Riparian and stream forests carbon sequestration in the context of high anthropogenic disturbance in Togo

Fousseni FOLEGA[1*], Badabate DIWEDIGA[1], Reginald T. GUUROH[2], Kperkouma WALA[1], Koffi AKPAGANA[1]

[1] Géomatique et Modélisation des Ecosystèmes, Laboratoire de Botanique et Écologie Végétale, Département botanique, Faculté des sciences, Université de Lomé, Togo

[2] CSIR-Forestry Research Institute of Ghana, KNUST-Kumasi, Ghana

[*] Corresponding author
ffolegamez@live.fr

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Abstract

This research was carried out in order to estimate the amount of biomass available in riparian ecosystems of Sudanian areas in northern Togo. It aimed at evaluating the land cover pattern and the productivity of tree biomass. A field survey was carried out in order to sample trees' diameter (DBH ≥10 cm) and height using rectangular sample plots of 500 m^2. An allometric equation was used to compute above and below ground biomass. Landsat ETM+ image (193r053p20160327) was then used to map the major land use cover patterns followed by the computation of net primary production (NPP) of green vegetation in buffer areas around rivers and streams. For the total area sampled in riparian landscapes, the total biomass density was estimated as 196.8± 1.4 $t.ha^{-1}$. Tree species such as *Daniellia oliveri* (32.7 ± 0.58 $t.ha^{-1}$) contributed a high proportion of the total biomass. Significant trees total biomass was found in the forest (157.8±40.7 $kg.ha^{-1}$) and savanna (122.0±21.64 $kg.ha^{-1}$) ecosystem. Five major land use cover patterns (forests, savannas, fallows-croplands, sparse vegetation-barren land and wetlands-rivers) were defined. Savannas (304 450 ± 1572.6 ha) and fallows-croplands (65 339 ± 456.3 ha) represent important land use. The NPP for the investigated zone was estimated at 1 249 294 ± 267.0 g C m^{-2} y^{-1}. However, forest (8708.1 ± 243.4 g C m^{-2} y^{-1}) and savanna (3821.0 ± 86.2 g C m^{-2} y^{-1}) accumulate more atmospheric carbon dioxide. The study showed that high important values of total plant biomass were located in forest ecosystems. The research in the current situation could be useful in the framework of UNFCC programs such as REDD+ and NAMA.

Keywords: Biomass, NPP, carbon sequestration, land cover, riparian ecosystem, Togo

INTRODUCTION

Biomass carbon stock constitutes an important link between living organisms and their environment. Both are involved in a complex process of nutrient cycling which is mainly concerned with carbon amount exchange. The land use practices and rapid industrialization in western countries during the 19th and 20th centuries and in emerging economies since the end of the 20th century have had many negative effects on the earth's carbon cycle (Thompson *et al.*, 2009). An important consequence is an increase of the atmospheric carbon concentration which, according to IPCC 2007 (Solomon, 2007), was approximately 36% higher in 2005 than in 1750. In 2009, the amount of carbon dioxide in the air was estimated at 387 ppm. From 1960 to 2005 the annual rate of increase was about 1.4 ppm y^{-1}. Stabilizing the concentration of atmospheric CO_2 became a matter of great concern because of the impact of this greenhouse gas on climate change and global warming.

Tropical and subtropical forest ecosystems with their 138 millions km^2 area worldwide have the greatest potential of sequestering and storing large amounts of carbon, greatly exceeding the potential of other biomes. Their contribution to the global carbon cycle is mainly due to their high net primary production that can be generated over time. For this high potential to mitigate carbon, the tropical forests store about 471 Pg C, higher than what is stored in the boreal and temperate forests (boreal: 272 Pg C, temperate: 119 Pg C) (Bonan, 2008; Pan *et al.*, 2011). 37% of the 90% of carbon stored in terrestrial ecosystems is sequestered by tropical forests. The majority of tropical forests do not reach maximum potential level of biomass density because of prevailing cultural and logging disturbances. However, variations in topography, hydrology, and edaphic features (soil nutrient availability) may also affect the tropical zone's stand biomass density over a local or regional scale. The reforestation and afforestation of the degraded areas may have led to an increase in the rate of carbon uptake by biomass in living plants (Mani et Parthasarathy, 2007; Baishya *et al.*, 2009; Juwarkar *et al.*, 2011).

West African forests are declining sharply; Togo (5.75%), Nigeria (4.0%), Ghana (2.2%) and Liberia (0.55%) are quoted among those countries which faced a high annual deforestation rate from 2000 and 2010. The West African tropical Sudanian zone is mainly covered by savanna which is very heterogeneous and divided by rivers and streams, thus creating linear strips of riparian vegetation. Despite their small, patch-like size, these areas are highly complex productive systems with great ecological, social, and economic value. Although they have been classified as endangered ecosystems; the riparian forests in the Sudanian zone continue to be threatened by human interference like deforestation, land-clearing, farming and by civil engineering works such as dam-building and hydroelectric developments (Sambaré *et al.*, 2011; Fousseni *et al.*, 2012). Those threats listed above have a severe impact on the performance of these unique wooded ecosystems which remain the most important pool of carbon storage in the savanna landscape.

In Togo, previous research activities have mainly focused on forest diversity assessment, including the identification of forest major plant community patterns and their structure (Fousseni *et al.*, 2010; Fousseni *et al.*, 2011). Few quantitative studies about forest productivity, forest performances in atmospheric carbon uptake at a local or national level were carried out. Examples include the research done on Atakora Mountain, in Lome city and the reserve of fauna of Abdoulaye (Pereki *et al.*, 2013; Folega *et al.*, 2015; Folega *et al.*, 2019). The lack of data on natural forests and afforested/reforested areas with respect to carbon sequestration may represent a great handicap for the country when trying to optimize its carbon credit gain through the clean development mechanism (CDM). This research aims to estimate the biomass and the carbon stock in riparian forests in Togo, particularly in the dry savanna ecological zone. In this study, we propose three methods to determine the living plant productivity: by field tree sample measurement, by remote sensing data and by the major land cover patterns existing in the landscape.

MATERIALS AND METHODS

Study area

The study area belongs to the tropical Sudanian zone and is located between latitude 11°N and 9°N, and between longitude 0°E and 1°E. The area is surrounded by the northern plains and is mostly covered with spiny and Combretaceae savanna vegetation, with some shrubs in the riparian and stream forests. The riparian and stream ecosystems occur in this region along the Oti, Ouale, Koumongou, Kara, Komkoumbou, Gambara, Wapoti, Yaweni, Yemboure, Namiele, Kambouanga, Siambouanga, Ouandegue, Koupoa, and Keran river banks (Fousseni *et al.*, 2014).

