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Carbon Stock and Land Use Changes: The Case of Arit

Birsen Durkaya
Associate Professor
Bartin University
Turkey

Tugrul Varol
Assistant Professor
Bartin University
Turkey

Ali Durkaya
Associate Professor
Bartin University
Turkey

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
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Birsen Durkaya

Tugrul Varol

Ali Durkaya

Abstract

The forest inventory in Turkey is kept by GDF (General Directorate of Forestry) at national and regional levels. But, many variables such as biomass and carbon holding capacity cannot be obtained from inventory data. It is an obligation of The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol to determine the carbon amount in the forest ecosystem. Determination of the change in carbon stock is made via the Biomass Expansion Factors (BEF) or Biomass Equations. In order to determine the carbon stock levels and changes accurately, it is required to analyze the estimations by using BEF or Biomass equations. In Arıt region, by using the forestry plans arranged in 4 periods since year 1968 (1968-1984, 1985-2001, 2001-2010, and 2011-2020), the land use and carbon stock changes of the region were determined through Geographic Information Systems (GIS) by utilizing BEF and Biomass Equations. The calculations of carbon by using biomass models show that the amount of stored carbon was increased from 317 209.3 t to 649 683.2 t in 43 years (1968-2011). The calculations of carbon by using BEF show that the amount of stored carbon was increased from 373 497.8 t to 444 865.3 t in 43 years (1968-2011). The increase is caused from 278 ha spatial change between the total lands in planning periods.

Keywords: Biomass expansion factors, Biomass models, Carbon storage, GIS, Land-use change.

Introduction

Forest ecosystems play an important role in the global carbon cycle because they hold atmospheric CO_2 and store it in vegetation and soil [1-4]. Considering the global carbon cycle and, especially, decreasing the effects of CO_2 emissions, the exact and accurate determination of amount of carbon stored in forest ecosystems and changes in carbon amounts gain more importance progressively. The measurement of carbon in forests is also necessary because of obligations from the United Nations Framework Convention on Climate Change (UNFCCC) and implementation compulsions of the Kyoto Protocol [5]. The UNFCCC obliges all parties having signs under convention to prepare, to publish and to update inventories for gas emissions and removals from land-use change and forestry by using comparable methods [6, 7].

Forest inventory data are accepted as important sources because they provide better C storage information through local measurements, and they reflect regional homogeneity better [8, 9]. The basic input of carbon storage calculation is the commercial wood volume obtained from the forest inventories, and then multiplied with biomass expansion factors [10]. Löwe et al., [11] evaluated the implementation of this method in their study about national land usage change and forestry reports of 15 EU member countries, and they found some deficiencies from the aspects of transparency, consistency and exactness. Good practice guidance for LULUCF activities requires carbon stock change calculations performed by using objective, transparent and appropriate data, and also predicts to eliminate uncertainties in time by specifying them [12]. With this purpose, there is an increasing interest on being able to specify forest carbon stocks accurately and truly [5]. Although IPCC projects the usage of "bottom-up approach" requiring the usage of forest inventory during calculating the carbon stock changes, forest inventories generally focus on wood volume in practice due to economic reasons, and they include information about biomass calculation [13]. If the carbon calculation is performed based on forest inventory, either aboveground or belowground carbon amounts are calculated by using BEFs, but biomass equations will be used if there is enough data [14-16].

Within the scope of this study, it was aimed to reveal the usability of Geographical Information Systems (GIS) in determination of land usage changes and carbon stock changes through a certain case, and to determine the efficiency and reliability of BEFs in determination of carbon stock changes. With this purpose, biomass and carbon amounts were determined and compared according to growth models of tree species and BEFs.

Materials and Methods

Study area: Neighbor Forest Sub-District Directorates (FSD) of Arıt which are reporting to Bartin Forest Directorate ($41^0$33'90''-$41^0$45'70'' N, $32^0$24'20''-$32^0$44'50'' E) were chosen as research field. The total field area was 18012.2 hectares (7137,5 ha productive forest area, 1342.3 ha nonproductive forest area, 9532, ha other areas). This field consists of mixed stands, and includes all of the possible heterogeneities of the region. Different operation methods are applied in these fields. The field was chosen because of its characteristics; thus, it allows various examinations. Since 1968, this field has been operated through management (forestry) plans.

