DETERMINATION OF CARBON STOCK CHANGES: BIOMASS MODELS OR BIOMASS EXPANSION FACTORS

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ABSTRACT

It was aimed to reveal the usability of Geographical Information System (GIS) in determination of land usage changes and carbon stock changes by an examined case, and to determine the efficiency and reliability of biomass expansion factors (BEFs) in determination of carbon stock changes. With this purpose, the maps of field usage changes and carbon stock changes according to plan arrangement periods were prepared, and then, biomass and carbon amounts were determined and compared according to growth models of tree species and BEFs. As a result of performed researches, it was understood that GIS technology, where forest inventory information can be evaluated during determining the field usage changes as well as stored biomass and carbon stock amounts in planning units, is efficient and smoother. The calculations performed by using BEFs gave values 17% more than those with models. This situation conflicts with the expectation that calculations must be complete and accurate, and it also casts doubts on usage of BEFs. Rather than usage of BEFs, it is seen that usage of models based on estimation of aboveground and belowground biomass values of standing stem volume data and their commercial and noncommercial parts are the most appropriate methods for obtaining reliable results

KEYWORDS: Land-use change, carbon storage, biomass models, biomass expansion factors, GIS

1. INTRODUCTION

Forest ecosystems play an important role in 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].

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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 forest inventories, and then multiplied with biomass expansion factors [1]. 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.

2. MATERIAL AND METHODS

Study area: Neighbor Forest Sub-District Directorates (FSD) of Kumluca, Sökü and Ardıç which are reporting to Bartın Forest Directorate ($41^0$18'29''-$41^0$30'16'' N, $32^0$23'46''-$32^0$39'48'' E) were chosen as research field. The total field area was 26,069 hectares (14,517.4 h in Kumluca Forest Sub-District Directorate, 6504.7 h in Sökü Forest Sub-District Directorate, 5046.9 h in Ardıç Forest Sub-District Directorate). This field consists of mixed stands, and includes all of possible heterogeneities of the region. Different operation methods are applied in fields. The field was chosen because of its characteristics; thus, it allows various examinations. Since 1967, 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 *Castanea sativa* Mill. The altitude of the field varies between 220 and 1480 m. Depending on locations, annual precipitation varies between 800 and 1000 mm, while the mean temperature in vegetation period varies between 16 and 20 °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 1967, 1985, 2001 and 2011. Among them, the plan of year 1967 is excluded from research because we could not obtain any positional maps in required accuracy level. The data were obtained from inventory data and appendixes of 9 forestry management plans of Kumluca, Ardıç and Sökü 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 below. The belowground biomass amounts were obtained by using BEF coefficients because there was no appropriate amount of biomass models to determine belowground biomass amounts.

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 1.24 for hardwood stands but 1.22 for softwood stands.

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 Ardıç, Kumluca and Sökü 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 2010 are numerical, the maps dated 1985 and 2001 have been digitized by using ARcGIS9.3 and 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.

TABLE 1 - All of aboveground tree biomass equations

Fagus orientalis Lipsky:	Log $Y=2,86264+0,012441d_{1,30}-14,90987(d_{1,30})^{-1}$	[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.:	$Y=-24.7765+0.525998{d_{1.30}}^2$	[22]

3. RESULTS

Land-use changes and changes in aboveground biomass and carbon storage in Ardıç, Kumluca and Sökü FSDs were evaluated by using forest inventory data obtained from 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 for 3 periods are seen in Table 2 and Fig. 1. While total forest area in the research field has shown continuous increase during periods (61.07; 63.30; 72.09%), the total amount of forestless area has shown progressive decrease in terms of periods (38.93; 36.70; 27.91%). 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 Fig. 1, the open fields and degraded forests within the forests became almost full-efficient forests in the 3rd period. 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 forest. The real reason of 11.2% increase observed in total forest is related to those left lands.

From the calculations performed by using biomass models (Table 3), it is understood that 3,004,883.76 t of alive aboveground was stored in the 1st period, while this value was 2,183,544.54 t in the 2nd and 2,448,484.95 t in the 3rd period. The amounts of aboveground carbon stored in the same land were 1,502,441.88 t in the 1st period, 1,091,772.27 t in the 2nd period, and 1,224,242.48 t in the 3rd period. In proportion to the 1st period, the amount of stored biomass was decreased by 27.33% in the 2nd period and 18.51% in the 3rd period. In proportion to the 2nd period, the amount of biomass stored was increased by 12.13% in the 3rd period.