The soils are mostly deep and are composed of muddy, clayey and sandy soils. Recent research has shown that the riparian forests in this landscape grow on the banks of the meandering rivers (Folega *et al.*, 2014a). The width of these embankments is about 50 m on either side of the rivers. The following plant species; *Pterocarpus santalinoïdes* L'Hér. ex DC., *Cola laurifolia* Mast., *Vitex madiensis* Oliv., *Mitragyna inermis (*Willd.*)* K.Schum., *Eugenia kerstingii* Engl. & Brehmer, *Parinari curatellifolia* Planch. ex Benth., *Diospyros mespiliformis* Hochst. ex A.DC., *Vitex simplicifolia* Oliv., *Margaritaria discoidea* var. triplosphaera, *Daniellia oliveri* (Rolfe*)* Hutch. and Dalziel, and *Ficus capreaeifolia* Del. were quoted to be frequent in the area (Folega *et al.*, 2014a; Folega *et al.*, 2014b; Fousseni *et al.*, 2014). Out of the 122 plant species determined as the main species found in the area, the average height of trees was 17.5 m, although alpha diversity in the riparian forest of this region is 6.40 ± 0.0021 and 0.92 ± 0.0003 bits respectively for the Shannon index and Pielou evenness (Fousseni *et al.*, 2011; Fousseni, 2012; Folega *et al.*, 2014b).

The riparian forest in this savanna area is affected mostly by high anthropogenic pressure, in the context of the Sudanese tropical climate variability, characterized by an alternation of a long dry season and a short rainy season. The mean annual rainfall is equal to 1076 mm, 1065 mm, 977 mm, 958 mm for the Mango, Takpamba, Barkoissi, and Borgou localities respectively. However, temperatures are between 20 and 35°C, according to the Mango meteorological station (Fousseni, 2012; Fousseni *et al.*, 2012). The major ethnic groups occupying this area include Bassar, Gourmantche, Gnande, Fulani, Kabye, Komkomba, Lamba, Moba, Mossi, Nawda, Ngamgam, Tamberma, Tchokossi, Tem and Yanga. The main economic activities are agriculture, pastoralism, transhumance and harvest of forest products. The main crop species are sorghum (*Sorghum bicolor* (L.) Moench), millet (*Pennisetum americanum* (L.) Leeke), peanut (*Arachis hypogaea* L.), cowpeas (*Vigna unguiculata* (L.) Walp.), maize (*Zea mays* L.) and yams (*Dioscorea ssp.*). Livestock includes poultry, caprine, cattle, donkey and sheep.

Riparian and stream zone design for ecosystem inventory

Three buffer zone systems are always recommended to describe the riparian and stream ecosystems. The three zones consist of native riparian vegetation (trees and shrubs) located adjacent to stream banks (Zone 1), forest zones immediately upslope from Zone 1 (Zone 2) and herbaceous filter strips located upslope from Zone 2 (Zone 3). The width defined by several authors depends on the function that planners aim to achieve by a riparian ecosystem in a typical context of environmental issues. Most forest agencies set riparian forest widths between 10 and 30 m (Lowrance *et al.*, 1997; Broadmeadow et Nisbet, 2004). Naiman *et al.* (1993) defined the width of the vegetation which evolved around a stream to be wider than 50 yards (45.72 m), which is also a suitable distance for ecosystem component functions and interactions. However, Broadmeadow and Nisbet (2004) reported in a review of best management practice of riparian forests, that by defining more than 100 m as a buffer zone, the riparian forest could play a more complete function (from denitrification to large woody debris and leaf litter supplier).

The connection of riparian woodland to surrounding and adjacent semi natural vegetation can create a network of wildlife corridors. For this study, the meandering state of the hydrographic network in the landscape, the presence of oxbow rivers and permanent ponds at a distance of about 1000 m from the main watercourse and taking into account the three buffer zones and some semi natural vegetation directly linked to the riparian area, have led us to select 2000 m as the width of the investigation area. To extract the riparian areas of the study zone, a buffer algorithm was applied to the rivers mentioned in the above section by means of ArcGIS. The map of Togo (IGN, 1991) was used to digitize the shapefile of the study area after geo-referencing under WGS (World Geodetic System) 1984 datum and UTM (Universal Transverse Mercator) zone 31 projections. The shapefile generated from this process was then used by a particular masking technique to extract the riparian zone from the remote sensing data. The remote sensing data employed consists of 2016 Landsat OLI8 (Operational Land Imager) image. This image is represented by the path 193, row 053, and spatial resolution of 30 m, acquired on 27/03/2016.

Data collection and processing

Above ground biomass

As defined above, the investigation zone spans across the riparian forest. To measure the above ground biomass (AGB) of a forest sanctuary in the tropical Sudanian savannah ecosystem, the field random quadrat sampling technique based on the Braun-Blanquet (Westhoff and van der Maarel, 1978) concept was employed. A total of 108 50x10 m plots were installed along the rivers. Rectangular and stretched plots were preferred, for practical reasons, to fit any shape of watershed and forest structural uniformity (Sambaré *et al.*, 2011). The height and diameter of all trees with Diameter at Breast Height (DBH) $\geq$ 10 cm (1.3 m) within the plots were measured. Trees with DBH < 10 cm were not measured because they normally contribute only a small proportion of total biomass in an area (Juwarkar *et al.*, 2011). Sample plots were only installed on the riverside which belongs to the territory of Togo.

Before applying a standard allometric equation to estimate the biomass, the data regarding the 2093 sampled trees was pre-processed in order to compute the basal area and find any correlation between DBH, basal area and height.

Several standard allometric equations have so far been developed to ensure easy above ground biomass computation from tree diameter, height, basal area, and existing volume data. These previously published equations include the equations of Brown (1997), developed for tropical trees from multi data set collected in different tropical countries and at different times. Another allometric equation was developed according to the pan-tropical trees allometric equation suggested by Chave *et al.,* (2005). For the current study, the allometric equations developed by Brown (1997), based on trees DBH and basal areas, were preferred to estimate above ground biomass of this threatened landscape. These equations were designed for tropical dry areas and were chosen for our study because our study area receives annual rainfall higher than 900 mm thus fitting well with the recommendation of Brown (1997).

