in 2001 to 15,905 in

2005. The tree density means stood at 2,112 and 1,767 in the years 2001 and 2005, respectively.

Table 6: Tree counts in image sampling frame 06

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
6.1	Baraagtaqol	1902	1507	-395	-20.8
6.2	Baraagtaqol	1884	1415	-469	-24.9
6.3	Baraagtaqol	1498	1213	-285	-19.0
6.4	Baraagtaqol	2638	2252	-386	-14.6
6.5	Baraagtaqol	2174	1925	-249	-11.5
6.6	Baraagtaqol	2058	1721	-337	-16.4
6.7	Baraagtaqol	1872	1691	-181	-9.7
6.8	Baraagtaqol	2059	1651	-408	-19.8
6.9	Baraagtaqol	2926	2530	-396	-13.5
	Sum	19011	15905		
	Mean	2112.3	1767.2	-3106	-16.7
	STDEV	430.0	412.6		

Figure 20 still shows that there has been a decrease in tree density over the period between 2001 and 2005, though the figure in tree density change is low.

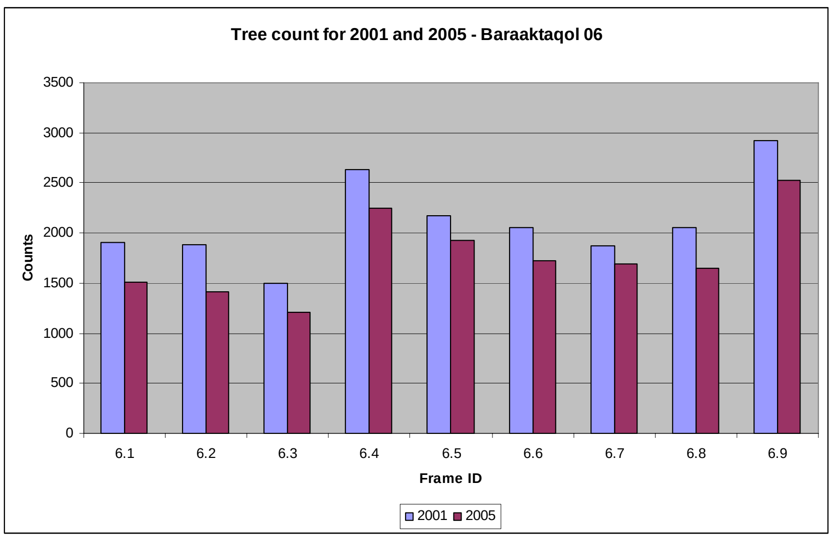


Figure 20: Tree counts in image sampling frame 6

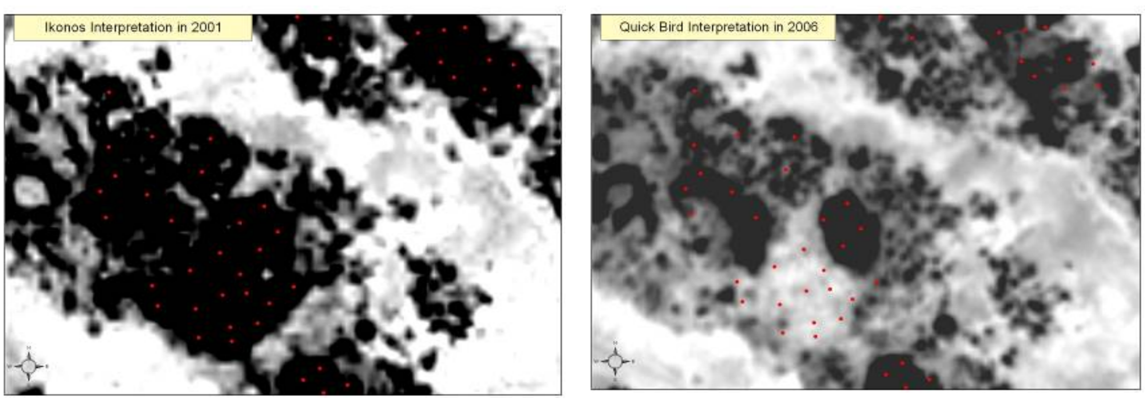


Figure 21: Multi-year satellite Image Interpretation - Baraagtaqol

Damal Cirrbidol 07

Close to Damal Cirbiido, this image sampling frame (Table 7 and figure 22) recorded a decrease in tree density that stood at 16% between the years 2001 and 2006. There were 831 trees lost within the studied time period, with 2001 counting 5,192 trees and 2006 counting 4,361 trees. The tree density averages for the two periods was 577 and 484 trees in the years 2001 and 2006, respectively.