The dominant tree species are *Fagus orientalis* Lipsky., *Abies bornmülleriana* Mattf., *Pinus sylvestris* L., *Pinus nigra* Arn., *Quercus* sp. and *Carpinus betulus.* L. The altitude of the field varies between 20 and 2020 m. Depending on locations, annual precipitation varies between 800 and 1000 mm, while the mean temperature in vegetation period varies between 16 and 22 °C.

Data

The data have been obtained from appendices and forestry plans arranged from the beginning of planned period to nowadays. The forestry plans in Turkey are updated decennially in accordance with the guide named Forestry Management Regulation which is published by General Directorate of Forestry. Updates are performed based on local measurements and observations and remote sensing data.

The diameters at breast height ($d_{1,3}$), planted tree reservoir amount and stand types which we used in our study have been obtained from local inventory studies of forestry management plans. While maps are appendixes of plans, they are forest cover maps which are designed through local controls of drafts (made by evaluation of air photos).

There are unplanned years in our research region due to some failures. After the end of plan periods, forestry activities have been conducted through annual forestry plans in those years. Four plans have been made until today in the years 1968, 1985, 2001 and 2011. Among them, the plan of year 1968 is excluded from the research because we could not obtain any positional maps in the required accuracy level. The data were obtained from inventory data and appendixes of forestry management plans of Arıt Forest Sub-District Directorates.

Estimation of biomass and carbon amounts: The biomass and carbon amounts were determined with 2 methods, using the biomass models and using the BEF coefficients. The data based on forestry inventory and required for implementing both methods have been obtained from forestry management plans. In Turkish forestry practice, the forest inventory data include the trees having stem diameters of 8 and higher.

Depending on models, the determination of aboveground biomass was performed by using one entrance aboveground models given in Table 1.

Table 1. *All of Aboveground Tree Biomass Equations*

Fagusorientalis Lipsky:	$LogY=2.86264+0.012441d_{1,30}-14.90987(d_{1,30})^{-1}$	[17]
Quercus sp.:	$Y=-302.193+26.56596d_{1,30}$	[18]
Castanea sativa Mill:	$Y=-376.794+28.7981d_{1,30}$	[19]
Pinus sylvestris L.:	$Y=-26.11437+.0.436421d^2$	[20]
Pinus nigra Arn.:	$Y=-106.555+(10.61818d)+(0.100728d^2)$	[21]
Abies bornmülleriana Mattf.:	$Y=-24.7765+0.525998d_{1.30}{}^2$	[22]

Biomass was calculated by using BEF coefficients according to the formula given below [23].

AGB = GS x BEF x ODWC

where, AGB is above ground biomass, GS is growing stock per hectare, BEF is biomass expansion factor, and ODWC is oven-dry weight coefficient. BEF is 1.310 for hardwood stands but 1.212 for softwood stands [24].

The carbon amounts were obtained by multiplying the total biomass amounts with carbon biomass conversion factors (0.48 for hardwoods, 0.51 for softwood). Then, those values have been converted to planning units and the whole research field in terms of plan years.

Mapping

For Arıt regions; the observed changes in land-usage-type maps and aboveground biomass and aboveground carbon values according to plan periods were mapped by using forest cover type maps and topographic maps. The map of stand types is scaled as 1/10000, while topographic maps are scaled as 1/25000. The carbon stock changes calculated by using both BEF coefficients and biomass models can be seen on maps. While stand type maps of research regions dated 2011 are numerical, the other maps have been digitized by using ArcGIS 9.3 and a positional database was established. In order to determine the biomass and carbon storage amounts, the growing stock per hectare, the number of trees, area and diameter data have been added to positional database. Calculations have been conducted by using stand types information existing in ArcGIS media.