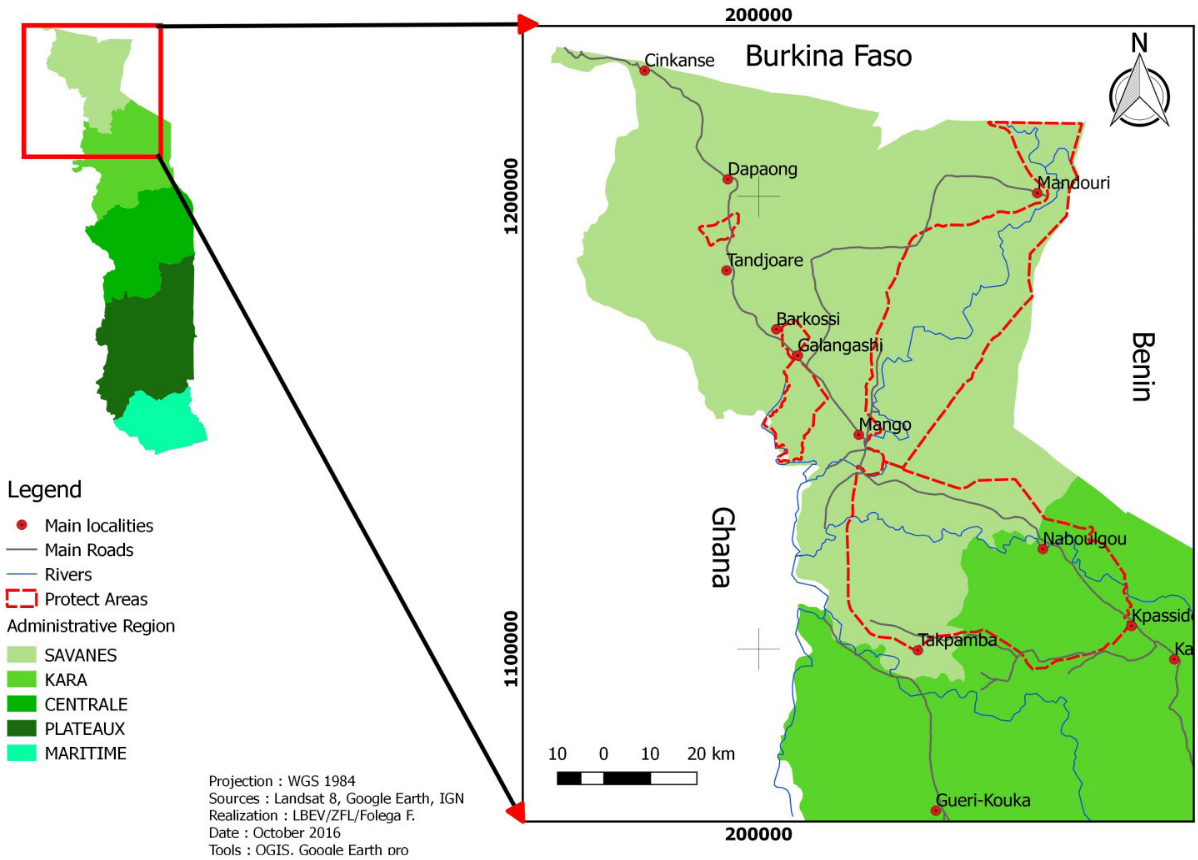

Figure 1. Study area design

The following equation was used to compute the above ground biomass (AGB):

$$Y = exp\,(-1.996 + 2.32\,ln\,(DBH))$$

Where Y is the biomass in kilograms, ln is natural logarithm, and DBH is diameter at breast height in centimeters.

As our study aims to estimate the carbon sequestration of living trees, the below ground biomass (BGB) needs to be estimated. Allometric relationships with DBH are useful for estimating biomass of both above and below ground components of trees. A ratio of 0.26 for below ground biomass/above ground biomass was found (Juwarkar *et al.*, 2011). Hence to obtain the below ground biomass of a tree, we multiplied the above ground biomass by this 0.26 (Juwarkar *et al.*, 2011).

Land cover assessment

For land cover analysis, a supervised classification was applied to a subset of the study area image from the Landsat OLI8 scene (193p053r dated 27/03/2016). The algorithm employed was that of maximum likelihood classification technique (MLC), because it can improve the accuracy of the classification. For classification purposes, five land classes were distinguished as major land cover types, according to their occurrence in the landscape as observed during field work. These land cover types include Forest lands (FL), Savannahs (Sa), Fallows-Croplands (FC), Sparse vegetation-Barren lands (Sv-Bl) and Wetlands-Rivers (WR). The choice of these classes followed mainly the buffer system around watersheds as defined in previous research works (Lowrance *et al.*, 1997; Broadmeadow and Nisbet, 2004). The land cover type follows the national classification systems which are mainly derived from the IPCC and FAO systems. The 112 GPS points obtained from vegetation sampling were used to define a training site and to compute the accuracy assessment. This batch of data had been implemented by previous land use research data as a general map of Togo of ING (1991) and Google Earth online resource data. The overall accuracy and Kappa statistical analysis, which are the key factors in classification confidence, were then computed.

Biomass estimation by remote sensing

To ensure the computation of biomass in the study areas using remote sensing data, an atmospheric scattering and haze reduction processing were applied to the Landsat ETM+ scene, which has been used to assess land cover analysis. These kinds of image preprocessing techniques are highly recommended if the remote sensing data is to be used for computing band ratios (Chavez, 1996). The atmospheric correction was achieved by using ATCOR 3 as add-on module to the image processing software ERDAS IMAGINE. The Carnegie Ames Stanford Approach (CASA) and Surface Energy Balance Algorithm for Land (SEBAL) models (Bastiaanssen and Ali, 2003) which belong to process based-models were employed to evaluate the net primary productivity (NPP) of the riparian ecosystem. NPP commonly expressed in $gC/m^2/yr$, is defined as the net amount of new carbon absorbed by plants per unit area and unit time, from which the autotrophic mass is deducted (Zhou *et al.*, 2007). This is necessary for understanding the carbon cycle of the terrestrial biosphere. The NPP computation from CASA and SEBAL model is mainly dependent on the plant's absorbed photosynthetically active radiation (APAR) and the light use efficiency factor (LUE) and follows the equation below:

$$NPP = APAR \times LUE \quad (1)$$

The equation (1) can also be further developed as follows (2):

$$NPP = FPAR \times PAR \times LUE \quad (2)$$

Where, FPAR is the fraction of incident photosynthetically active radiation, PAR the photosynthetically active radiation.