Table 7: Tree counts in image sampling frame 07

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
7.1	Damal Cirbiido	790	601	-189	-23.9
7.2	Damal Cirbiido	728	621	-107	-14.7
7.3	Damal Cirbiido	711	667	-44	-6.2
7.4	Damal Cirbiido	464	374	-90	-19.4
7.5	Damal Cirbiido	598	545	-53	-8.9
7.6	Damal Cirbiido	682	551	-131	-19.2
7.7	Damal Cirbiido	191	157	-34	-17.8
7.8	Damal Cirbiido	538	484	-54	-10.0
7.9	Damal Cirbiido	490	361	-129	-26.3
	Sum	5192	4361		
	Mean	576.9	484.6	-831	-16.3
	STDEV	183.2	161.4		

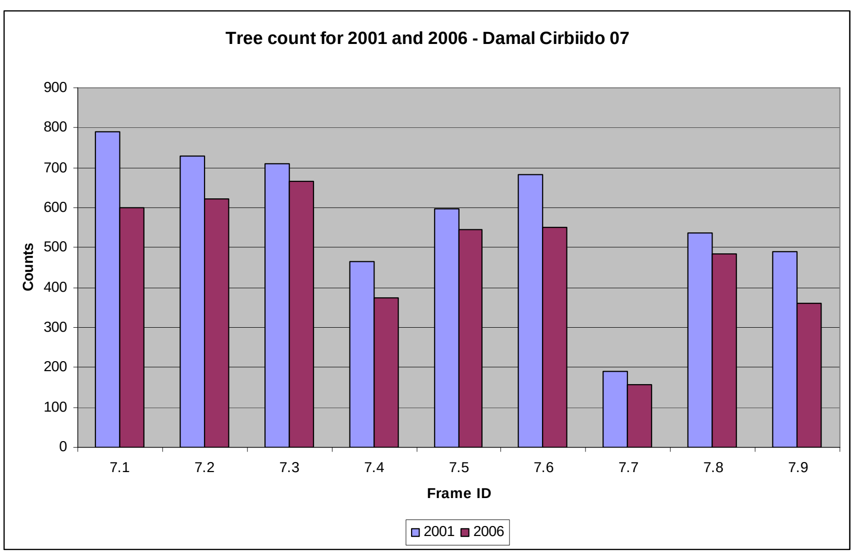


Figure 22: Tree counts in image sampling frame 7

Qol 08

This image sampling frame (Table 8), close to Qol settlement, recorded a low decrease in the number of trees within the two years 2001 and 2006. The decrease stood at 10% of the 11456 trees counted in 2001. Trees counted in the year 2006 stood at 10595. The tree density averages were 1,273 and 1,177 trees in the year 2001 and 2006, respectively.

Table 8: Tree counts in image sampling frame 08

Quadrat	Settlement	Tree Count 2001	Tree Count 2006	Change in tree counts	% Change in tree counts
8.1	Qol	2796	2792	-4	-0.1
8.2	Qol	1317	1506	189	14.4
8.3	Qol	1778	1594	-184	-10.3
8.4	Qol	689	588	-101	-14.7
8.5	Qol	2310	2112	-198	-8.6
8.6	Qol	225	185	-40	-17.8
8.7	Qol	410	361	-49	-12.0
8.8	Qol	508	467	-41	-8.1
8.9	Qol	1423	990	-433	-30.4
	Sum	11456	10595		
	Mean	1272.9	1177.2	-861	-9.7
	STDEV	897.5	887.4		

The figure 22 shows that the change in tree density around Qol remained low at about 10 %.

