Estimating the potential for charcoal production

Charcoal production in Africa

Africa uses approximately 90 % of its wood removals for energy production, and 30 % of wood fuel extraction is used directly for charcoal production (FAO 2011a, b). Africa alone accounts for 63 % (~ 30 million tonnes) of global charcoal production, and since 2004 the production of charcoal in Africa has increased by 30 %, the highest rate of increase globally (FAO 2011a). Increasing demand from growing urban populations drives the charcoal market (DeFries et al. 2010), driven ever further by increasing economic incentives as resources steadily deplete close to demand centres (Ahrends et al. 2010; Hofstad 1997).

Charcoal production involves the selective logging of tree stems of a preferred size and species, where extraction is concentrated around temporary traditional earthen kilns (Chidumayo 1991). The earthen kilns have a low efficiency requiring large amount of biomass for low charcoal returns, and take several months for combustion completion, where after they are abandoned. The charcoal is sold along roads for transport to larger urban centres, causing forest disturbance and degradation to occur along roads (Hofstad 1997; Luoga et al. 2002; Malimbwi et al. 2005). Areas with high demands for charcoal can become almost completely deforested, as selectivity of trees for size and species is superseded by economic incentives (Ahrends et al. 2010).

For the study site in Gorongosa district, central Mozambique, ground data collected by Herd (2007) surveyed charcoal producers in the area. The top five preferred species for charcoal production in the area were *Brachystegia spiciformis, Brachystegia boehmii, Burkea africana, Julbernardia globiflora,* and *Pterocarpus rotundifolius rotundifolius*. However, a wider variety of tree species are used, as the preferred means of tree selection is not dependent solely on species, but the size of trees emerged as a dominant parameter for decision making of tree selection for charcoal production. The preferred size class for cut stems was between 13-95 cm in diameter. The surveyed kilns were all within 2 km from the main road, where charcoal is sold in 45 kg bags for further transport to Inchope and to larger urban centres such as Beria.

Estimating charcoal potential from biomass maps

In order to estimate the potential for charcoal production from the radar derived above-ground biomass (AGB) maps, we produce estimates of the number of 45 kg bags of charcoal which could be produced from the available biomass in forested areas (i.e. all areas where AGB density was > 20 Mg C ha^{-1}). In order to convert from above-ground biomass (AGB) density (Mg C ha^{-1}) (i.e. the units of the biomass maps) to bags of charcoal, the following equation was used:

$$B = \frac{B_d FCPEK}{W} \quad \text{(Eq. 1)}$$

where the number of bags of charcoal (B) which could be produced in an area is a function of the summed biomass density (B_d , Mg C ha^{-1}), the fractional area of a pixel to a hectare (F), the amount of carbon in biomass (C, decimal percent), the percent of total biomass which is suitable for charcoal production (P, decimal percent), the kiln efficiency (E, decimal percent), conversion factor to convert to kg (K), and the weight of an average bag of charcoal (W, kg).

We convert from AGB in units of Mg C ha^{-1} to total AGB stocks in units of Mg C by multiplying the sum of AGB (Mg C ha^{-1}) by the fraction of one pixel to one hectare (38 m pixels is 0.1444 of a hectare), which gives the total stock of AGB (Mg C) in a query area. This total stock was corrected for re-sampling errors using a linear regression correction equation (see errors report for full details). We then convert AGB stocks from units of Mg C to Mg, by assuming 50 % of AGB is carbon (i.e. multiply by two). From ground measurements conducted in mature miombo woodland in the study site, it was determined that on average 83 % of total AGB in forested areas is of the preferred stem diameter (13-95 cm) for charcoal production. We therefore multiply the total AGB stock (Mg) by the percent of total AGB which is likely to be good for charcoal production (fractional percent 0.83). We did not take account of species preference, as the dominant decision parameter for selection of trees for charcoal production was dependent on tree stem size over species (Herd 2007). Finally, the estimated amount of biomass which is suitable for charcoal production is multiplied by the kiln conversion efficiency (17.6 % in the study site, or 0.176 fractional percent) to estimate the amount of charcoal (in tonnes) which could be produced in the query area, convert this value to kilograms of charcoal (multiply by 1000), and divide by the average weight (45 kg) of a charcoal bag.

Thereby, this calculation (Eq. 1) assumes that all suitable biomass in forested areas in the query area is converted to charcoal using the traditional earthen kiln method over a period of one year. This assumption is unrealistic in most cases, as producing charcoal is both a physical and time consuming activity. Furthermore, assuming 83% of all biomass is suitable for charcoal production based on stem size structures of mature woodlands is unrealistic, as it does not take account of variable woodland structures, past degradation or diminishing returns. Therefore, this calculation is likely to overestimate the number of bags of charcoal which will be produced in a given area and year, and should only be used as an indicator of resource availability in the study area. Areas which are remote or have little road access are not likely to be prime areas for charcoal production, and therefore this calculation is more suitable for areas which are within close (< 2 km) proximity to roads.