The product of PAR and FPAR determines the amount of PAR absorbed by vegetation (APAR, MJ/m^2). The PAR is a constant and is defined for clear sky and Tropical countries to be 0.51 (Christensen and Goudriaan, 1993). However, the FPAR calculation is mostly derived from the normalized difference vegetation index (NDVI) and the simple ratio vegetation index (SR):

$$NDVI = (\rho NIR - \rho R)/(\rho NIR + \rho R) \quad (3)$$

$$SR = (1 + NDVI)/(1 - NDVI) \quad (4)$$

$$FPAR_{NDVI} = [(NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})] \times (FPAR_{max} - FPAR_{min}) + FPAR_{min} \quad (5)$$

$$FPAR_{SR} = [(SR - SR_{min})/(SR_{max} - SR_{min})] \times (FPAR_{max} - FPAR_{min}) + FPAR_{min} \quad (6)$$

$$FPAR = (FPAR_{NDVI} + FPAR_{SR})/2 \quad (7)$$

$FPAR_{max}$ and $FPAR_{min}$ are respectively assumed to be 0.95 and 0.001.

$$LUE = T_{\varepsilon 1} \times T_{\varepsilon 2} \times W_{\varepsilon} \times \varepsilon^* \quad (8)$$

Where $T_{\varepsilon 1}$ and $T_{\varepsilon 2}$ relate to plant growth regulation (acclimation) by temperature, W_{ε} is the evaporative fraction, and ε^* the light use efficiency.

The temperature stress factors are computed as below:

$$T_{\varepsilon 1} = 0.8 + 0.02T_{opt} - 0.0005T_{opt}^2 \quad (9)$$

$$T_{\varepsilon 2} = 1.1919/\{1 + e^{[0.2(T_{opt}-10-T)]}\}/\{1 + e^{[0.3(-Topt-10+T)]}\} \quad (10)$$

$T_{\varepsilon 1}$ is related to the mean temperature during the month of maximum NDVI, while $T_{\varepsilon 2}$ is related to the mean temperature during the month of maximum NDVI, which is August and to mean monthly air temperature.

The water stress factor which reflects the water use by plants in concordance with the solar energy conversion incidence effect is calculated as follows.

$$W_{\varepsilon} = 0.5 + 0.5(EET/PET) \quad (11)$$

Where PET is the potential evapotranspiration and EET is the estimated evapotranspiration.

Based on CASA model, the optimal value of maximum possible light utilization efficiency or maximum solar energy conversion rate (ε*) is estimated to be 0.389 gC.MJ^{-1}. The solar energy conversion rate ε* is the fraction of the energy fixed by a living plant and the absorbed energy is converted into carbon (Los *et al.*, 1994; Field *et al.*, 1998; Bastiaanssen et Ali, 2003).

RESULTS

Biomass estimation by allometric equations

The 2093 individual trees sampled throughout the 108 forest plots along the rivers belong to eighty plant species. The average structure parameters for the batch of data were equal to 10.2 m, 21.2 cm, 5 n.ha^{-1} and 24.2 m^2.ha^{-1} respectively for tree height, diameter, density and basal area. The above ground biomass (AGB) was estimated to be 156.1 t.ha^{-1}, while the below ground biomass (BGB) derived from AGB was 40.7 t.ha^{-1}.

Ten species, by their abundance in the landscape and/or their mature state, accumulated around 158.1± 3.59 t.ha^{-1} of total computed biomass (Table 1). These species are *D. oliveri* (32.7 ± 0.58 t.ha^{-1}), *E. kerstingii* (30.1 ± 1.38 t.ha^{-1}), *Anogeissus leiocarpa* (25.1 ± 0.006 t.ha^{-1}), *P. santalinoïdes* (23.6 ± 0.005 t.ha^{-1}), *M. inermis* (18.1 ± 0.03 t.ha^{-1}), *C. laurifolia* (8.27 ± 0.008 t.ha^{-1}), *Celtis integrifolia* (6.83 ± 0.22 t.ha^{-1}), *P. erinaceus* (5.04 ± 0.0009 t.ha^{-1}), *Cynometra megalophylla* (4.24 ± 0.08 t.ha^{-1}) and *Diospyros mespiliformis* (4.23 ± 0.04 t.ha^{-1}).

Based on field observation and computed tree species density, 41 individuals (DBH ≥ 10 cm) of *D. oliveri* (7.5 n.ha^{-1}) had an average of 0.39 ± 0.29 t.ha^{-1} as accumulated organic carbon. However *P. santalinoïdes* (75 n.ha^{-1}), *A. leiocarpa* (59 n.ha^{-1}), *M. inermis* (33 n.ha^{-1}), *E. kerstingii* (28 n.ha^{-1}) and *C. laurifolia* (25 n.ha^{-1}) respectively had an accumulated organic carbon of 0.2 ± 0.002 t.ha^{-1}, 0.039 ± 0.0003 t.ha^{-1}, 0.04 ± 0.01 t.ha^{-1}, 0.09 ± 0.69 t.ha^{-1} and 0.02 ± 0.004 t.ha^{-1} (Table 1).

We found a correlation between tree height class, diameter class and total biomass. For height classes of [15-19.99], [20-24.99] and [25-29.99], the mean DBH and biomass are higher. However, for the same height classes, the total biomass values were respectively 64.8 t.ha^{-1}, 18.4 t.ha^{-1} and, 4.3 t.ha^{-1}. In spite of the low mean biomass per tree of trees within small height/diameter classes, their contribution to the total biomass of the area was significant due to their high abundance. For [10-14.99] class, the average biomass amount was 0.09 t.ha^{-1} while the total was 75.5 t.ha^{-1}.

Land use coverage and net primary productivity of green vegetation

The overall accuracy classification was found to be 95.0% after the accuracy assessment process. With an overall Kappa statistic of 0.8093 (80.9%) the accuracy of the land cover map (Figure 2) was excellent. When looking at the 2000 m defined as a buffer zone around the rivers, the area covers a total of 382 120 ha. This area is unequally divided up between the different land cover types.

The forest ecosystems composed mostly of the riparian forest and its adjacent dry forest and swampy forest representing 9427.3±12.52 ha. The savanna ecosystems, mostly dominated by trees and shrubs, represents 65339.5±456.3 ha while Fallows-Croplands which are composed of 304 450.2 ± 1572.6 ha (Figure 2) express the degree of anthropization of the landscape and are very pronounced in the northern part. Other land uses, such as Sparse vegetation-Barren lands and wetlands, which represent 2898.9±112.2 ha includes major human settlements (urban cities and counties), temporal bounds and seasonally flooded lands. The wetlands are characterized by permanent ponds and rivers whose flow sharply decreases in the dry season.