Results

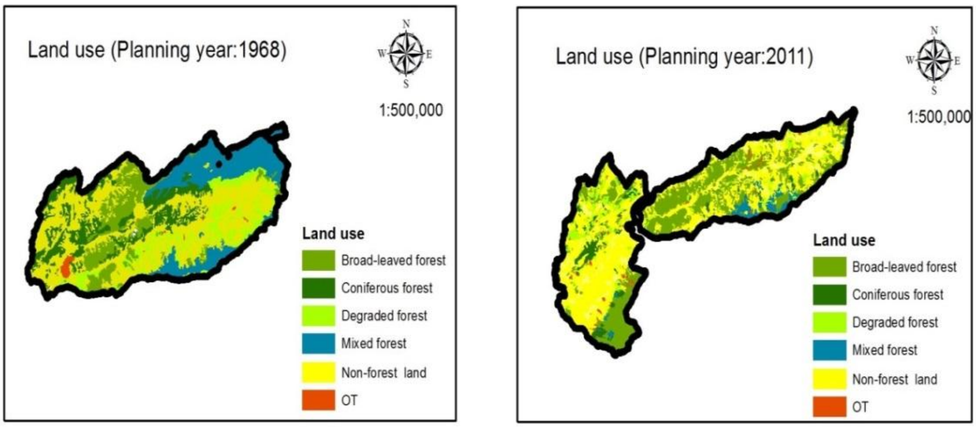
Land-use changes and changes in aboveground biomass and carbon storage in Arıt FSD were evaluated by using forest inventory data obtained from the management plans and appendices. The amounts of biomass and carbon stored above ground were calculated by using both biomass models and BEFs.

Land changes in terms of cover types are seen in Table 2 and Figure 1. While the total forest area in the research field has shown nearly stationary during periods (18 279-18 002), the total amount of forestless area has shown an important increase in terms of periods (6 734-9 273). Besides there are translocations between forests having different structures in time, the major significant changes occurred in in-forest open fields and degraded forests. As seen while evaluating Figure 1, the degraded forests within the forests became almost full-efficient forests in the 3rd period. Open areas has shown an increase more than 10 times from 1968 to 2011. The rest of low amount of fields is, in fact, the fields separated for wild life. The major increase has been seen in lands used with agricultural purpose. When those lands are left by their owners and have no valid property license, they are recorded as a forest.

Table 2. *Land Usage Changes in terms of Periods and Cover Types*

	1968	1985	2001	2011
Coniferous	0,0	110.0	179.0	833.5
Broadleaved	2613.9	8587.0	7636.0	5650.5
Mixed	3483.5	1891.5	6728.0	643.3
Degrade	5424.4	4993.5	0.0	1342.3
Open area	23.1	182.5	132.0	258.8
Non-forest	6734.0	11893.5	9756.5	9273.6
Total	18279.0	27658.0	24431.5	18002.0

Figure 1. *Land-use Changes in the Research Field, in terms of Periods*



From the calculations performed by using biomass models (Table 3), it is understood that 634 418.6 t of alive aboveground was stored in the 1st period, while this value was 1 619 612.6 t in the 2nd, 380 093.6 t in the 3rd and 1 299 366.4 t in the 4th period. The amounts of aboveground carbon stored in the same land were 317 209.3 t in the 1st period, 809 806.3 t in the 2nd period, 190 046.8 t in the 3rd and 649 683.2 t in the 4th period. The calculations of carbon by using biomass models show that the amount of stored carbon was increased from 317 209.3 t to 649 683.2 t in 43 years (1968-2011).

The results of calculations performed by using biomass expansion factors are given in detail in Table 3. According to those results; it is understood that the stored aboveground biomass is 776 454.4 t in the 1st period, 2 011 203.3 t in the 2nd period, 310 303.9 t in the 3rd and 916 574.2 t in the 4th period. The stored aboveground carbon amount is 373 497,8 t in the 1st period, 967 862.5 t in the 2nd period, 148 607.1 t in the 3rd and 444 865.3 t in the 4th period (Figure 2). The amount of carbon stored was increased from 373 497.8 t to 444 865.3 t in 43 years (1968-2011).