The results of calculations performed by using biomass expansion factors are given in detail in Table 4. According to those results; it is understood that the stored aboveground biomass is 3,476,313.06 t in the 1st period, 2,605,279.70 t in the 2nd period, and 2,669,981.99 t in the 3rd period. The stored aboveground carbon amount is 1,701,725.19 t in the 1st period, 1,278,056.06 t in the 2nd period, and 1,305,191.09 t in the 3rd period. In proportion to the 1st period, the amount of biomass stored was decreased by 25.05% in the 2nd period and 23.19% in the 3rd period. The amount of stored biomass was increased by 2.42% in the 3rd period, in proportion to the 2nd period.

TABLE 2 - Land usage changes in terms of periods and cover types.

Periods		1. period	2. period	3. period
Ardıç	Coniferous	214.64	-	19583
	Broadleaved	-	8739	4832
	Mixed	4672.21	4,884.03	4,691.15
	Degrade	75.45	-	25.71
	Open area	84.11	74.99	85.39
	Non-forest	-	-	-
	Total	5046.42	5046.42	5046.42
Kumluca	Coniferous	183.14	135.91	316.01
	Broadleaved	5,019,.3	4858,.6	5315.30
	Mixed	2164.5	3054.42	2815.90
	Degrade	27.8	-	629.40
	Open area	25.84	20.80	84.62
	Non-forest	7070.2	6420.67	5329.04
	Total	14490.29	14490.29	14490.29
Sökü	Coniferous	7.97	15.97	93.85
	Broadleaved	2086.71	1614.87	2059.34
	Mixed	1227.24	1721.26	1558.72
	Degrade	83.93	-	601.96
	Open area	15.19	-	234.05
	Non-forest	3058.29	3127.23	1931.41
	Total	6479.36	6479.36	6479.36
Total	Forest	15887.25	16468.15	18755.61
	Non-forest	10128.81	9547.91	7260.45
	Overall total	26016.07	26016.07	26016.07
	Forest %	61.07	63.30	72.09
	Non-forest %	38.93	36.70	27.91