For the defined buffer zone around the rivers, the net primary production by the green vegetation component was unequally and spatially distributed (Figure 3). The NPP distribution map is well in line with the land use cover map (Figure 2). The more dark green a given area is, the more it produces biomass and sequesters atmospheric carbon into organic matter (Figure 3). The total net primary production generated by living plants in the area was estimated to be 1300000 ± 300 gCm^{-2}y^{-1} which is equivalent to 630000 ± 133 gCm^{-2}y^{-1} of atmospheric carbon sequestrated by this living vegetation.

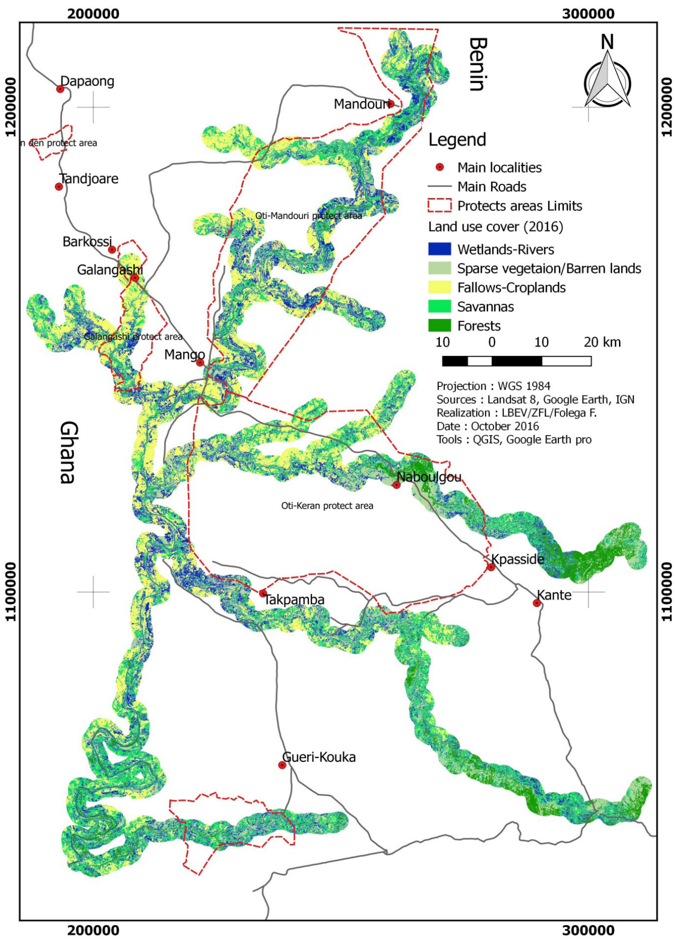

Figure 2: Major land use cover types around rivers and ponds

Table 1. Summary of biomass and forest structure information

Species	H(m)	DBH (Cm)	D(n/ha)	BA(m/ha)	TB(t/ha)	CB(t/ha)
Acacia dudgeonii Craib ex Holland	2.50	6.21	0.37	0.01	0.005	0.01
Acacia flava (Forssk.) Schweinf.	4.99	14.29	4.26	0.41	0.41	0.82
Acacia gourmaensis A.Chev.	5.92	15.52	1.85	0.27	0.32	0.63
Acacia polyacantha Willd.	7.73	23.35	4.07	1.39	1.83	3.67
Adansonia digitata L.	14.00	76.91	0.37	0.97	1.62	3.24
Afzelia africana Sm. ex Pers.	15.00	30.25	0.19	0.07	0.09	0.17
Anacardium occidentale L.	8.25	16.88	0.74	0.09	0.09	0.18
Annona glauca Schumach. & Thonn.	1.50	4.99	0.56	0.01	0.00	0.01
Anogeissus leiocarpa (DC.)Guill. and Perr.	13.37	24.41	59.07	19.51	25.05	50.10
Argocoffeopsis rupestris (Hiern)Robbr.	6.89	18.02	1.67	0.33	0.39	0.79
Azadirachta indica A.Juss.	7.27	19.34	2.04	0.60	0.80	1.60
Balanites aegyptiaca (L.) Delile	4.63	18.79	1.30	0.20	0.22	0.43
Bombax costatum Pellegr. and Vuill.	9.51	32.51	2.04	1.10	1.47	2.95
Bridelia ferruginea Benth.	8.14	13.35	2.04	0.17	0.16	0.33
Canthium multiflorum (Schumach. & Thonn.) Hiern	4.00	10.51	0.19	0.01	0.01	0.01
Celtis integrifolia Lam.	21.17	68.76	1.67	4.02	6.83	13.66
Cola laurifolia Mast.	11.74	22.68	25.56	6.77	8.27	16.54
Combretum acutum M.A.Lawson	8.33	23.72	0.56	0.21	0.29	0.57
Combretum glutinosum Perr. ex DC.	3.95	11.07	3.89	0.50	0.66	1.33
Combretum micranthum G.Don.	3.00	7.49	1.85	0.05	0.04	0.08
Combretum paniculatum Vent.	6.20	12.74	0.93	0.07	0.07	0.14
Combretum molle R.Br. ex G.Don	3.39	7.78	3.33	0.10	0.08	0.17
Crateva adansonii DC. subsp. adansonii	7.78	18.71	4.26	0.82	0.97	1.94
Crossopteryx febrifuga (Afzel. ex G.Don) Benth.	7.00	14.94	0.74	0.07	0.07	0.14
Cussonia kirkii Seem.	6.00	17.83	0.37	0.07	0.08	0.16
Cynometra megalophylla Harms	10.62	33.98	4.07	2.83	4.24	8.49
Daniellia oliveri (Rolfe)Hutch. and Dalziel	13.82	46.90	7.59	15.15	32.65	65.31
Detarium microcarpum Guill. & Perr.	2.00	4.46	0.93	0.01	0.01	0.01
Diospyros mespiliformis Hochst. ex A.DC.	11.11	23.17	8.15	2.97	4.23	8.46
Entada abyssinica Steud. ex A.Rich.	4.64	10.05	1.30	0.08	0.08	0.16
Entada africana Guill. and Perr.	9.00	23.10	0.56	0.13	0.15	0.29
Eugenia kerstingii Engl. & Brehmer	10.63	23.92	28.33	16.01	30.11	60.22
Faidherbia albida (Delile) A.Chev.	17.33	76.65	0.56	1.43	2.35	4.70
Feretia apodanthera Delile Ssp. apodanthera	2.00	3.82	0.19	0.00	0.001	0.001
Ficus capreaeifolia Del.	14.66	11.04	2.78	0.15	0.13	0.26
Ficus exasperata Vahl	10.50	19.97	0.37	0.07	0.08	0.16
Ficus sycomorus L.	8.40	37.20	0.93	0.68	0.96	1.92
Gardenia aqualla Stapf & Hutch.	1.13	5.89	0.37	0.01	0.005	0.01
Gardenia erubescens Stapf & Hutch.	1.96	8.92	1.85	0.07	0.06	0.13
Gardenia ternifolia Schum. and Thonn.	2.00	8.28	0.56	0.02	0.01	0.03
Grewia venusta Fresen.	3.88	8.12	0.74	0.02	0.02	0.04
Isoberlinia doka Craib and Stapf	9.18	25.02	0.56	0.15	0.18	0.36
Khaya senegalensis (Desr.)A.Juss.	15.00	82.80	0.19	0.54	0.89	1.79
Kigelia africana (Lam.) Benth. subsp. africana	11.50	43.14	0.74	0.70	1.02	2.03
Lannea acida A.Rich.	5.75	31.70	2.04	1.16	1.58	3.17
Lannea barteri (Oliv.) Engl.	13.33	41.05	1.67	1.47	2.16	4.32
Lannea microcarpa Engl. and K.Krause	6.40	25.62	1.85	0.59	0.72	1.44
Lonchocarpus sericeus (Poir.)Kunth ex DC.	7.08	17.76	1.11	0.18	0.20	0.41
