Tropentag 2016, Vienna, Austria
September 18-21, 2016

Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the University of Natural Resources and Life Sciences (BOKU Vienna), Austria

Urban green spaces and carbon sequestration in Kumasi, Ghana.

Bertrand Nero, Daniel Callo-Concha, Manfred Denich, and Christian Borgemeister[1]

[1]*Junior Researcher, Senior Researcher, Senior Researcher, and Professor, respectively, Center for Development Research, ZEF, University of Bonn, Email:* nerbefest@yahoo.com

Abstract
Urban green spaces (UGS) contribute to mitigate climate change impacts via carbon (C) sequestration and offer several co-benefits in cities. This contribution, however, is omitted in most national and regional C stock estimates, and related literature in the global south is – at best – fragmentary. Therefore, this paper quantifies and maps the distribution of UGS above and below-ground vegetation C pools in Kumasi, Ghana. Carbon stocks were estimated using allometric equations for trees and destructive sampling for crops and other herbaceous plants. Satellite imagery and GIS were used to map and extrapolate C stock estimates to a citywide scale. In the metropolitan area of Kumasi, a total of 2,180 Gg of C is stored above- and below-ground (roots). On average, 239 Mg C/ha is stored in trees and 1.3 Mg C/ha in crops, herbs, and grasses. Crops and herbs account for <1% of the total C stock. Vegetation carbon stocks differ among UGS types (p=0.0071). Natural forest, cemeteries, and public parks hold the highest C stocks per unit area (330 – 690 Mg C/ha). On the other hand, grasslands, farmlands and home gardens within the city contained the least C per unit area (50 – 110 Mg C/ha). Aboveground C stocks in Kumasi are quite enormous and sensitive to the UGS type. UGS should be accounted for in urban planning and included in national and regional C budgets. These findings complement the global C budget datasets and are relevant to urban climate change policy.

Keywords: Green spaces, satellite imagery, carbon, aboveground, Kumasi

Introduction

To keep global warming below 2°C relative to preindustrial era requires cutting emissions from fossil fuel consumption and better management of forest and agricultural landscapes. Cities, which are palpably warmer than rural landscapes and account for over 70 % of CO_2 emissions including other greenhouse gases (GHG) (OECD, 2014; UN-Habitat, 2011), are vital in cutting GHG emissions and hence reducing warming locally and globally. One dimension of cities contribution to this goal is adequate integration of green spaces into the city matrix. Urban green spaces (UGS), often recognized as part of nature based solutions, offer several co-benefits in addition to carbon (C) sequestration and climate regulation, are more efficient to maintain and are more resilient to stress and collapse slowly (European Commission, 2015).

However, whilst C sequestration and climate regulatory functions of urban vegetation (particularly trees) in cities in the global North have been thoroughly explored (Nowak and Crane, 2002; Davies et al., 2011; Strohbach and Haase, 2012), there is a conspicuous paucity of similar data from the global South. In addition, in Africa, national and regional C budget estimates typical neglect this contribution from cities (Henry et al., 2011). To fill these voids and help provide a more comprehensive perspective of the global urban budget, this study quantifies and maps the distribution of vegetation C storage in Kumasi, Ghana. More specifically, the study analyzes C storage differences among UGS types and urban zones in the city and maps its distribution using satellite imagery.

Material and Methods

Kumasi is located in south central Ghana (6° 41"N, 1° 37"W), has a population of about 2.5 million, and a land area of 254 Km^2. The mean annual rainfall and temperature are respectively, 1250 mm and 26.4°C. It is sited in the moist semi-deciduous high forest zone of Ghana with Haphic Alisols and Lithic Leptosols as the major soil types at the north and southern halves.

The city was divided into two based on normalized difference vegetation index, NDVI: Core or HDUZ area with mean NDVI < 0.11 and peri-urban or LDUZ area with mean NDVI > 0.11 Supervised classification was performed on a rapidEye image (May 2014) to generate 8 UGS types; plantations, natural forest, home gardens, institutional compounds, farms, cemeteries, public parks, and grasslands. Overall accuracy and kappa coefficient were respectively 62.3 ± 5.5 % and 0.56 with producer's and user's accuracies in the range of 45 – 99 %. Detailed description of supervised classification is presented in Nero, (2016). Sample points were randomly generated on the map for each UGS type within each urban zone using a stratified random sampling technique. Each point was visited on the ground with the aid of a GPS receiver. A 10 x 10 m quadrat was established on each sampling point (except in home gardens where the entire area was considered) with the help of a compass, a distance tape measure, and ranging poles. Within each plot, the height and diameter at breast height (DBH) of all trees with DBH > 5 cm were measured and identified to the species level. The area coverage of trees, bare ground, and grass/crops were also determined. On plots with grass and/or annual crops, a 1 x 1 m quadrat was randomly established and the vegetation within it clipped to ground level and conveyed to the laboratory for carbon determination. Biomass in trees was estimated using pan-tropical allometric equations (Chave et al., 2014) and converted to carbon using a factor of 0.474 (Martin and Thomas, 2011). Total plot C was expressed as C per unit area based on sound computational principles. Total C per UGS was determined as a function of C per unit area and the total area of the specified UGS type within the study area.

