Mapping land enclosures and vegetation cover changes in the surroundings of Kenya's Dadaab refugee camps with very high resolution satellite imagery

Authors:

Rossi, M. [1*], Rembold, F. [1], Bolognesi, M. [2], Nori, M. [3], Mureithi, S.M. [4], Nyberg, G. [5]

[1] European Commission, Joint Research Centre (JRC), Via Fermi 2749, TP. 266, 21027, Ispra (VA), Italy

[2] iMMAP, 1300 Pennsylvania Avenue, NW Suite 470, Washington, DC 20004 USA

[3] European University Institute, Via dei Roccettini 9, I-50014 San Domenico di Fiesole (FI) - Italy

[4] University of Nairobi, Department of Land Resource Management and Agricultural Technology, P.O. Box 29053 Nairobi, 00625 Kenya

[5] Swedish University of Agricultural Sciences, Department of Forest Ecology and Management, 901 83 Umeå, Sweden

* Tel: +39 033278 6062, email: massimiliano.rossi@ext.jrc.ec.europa.eu

Abstract

The immediate surroundings of refugee camps in drylands are among the areas exposed to highest pressure on natural resources including vegetation and soil. Understanding the dynamics of land fencing in these areas is critical for sustainable camp management and can help to improve the knowledge about land management in drylands in general. Very high resolution satellite imagery provides a mean to observe such areas over time and to document land cover and use changes. This study uses satellite images to map fenced areas which can be divided into pastoral enclosures and the so called "green belts" (areas fenced for afforestation) around the Hagadera camp in Dadaab (Kenya). It then analyses change dynamics between 2006 and 2013, a period where the refugee camp has been subject to high oscillations in camp population, due to a combination of conflicts and droughts in Somalia. The applied methodology allows detailed fence mapping and shows a large increase in fenced area (56 %) over the 7 years period. While new pastoral enclosures expanded into more densely vegetated surroundings, land cover density inside already fenced areas either decreased or remained stable. Green belt areas grew at a similar rate (58 %) but did not show evidence of greening over time and their longer term success is strongly dependent on maintenance. The settlement area did also expand remarkably in the same time (65 %), and human and animal movements in the surroundings intensified with a negative impact on vegetation density. The study could not fully investigate the socio-economic drivers and impacts linked to the rapid increase of enclosures, which are inextricably linked to evolutions in local agro-pastoral practices. However, by documenting spatial and temporal dynamics of fenced areas it adds new evidence to their increasing relevance in rangeland management, and opens the way to a

number of hypotheses, stimulating the debate about long-term ecological and socio-economic impact.

Keywords: refugee camps, Dadaab, land enclosures, fencing, pastoral land governance, very-high resolution imagery.

Introduction

Drylands cover around 40 % of the global land area, host nearly 1/3 of the human population and 50 % of the livestock. To a large extent they were traditionally used and managed by pastoralists through communal or common property rights based land tenure systems (McDermott et al., 2010; United Nations Environment Management Group 2011). In Sub-Saharan Africa (SSA), 40 % of the total available land is utilized by 25 million pastoral and 240 million agro-pastoral farmers for livestock keeping, which is their primary source of livelihood (Neely et al., 2009). Many dryland areas have a history of overgrazing and degraded lands with low productivity, recurrent famines, resources conflicts, and economic and political marginalization of pastoralist communities (Nori et al., 2008; Opiyo et al., 2011). Dryland areas also face the challenges posed by the combination of climate variability and change and rising demand for livestock products due to human population growth, urbanization and changing dietary preferences. This increased pressure has exposed drylands to greater levels of degradation in SSA, leading to the displacement of large numbers of people, their livestock and a consequent impact on land management practices. In pastoral areas and in particular in the proximity of areas experiencing a reduction of nomadic livelihoods, the establishment of enclosures or fencing of land (Behnke, 1985; Beyene, 2009; Nyberg et al., 2015; Mureithi et al., 2015) is an increasingly common practice to protect and manage livestock, to increase and protect fodder production, to demarcate and claim land tenure as a follow up of sedentarisation and for land rehabilitation among other reasons. Woodhouse (2003) even claims that the establishment of enclosures is a "default" development when population pressure increases, which might link to the broader property rights theory (Ostrom, 1990). However, private enclosure systems in drylands are often disputed and can increase the risk of conflict for land. For example in many of the pastoral livelihoods which according to Catley 1999 can be associated to one large "Somali pastoral ecosystem" (Fig. 1), it is claimed that enclosures fragment the land, hinder mobility and access to other herders, and are used for land tenure claims by the elite, leading to an erosion of traditional values and livelihoods (Napier and& Desta 2011; Ahmed et. al 2016).

Conflicts, political instability or natural disasters are additional drivers for displacing people and reducing the mobility of nomadic pastoralists by pushing them towards mixed agro-pastoral livelihoods and increasing sedentarization. Most African countries host refugees from neighbouring areas or internally displaced populations in refugee camps. These are generally large temporary settlements of elementary infrastructure causing pressure on the host community and on natural resources (UNHCR, n.d.) and it can be expected that pastoral intensification strategies such as fencing occur at an accelerated rate in such environments as compared to areas with no refugee influx. The environmental impact of refugee camps in semi-arid regions is at the centre of research and impact monitoring (Lodhi, 1998; Berry, 2008; Kariuki et al., 2008, Braun & Hochschild 2015, Braun et al., 2016) and a variety of mitigation strategies and interventions have been proposed in particular by international agencies and Non-Governmental Organizations (NGOs) (Hoerz et al., 1999; Lahn and Grafham, 2015). The largest refugee complex in the world is located in a semi-arid area of north eastern Kenya called Dadaab (with over 350,000 inhabitants in 2014). The Dadaab camps in Kenya are of particular interest in understanding

environmental impact of mass displacements, due to their long history (since the early nineties), their size and the rich bibliography on sustainability questions (Beaudou et al., 1999; Bizzarri, 2010; Enghoff et al., 2010; Lindley, 2011). The originary pastoral system of Dadaab's host population has adapted to close interconnections with the Somali refugees with a large portion of the host population converting from nomadic pastoralists to livestock producers supplying meat and milk products to the camps. (Kamau & Fox 2013). Pastoralists from the local community also tend to aggregate around refugee camps such as Dadaab due to the better access to social services and to drinking water (De Montclos & Kagwanja, 2000). Such changes in local pastoral resource management carries relevant consequences on the overall land cover and resource access, and grazing dynamics around the camps are complex and often conflictual. Finally, since the opening of the camp, the dependency of the refugees on wood for cooking and building has exacerbated the conflicts for natural resources in an already fragile ecosystem.

For decades, satellite-based earth observation has provided means to monitor land cover dynamics and status of natural resources over relatively large areas. Previous remote sensing studies on refugee camps in the area have focused primarily on the estimation of camp population through the identification of dwellings and used different data sources in terms of resolution and sensors (Füreder et al., 2012, Gorsevski et al., 2012, Baker et al., 2013,). Despite the high interest on evidence and trends in environmental impact, analyses in this sense carried out by several teams and mainly based on Landsat data, have not been very conclusive due to limited image availability and insufficient spatial resolution for identifying vegetation changes linked to firewood collection and grazing (Enghoff et al., 2010). To overcome these limitations other studies have used very high resolution imagery (Johannessen et al., 2001; Hagenlocher et al., 2012), while another approach proposed by Braun et al. in 2015 makes use of SAR imagery to address limitations linked to cloud coverage or insufficient spatial resolution. Further studies, aimed at investigating environmental degradation associated with rapidly increasing anthropogenic pressure were executed within the Copernicus programme[1]. Among the results of these exercises, there is clear evidence that contrarily to expectations, over the 15 years study period (2000 to 2014) there is no major decrease in woody vegetation cover in a 50 km radius around the camps, but rather a very slow degradation. Only in the immediate surroundings of the camps (<2 km) completely bare areas are generally well visible and correspond to the high transit frequency belts of humans, livestock and vehicles. Beyond the 2 km radius up to various kilometres the most noticeable land use change is the rapid increase of fenced areas.