Margaritaria discoidea var. triplosphaera Radcl.-Sm.	15.17	18.65	3.89	0.70	0.80	1.59
Maytenus senegalensis (Lam.) Exell	1.95	5.41	0.93	0.01	0.01	0.02
Mitragyna inermis (Willd.) K.Schum.	9.91	24.31	33.70	12.57	18.08	36.15
Sarcocephalus latifolius (Sm.) E.A.Bruce	5.40	14.63	3.70	0.45	0.49	0.98
Parinari curatellifolia Planch. ex Benth.	20.88	31.68	4.07	2.44	3.48	6.95
Parkia biglobosa (Jacq.)R.Br. ex G.Don f.	15.56	35.26	3.15	1.78	2.32	4.65
Pericopsis laxiflora (Benth.) Meeuwen	6.00	13.06	0.19	0.01	0.01	0.02
Piliostigma thonningii (Schumach.)Milne-Redh.	3.99	10.14	5.93	0.33	0.32	0.65
Prosopis africana (Guill. and Perr.)Taub.	8.58	16.39	2.41	0.32	0.34	0.68
Pseudocedrela kotschyi (Schweinf.) Harms	7.12	17.97	0.74	0.13	0.15	0.30
Pteleopsis suberosa Engl. and Diels	2.63	6.05	0.74	0.01	0.01	0.02
Pterocarpus erinaceus Poir	9.92	23.24	13.70	4.05	5.04	10.08
Pterocarpus santalinoïdes L'Hér. ex DC.	11.22	20.92	75.00	18.74	23.55	47.11
Sclerocarya birrea (A.Rich.) Hochst. subsp. birrea	6.94	16.90	3.33	0.46	0.48	0.97
Securidaca longipedunculata Fresen.	4.00	10.83	0.19	0.01	0.01	0.02
Sterculia setigera Delile	11.20	36.27	1.85	1.21	1.67	3.33
Stereospermum kunthianum Cham. var. kunthianum	7.00	15.93	0.93	0.12	0.12	0.24
Strychnos nigritana Baker	7.00	8.60	0.56	0.02	0.01	0.03
Strychnos spinosa Lam.	3.33	7.75	0.56	0.02	0.01	0.02
Tamarindus indica L.	12.31	38.45	0.74	0.48	0.63	1.25
Terminalia avicennioides Guill. & Perr.	8.00	24.52	0.37	0.10	0.12	0.24
Terminalia glaucescens Planch. ex Benth.	11.14	25.89	1.30	0.50	0.66	1.32
Terminalia laxiflora Engl. and Diels	7.13	14.67	4.26	0.50	0.55	1.10
Terminalia macroptera Guill. and Perr.	6.28	21.25	6.11	1.64	2.10	4.20
Trema orientalis (L.)Blume	2.00	3.50	1.48	0.01	0.005	0.01
Vitellaria paradoxa C.F.Gaertn.	6.13	17.97	7.78	1.52	1.83	3.65
Vitex madiensis Oliv.	7.58	14.65	14.44	1.48	1.50	3.01
Vitex doniana Sweet	7.77	20.13	2.41	0.50	0.58	1.15
Vitex simplicifolia Oliv.	2.00	4.46	0.19	0.00	0.001	0.002
Xeroderris stuhlmannii (Taub.) Mendonça & E.C.Sousa	15.00	35.03	0.19	0.10	0.12	0.24
Ziziphus abyssinica Hochst.	4.00	8.01	0.37	0.01	0.01	0.02
Ziziphus mucronata Willd.	3.00	5.67	0.93	0.01	0.01	0.02

H (m): Average tree height, DBH (Cm): average tree diameter, D (n.ha^{-1}): tree species density, BA (m^2.ha^{-1}): Species average basal area TB (t.ha^{-1}): species total biomass and TC (t.ha^{-1}): species Total carbon

By sorting pixel area quantitatively on both NPP and land use map, the following findings are observed. The dark green areas correspond mostly to forestlands where plant photosynthetic activities are generally important. Forest lands accumulate 1 097 225 ± 243.4 $gCm^{-2}y^{-1}$ while savannas in general store a total amount of 84 061.7± 86.25 $gCm^{-2}y^{-1}$ of atmospheric CO_2. The Fallows-Croplands shows significant NPP values, which are estimated to be 52111.8± 84.3 $gCm^{-2}y^{-1}$. Other land uses such as mosaic Sparse vegetation-Barren lands and wetlands has an NPP estimated at 15895.6± 84.1 $gCm^{-2}y^{-1}$.

We found a strong correlation between biomass computed from sampled trees, and the net primary productivity (Table 2). Higher values of total plant biomass were located in forest ecosystems dominated by a stream and dry forest. The mean density of total biomass and NPP was respectively 157.8±40.7 kg/ha and 8708.1±243.4 $gCm^{-2}y^{-1}$. This was followed by savannas and fallows-croplands ecosystems. The total amount of biomass and carbon sink in other land uses (sparse vegetation-barren land and wetlands) were fewer compared to other land uses mentioned above. Thus, the more conserved an ecosystem is and the closer the canopy cover, the higher its capacity to accumulate organic matters. Despite the unequal distribution of biomass and areas among the mapped ecosystem, sampled tree structure parameters (tree diameter, and height) are quietly equal in both five major land use cover surveyed in the buffer zone.