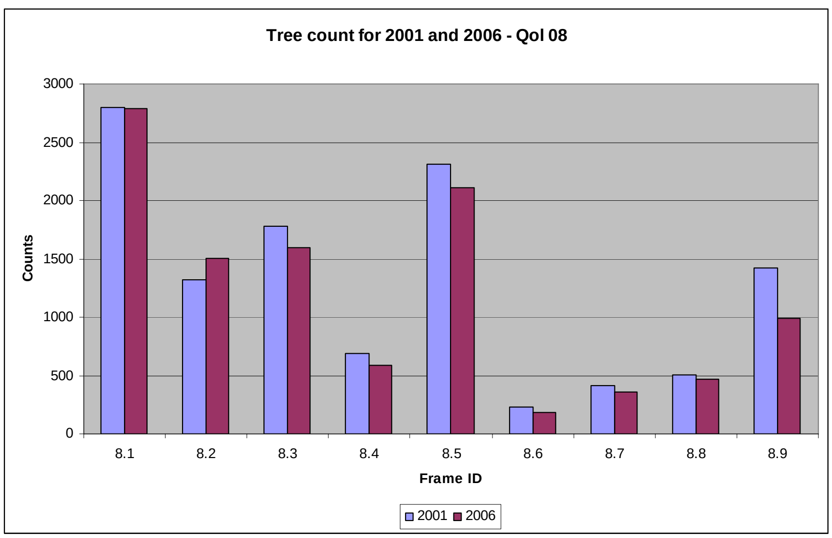


Figure 23: Tree counts in image sampling frame 8

3.1.2 Tree count means related to distance from Baraagtaqol

Figure 24 shows the relationship between the tree count means in the 2006 counts and the distance of the sample frame from Baraagtaqol settlement. These results indicate that as the distance from Baraagtaqol increases, the tree count means decrease. Baraagtaqol is a major charcoal transit town in this area.

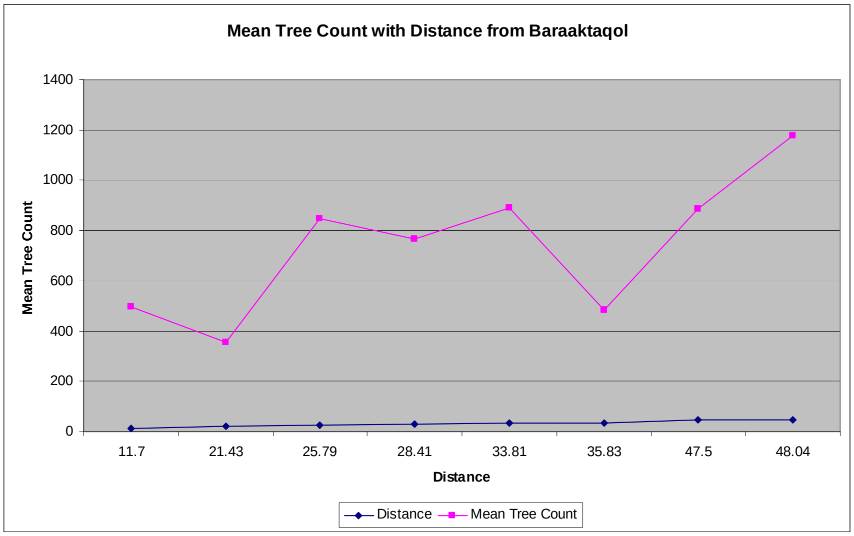


Figure 24: Tree count means with distance from Baraagtaqol

3.1.3 Final tree counts

Table 9 indicates the overall tree counts for the two periods of focus, 2001/2002 and 2005/2006. In total, 84,587 trees were counted for the 2001/2002 period while 62,145 trees were counted for the period 2005/2006. The table shows that the overall percentage change in tree count for the two periods is estimated at about -27%. The count for all the image frames is also shown in the table. The table shows that in the image sampling frame 1, there was an increase in tree density over the 4 year period. This image sampling frame 1 is near the settlement Wardheer. The figure 25 is a pictorial representation of the contents of table 9.