To better understand changes in pastoral land management and impact of the increasing anthropic pressure in the surroundings of a refugee camp as Dadaab, but potentially also in other dryland areas, this study focussed on mapping the extent and nature of all fenced areas and on analysing their spatial and vegetation density changes over a 7 years period. More specifically, the objective was to improve the understanding about the impact of enclosures and fenced green belt areas on ecological sustainability and related changes in the pastoral livelihoods around the Dadaab refugee camps and ultimately to provide useful considerations for camp management.

Materials and methods

Description of the study area

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[1] Activation of the risk and recovery and validation components, European Union - Copernicus Emergency Management Service, 2015

The Dadaab refugee complex is located approximately 100 km from the Somali border, in one of the 7 administrative units of the Garissa County in the North East Province of Kenya. The climate is hot and arid, with daytime temperatures average between 25°C/77°F and 37°C/98°F during the wet season and between 21°C/70°F and 32°C/90°F during the dry season (Climatic Research Unit CRU, University of East Anglia, 2016). Precipitations follow a bimodal pattern with a total mean annual rainfall of around 380 mm (2000-2014 time series, NASA-GSFC TRMM: Tropical Rainfall Measuring Mission). Long rains generally occur from March to May and short rains range from October to December. Intense repeated rainfalls have resulted in flood events and camps evacuation in 2006.

Soils are classified as red sand, reddish sandy soils, sandy and loamy-clayey soils ranging from deep soils in seasonally flooded areas to very shallow and superficial in more arid zones (Beaudou et al., 1999). Following the FAO/UNEP LCCS, Land Cover Classification System (Di Gregorio et al, 2000) shrubs life forms are dominant (77%) while trees prevailing land cover classes account for around 7% of the area. The surrounding landscape is largely dominated by shrubby vegetation as principal life form, with densities varying from very open to close and a combined presence of grassland and trees. Grassland (mostly seasonal in character) is associated with open shrubs and becomes the dominant layer in riverine areas of the Lag Dire River and temporarily flooded lands. Trees are scattered within the whole area, typically present around the edgings of the alluvial valleys and the seasonal ponds in which water accumulates during the wet season. Dry forest areas, gathering bushy forms, tall shrubs and small trees are principally located in the northern plains and the southeast of Hagadera camp. The study area corresponds with the surrounding of the Hagadera, the largest and third oldest refugee camp of Dadaab (UNHCR, 2015).

Pastoral enclosures used primarily by the host community and private land concentrate in the West of Ifo and North of Hagadera camps (Enghoff et al., 2010). As opposed to traditional pastoralism in the region, the herd mobility is strongly reduced with few herds grazing further away than daily movements and the loss of mobility is partially compensated by private fencing of grazing land (Enghoff et al., 2010). Part of the herd is kept around the settlements and fed with relief fodder, thorn-fenced enclosures are used for grazing of family owned livestock and fodder production especially during the dry season (Fig. 2). Other fenced plots common in the immediate camp proximity and generally with more regular shape than pastoral enclosures are afforestation areas called "green belts", whose construction was supported since the 90's mainly by NGO's, for increasing soil cover and firewood availability (Hoerz et al., 1999; UNHCR, 2015).

Both pastoral enclosures and green belt fences are usually made of thorny branches of Acacia and Commiphora spp. as well as invasive tree species such as *Prosopis juliflora* (Bizzarri, 2010; Bradford 2016 personal communication*)*. For green belts live hedges are also common (Beaudou & Cambrézy, 1999).

Remote sensing datasets

The selection of images relies on previous activations of the Emergency Management Service of the EU's Copernicus programme and was driven mainly by large reported movements of refugees: 2005 before the collapse of the Somali Islamic Courts Union, 2010 before the big famine-induced influx in 2011 and 2014 immediately before the start of the mapping work. In terms of seasonality the criterion was to prefer dry season images in order to reduce the impact of inter-annual variability on the analyses. The scarcity of cloud-free scenes for the whole area surrounding the camps according to those criteria implied the choice of three different sensor types (Quickbird, WorldView-2, Pléiades-1A).

Selected images were acquired respectively on 22 Jan 2006, 7 Oct 2010 and 25 Dec 2013 (Table 1).

The first two dates roughly correspond with observed dry seasons in the area, while the 2013 image is in fact still close to the peak of the short rainy season. Comparison with lower resolution satellite images of the MODIS sensor with the closest acquisition dates show mean Normalized Difference Vegetation Index values of respectively 0.208 (25 Oct 2006), 0.197 (8 Oct 2010) and 0.255 (27 Dec 2013). This suggests a reasonable similarity of seasonal conditions (Fig. 3). The area covered by very-high resolution imagery of all 3 dates extends of 65.36 Sq. Km and covers the Hagadera camp and its surroundings to the North and North East.

All satellite images were acquired with similar geometric processing levels corresponding to ortho-correction using relief models (i.e. SRTM). Raw Digital Number (DN) values of each pixel were converted to reflectance values using specific metadata information. This calibration procedure allows the extraction of quantitative information about features on the surface. Radiance values were obtained first, using absolute radiometric calibration coefficients. Subsequently Top of Atmosphere (TOA) Spectral Reflectance was obtained normalizing the TOA radiance with the solar incoming irradiance, and a solar angle correction (European Union, 2015). Pan-sharpening aims at obtaining high resolution multispectral imagery integrating low-resolution multi spectral information with the high resolution panchromatic band. The QuickBird scene was acquired already pan-sharpened where the UNB (University of New Brunswick) fusion algorithm (Zhang, 2004) was applied. In order to avoid significant changes to the DN values of multispectral bands, another pixel-level fusion, a wavelet-based algorithm was employed for Pan-Multispectral image sharpening of the WordView2 image. Pleiades images instead were pan-sharpened using an iterative implementation of IHS resolution merge. A final alignment of images was made through image co-registration in order to maximize the geometric agreement between images. Pleaides scene with the highest declared positional accuracy was used as base image and WorldView-2 and Quickbird as warp images, locating and matching 20 tie points per scene.

Detection of pastoral enclosures and vegetation cover (object oriented image analysis)

In this study, eCognition software (Trimble Navigation Ltd.) was used to perform the object-based image analysis (OBIA) (Baatz, 2000). In particular, the multi-resolution segmentation algorithm was applied to the three acquired images. Over the last twenty years, object-based image analysis has gained rapidly reputation in geospatial applications over per-pixel and sub-pixel analyses, with increased spatial resolution of images being one of the preconditions for detecting objects from groups of pixels significantly smaller than the object size. The group of pixels, also called segments, are regions defined by one or more criteria of homogeneity in one or more dimensions (Blaschke, 2009). Particularly in the exploitation of multi-temporal high resolution imageries, an OBIA approach is generally preferable to pixel-based methods for the detection of objects that can be classified based on texture, context (using different thematic layers) and geometry. This has been applied in literature for the detection of linear features such as fences, mapping land cover, and in particular land restoration interventions (Chepkochei, 2011; Spiekermann et al., 2015; Fava et al., 2015).