The monetary value of C sequestered was estimated as a function of the C stored and a factor of $135 per tonne of carbon (range = $ 40.4 – 187.2 Mg C^{-1}) based on the estimated social cost of C for 2013 with a 3 % discount rate (Interagency Working Group, 2013).

Results and Discussion

A total of 3,527 stems belonging to 2,755 trees were sampled from the 55 % green cover of the metropolitan area of Kumasi. Home gardens and institutional compounds account for 46 and 18 %, respectively of the total UGS area of the city. The UGS cover of Kumasi stores a total of 2,180,845 ± 26,572 Mg C (Table 1; Figure 1), equivalent to 239.3 Mg C/ha for UGS within the study area (and 111 ± 7.0 Mg C/ha for the entire metropolitan area covered in this study). More than 99 % of this total carbon is stored in trees, out of which 12 % is in the roots. Carbon stored in the aboveground (AGC) shoot (p = 0.0088) and belowground root carbon (BGC) (p = 0.0097) of trees is significantly different among UGS types in the city. Natural forest, cemeteries, and public parks which had a considerable proportion of large trees (higher DBH) and native species (with considerably higher specific wood gravity) had the highest carbon stocks per unit area (Table 1). On the other hand grasslands, home gardens, and farmlands which have either smaller sized trees or fewer trees per unit area had the least C stocks per unit area. Aboveground forest C storage varies markedly in the tropics (Bombelli et al., 2009) and in sub-Sahara Africa ranges between 202 - 208 Mg C/ha (Adu-Bredu et al., 2011; Kotto-Same et al., 1997). The findings of this study are also comparable to carbon stock analysis in cities in central Asia, Europe and North America and consistent with explanations that UGS carbon storage processes are influenced by multiple factors: the proportion of large trees, species composition and diversity (Nowak, 1993; Jo, 2002; Davies et al., 2011; Strohbach and Haase, 2012).

Table 1. Vegetation carbon storage partitioned between shoots (aboveground carbon, AGC) and roots (belowground carbon, BGC) in different green space types in Kumasi. Means within the same column followed by the same letter are not significantly different at alpha = 0.05. Numbers in parenthesis are standard errors.

UGS[1] type	**AGC (Mg C/ha)**	**BGC (Mg C/ha)**	**DBH (cm)**	**Stocking (#/ha)**	**Crops/Herbs (Mg C/ha)**	**Total carbon (Mg)**
Plantation	255.6b	36.0b	32.4b	761		333,390 (1,199)
Natural forest	617.9a	72.5a	54.5a	296		408,326 (5,730)
Home garden	71.2c	10.8c	33.6b	241	1.4	503,261 (11,775)
Institutional compound	228.5b	31.6b	61.8a	321		756,578 (4,069)
Farmlands	94.6c	13.1c	42.0b	204	1.5	77,645 (2,558)
Cemetery	291.2ab	38.3ab	51.0a	277	2.2	9,331 (233)
Public park	420.0ab	54.7ab	45.1ab	535		74,021 (80)
Grassland	41.9c	6.8c	35.1b	200	0.0005	18,294 (975)
Mean	211.3 (18)	28.8 (2)	44.6	377 (38)		
Total						2,180,846 (26,572)