Table 9: Overall tree counts for the IKONOS and QUICKBIRD images

Image sampling Frame ID	Tree count 2001/2002	Tree count 2005/2006	Change in tree count	% Change in tree count
1	6453	7979	-1526	20.8
2	9419	8002	1417	-18.7
3	17841	7630	10211	-61.8
4	6758	4478	2280	-33.9
5	8457	3195	5262	-62.7
6	19011	15905	3106	-16.7
7	5192	4361	831	-16.3
8	11456	10595	861	-9.7
Total	**84587**	**62145**	**22442**	**-26.5**

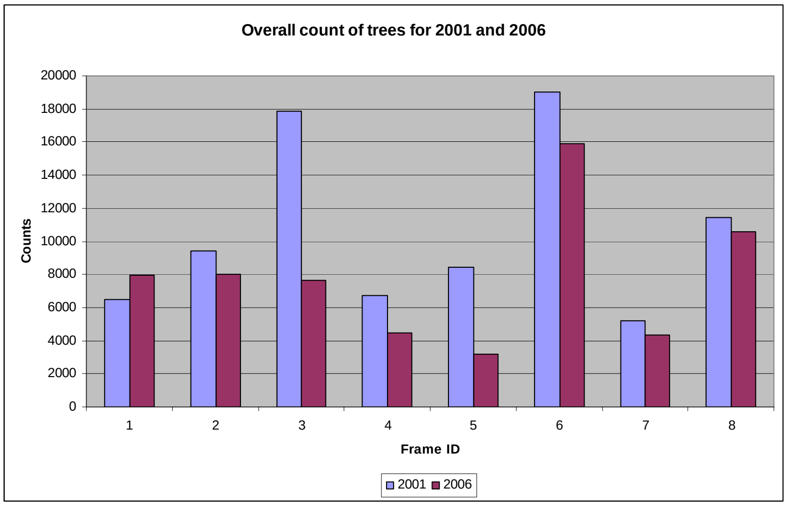


Figure 25: Overall tree density for the IKONOS and Quick Bird counts

3.1.4 Overall tree identification success

The area identified as pasture during the field work may have been a result of the change in land cover due to loss of trees over the years. The satellite images used were 4 years old and a lot may have changed since. Tree density change is minimal around Wadheer settlement and this may explain why the accuracy of interpretation was highest in this place. The trees remained unchanged.

Overall, the tree identification success of the visual interpretation was very high and was estimated at 97% (Table 10).

The study was lucky to have had a Somali surveyor carrying out the field activity to verify if what had been interpreted, on the images, as a tree was actually a tree. However, this tree identification test to establish the overall success of the image interpretation had limitations. First, the high resolution images were about 4 years old. Changes in land cover may have occurred during this period. Some of the trees may have been cut during this period. Second, the security situation on the ground was so tense that some of the points were not visited for verification. The field surveyor was harassed before he could complete the field activity. However, only 15 points out of the planned 130 points were not visited.

Nevertheless, the identification success results indicated that the interpretation was good as most of the features identified as trees during the visual interpretation were verified as trees during the field activity, where the tree had not been cut. Some trees that had been cut only remained as tree stamps.

Table 10: Overall average identification success for trees sited on the images

Settlement	Counted Trees	Field Trees Confirmed	Trees identified as pasture	Identification success %	Remarks
Wardheer 01	15	15	0	100	Tree density change is low over time
Wardheer 02	18	18	0	100	Tree density change is low over time
Damal-Cirbiido 03	19	17	2	90	Tree density change is low over time
Damal-Cirbiido 04	19	19	0	100	High Tree cutting activity
Qol 06	11	10	1	91	High Tree cutting activity
Baragtaqol 07	21	21	0	100	High Tree cutting activity
Baragtaqol 06	11	11	0	100	High Tree cutting activity
TOTAL	114	111	3	681	
%	**100**	**97**	**35**	**97**	

3.2 Tree maps from automatic detection

The 2 approaches of visual and automatic tree detection can be compared by overlaying the results in a GIS environment. A snapshot of that comparison is visible below and shows also the main difference between the 2 approaches:

1. in the visual interpretation a centroid was assigned to each object corresponding to the interpretation keys,
2. the automatic procedure identifies each pixel responding either to the spectral or to the morphological criteria of the algorithm

The spatial difference between the 2 approaches makes a quantitative comparison of the results quite difficult.