The approach was used for a first automatic detection of pastoral enclosures and green belt fences (1) and for the classification of vegetation cover (2). The segmentation settings and the following rule parameters depended on the data type. As the optical properties of the images change due to sensor characteristics and time of acquisition, the reflectance values of the three images were not directly comparable and common thresholds valid for

all images could not be used. This segmentation algorithm is based on the scale parameter, used to control heterogeneity and size of objects, and shape and compactness parameters that control relationships between spectral and spatial homogeneity. The scale, shape and compactness parameters of the multi-resolution segmentation were selected on empirical basis until the segments were well delineating visually-observed boundaries of enclosures.

The analysis started with WorldView-2 data, which was prioritized among the set of images for its better spectral and spatial characteristics (Table 1). Rules were constructed to identify and separate the enclosure fences from other land cover types so to progressively eliminate unwanted image objects following an iterative process. Fences were first detected based on brightness values, results were subsequently refined through selection of object size. The segmentation process was repeated and followed by a final selection based on size. The algorithm merges two neighbouring objects if the difference between their average band reflectance value is smaller than a pre-defined parameter. Red Edge, Near-IR1 and Near-IR2 were selected as inputs presenting the highest mean radiometric difference between fences and surroundings (Red Edge: 705 - 745 nm, Near-IR1: 770 - 895 nm, Near-IR2: 860 - 1040 nm). Similarly, a selection based only on thresholds of brightness values was applied to further merge neighbouring polygons with similar values. At this stage objects with a very small area were merged into the adjacent objects with longest common border. The process was repeated with adjusted thresholds to refine results. The development of workflows based on Quickbird and Pleiades-1A followed the same structure and processes. The resulting segments were refined within the ArcGIS environment (ESRI, Redlands, CA). Lines and dangling nodes shorter than 20 m were removed.

A semi-automatic object-based land cover classification was implemented with the aim of obtaining a dichotomous distinction between vegetated and non-vegetated areas. A 2 m buffer was applied to the final enclosure boundaries delineation. The result was used as mask to separate fences from the vegetation class. All bands were used in the first segmentation process, classification of vegetation clusters was primarily achieved using Normalized Difference Vegetation Index (NDVI) and Modified Soil-adjusted Vegetation Index (MSAVI2). The choice of MSAVI2 was justified by the better performances of the index when applied to terrains with significant presence of bare soil as compared with vegetation cover.

NDVI formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

MSAVI2 formula:

$$MSAVI2 = \frac{2 * (NIR + 1) - \sqrt{(2 * (NIR + 1))^2 - 8 * (NIR - RED)}}{2}$$

All polygons not classified as fences or vegetation cover were assigned to the non-vegetated class.

Validation of detection of pastoral enclosures and vegetation cover

In the absence of ground based measurements, the OBIA results for fences and vegetation cover were verified through comparison with visual photointerpretation on the same

images conducted by an independent operator. Manual digitization of features (enclosure fences and vegetation cover) was executed within 50 randomly selected square plots (30 x 30 m) distributed over the study area, accounting for roughly 10% of the area analysed, and used as reference data. The size of the squares was selected by taking into account that most fenced areas are clearly smaller than 1 ha. Table 2 presents results of the validation of the sampled area conducted on the analyses carried out on the WorldView-2 image.

Thematic accuracy assessments for the vegetation cover classification were performed through confusion matrix. For the 3 inquired years accuracy metrics present substantial performances (Table 2) with average overall accuracy of 0,984 and Kappa coefficient of 0,959.

Local land use maps were further derived from the classifications obtained in order to understand main changes in land use and to analyse vegetation dynamics within each land use category. Polygons resulting from the analysis and representing fenced areas were further manually subdivided separating areas with irregular shape (pastoral enclosures) from squared polygons (green belt areas). Areas close to the camps were defined by buffer analyses (500 m) using as baseline the manual demarcation of settlements. Remaining unclassified zones were attributed to the class "open grazed areas".

The results of the classifications were also used to derive indicators of vegetation density. Vegetation canopy cover as well as count of objects derived from the application of the multi-resolution algorithm were both considered good proxy of vegetation density. However, lacking of a complete knowledge about local vegetation species and allometric relations, the vegetation cover was considered a more reliable indicator of vegetation density as compared to the use of number of trees or shrubs. Vegetation density maps were thus computed overlaying the classification of vegetation cover with a 30 m square cells grid (n = 68,800). Vegetation density values were processed calculating the area covered by pixel classified as 'vegetation' and subdividing by the unit area (900 sq. m). Areas covered by clouds and prone to strong seasonal vegetation changes (e.g. seasonally flooded areas) were removed from the analyses, bringing the total of the analysed area to 57.90 out of 65.36 Sq. Km. This approach permitted to downscale the results to 30 m resolution minimizing errors associated with object location, shadows, and seasonal variations. Indeed, image registration processes, different image acquisition dates (and so phenological stages) may all lead to inter-annual changes in crown diameter not necessarily associated with canopy growth. Statistics of vegetation density were finally aggregated by land use category.

Questionnaires on land use practices

In order to verify the main assumptions made about enclosure construction and management, we used 2 types of group questionnaires carried out among pastoralists in the Dadaab area during June 2016. One was centred on the nature and use of green belts, while the second focused on the establishment and use of pastoral enclosures. Due to the difficulties to recover information from inside Dadaab, it was not possible to complete the questionnaires with more detailed ground observation, nor by introducing more complex questions about socio-economic aspects or about environmental degradation aspects. Finally only 2 interviews could be hold, one for pastoral enclosures and one for green belts. The respondents were selected by a local consultant of Nairobi University.

Results

Fenced area mapping

The first result of the image analysis is the semi-automatic detection of fences for the surveyed area and for the three inquired years. An example of delineation of fenced areas is offered in Fig. 4, showing both communal green belts close to the informal settlements (a) and irregularly-shaped fenced areas defined as pastoral enclosures (b). As further result of the analyses, mosaics of vegetation / non-vegetation classifications were obtained for the same dates of observation. Areas covered by fences were excluded from the vegetation cover, thus including in the classification any kind of woody vegetation except fences. Fig. 4 b shows an example of classification of vegetation cover present both inside and outside the fenced areas.

Main spatial and temporal dynamics

The monitoring of fenced areas over time shows a clear increase in terms of total fenced area during the observation period (Table 3). The trends suggest a progressive expansion of land fencing through the years, with green belts concentrated next to the camp and pastoral enclosures increasing mainly in the peripheral areas of the study area. Results of vegetation cover changes through the years are shown in Fig. 5. Main vegetation losses are observed in the Northern part of the study area, in correspondence with a large increase in number of pastoral enclosures (Fig. 5 a). North/East of Hagadera camp, pastoral enclosures are also increasing, but there is less evidence of clearing the newly included areas covered by dense shrubs (Fig. 5 b). In the North/West close to the camp, a slight increase in the number of green belts is visible, but both pastoral enclosures and green belts are scarcely vegetated. (Fig. 5 c). To the South of the camp (Fig. 5 d) pastoral enclosures have been replaced by new settlements accompanied by an increase of biomass, probably including fast growing trees and vegetable gardens close to the dwellings.