Table 3. *The Amounts of Biomass and Carbon Calculated by Using Biomass Models and Biomass Expansion Factors (BEFs) (t)*

		Models		BEF's	
		Biomass	**Carbon**	**Biomass**	**Carbon**
1968	**Coniferous**	0	0	0	0
	Broadleaved	247685.4	123842.7	266085.2	127720.9
	Mixed	386733.2	193366.6	510369.2	245777.0
	Degrade	0	0	0	0
	Total	634418.6	317209.3	776454.4	373497.8
1985	**Coniferous**	11536.6	5768.3	7865.4	3843.7
	Broadleaved	1347250.1	673625.0	1683025.5	807853.9
	Mixed	260825.9	130413.0	320312.4	156164.9
	Degrade	0	0	0	0
	Total	1619612.6	809806.3	2011203.3	967862.5
2001	**Coniferous**	4551.8	2275.9	3783.8	1929.7
	Broadleaved	204098.1	102049.0	164476.6	76536.9
	Mixed	171443.7	85721.8	142043.5	70140.6
	Degrade	0	0	0	0
	Total	380093.6	190046.8	310303.9	148607.1
2011	**Coniferous**	236700.7	118350.4	70187.5	35654.4
	Broadleaved	883570.9	441785.5	673669.3	323411.4
	Mixed	179094.7	89547.4	172717.4	85799.5
	Degrade	0	0	0	0
	Total	1299366.4	649683.2	916574.2	444865.3

As seen in Table 3, some mutual translocations were observed between coniferous, broadleaved and mixed stands. Also it was understood that the degraded fields seen in the 1st period were transformed into efficient forests. In addition, significant increases in aboveground alive biomass and carbon amounts have been observed in the next periods with a reference to the 1st period.

As understood from the evaluation of Table 4, there are significant differences between values calculated by using biomass models and BEF coefficients (models-BEFs). Considering the total values, it is seen that there is a significant surplus in the favor of BEFs in the 1st and 2nd period and in favor of models in the 3rd and 4th period.