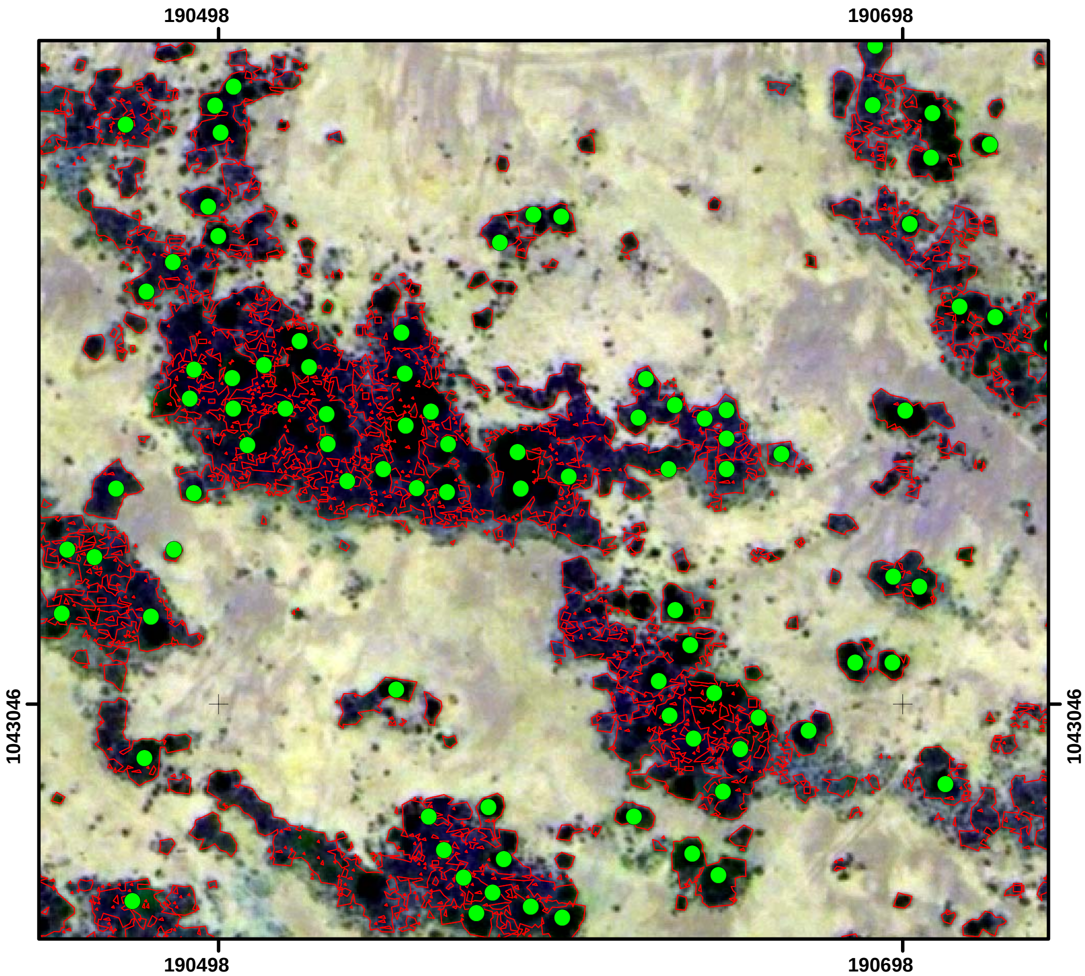


Figure 26: Results of the automatic detection (in red) and the visual interpretation (in green) for a small subset of frame 8

By making a simple confusion matrix between the visual interpretation results (assigning a single pixel to each centroid) and the automatic detection results, it can be concluded that < 10% of trees resulting from the visual interpretation were not identified by the automatic procedure. Of course this is not an accuracy measurement but only an attempt to evaluate possible omission by the automatic procedure; it is not possible to compute a commission error in this way.

Also it can be observed, that by making the total difference between pixels identified as trees at time 1 and time 2, the automatic procedure gives a result on the full scene of – 16%. This is close to the results of the visual interpretation which gave a result of -15% decrease in tree density between 2001 and 2006.
From a visual comparison it is evident that the main dark and round objects have been well identified by the automatic procedure. However, the tree-membership

area in the automatic procedure is relatively large in sparsely vegetated areas where only a few trees have been identified by visual interpretation.

Finally and most importantly, the visual comparison of the two results shows that the main areas with a clear decrease of tree cover have very clearly been identified by both approaches (see figure 27 below).