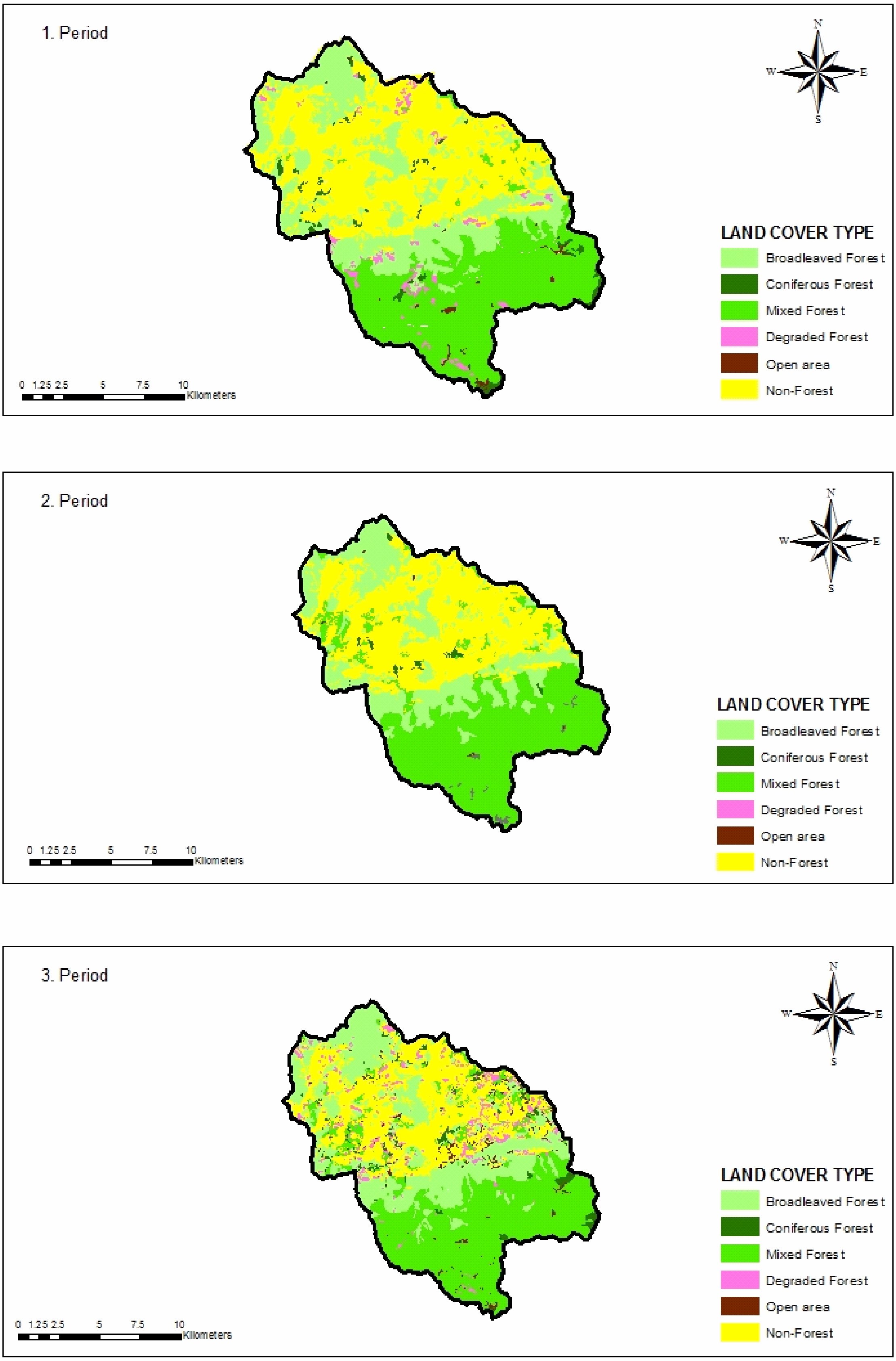

FIGURE 1 - Land-use changes in the research field, in terms of periods.

TABLE 3 - The amounts of biomass and carbon calculated by using biomass models (t).

		Ardıç		Kumluca		Sökü		Total	
		Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon
1.Period	Coniferous	47189.02	23594.51	14103.26	7051.63	564.29	282.14	61856.57	30928.29
	Broadleaved	-	-	781549.03	390774.51	304913.62	152456.81	1086462.65	543231.32
	Mixed	937225.74	468612.87	583061.98	291530.99	327726.54	163863.27	1848014.26	924007.13
	Degrade	1693.23	846.61	5136.20	2568.10	1720.86	860.43	8550.29	4275.14
	Total	986107.99	493053.99	1383850.47	691925.24	634925.30	317462.65	3004883.76	1502441.88
2.Period	Coniferous	-	-	-	-	276.30	138.15	276.30	138.15
	Broadleaved	9142.75	4571.38	190452.28	95226.14	196953.82	98476.91	396548.85	198274.43
	Mixed	1074567.88	537283.94	417430.55	208715.27	294720.96	147360.48	1786719.39	893359.69
	Degrade	-	-	-	-	-	-	-	-
	Total	1083710.64	541855.32	607882.82	303941.41	491951.08	245975.54	2183544.54	1091772.27
3.Period	Coniferous	48070.40	24035.20	39558.56	19779.28	11317.91	5658.96	98946.87	49473.44
	Broadleaved	6331.24	3165.62	699780.97	349890.49	316454.60	158227.30	1022566.82	511283.41
	Mixed	1048766.14	524383.07	210517.77	105258.89	67687.35	33843.67	1326971.26	663485.63
	Degrade	-	-	-	-	-	-	-	-
	Total	1103167.79	551583.89	949857.30	474928.65	395459.86	197729.93	2448484.95	1224242.48

TABLE 4 - The amounts of biomass and carbon calculated by using biomass expansion factors (BEFs) (t).

