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Rapid mapping and impact estimation of illegal charcoal production in southern Somalia based on WorldView-1 imagery

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A B S T R A C T

Following more than 20 years of civil unrest, environmental information for southern Somalia is scarce. Wood charcoal production and export is a major activity supporting war regimes in this area such as the extreme Islamist group Al-Shabaab. However, little quantitative information exists on the extent of this charcoal production. In this study, we developed a semi-automatic detection method to identify charcoal production sites from very high resolution (0.5 m) satellite imagery. We then applied it to a 4700 km^2 area along the Juba River in southern Somalia using 2011 and 2013 WorldView-1 imagery. Based on the sites detected exclusively for 2013 we estimated an average production of 24,000 tonnes of charcoal and 2.7% tree loss for the two-year interval, using literature- and local-knowledge-based assumptions on likely ranges of kiln and tree parameters. Our large-area assessment helps to better understand the dimension and impact of charcoal production in southern Somalia and reveals a rapid depletion of tree cover. The analysis provides a first step towards the development of a charcoal production monitoring system that could be extended to other parts of the country.

Introduction

In developing countries woodfuel accounts for 67 to 80% of the total energy used (FAO, 2010) and is the main source of household energy (Zulu and Richardson, 2013). The woodfuel related market is an important source of income for many people (Clancy, 2008). Evidence exists that at the local level it can have significant impacts on forest degradation (FAO, 2010; Kanninen et al., 2007). Woodfuel refers to any energy source that is derived from woody biomass. These include fuelwood, charcoal, wood pellets, biogas, cellulosic ethanol, and other forms of bioenergy. Charcoal is the dominant form of woodfuel used by urban households in Africa and other developing countries (Akpalu et al, 2011).

Charcoal is a woodfuel made by burning wood in a low-oxygen environment. Compared to wood, it weighs about five times less and produces more heat per kilogram (Boucher et al., 2011) making it a more efficient form of transporting woodfuel (Akpalu et al, 2011). According to FAO statistics, Africa produces 60% of the global charcoal production (FAO, 2014). However, these charcoal production estimates are often inaccurate when disaggregated at the national level. For many African countries, detailed information is lacking partly due to the informality and clandestine nature of production sector and the scattered production by rural population (Mwampamba et al, 2013). Estimates are consequently based on analytical and projection models that use woodfuel information of countries in similar socioeconomic and geographical situations, or by multiplying the country population by a per capita estimate based on a literature review carried out in 1980 (Wardle and Pontecorvo, 1981; Whiteman et al., 2002). The datedness of some of the estimates that are used as input in combination with the difficulty of data collection, makes that national charcoal production data are often at best “guesstimates” with limited accuracy (Mwampamba et al., 2013). Levels of woodfuel harvesting may be in balance with the productive capacity of the wood stocks, but overall tree loss occurs when the intensity of woodfuel production prevents regeneration and therefore sustainable production (Ribot, 1998).

In Somalia, charcoal production is not only triggered by domestic consumption, which accounts for only a fifth of the total production and is the main source of energy in urban areas such as Mogadishu and Hargeisa, but mostly by foreign demand, which accounts for the remaining 80% (UNEP, 2005). In fact, charcoal has developed into one of the major export products, and is sometimes referred to as “black gold” (Bakonyi and Abdullani, 2006; UN Security Council, 2011). UNEP (2005) estimated that 4.4 million trees are logged annually to produce the 250,000 tonnes of charcoal that is exported every year from Somalia to Saudi Arabia, Yemen and the United Arab Emirates. While part of the charcoal exported from Somalia may originate from

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neighboring countries like Ethiopia, the bulk of the exported charcoal is produced in Somalia itself (Belward et al., 2011). Even if national production estimates may be inaccurate (Mwampamba et al., 2013), the FAO database indicates a significant increase in production levels, i.e. from about 180,000 tonnes in 1961 to 420,000 tonnes in 1991, to almost 1.2 million tonnes in 2012 (FAO, 2014). Since the collapse of Somalia's central government in 1991, militia groups fight for political control and finance their activities partly with illegal charcoal exports (UN Security Council, 2011; UNEP, 2014). For this reason, in February 2012 under resolution 2036 the UN Security Council banned charcoal export from Somalia, regardless of the origin of the charcoal. The charcoal trade is the main driver of the fast depletion of forests and woodlands in Somalia (UNEP, 2005).

Despite high exports of charcoal from Somalia, and its contribution to tree cover loss, consequent land degradation (Omuto et al, 2009; Richardson et al., 2010), and reduction of ecosystem services provided by trees (ICRAF, 2014), little quantitative information on tree cover loss in Somalia during the past two decades is available. Moreover, Somalia is predicted to be one of the nine African countries that will face water scarcity by 2025 (Boko et al., 2007), and therefore land degradation will worsen the water scarcity effects by increasing the population's vulnerability to drought (Holleman, 2003). Existing studies on tree cover loss have focused on the north-eastern part of Somalia (MPDES-CHE, 2004; Oduori et al., 2009), because in that region fieldwork was possible due to the relatively better security situation. For example, a recent study by FAO investigated tree loss of an area located in the arid Sool-Sanag Plateau, in northern Somalia, characterized by sparse vegetation (Oduori et al., 2011). The researchers estimated a tree loss of about 13% between 2001 and 2006, based on visually identified individual trees from aerial photos covering eight sampling frames, for a total area of 128 km^2. The only recent study available for southern Somalia estimated a tree loss of 7.2% over the period 2006–2012 for two sample areas covering about 60 km^2 in southern Somalia (Rembold et al., 2013).