The evolution of main land use classes shows a clear increase of the settlements area (Fig 5 d and 6), particularly from the year 2006 (431 ha) to the year 2010 (604 ha). The increase of fenced land is also visible both for enclosures (dark green) and green belts areas (orange). Conversely, the area defined as open areas (light green) slightly decreased as consequence of the expansion of the other classes. The changes for bareland around the camps cannot be fully accounted for, due to the increase in camp size towards South/East, part of the new area close to camps falls outside the study area. These trends are confirmed by land use transitions between 2006 and 2013 (Fig. 6), and in particular looking at the conversion from open areas to enclosures (770 ha) and the enlargement of settlements into former "bareland around the camps" (204 ha). In a number of cases covering 74 ha, older pastoral enclosures next to the settlement have been converted into green belt areas.

Vegetation cover and vegetation cover density observed within the same land use categories are shown in Table 3. For bareland around the camps, a progressive decline of cover and consequent increase of bare soil is confirmed. Looking at the mean density of vegetation cover inside pastoral enclosures instead, shows an overall increase through years. This total cover density data for pastoral enclosures however, is hiding important local differences as well as the trend for areas that have always been fenced during the 3 observation dates. Two separate trends can in fact be observed in the study area for new enclosures: in the Western part and at a certain distance from the camp, new enclosures appearing in 2010 and 2013 show clearing as compared to the original vegetation in 2006 and remain at a relative low vegetation density for the following dates (Fig. 5 b and 7). For enclosures in the Eastern part on the contrary vegetation cover increases with the expansion of enclosures into surrounding areas covered by dense shrub lands. Despite

these differences, monitoring areas which have been occupied by enclosures for all 3 dates and which are therefore directly comparable, shows that vegetation cover density decreased strongly in the period 2006-2010 and remained nearly constant in the period 2010-2013 (Table 4) The different clearing practices in the Western and Eastern parts of the study area could correspond to different use patterns by different population groups, where in the second case there is a more conservative use of woody vegetation inside the enclosures. In any case, areas in between enclosures and corridors are exposed to higher livestock density and transit and show a strong decrease of vegetation density (Fig. 5 b). For green belts a negative mean trend in vegetation density can be noticed by looking at all green belts for each date. While considering only the areas with green belt use for all three dates, cover density remains stable (Table 4). Both observations suggest that long term success of green belts in terms of increasing biomass on degraded areas is challenging and requires intensive maintenance. The increasing pressure on resources and the public nature of green belts (as opposed to the generally private management of pastoral enclosures) might also be responsible for the observed absence of biomass increase in green belts, which is also confirmed by the findings of the group questionnaires. Finally, the overall vegetation density inside the camp is generally decreasing, except for new trees planted in the more recent areas of the camp as well as to rapidly growing invasive species such as Prosopis *Juliflora* (Bradford 2016, personal communication). Analysis of vegetation inside the enclosures by classes of vegetation density (Fig. 7) confirms the increasing trend for the class close to open (40 % - 70 %) and major changes attributed to the class close (> 70 %) with a sharp increase from the year 2010 evidencing new portions of peripheral land with high vegetation density transited from open areas to enclosures, particularly in the Eastern part of the study area. The expansion of pastoral enclosures is most likely triggered both by the continuously increasing number of animals as well as by loss of productivity of older enclosures.

The limited ground inspection in October 2016 mainly documents the severe degradation of both green belt and pastoral enclosures. Both types of fenced areas include only scattered trees and shrubs while herbaceous cover is generally missing as visible in Fig. 2. The questionnaires confirm basic assumptions about enclosures management such as the private nature and predominant use as fodder reserve during the dry season. They also reveal that the degradation of many green belt plots is due to their limited size in relation to the rapidly increasing livestock population around the camps as well as to a gradual decrease in maintenance due to lower external support. The first is in line with information reported by De Montclos & Kagwanja (2000) and confirmed by Enghoff et al. (2010). Reasons for a possible decreasing support of green belts are not known. However both De Montclos and Enghoff remind that planting of trees inside and in the surroundings of refugee camps is often not encouraged by host governments and communities since it is seen as derogation to the temporary nature of refugee settlements. This is also in line with the reported lack of a long term policy strategy for Dadaab management of the Kenya government (Kamau & Fox 2013)

Looking at the 7 years period of observation it also appears (Fig. 7 a) that the increase of both enclosure number and size was more pronounced in the period between 2006 and 2010 than in the second 3 years time span. Apart from the different length of the observation periods, this could be partially explained by looking at the history of population dynamics in Dadaab. In fact while the 1995 - 2005 period was relatively stable in terms of refugee (and animal) migration to the camps, the collapse of the Islamic courts regime in December 2006 and heavy fighting with Somalia transitional government forces lead to a high level of displacement. The second major event was the East Africa drought in

2010/2011 that increased the camps' population number by more than 100.000 people in 2011. However, the impact on Dadaab population of the 2011 famine was relatively short and the population went down again to approximately 350.000 in 2013 and stabilized slightly above 300.000 in 2014 (UNHCR, 2015). An interview carried out by the organization Médecins Sans Frontières in 2014 showed that over 60 % of the residents had settled in the camp between its opening in 1991 and 2006, nearly 30 % in the period 2007-2010 and less than 10 % only in the period 2010-2013. This suggests that, although there was a major population increase in the 2010-2013 period, this was of more temporary nature than the migrations of the previous periods and it is possible to assume that less enclosures were built in the 2010-2013 period, since they require a certain work investment and longer term perspective.

Discussion

The use of multi-spectral, very high spatial resolution images and object-based image analyses permits to detect linear features such as vegetation fences and to derive estimates of vegetation canopy cover on spectral and contextual basis with a certain grade of reliability (Blaschke T., 2009). Limitations in the accuracy of fences detection are mostly attributed to the spectral discrimination between surrounding vegetation and vegetation used to build enclosure fences. In fact, the algorithm can clearly detect fences when there is a good contrast with neighbouring objects (e.g. bare soil), but accuracy decreases in presence of vegetation close to enclosures edges or objects with similar spectral characteristics. WorldView-2 provided more accurate results of classification of enclosure fences if compared with results obtained from the other images. This is due to a combination of factors ranging from highest number of bands (8), spatial resolution (ground sample distance, GSD: 0,46 m Panchromatic at nadir) and suitable view and period of the year conditions. In the same way, the Quickbird scene performed less. This confirms the difficulties of using images from different sensors and leads to the recommendation of possibly using more homogenous time series for similar work, even taking into account a possible loss in spatial resolution. The spatial resolution applied and the temporal intervals observed (2006, 2010, 2013) may not be sufficient alone to detect all meaningful changes in land use and vegetation cover. It is also important to mention that this study concentrates on changes in woody vegetation, and image acquisition frequency is not sufficient to look at seasonal changes related to grassland management, which is the main function of pastoral enclosures for grazing resources.

The use of change detection methods applied to high resolution satellite images reserves several challenges and it is not sufficient to detect and understand the nature of vegetation and soil degradation. The different dates of acquisition of the images reflect different seasons and consequently different phenological phases. Verification of the results through household surveys and in-situ data collection gaining knowledge on livelihood practices, species composition and vegetation associations is sought to deepen this research.

Conclusions

Detailed maps of pastoral enclosures and green belts were first produced by this study around the Hagadera camp in Dadaab for three different dates and show a major increase of fenced areas over the analysed period. At the same time little vegetation change dynamics were found for areas not concerned by fencing with the exception of the immediate camp surroundings and major transit areas, which appear progressively more degraded. Overall, the area occupied by pastoral enclosures increased by 56% and overall

vegetation density inside the enclosures increases by 29% in 7 years. This apparently positive change appears however due to expansion of fenced area into surrounding dense natural vegetation, while older enclosures show a negative or stable trend in terms of woody vegetation density. Building pastoral enclosures implies an initial decrease in vegetation cover linked to the need for fencing material, while the longer term biomass density depends strictly on management patterns which vary across the study area, with enclosures in the Western part of the study area showing progressive clearing, while woody vegetation density in the Eastern part is more stable.