Figure 2. *The Carbon Stock Changes in the Research Field, in terms of Periods*

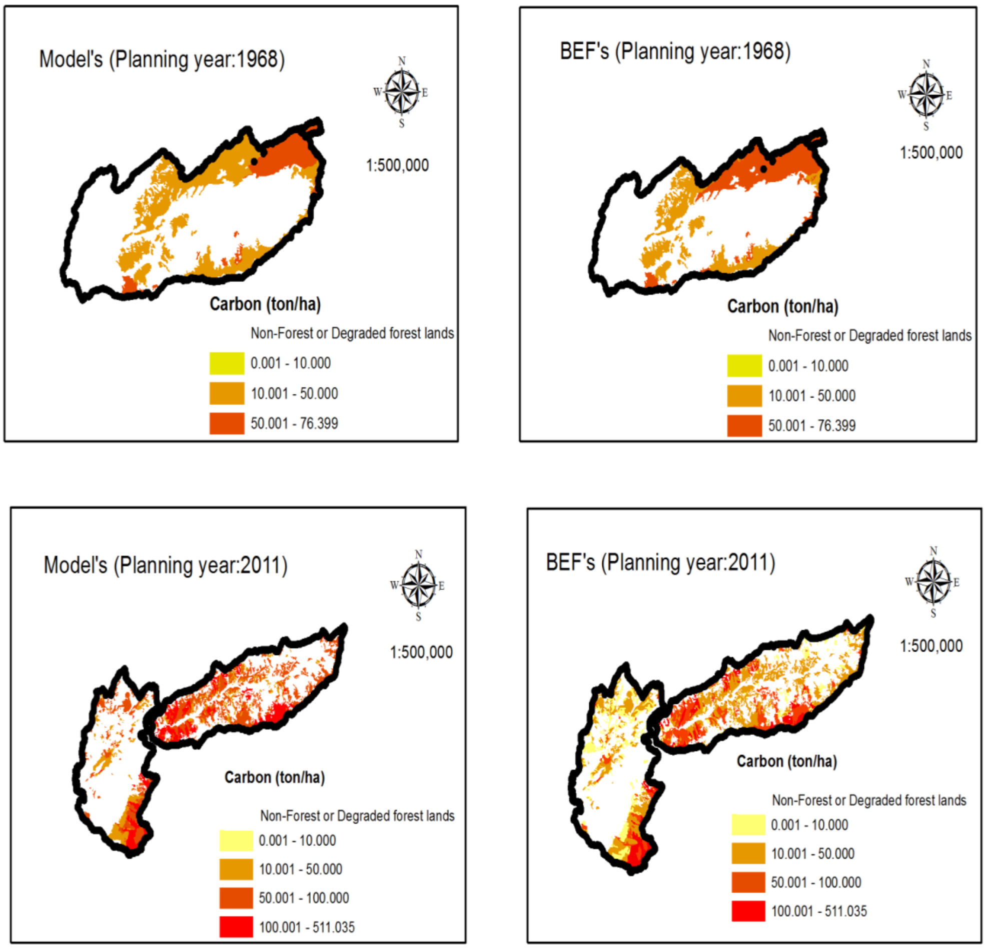


Table 4. *Differences between Amounts Calculated with Biomass Models and BEFs (models-BEFs) (t)*

		Biomass	Carbon
1968	Coniferous	0	0
	Broadleaved	-18399.7	-3878.2
	Mixed	-123636.0	-52410.4
	Degrade	0	0
	Total	-142035.7	-56288.5
1985	Coniferous	3671.2	1924.6
	Broadleaved	-335775.4	-134228.8
	Mixed	-59486.5	-25751.9
	Degrade	0	0
	Total	-391590.6	-158056.2
2001	Coniferous	768.0	346.2
	Broadleaved	39621.5	25512.2
	Mixed	29400.2	15581.3
	Degrade	0	0
	Total	69789.7	41439.6
2011	Coniferous	166513.3	82695.9
	Broadleaved	209901.6	118374.1
	Mixed	6377.4	3747.8
	Degrade	0	0
	Total	382792.3	204817.9

Discussion and Conclusions

The efficiency and smoother effect of GIS technology, where the forest inventory information can be evaluated during determining the land usage changes and amounts of biomass and carbon in plan units, are understood as a result of this study. Designed maps provide significant conveniences in observing the land usage styles and their changes in time.

It was shown in our study for 4 planning periods that the amount of biomass stored during the 2nd plan period showed a dramatic decrease in the 3rd period. But in the 4th period, an increase in proportion to the 3rd period is observed. The reason of this situation is the existing intense population living in in-forest residential areas. Forest villagers have satisfied their vital necessities mostly from the forest in this period. Since the 90s, forest villagers started to migrate to cities, and to leave their lands. As a result of this situation, a biomass increase in the last period was observed. This increase is expected to increase in the next years as a result of rehabilitation efforts in low efficiency regions and foresting of lands which have been used for agricultural purposes. When the maps are analyzed, it is seen that the mixed stand regions are the regions where there is the highest biomass, and therefore, the highest carbon storage. The situation that mixed stand regions store more carbon than pure stand regions is an expected situation [25], and it shows the efficiency of mixed stand regions in storing the carbon.

It is understood from the research results that the temporal and positional changes of biomass and carbon stocks can be efficiently determined by using the forest inventory data. However, there are significant differences between stock values calculated with biomass models and BEFs in favor of values calculated by using BEFs at the end of four periods.

When considering the national and international aspects, the exact and accurate determination of carbon amount stored in the forest ecosystems and its changes gain gradually increasing importance for the global carbon cycle and, especially, for decreasing the effects of CO_2 emissions [5, 26]. The calculations using BEFs give results different values than those using models. This situation conflicts with the expectation that calculations must be “complete and accurate”, and it also casts doubts on usage of BEFs. That is why it is very important for determining the carbon storage to develop and to use regional models. The models we used herein are based on DBH (distributed biosphere-hydrological) systems, which require the re-processing of the inventory information, and this makes the tasks difficult. The data which is obtained from forest inventory and management plans at easiest way is the standing stem volume. That is why the regional models to be developed should allow the estimation of commercial and non-commercial parts of aboveground and belowground biomass values according to the standing stem volume data.

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