		Ardıç		Kumluca		Sökü		Total	
		Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon
1.Period	Coniferous	61099.04	31147.38	11974.93	6107.22	368.54	187.96	73442.51	37442.55
	Broadleaved	-	-	752287.14	361113.32	331786.53	159470.46	1084073.68	520583.79
	Mixed	1406000.33	696838.77	641297.29	313528.11	260040.53	127748.10	2307338.15	1138114.98
	Degraded	2428.00	1237.49	7031.29	3386.66	1999.43	959.73	11458.72	5583.87
	Total	1469527.37	729223.64	1412590.66	684135.31	594195.03	288366.25	3476313.06	1701725.19
2.Period	Coniferous	-	-	-	-	153.25	78.16	153.25	78.16
	Broadleaved	9089.60	4363.01	212389.17	101957.00	244186.05	117288.21	465664.82	223608.22
	Mixed	1363137.90	675261.45	429441.29	209983.64	346882.43	169124.59	2139461.62	1054369.68
	Degraded	-	-	-	-	-	-	-	-
	Total	1372227.50	679624.46	641830.46	311940.64	591221.73	286490.95	2605279.70	1278056.06
3.Period	Coniferous	57958.86	29476.98	32931.29	16787.33	13164.84	6555.39	104054.99	52819.70
	Broadleaved	6710.94	3228.13	614319.08	294958.45	414855.82	199162.91	1035885.84	497349.49
	Mixed	1224880.54	605829.04	217397.03	106481.04	87763.60	42711.82	1530041.17	755021.90
	Degraded	-	-	-	-	-	-	-	-
	Total	1289550.33	638534.15	864647.41	418226.83	515784.25	248430.12	2669981.99	1305191.09

As seen in Tables 3 and 4, some mutual translocations were observed between coniferous, broadleaved and mixed stands. Also it was understood that the degraded fields seen in 1st period were transformed into efficient forests. However, significant decreases in aboveground alive biomass and carbon amounts have been observed in next periods with regard to 1st period. In proportion to 2nd period, a small increase was observed in amounts of storage in 3rd period. This situation can be explained with intense in-forest residence in the previous year. This intense residence rate significantly decreased at the beginning of the 2nd period through migration from forest villages to cities, and it also reflected on stock rates. As seen in comparative evaluation of Figs. 1 and 2, the high carbon stock values are seen in mixed stand regions.

As understood from evaluation of Table 5, 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 favor of BEFs. In proportion to amounts calculated with biomass models, the amounts of carbon calculated with BEFs are 13.26% more in the 1st period, 17.06% more in the 2nd period and 6.61% more in the 3rd period.