It is also interesting to observe that while the number of green belts in proximity to the camp increases over time, overall woody vegetation density inside green belts decreases. By selecting only green belts visible for all three dates, vegetation density remains fairly stable. The absence of clear biomass increase in green belt areas indicates the difficulties in the recovery of degraded areas and could possibly also be due to dwindling external support to afforestation around the camps.

The study also confirms the increase of settlement area over time as documented by other sources, but more interestingly adds information on woody vegetation density inside the settlement area. The results seem to indicate that, while vegetation density slightly decreases over the initial settlement area, it rapidly increases for more recently built areas, possibly indicating an increased use of fast growing species and suggesting a stronger attention towards tree planting inside the settlement area.

In general all results reflect the increasing demand for fodder linked to the rise in animal numbers, to the central role of livestock and animal products trade for the host community and to the progressive sedentarisation of pastoralists around the camps. The investment in fencing, although often leading to conflicts among residents and hosting population and despite little external support to the pastoralist system (De Montclos & Kagwanja 2000), appears clearly successful in developing economic opportunities and interests in the region, such as the production of forage to feed the growing demand for animal products in the area and beyond. Milk consumption and extended livestock trade are traditional features of the Somali pastoral system, and the Dadaab camp provides in such settings, an opportunity for further investment, commercialisation and labour force at the same time. The implications on the local ecological dynamics however need to be monitored closely and represent critical elements towards the sustainability of such evolutions.

The findings of this study and the limited ground evidence gathered in 2016 suggest that both green belts and pastoral enclosures show clear signs of progressive degradation and are apparently not sufficient to cope with the high pressure on natural resources in the surroundings of Dadaab. Based on these conclusions it is recommended that development activities around Dadaab pay closer attention to the importance of pastoralism as prevailing form of host community livelihood and to the optimization of livestock sustainability, such as including land enclosures management and participatory approaches to conflict resolution over scarce pastoral resources.

Extending the study methodology to a larger area, especially by mapping the whole of Dadaab Sub-County would add valuable information about the representativeness of the results of this work for the other camps. This should ideally be implemented in parallel with a ground survey on the management practices and trends of both green belts and enclosures. Such information is particularly interesting in the light of the conflicting situation between the increased pressure by the Kenyan government for repatriation of Somali refugees on one side and the new drought taking place in Somalia since 2016, which could lead to new displacements.

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Bibliography

Ahmed, S., Livingstone, J., Shibeshi, A., & Pasiecznik, N. (2016). Who calls the shots? Adapting traditional land governance in Somaliland. In *Farming matters* (p. 16). Wageningen, the Netherlands: ILEIA.

Baatz, M., & SCHÄPE, A. (2000). Multiresolution Segmentation : an optimization approach for high quality multi-scale image segmentation. In W. V. Strobl, J., Blaschke, T. and Griesbner, G., Eds., Angewandte Geographische Informations-Verarbeitung, XII (Ed.) (pp. 12–23). Karlsruhe, Germany.

Beaudou, A. G., & Cambrézy, L. (1999). *Landscape and deforestation in Dadaab region (Kenya)*. (UNHCR – IRD, Ed.) (Vol. I). Dabaab, Kenya: UNHCR – IRD.

Beaudou, A. G., Cambrézy, L., & Souris, M. (1999). *Environment, cartography, demography and geographical information system in the refugee camps Dadaab, Kakuma-Kenya: final report, major findings*. (UNHCR, Ed.). Nairobi, Kenya.: UNHCR.

Behnke, R. H. (1985). *Open-range management and property rights in pastoral Africa: a case of spontaneous range enclosure in South Darfur, Sudan*. *Network paper; ODI, Pastoral Development Network* (PASTORAL D, Vol. 20f). London, UK: Overseas Development Institute.

Berry, L. (2008). The impact of environmental degradation on refugee-host relations: a case study from Tanzania. *New Issues in Refugee Research*. Denver, Colorado, USA: University of Denver.

Beyene, F. (2009). Exploring incentives for rangeland enclosures among pastoral and agropastoral households in eastern Ethiopia. *Global Environmental Change*, *19*(4), 494–502. https://doi.org/10.1016/j.gloenvcha.2009.07.002

Bizzarri, M. (2010). Safe access to firewood and alternative energy in Kenya: an appraisal report. Rome, Italy: WFP.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(1), 2–16. https://doi.org/10.1016/j.isprsjprs.2009.06.004

Braun, A., Lang, S., & Hochschild, V. (2016). Impact of Refugee Camps on Their Environment A Case Study Using Multi-Temporal SAR Data. *Journal of Geography, Environment and Earth Science International*, *4*(2), 1–17. https://doi.org/https://doi.org/10.9734/JGEESI/2016/22392

Chepkochei, L. C. (2011). Object-oriented image classification of individual trees using Erdas Imagine Objective: Case study of Wanjohi area, Lake Naivasha Basin, Kenya. In *Proceedings, Kenya Geothermal Conference*. Nairobi, Kenya: The Geothermal Association of Kenya (GAK).

De Montclos, M.-A. P., & Kagwanja, P. M. (2000). Refugee Camps or Cities? The Socio-economic Dynamics of the Dadaab and Kakuma Camps in Northern Kenya. *Journal of Refugee Studies*, *13*(2), 205–222. https://doi.org/10.1093/jrs/13.2.205

Di Gregorio, A., & Jansen, L. J. M. (2000). *Land cover classification system: LCCS: classification concepts and user manual*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Enghoff, M., Hansen, B., Umar, A., Gildestad, B., Owen, M., & Obara, A. (2010). *In search of protection and livelihoods: Socio-economic and environmental impacts of Dadaab refugee camps on host communities*. Nairobi, Kenya: Danida - Danish International Development Assistance, Government of Norway.

European Union. (2015). *Validation of the Risk and recovery activation EMSN011 - Analysis of environmental degradation around Dadaab Refugee Camps [EMSV006]*. Brussels, Belgium: Copernicus Emergency Management Service, European Union.

Famine Early Warning Systems Network. (2011). Kenya - Livelihood Description. Famine Early Warning Systems Network. [Accessed at http://www.fews.net/east-africa/kenya/livelihood-description/march-2011]

Funk, C. C., Peterson, P. J., Landsfeld, M. F., Pedreros, D. H., Verdin, J. P., Rowland, J. D., … Verdin, A. P. (2014). A Quasi-Global Precipitation Time Series for Drought Monitoring. *U.S. Geological Survey Data Series*, *832*, 4. https://doi.org/http://dx.doi.org/110.3133/ds832

Füreder, P., Hölbling, D., Tiede, D., Zeil, P., & Lang, S. (2012). Monitoring refugee camp evolution and population dynamics in Dagahaley, Kenya, based on VHR satellite data. In *9th International Conference African Association of Remote Sensing of the Environment (AARSE)*. El Jadida, Morocco: Faculty of Sciences, Chouaib Doukkali University.