NB: the difference between the automatic detection on Ikonos and Quickbird also shows the increase in tree cover (green), in certain areas and a decrease in others. However, the change in tree density reflects an overall decrease in the two images. It must be noted here that the two images are of two different months, September and December. Nonetheless, given that the tree crowns are distinct in the characteristic tiger bush of the arid area, and that both months are more or less dry, it was still possible to identify the trees in the two different images.

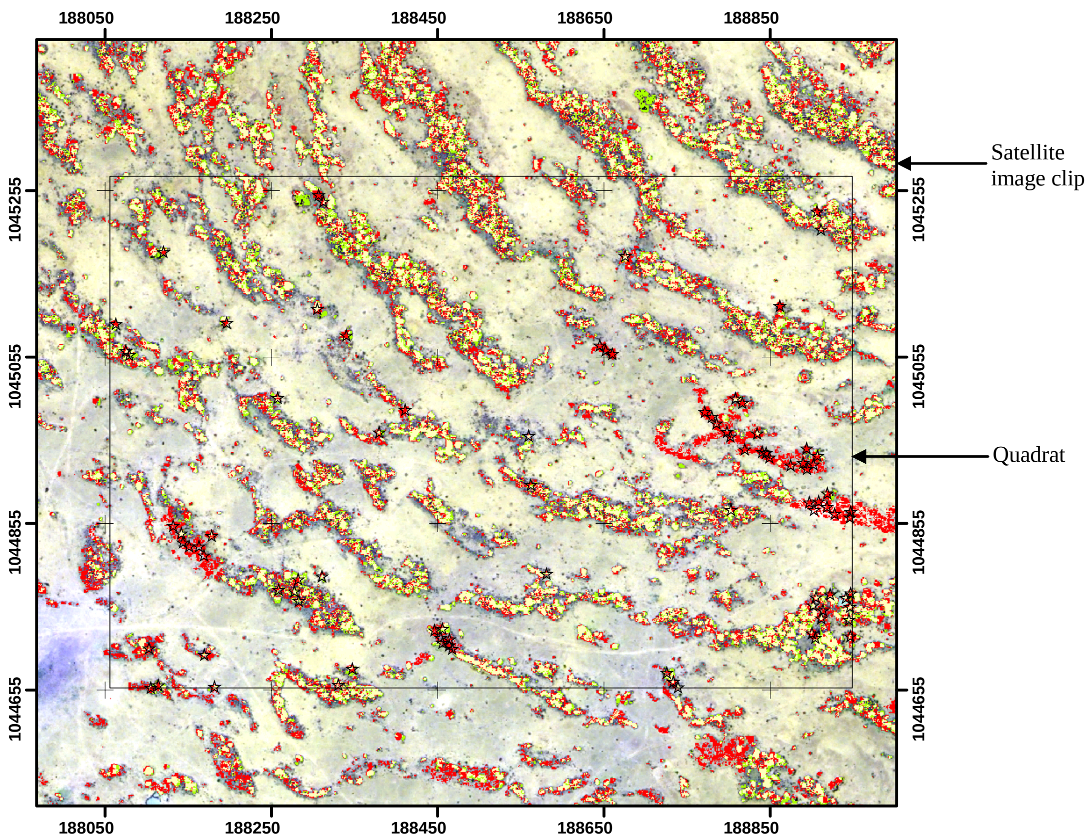


Figure 27: Results of the automatic detection (yellow=no change, red=decrease of tree cover, green=increase) and of the visual interpretation (stars) for quadrat 5 of the visual interpretation on scene 2.

3.3 Rate of tree density change

Table 11 shows that the tree density dropped from 381 trees per hectare in 2001 to 162 trees per hectare in 2006. Overall, the tree density percent loss stands at about 27%.

The image sampling frame 1 recorded gain in tree density over the studied time period with the figure standing at about 24%, while all the other frames recorded loss in tree density as shown in the table. For example, in frame 5 the loss in tree density stood at -62%. The total area of sampled sampling frames in each frame stood at 47.7 hectares.