Applying errors on estimates

In order to provide some form of error estimate on calculations, we apply error associated with converting radar backscatter to AGB density values (see error report for full details). The AGB maps have a bias error of 1.6 Mg C ha^{-1}, and this error was applied on a per hectare basis (e.g. 100 ha will have an error of ±160 Mg C). When we sum AGB over several thousand pixels, we propagate this error, which can amount to several thousands of tonnes of error on AGB estimates. Therefore, we apply the error of 1.6 Mg C ha^{-1} to the calculations of charcoal potential as follows:

$$B_{error} = \frac{B_i HCEK}{W} \qquad \text{(Eq. 2)}$$

where the error on the number of bags of charcoal (B_{error}) in an area is a function of the measurement bias (B_i, Mg C ha^{-1}), the query area in hectares (H), the amount of carbon in biomass (C, decimal percent), the kiln efficiency (E, decimal percent), conversion factor to convert to kg (K), and the weight of an average bag of charcoal (W, kg).

Thereby we multiply the measurement bias of 1.6 Mg C ha^{-1} by the number of hectares in the query area, multiply by two to get tonnes of biomass (Mg) error, apply the kiln conversion efficiency (17.6 %) and divide the charcoal output in kg by the average weight of a charcoal bag (45 kg). This calculation then gives us the number of bags of charcoal which may be over or underestimated due to error on the biomass maps. We then apply this value as an error estimate (±) on the potential number of bag of charcoal which can be produced for a query area as above (Eq. 1).

Sustainable charcoal production potential

In order to estimate how much charcoal could be produced for an area sustainably, we need to consider the re-growth and recovery of miombo woodland from clearance and disturbance activities. A study conducted in miombo woodlands, which had been deforested due to charcoal production activities in Zambia, found an annual growth rate of 2-3 Mg ha^{-1} $year^{-1}$ of which 1.1 Mg ha^{-1} was cord wood suitable for charcoal production. Another study conducted in the Mozambican study region, in areas which had been cleared for agricultural fields, estimated an annual growth rate of 1.4 Mg ha^{-1} $year^{-1}$ (Williams et al. 2008). We can use these re-growth rates to estimate the amount of charcoal which could be sustainably extracted from a given area.

If we assume that the average growth rate of our study site is the same as the value reported in Williams et al (2008) of 1.4 Mg ha^{-1} $year^{-1}$, and we then assume that half of this growth will be cord wood suitable for charcoal production (as in the Chidumayo (1993) study), we get an estimated annual growth of sustainably extractable biomass for charcoal production of 0.7 Mg ha^{-1} $year^{-1}$. We can then extrapolate this estimate to the total wooded area (i.e. has biomass > 20 Mg C ha^{-1}) of the query area to estimate the total amount of biomass which can sustainably be harvested. We report this sustainable value in terms of number of bags of charcoal by multiplying the total amount of sustainably harvested biomass by kiln efficiency (0.176 fractional percent) and divide by the average weight of a charcoal bag (45 kg), as above (Eq. 1 and 2).

However, this sustainable extraction estimate assumes an equal extraction rate of 0.7 Mg ha^{-1} $year^{-1}$over the wooded area, which is unrealistic. Extraction for charcoal production is concentrated around the earthen kilns, and can almost completely deforest the area immediately surrounding the kiln. In order to allow this area to regenerate to its pre-disturbance level (i.e. > 20 Mg C ha^{-1}) it would have to be left to re-grow for approximately 30 years. Therefore, the number of bags of charcoal we estimate can be sustainable extracted for an area per year must also take account of the fact that extraction is spatially concentrated, and an appropriate rotation period of approx. 30 years would need to be applied to ensure the area is not degraded and resources are sustainably extracted. Evidence from the study site indicates that current extraction rates are unsustainable, as net biomass change shows a loss in most areas, particularly when in close proximity to the main road.

References

Ahrends A et al. (2010) Predictable waves of sequential forest degradation and biodiversity loss spreading from an African city. Proceedings of the National Academy of Sciences of the United States of America 107:14556-14561

Chidumayo EN (1991) Woody biomass structure and utilisation for charcoal production in a Zambian miombo woodland. Bioresource Technology 37: 43-52

Chidumayo EN (1993) Zambian charcoal production: miombo woodland recovery. Energy Policy: 586-597

DeFries RS, Rudel T, Uriarte M, Hansen M (2010) Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience 3:178-181

FAO (2011a) Highlights on wood charcoal: 2004-2009. FAO Forestry Department. FAOSTAT-ForesSTAT

FAO (2011b) Highlights on wood fuel: 2004-2009. FAO Forestry Department. FAOSTAT-ForesSTAT

Herd ARC (2007) Exploring the socio-economic role of charcoal and the potential for sustainable production in the chicale regulado, Mozambique. MSc thesis, School of GeoSciences, University of Edinburgh, Edinburgh

Hofstad O (1997) Woodland deforestation by charcoal supply to Dar es Salaam. Journal of Environmental Economics and Mangement 33:17-32

Luoga EJ, Witkowski ETF, Balkwill K (2002) Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. Forest Ecology and Management 164:15-30

Malimbwi RE, Zahabu E, Monela GC (2005) Charcoal potential of miombo woodlands at Kitulangalo, Tanzania. Journal of Tropical Forest Science 17:197-210

Williams M, Ryan CM, Rees RM, Sambane E, Fernando J, Grace J (2008) Carbon sequestration and biodiversity of re-growing miombo woodlands in Mozambique. Forest Ecology and Managment 254: 145-155