Gorsevski, V., Kasischke, E., Dempewolf, J., Loboda, T., & Grossmann, F. (2012). Analysis of the Impacts of armed conflict on the Eastern Afromontane forest region on the South Sudan — Uganda border using multitemporal Landsat imagery. *Remote Sensing of Environment*, *118*, 10–20. https://doi.org/10.1016/j.rse.2011.10.023

Hagenlocher, M., Lang, S., & Tiede, D. (2012). Integrated assessment of the environmental impact of an IDP camp in Sudan based on very high resolution multi-temporal satellite imagery. *Remote Sensing of Environment*, *126*(May 2016), 27–38. https://doi.org/10.1016/j.rse.2012.08.010

Hoerz, T., Chege, N., Jacobsen, K., Kimani, M. J., & Nyandiga, C. O. (1999). Participatory Environmental Management for Refugee Hosting Areas. A Sourcebook for Decision Makers and Fieldworkers. *Energy*. Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Johannessen, O., Dalen, Ø., Bjørgo, E., Bouchardy, J., Babiker, M., Andersen, G., Haglund, A., Ordonez, C., & Sandven, S. (2001). Environmental monitoring of refugee camps

using high-resolution satellite images (EnviRef) - Final report. *Technical Report No. 201*. Bergen, Norway: NERSC.

Kamau, C., & Fox, J. (2013). *The Dadaab Dilemma. A Study on Livelihood Activities and Opportunities for Dadaab Refugees The Dadaab Dilemma: A Study on Livelihood Activities and Opportunities for Dadaab Refugees*. (iDC (Intermedia Development Consultants), Ed.). Nairobi, Kenya: DRC, UNHCR.

Kariuki, J. G., Machua, J. M., Luvanda, A. M., & Kigomo, J. N. (2008). *Baseline Survey of Woodland Utilization and Degradation Around Kakuma Refugee Camp*. (K. F. R. Institute, Ed.). Nairobi, Kenya: KEFRI/JOFCA.

Lahn, G., & Grafham, O. (2015). *Heat, Light and Power for Refugees. Saving Lives, Reducing Costs*. London, UK.: Chatham House, the Royal Institute of International Affairs.

Lindley, A. (2011). Between a protracted and a crisis situation: Policy responses to somali refugees in Kenya. *Refugee Survey Quarterly*, *30*(4), 14–49. https://doi.org/10.1093/rsq/hdr013

Lodhi MA, Echavarria FR, K. C. (1998). Using remote sensing data to monitor land cover changes near Afghan refugee camps in northern Pakistan. *Geocarto International*, *13*, 33–39. https://doi.org/10.1080/10106049809354626

McDermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., & Van de Steeg, J. A. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, *130*(1–3), 95–109. https://doi.org/10.1016/j.livsci.2010.02.014

Neely, C., Bunning, S., & Wilkes, A. (2009). Review of evidence on drylands pastoral systems and climate change. *World*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Nori, M., Taylor, M., & Sensi, A. (2008). *Browsing on fences and adaptation to climate change. Russell The Journal Of The Bertrand Russell Archives*. Nottingham, UK.: Russell Press.

Nyberg, G., Knutsson, P., Ostwald, M., Öborn, I., Wredle, E., Otieno, D.J., Mureithi, S., Mwangi, P., Said, M.Y., Jirström, M., Grönvall, A., Wernersson, J., Svanlund, S., Saxer, L., Geutjes, L., Karmebäck, V., Wairore, J.N., Wambui, R., Leeuw, J.D., & Malmer, A. (2015). Enclosures in West Pokot , Kenya: Transforming land , livestock and livelihoods in drylands. *Pastoralism*, *5*(25), 1–12. https://doi.org/10.1186/s13570-015-0044-7

Opiyo, F. E. O., Mureithi, S. M., & Ngugi, R. K. (2011). The Influence of Water Availability on Pastoralist' s Resource Use in Mwingi and Kitui Districts in Kenya. *Journal of Human Ecology*, *35*(1), 43–52. https://doi.org/10.1080/09709274.2011.11906389

Ostrom, E. (1990). *Governing the commons. The Evolution of Institutions for Collective Action*. (J. E. & Douglass C. North, Eds.). Cambridge, UK: Cambridge UNIVERSITY PRESS.

Spiekermann, R., & Brandt, M. (2015). Woody vegetation and land cover changes in the Sahel of Mali (1967–2011). *International Journal of Applied Earth Observation and Geoinformation*, *34*, 113–121. https://doi.org/10.1016/j.jag.2014.08.007

United Nations Environment Management Group. (2011). *Global Drylands: A UN system-wide response*. Bonn, Germany: The Environment Management Group Secretariat.

United Nations High Commissioner for Refugees. (n.d.). UNHCR Refugees in the Horn of Africa: Somali Displacement Crisis. [Accessed at http://data.unhcr.org/horn-of-africa/region.php?id=3]

United Nations High Commissioner for Refugees. (2015). Safe access to fuel and energy. A UNHCR strategy and plan of action for refugee operations in Kenya, 1–41. Geneve, Swirtzerland: United Nations High Commissioner for Refugees.

United Nations High Commissioner for Refugees. (n.d.). Refugee Operations and Environmental Management - Selected Lessons Learned. Geneve, Swirtzerland: United Nations High Commissioner for Refugees.

Vancutsem, C., Marinho, E., Kayitakire, F., See, L., & Fritz, S. (2013). Harmonizing and combining existing land cover/land use datasets for cropland area monitoring at the African continental scale. *Remote Sensing*, *5*(1), 19–41. https://doi.org/10.3390/rs5010019

Woodhouse, P. (2003). African enclosures: A default mode of development. *World Development*, *31*(10), 1705–1720. https://doi.org/10.1016/S0305-750X(03)00140-2

Zhang, Y. (2004). Understanding Image Fusion. *Photogrammetric Engineering & Remote Sensing*, *70*(June), 657–661.

Table 1: Specifications of selected satellite images with sensors characteristics (name, acquisition date, number of bands, spatial resolution, sun and elevation angles).

Sensor	Date	Bands (n)	Spatial resolution (m)	Sun angle (degree)	Elevation angle (degree)
Quickbird	22 Jan 2006	4	0,65	135,70	31,90
WorldView-2	7 Oct 2010	9 (1 + 8)	0,46	108,70	17,41
Pleiades-1A	25 Dec 2013	5 (1 + 4)	0,50	137,32	22,28

Table 2: Accuracy measures for the semi-automatic classification of vegetation cover.

	Overall accuracy	Producer accuracy	User accuracy	K coefficient
QuickBird (2006)	0,960	0,945	0,953	0,898
WorldView-2 (2010)	0,994	0,995	0,990	0,986
Pleaides1A (2013)	0,997	0,998	0,996	0,994

Table 3: Total vegetation cover and vegetation density by land use category. Areas not analysed (i.e. clouds, strong seasonal vegetation changes) were removed from calculations, therefore density and change figures cannot be derived directly from land use and vegetation cover)

Land use categories	Land use area (ha)			Vegetation cover (ha)			Vegetation density (cover/area)			Vegetation change (2006-2013)	
	2006	2010	2013	2006	2010	2013	2006	2010	2013	area	veg density
Settlements	431	604	709	155	183	205	0,360	0,303	0,289	+65%	-20%
Bareland around camps	488	407	397	64	40	38	0,131	0,098	0,096	-19%	-27%
Enclosures	1017	1459	1590	155	269	311	0,152	0,184	0,196	+56%	+29%
Green belt areas	124	150	196	20	18	21	0,161	0,120	0,107	+58%	-34%
Open areas	3731	3170	2897	1297	797	1017	0,348	0,251	0,351	-22%	+1%
Total	5790	5790	5790	1690	1307	1593	0,292	0,226	0,275	0%	-6%

Table 4: Vegetation cover and vegetation density by selecting only enclosures and green belts observed for all 3 dates.