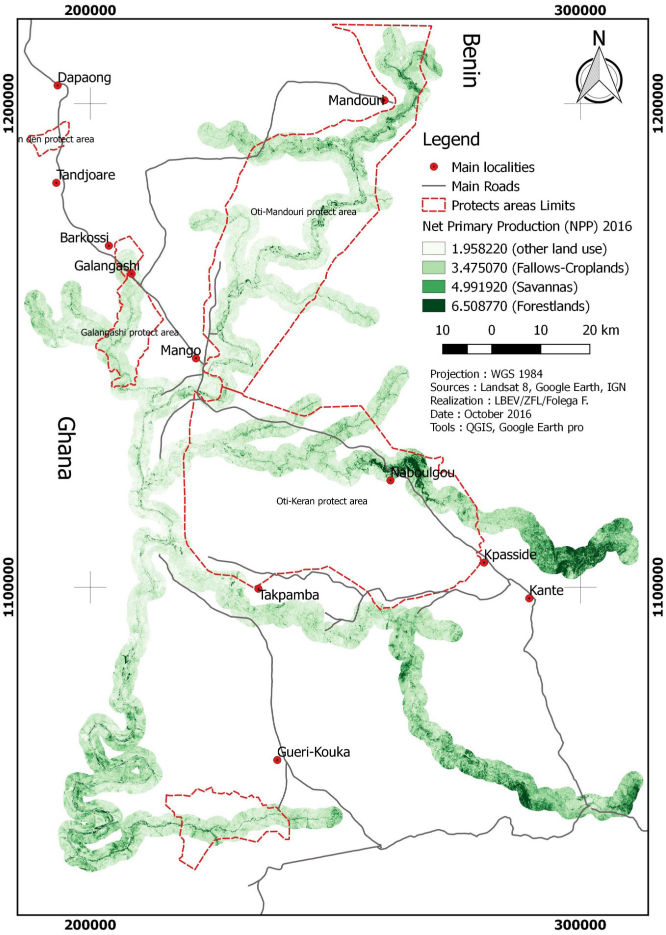

Figure 3: Net primary productivity, spatial distribution

DISCUSSION

The research allowed measuring of 2093 individual tree species within 108 forest samples along the rivers and ponds in the northern (savanna) zone of Togo. This number is less than that obtained during the sampling of wooded vegetation in protected areas (170 forest samples) in the same region. In the landscape, where water remains the major environmental gradient which influences the growth of trees, a greater amount of sampling should be done in moist areas. Unfortunately, the low sample size was observed and was mainly due to the high potential regeneration of mature trees. The intra or inter specific competition along rivers and streams where sunlight could be the main factor of the growth could also explain the high rate of juvenile individuals around mature trees. Trees with DBH ≤ 10cm which were not recorded in the framework of the research were considered as individuals in regeneration. It is also important to note that young trees, with small diameters, usually have low ability to accumulate biomass carbon and hence account for only a small proportion of global atmospheric carbon sequestration (Juwarkar *et al.*, 2011; Fousseni *et al.*, 2012; Neto *et al.*, 2012).

Consistent with previous research findings, this study found that trees with low DBH (<10 cm) were well distributed with a significant density (number of individuals per hectare), however, they accumulated low organic carbon from the atmosphere and soil. On the other hand, tree species with high values in DBH were sharply less abundant in the landscape but accumulated higher carbon. Individuals of *P. santalinoïdes* L'Hér. ex DC. illustrate well the first case, while those of *D. oliveri* illustrates the second statement (Folega *et al.*, 2014b; Fousseni *et al.*, 2014). From the finding mentioned above, it appears that there exists a strong relation between tree diameter, height, density and above ground biomass (Mani et Parthasarathy, 2007; Baishya *et al.*, 2009; Zeng *et al.*, 2010; Henry *et al.*, 2011; Juwarkar *et al.*, 2011; Ullah et Al-Amin, 2012).

Table 2. Overview of ecosystems productivity and structures

Ecosystems	Land use	Mean NPP	Mean DBH	Mean Height	Mean Biomass
Forests	9427.3±12.5	8708.1±243.4	22.57±0.9	11.67±0.77	852.3±219.6
Savannahs	65339.5±456.3	3821.0±86.2	22.43±1.4	8.33±0.42	658.7±116.9
Fallows-Croplands	304450.2±1572.6	2481.5±84.3	20.07±3.3	9.42±1.35	238.2±32.8
Others lands	2898.9±112.2	1445.0±84.1	26.94±4.7	7.31±0.88	164.0±53.5
Total	382116.0±391.4	6940.5±267.0	23±2.6	9.18±0.85	528.0±82.6

Land use: ha; Mean NPP: $gCm^{-2}y^{-1}$; Mean DBH: cm; Mean Height: m; Mean biomass: kg

Based on the total biomass calculated in the study site, the computed density was equal to 196.7 $t.ha^{-1}$ for an average of 2.45 tha^{-1}. The average value identified is very low compared to the results reported for dry forest in Benin (175000 $t.ha^{-1}$). The biomass density of the investigated riparian area falls outside the range (23000 to 268000 $t.ha^{-1}$) defined for tropical dry forests. However, the total biomass (TB) and total biomass carbon (TC) in the current investigation were greater than those estimated and reported for Tankawati forest in Bangladesh (126.8 $t.ha^{-1}$) (Ullah et Al-Amin, 2012). The finding is fairly similar to total average above ground biomass (13500 $tgha^{-1}$) defined in trans-boundary River Sio Sub-catchment (Uganda) (Barasa *et al.*, 2010). In the Amazonian basin, the average of aboveground live biomass was 4400 $t.ha^{-1}$ and 20100 $t.ha^{-1}$ respectively for shrublands and woodland savanna (Barasa *et al.*, 2010; Juwarkar *et al.*, 2011; Ullah et Al-Amin, 2012).