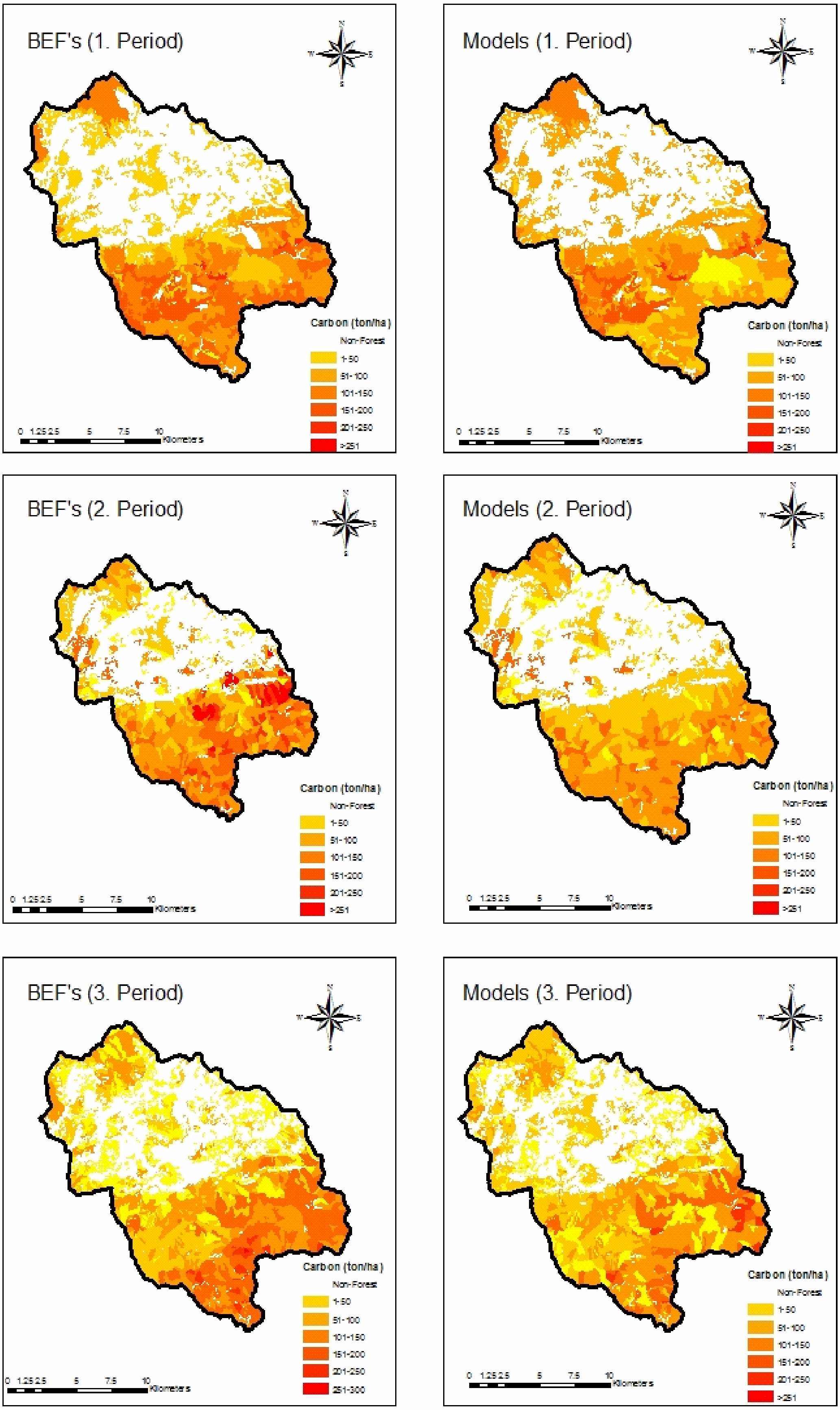

FIGURE 2 - The carbon stock changes in the research field, in terms of periods.

TABLE 5 - Differences between amounts calculated with biomass models and BEFs (models-BEFs) (t).

		Ardıç		Kumluca		Sökü		Total	
		Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon
1.Period	Coniferous	-13910.02	-7552.87	2128.33	944.42	195.75	94.19	-11585.94	-6514.26
	Broadleaved	-	-	29261.88	29661.19	-26872.91	-7013.66	2388.97	22647.53
	Mixed	-468774.59	-228225.90	-58235.31	-21997.12	67686.00	36115.17	-459323.89	-214107.85
	Degraded	-734.77	-390.87	-1895.09	-818.56	-278.57	-99.29	-2908.43	-1308.73
	Total	-483419.38	-236169.64	-28740.19	7789.93	40730.27	29096.40	-471429.29	-199283.31
2.Period	Coniferous	-	-	-	-	123.05	59.99	123.05	59.99
	Broadleaved	53.15	208.37	-21936.89	-6730.86	-47232.23	-18811.30	-69115.97	-25333.79
	Mixed	-288570.02	-137977.51	-12010.75	-1268.37	-52161.47	-21764.11	-352742.23	-161009.99
	Degraded	-	-	-	-	-	-	-	-
	Total	-288516.86	-137769.14	-33947.64	-7999.23	-99270.65	-40515.41	-421735.15	-186283.78
3.Period	Coniferous	-9888.45	-5441.78	6627.27	2991.95	-1846.93	-896.43	-5108.11	-3346.26
	Broadleaved	-379.70	-62.51	85461.89	54932.03	-98401.22	-40935.61	-13319.02	13933.92
	Mixed	-176114.40	-81445.97	-6879.26	-1222.16	-20076.25	-8868.15	-203069.91	-91536.27
	Degraded	-	-	-	-	-	-	-	-
	Total	-186382.55	-86950.25	85209.89	56701.83	-120324.39	-50700.19	-221497.04	-80948.62

4. 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 3 planning periods that the amount of biomass stored during the 1st plan period showed dramatic decrease in the 2nd period (models 27.33% - BEFs 25.05%). But in the 3rd period, an increase in proportion to the 2nd 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 90s, forest villagers started to migrate to cities, and to leave their lands. As a result of this situation, a biomass increase in 3rd 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 [24], 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 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 (13.26% in the 1st period, 17.06% in the 2nd period, 6.61% in the 3rd period).

When considering the national and international aspects, the exact and accurate determination of carbon amount stored in 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, 25]. The calculations using BEFs give results up to 17% more 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 standing stem volume data.

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