	tot area (ha)	veg area (2006)	density (2006)	veg area (2010)	density (2010)	veg area (2013)	density (2013)	Diff. 2010-2006	Diff. 2013-2010
Enclosures	774	142	18,3%	99	12,8%	110	14,3%	-5,5%	1,4%
Green belts	82	13	15,3%	12	14,8%	14	17,2%	-0,4%	2,4%
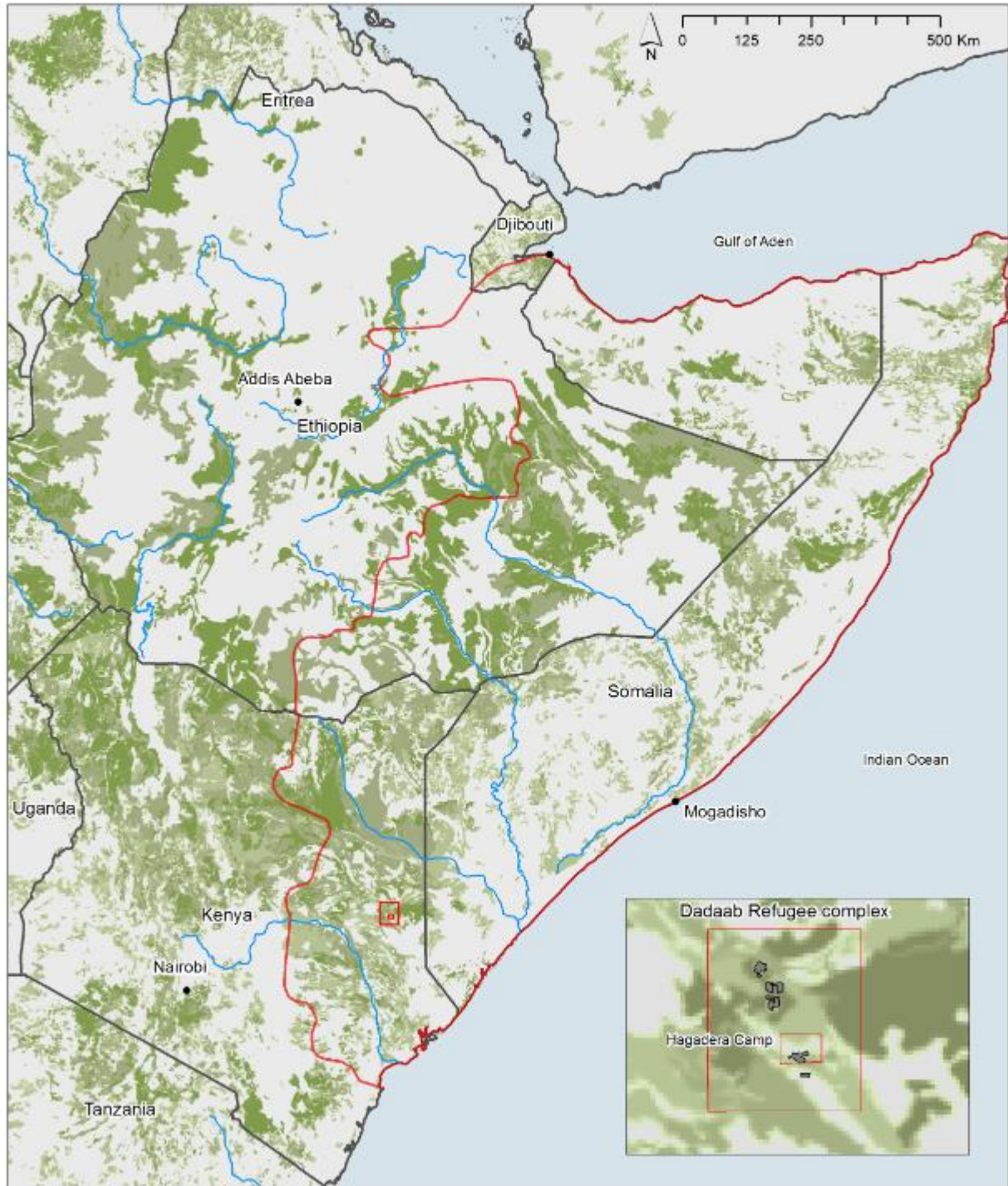
Fig 1: Extent of the Somali pastoral ecosystem according to Catley, 1999 (red contour line) and grazing zones (light green: low density grassland; dark green: high density grassland derived from existing land cover/land use datasets) according to Vancutsem et al., 2013. Location of the Hagadera camp (the study area corresponds to the smaller red rectangle) within the Dadaab Refugee complex.