A given landscape's total net productivity dynamic was almost led by the long-term processes of plant growth. Fast growing tree species generally store high amount of carbon during the earlier stage of their lifespan while slow growing species become more efficient in atmospheric carbon sequestration after attaining maturity. Biological factors as well as environmental factors, such as climatic changes and soil conditions (usually influenced by anthropogenic activities), exert negative effects on the growth of living plants and their ability to sequester carbon (Folega *et al.*, 2017; Fousseni *et al.*, 2017; Folega *et al.*, 2019). In the study areas, carbon sequestration by green vegetation is stressed by the long dry seasons (November to May), coupled with air temperature which can rise to 35° C in March. The reduced biomass production during the dry season is greatly influenced by the Harmattan season during which trees shed their leaves. During this season (Harmattan), common practices such as harvesting of trees, bush burning and land clearing for farm establishment also exert negative effects on biomass production. As some previous researches concluded; tree growth is controlled by a complex mix of climate related factors such as soil and air temperatures, soil moisture conditions, sunshine, and wind (Sankaran *et al.*, 2005; Mani et Parthasarathy, 2007). Water availability, commonly taken as precipitation, is often cited as the cardinal driver of plant growth in tropical Sudanian areas (Sankaran *et al.*, 2005; Bucini and Hanan, 2007). However, the occurrence of high atmospheric temperatures during the dry season may reduce tree growth rate and lead to reduced plant diversity (Mani et Parthasarathy, 2007; Baishya *et al.*, 2009; Barasa *et al.*, 2010; Juwarkar *et al.*, 2011; Fousseni, 2012).

Inferring from the land cover map, it appeared that dense vegetations were well distributed along watercourses and confirmed the fact that moisture gradient is the key factor for plant growth in the study area. The classification results were much improved compared to those obtained from the land cover map of three protected areas in Togo (Barkoissi, Galangashi and, Oti-Keran) (Fousseni *et al.*, 2011; Folega *et al.*, 2014a; Polo-Akpisso *et al.*, 2016). The delimited zones around the rivers are dominated by permanent woody vegetation (riparian forest, dry-dense forest and woody savannas), which in most of the cases belong to the protected areas. The protection status of the woody vegetation hasn't appeared to be efficient because of the presence of a high proportion of secondary vegetation component (fallows and farmlands) along the river bank, adjacent to the forest and sometimes in a homogenous forest pattern. The wooded vegetation cover pattern changes in agroforestry parkland (Fallows and farmland) and into barren land which would be more sensitive around urban areas and new settlements along the rivers. But barren lands in most of the cases were the areas which were progressively cleared following a long process determined by the orientation of peasant socioeconomic activities (Folega *et al.*, 2011). Aside barren lands resulting from human activities, there are still some patterns which usually occur during the dry season due to the drying up of temporal ponds that usually form during rainy seasons.

The net primary productivity distribution map was well in line with the land cover map. The average biomass produced by living vegetation was estimated to be 1249294.5 ± 267.0 $gCm^{-2}y^{-1}$, while the average biomass carbon sequestered was estimated to be 624647.3 ± 133.5 $gCm^{-2}y^{-1}$. The estimated values in the current research are very low compared to the amount estimated by MODIS image for wooded deciduous savanna in Gabon ($4.63x10^6$ $ton.ha^{-1}$) and in Equatorial Guinea ($2.89x10^6$ $ton.ha^{-1}$) (Hayford, 2008; Potter *et al.*, 2012). One factor that might account for this difference is that these previous studies were done at national and regional scale, while the scale of our study was very limited. However, the carbon stock of African woodlands (Mozambique) range from 3×10^{10} $gCha^{-1}$ to $6 \times 10^{10} gCha^{-1}$ respectively, for the disturbed zone to less disturbed ones; but in any pixel the authors found that the above ground biomass are almost higher than 15 $MgCha^{-1}$. From some previous global NPP studies (Hayford, 2008; Ciais *et al.*, 2011), the average NPP in the African tropical region was estimated to be 805 $gCm^{-2}y^{-1}$, but the carbon stock in the biomass of the same areas was estimated to 255 t. Cha^{-1}. In Amazonian forests, the global biomass average was estimated to be 1.77×10^{11} $gCm^{-2}y^{-1}$. In the case of the tropical seasonal deciduous forests, gallery forests, grasslands or savanna /agriculture as well as urban and converted lands (representing 248000 km^2), the estimated NPP value was 3454.3 $gCm^{-2}y^{-1}$ (Hayford, 2008; Ciais *et al.*, 2011; Potter *et al.*, 2012; Ryan *et al.*, 2012).

The biomass carbon estimated via remote sensing data mostly interacts with land cover patterns associated with complex vegetation features on the ground.

Inside the zone delimited as research landscape, a positive correlation was found between the areas sampled and the areas covered by each land type. The total biomass computed by using the allometric equation and the biomass carbon estimated by remote sensing image were also correlated to the area occupied by the four land cover types. By visual comparison of figures 3 and

4, the assertion that the performance of living plants in total NPP production is commonly linked to the quality vegetation cover on the ground could be deduced. This assertion can be implemented by the values of total biomass computed in each land cover type; which shows that dense wooded vegetation in this area constitutes the major pool of organic carbon. In spite of being correlated, the performance of productivity of plant growth, net primary productivity and vegetation cover in a given ecosystem is almost controlled by global geographical conditions like topographic and climatic factors (Zhang *et al.*, 2009). However, productivity can also be altered by several complex environmental factors such as the climate change, fire, plant diseases, insect pests and human socioeconomic activities (Wang *et al.*, 2011).

The study can very well complement the conclusion of recent researches about the riparian and seasonal deciduous forest diversity and structure contained in Sudanian tropical zone (Togo) within the framework of global ecological management, restoration and conservation of the zone. The buffer zone set in the current study deals with all kinds of threats, mainly caused by the local population. These threats impact negatively on the performance of the ecosystem as well as the quality and the quantity of ecosystem services that it can provide to local stakeholders for their daily needs. As mentioned in many researches focused on the riparian ecosystem, a strict protection of the riparian and stream ecosystem over 100 m from the bank can provide several crucial functions for enhanced environmental performance. These functions are gradually ordered from the bank to far away by denitrification, temperature moderation, invertebrate diversity, sediment removal and large woody debris and leaf litter supply. This way of management can enhance water quality through the control of nonpoint source pollution and protection of the stream environment suitable for the conservation, development and explosion of the biological diversity which can highly contribute to the accumulation of biomass carbon through the cycle of carbon.

CONCLUSION

This research enabled us to get a synoptic view of biological production around riparian and stream ecosystems in the landscape which is most sensitive to climatic change at national and regional scale. Eighty plant species were recorded in the defined buffer zone. The AGB and the BGB are respectively estimated to be 156.1 $t.ha^{-1}$ and 40.7 $t.ha^{-1}$. The buffer zone covers a total area of 382120 ha. Four types of land cover have been defined. The net primary production of living plants in the study area was estimated to be 1300000 ± 300 $gCm^{-2}y^{-1}$. The carbon stock estimation obtained in this study can be directed to researchers and administrators to analyze for global carbon credit, which can be helpful to improve the forest resources and environmental sectors in Togo and for West African countries with the same conditions in the framework of clean development mechanism (CDM).

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