Table 11: Tree densities over the two time periods (2001 and 2006)

Image sampling Frame	Tree count (2001)	Area (Ha)	Trees/Ha	Tree count (2006)	Area (Ha)	Trees/Ha	Loss in tree density	% Loss and gains in tree density
1	6453	47.7	135.3	7979	47.7	167.3	32.0	23.6
2	9419	47.7	197.5	8002	47.7	167.8	-29.7	-15.0
3	17841	47.7	374.0	7630	47.7	160.0	-214.1	-57.2
4	6758	47.7	141.7	4478	47.7	93.9	-47.8	-33.7
5	8457	47.7	177.3	3195	47.7	67.0	-110.3	-62.2
6	19011	47.7	398.6	15905	47.7	333.4	-65.1	-16.3
7	5192	47.7	108.8	4361	47.7	91.4	-17.4	-16.0
8	11456	47.7	240.2	10595	47.7	222.1	-18.1	-7.5
Final	**84587**	**381.6**	**221.7**	**62145**	**381.6**	**162.9**	**-58.8**	**-26.5**

4 CONCLUSIONS

From the tree densities calculated for all the frames, it is evident that trees have disappeared in large numbers over the period of investigation (2001-2006). An average rate of 26.5 % tree loss between 2001 and 2006 was recorded. This means an average annual tree loss of 5.3% which is an alarming figure considering the characteristics of the fragile tiger bush ecosystem. These frightening results should receive appropriate attention by all the involved stakeholders and should be used as starting point for designing actions to reverse or control this negative situation.

If the trees are disappearing due to charcoal production activity, more detailed research needs to be carried out to establish the impact on the long term environmental sustainability. What are the exact socio-economic implications of charcoal burning? Who is loosing and who is winning? How large is the rate of exported charcoal against local consumption? What would be the alternative options for local populations and how could they be implemented?

This study needs to be extended to other parts of Somalia that are also experiencing the tree cutting menace. This should include Somaliland and south central Somalia. A lot has been said about the charcoal production activity in these areas too, but precise figures and rates are missing in this regard.

The latest images used are dated 2006 while we are now in 2009. There is therefore a need to update the images archive so that we can have the most up-to-date images interpreted for tree cutting. Change analysis should possibly be done on images of the same sensor. For short time lags like in this case (5 years) this should be possible soon. More extensive ground truth should be envisaged for similar studies where possible.

The visual interpretation of the very high satellite images turned out to be an easy to perform exercise and the Somali counterparts therefore need to train in the approach so that they can perform the monitoring of the tree cutting activity using the very high satellite images. The visual interpretation approach is an easy to repeat method, although labour intensive.

The automatic tree detection was only used experimentally for this report but has provided promising results. In addition, several intermediate products of the automatic detection could be helpful for the visual interpretation too. This is particularly true for the automatic rule based classifier outputs which could be used for stratification of the area frame sampling as well as the pansharpened images which can greatly simplify the task of the interpreters compared with black and white panchromatic images.

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6 ANNEXES

SWALIM

(i)

Tree Counting Data Form

Settlement: Wardheer Frame: One Observer: A. A. Omar Date: 01/02/09

ID	Coordinates (UTM)		Object Type Tree=T, Shrub=S, Other=O (describe)	Single stem=S Clamp of Trees=C	Standing Tree=ST Tree remnants=TR	Tree Height Class (m)			
	X	Y				<1	1-7	7-14	>14
1	0181201	1071046	T	S	St		✓		
2	0181160	1071002	T	S	St		✓		
3	0181113	1071025	T	C	TR	✓		✓	
4	0180939	1070909	T	S	St			✓	
5	0180970	1070891	S	C	St		✓		
6	0181007	1070892	T	C	St		✓		
7	181079	1070868	T	C	St		✓		
8	181106	1070848	O	-	-	✓			
9	181089	1070914	S	C	St		✓		
10	181190	1070876	T	S	St		✓		
11	181220	1070843	S	C	St	✓	✓		
12	181151	1070898	T	C	St				
13	181135	1070915	T	S	St		✓		
14	181049	1070963	T	C	St	✓	✓		
15	181022	1070995	S	C	St	✓			
16									
17									
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General Comments: the features of ~~the~~ Land is slopy ares that grown deferent species of trees and grases but most trees are accacis bussei species ~~and~~ those used for ~~charcoal~~ Charcoals