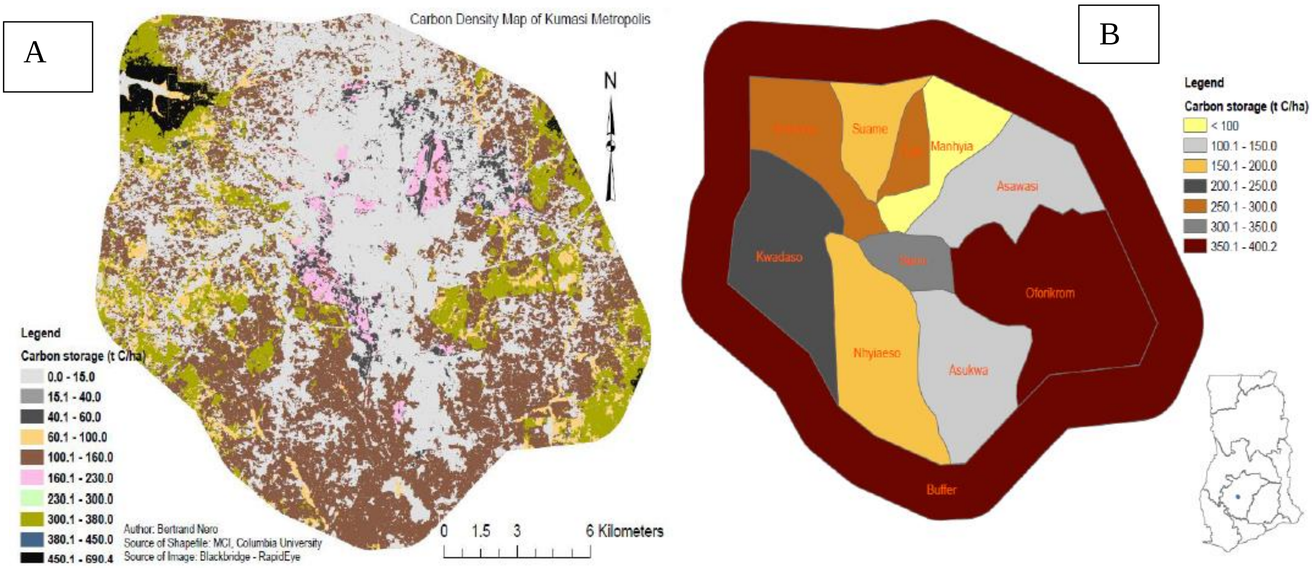

Figure 1. Pixel level aboveground (AGC) tree carbon storage (A) and submetropolis-level aboveground tree carbon storage (B) distribution map of Kumasi metropolitan area.

Mean above ground and belowground tree C storage in the LDUZ are statistically greater (p= 0.0121 and p=0.0115, respectively) than in the HDUZ. The distribution of the vegetation C is spatially uneven. Pixel-level C storage increases from the middle of the city to the peri-urban fringes (Figure 1A). Vegetation C storage ranges from 0 Mg C/ha in built-up areas, bare ground and roads to 690 Mg C/ha in the relics of natural forests found in the peri-urban fringes in riparian areas e.g. the Owabi Wildlife sanctuary behind Bantama (Figure 1). Submetropolitan UGS C storage also varies widely, with the buffer around the metropolitan assembly area having the highest C stocks per unit area (Figure 1B). Expectedly the city's periphery is less developed and comprises of residential housing (with large home gardens) which are far apart, hence the higher C stocks than in the core urban (HDUZ) area. However, the current rapid pace of sprawl into the perighery (LDUZ) of Kumasi renders this carbon sink susceptible to degradation and loss if not adequately managed and protected. The social cost of carbon (SCC) in the vegetation within Kumasi is valued at US$ 296,137,078.00, equivalent to a mean of US$ 32,600 per ha and distributed unevenly among the UGS types. This represents the value of the economic damages (e.g. flood risk damages, health impacts, changes in agricultural productivity) avoided by capturing CO_2 in the vegetation of Kumasi.

Conclusions and Outlook

Cities are undoubtedly major sources of GHGs but may also serve as sinks. For most developing countries, cities have typically been marginalized in national and regional C budget estimations. In the metropolitan area of Kumasi, 2.2 million t C is captured in living vegetation in both shoots and roots. Apparently UGS with relatively higher proportion of large-sized and native trees; natural forest, public parks, cemeteries had the highest C stocks per unit area. The peripheries also carried more C than the core urban area. Therefore, it is recommended that greening bare areas with trees in the HDUZ area while conserving existing tree cover in the LDUZ area should be integrated into and prioritized in urban planning. Considering that mean C stock of UGS in the city is similar to mean tropical forest C stock of Africa, the study provides baseline information for cities to be included in national and regional C budget estimates. Quantifying citywide emissions and estimating C storage in buildings, furniture, landfill sites and soils in cities in developing countries remains a grey area of research.

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