Given the limited security in large parts of Somalia in the last 20 years, and especially in the southern and central parts of the country since 2006, when the Islamist terrorist group Al-Shabaab took control, field surveys have been impossible to execute and consequently direct evidence of tree cover changes can exclusively be obtained through remote sensing. Using medium resolution MODIS imagery (500 m), Miles et al. (2006) assessed the distribution of tropical dry-forest at the global scale, while Brink et al. (2014) monitored 20 years of land cover change in Eastern Africa with 30 m resolution Landsat data. However, for charcoal production in Somalia, tree cover clearances typically occur in a patchy distribution (Oduori et al., 2011) that may not be detected, or at least not accurately, following change detection with MODIS-type imagery (Ryan et al., 2012) or on a widely spaced grid of Landsat imagery (Brink et al., 2014).

DeFries et al. (2007) suggested that for monitoring small-scale changes in forest cover the use of aerial photos or high resolution (10–60 m) satellite imagery is appropriate. Studies in the low density forests and tiger bush areas of northern Somalia indicate that accurate estimation of tree-cutting rates requires the detection of changes in the presence of individual trees (Oduori et al., 2009; Oroda et al., 2007). However, in southern Somalia where charcoal production typically occurs in the denser parts of dry woodlands or woody savannah it can be hard to discern individual trees, even from very high resolution imagery. In fact, about 50% of southern Somalia is covered by such areas, comprising the *Acacia–Commiphora* deciduous bushland and thicket ecoregion (White, 1983). Rembold et al. (2013) showed that for those areas loss of tree cover can be estimated by the identification of charcoal production sites, as they form clear circular objects that are spectrally different from their surroundings. In general for efficiently detecting single objects from remotely sensed data, the spatial resolution of the images should be less than half the object size (Woodcock and Strahler, 1987). Hence, to detect small charcoal production sites in Somalia (approximately 3–10 m in diameter), only aerial photos and very high resolution (<5 m) satellite imagery provide the required resolution. Rembold et al. (2013) used visual interpretation of very high resolution imagery to identify changes in charcoal production sites for a relatively small area of 60 km^2. However, for larger areas visual interpretation requires large time investments, so rapid (semi-) automated techniques are required that can reduce interpretation costs. The objective of this study is to assess regional (>4000 km^2) tree cover loss in southern Somalia due to charcoal production using semi-automated identification and mapping of charcoal production sites from very high resolution (VHR) satellite imagery.

Study area and data

For this study we selected a study area in the south-western part of Somalia that was known to be a key production zone (Rembold et al, 2013) and for which multi-temporal WorldView-1 imagery was available (Fig. 1). WorldView-1 imagery covered nearly 6000 km^2 for February and March 2011 (16 scenes of 18 February and 8 scenes of 3 March) and for February 2013 (16 scenes of 19 February and 11 scenes of 23 February). The WorldView-1 sensor produces panchromatic images with a resolution of 0.5 m. All images were acquired during the main dry season (locally known as *Jiilaal*) of the respective year which covers February and March. The satellite sensor therefore recorded the land cover in similar climatic conditions. For our analysis the digital numbers contained in the imagery were converted to top-of-atmosphere reflectance using standard radiometric calibration procedures (Chander and Markham, 2003), taking WorldView-1 specific calibration coefficients and parameters delivered with each image as input. This is a standard procedure that corrects the digital numbers contained in scenes of different acquisition dates for the effect of relative sun illumination and satellite viewing angles.

The study area boundaries were defined by considering the area covered by 2013 imagery that was also available for 2011. From the imagery available, large contiguous areas of agricultural land were digitized by visual interpretation (based on presence of structures like neat field contours, fences, roads, and villages). These areas can be easily and quickly identified, and were excluded from the research analysis, since charcoal production only occurs where natural woody vegetation is found. Hence, the final area of interest used for this research comprised a dry woodland area of approximately 4700 km^2 that extends on both sides along the Juba River, and is geographically located between the city of Bu'aale in the north and the port city of Kismayo in the south (Fig. 1).

Access to the area has been limited since the beginning of the civil conflict in the early 1990s, and impossible from 2006 to date under the control of Al-Shabaab. After the capture of Kismayo port by Kenyan forces in September 2012, conflicts over political power arose between local groups that declared autonomy for sub-regions and the federal government in Mogadishu. Despite a new agreement for the establishment of the Interim South West Administration comprising the regions of Bay, Bakool and Lower Shabelle (UN News Centre, 2014), it is unlikely that in the near future south-central Somalia will have a stable well-functioning government, much needed to effectively oppose to Al-Shabaab's influence (International Crisis Group, 2014).

The most common charcoal production method in the study area is known as the Bay Method, and it was described by Robinson (1988). To produce charcoal, a type of oven known as 'kiln' is used. Kilns are built by piling the timber straight on the soil floor. The timber is collected from the surroundings and arranged into a circular mound with stronger poles erected at the center, and other shorter pieces of wood positioned around it. The mound is packed as close as possible, and the gaps are filled with smaller pieces of wood, shrubs, and grass to facilitate kiln lighting. The whole structure is then covered with iron sheets and finally buried with sand and loose soil. The study conducted by Robinson (1988) revealed a carbonization time ranging from 3 to