Fig. 2: a, b Pastoral enclosures as seen from outside. The enclosed area is typically delimited by a fence of dry branches of thorny bushes and trees. In both a and b, there is limited grass for pastoral use inside the enclosure as typical for the late dry season, but shows a higher density of trees and shrubs. The foreground shows mainly bare soil typical for the high transit areas in between enclosures (2 b).
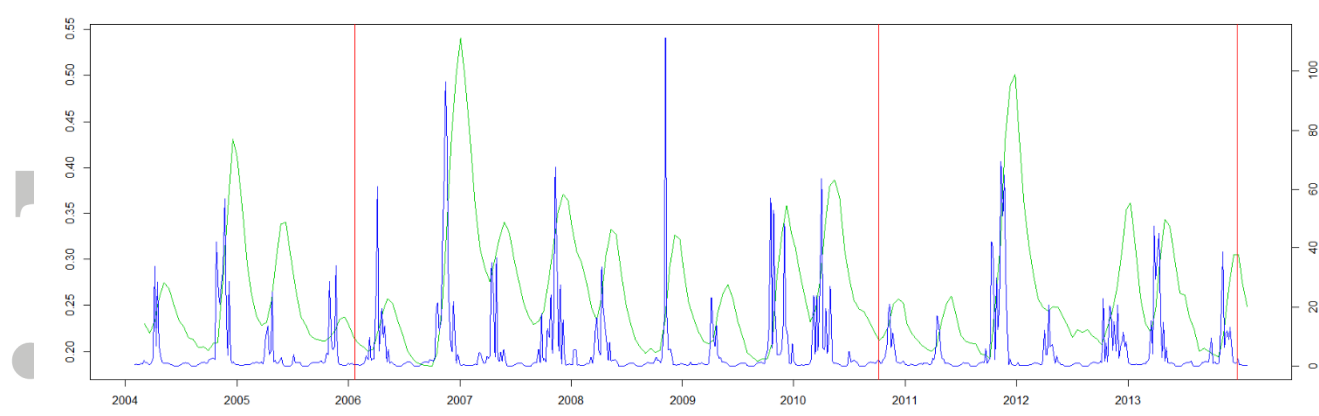
Fig. 3: image acquisition dates (red vertical markers) with MODIS NDVI (green line) and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) rainfall (blue line) measurements (Funk et al. 2014).
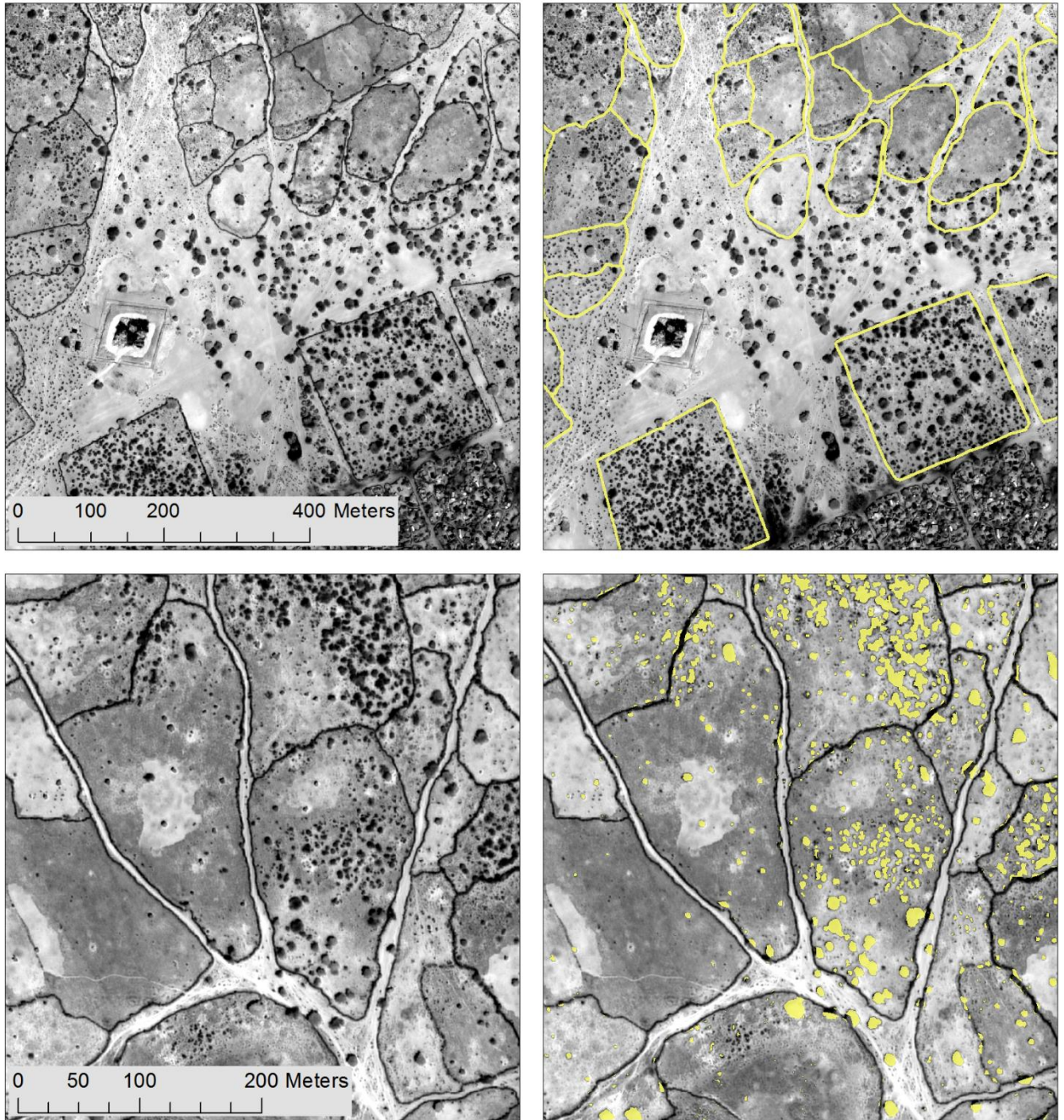
Fig. 4 a (upper pair) result of fence delineation and b (lower pair) woody vegetation classification (yellow), Background image: WordView-2 (2010). Among the identified fences the difference between green belts (squared and with denser tree woody vegetation) and pastoral enclosures (irregular shape) is clearly visible.
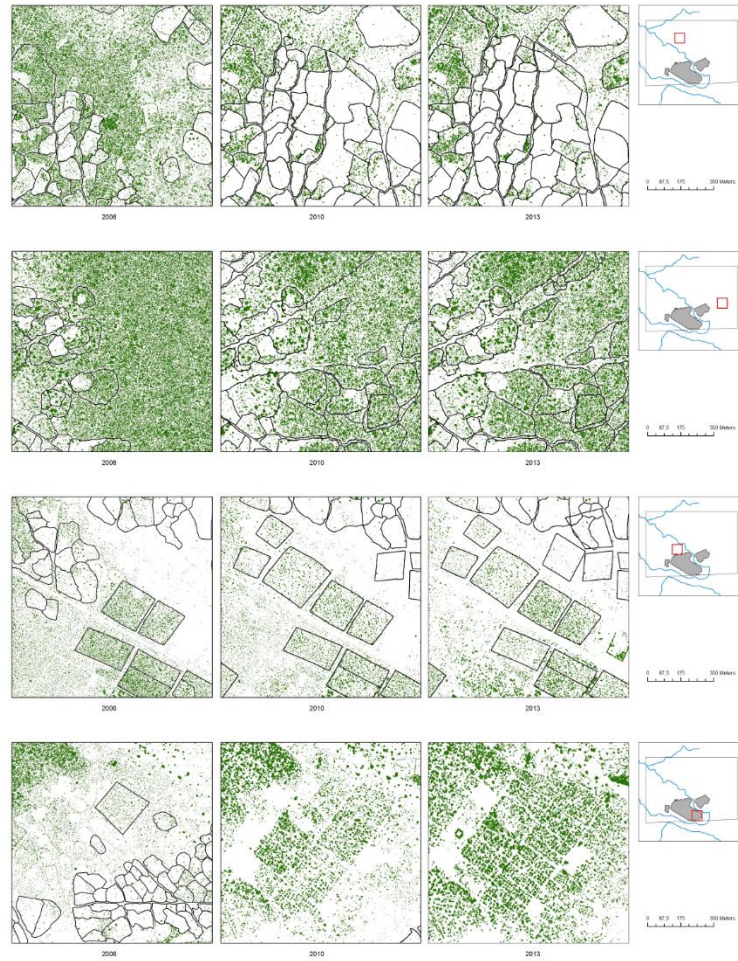
Fig. 5: a, b) Expansion of enclosures system associated with loss of vegetation density (North and North/East of Hagadera camp); c) Green belt areas in the immediate proximity of Hagadera camp (East and North); d) growth of vegetation associated with the expansion of the encampments (South). Legend: results of the vegetation classification in green, fences in black.
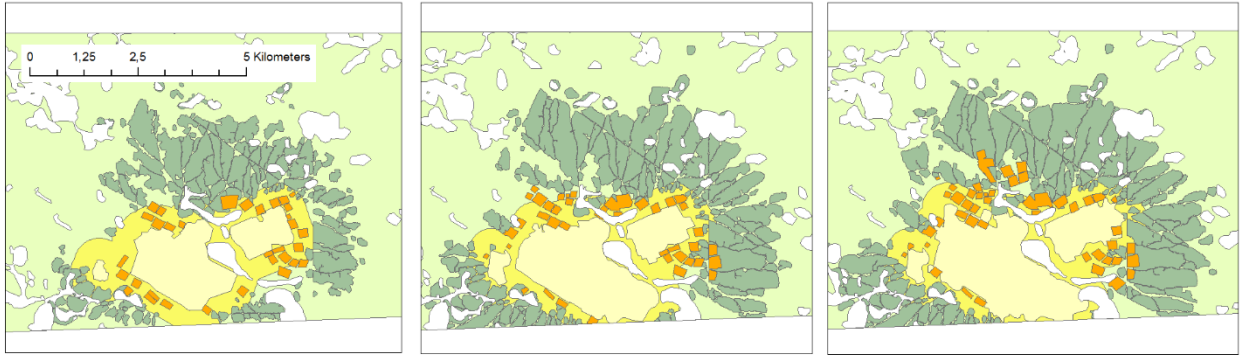
Fig 6: land use maps: settlements in light yellow, bareland around the camps in dark yellow, green belts in orange, enclosures in green and open areas in light green (2006, 2010 and 2013).