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Forest Stand Structure, Site Characteristics and Carbon Budget of the Kwangneung Natural Forest in Korea

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광릉 활엽수천연림의 산림식생구조, 입지환경 및 탄소저장량

임종환 · 신준환 · 김광택 · 천정화 · 오정수
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ABSTRACT

The study area, Kwangneung Experiment Forest (KEF) is located on the west-central portion of Korean peninsula and belongs to a cool-temperate broadleaved forest zone. At the old-growth deciduous forest near Soribong-peak (533.1 m) in KEF, we have established a 1 ha permanent plot (100 m×100 m) and a flux tower, and the site was registered as a KLTER(Korean long-term ecological research network) and DK site of KoFlux. In this site, we made a stemmap of trees and analyzed forest stand structure and physical and chemical soil characteristics, and estimated carbon budgets by forest components (tree biomass, soils, litter and so on). Dominant tree species were *Quercus serrata* and *Carpinus laxiflora*, and accompanied by *Q. aliena, Carpinus cordata*, and so on. As a result of a field survey of the plot, density of the trees larger than 2 cm in DBH was 1,473 trees per ha, total biomass 261.2 tons/ha, and basal area 28.0 m^2/ha. Parent rock type is granite gneiss. Soil type is brown forest soil (alfisols in USDA system), and the depth is from 38 to 66 cm. Soil texture is loam or sandy loam, and its pH was from 4.2 to 5.0 in the surface layer, and from 4.8 to 5.2 in the subsurface layer. Seasonal changes in LAI were measured by hemispherical photography at the 1.2 m height, and the maximum was 3.65. And the spatial distributions of volumetric soil moisture contents and LAIs of the plot were measured. The carbon pool in living tree biomass including below ground biomass was 136 tons C/ha, and 5.6 tons C/ha is stored in the litter layer, and about 92.0 tons C/ha in the soil to the 30 cm in depth. Totally more than about 233.6 tons C/ha was stored in DK site. These ground survey and monitoring data will give some important parameters and validation data for the forest dynamics models or biogeochemical dynamics models to predict or interpolate spatially the changes in forest ecosystem structure and function.

Key words : **KoFlux DK site, vegetation, biomass, carbon budgets, LAI, forest stand structure**

I. INTRODUCTION

Carbon budgets of forest ecosystems are important because forest ecosystem have been a major sink for storing carbon in living biomass and soil, and at the same time have the potential of emission in cases of deforestation or degradation. To understand processes of ecosystem changes and to study or develop models, lots of site-specific parameters and long-term ground survey data are often required. However, very little research and monitoring of forest ecosystem changes have been carried out comprehensively in Korea.

The study area, which is the KEF (Kwangneung Experiment Forest of KFRI) is a well reserved forest in

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the central cool-temperate forest sub-zone of Korea. This area was originally protected as a royal tomb forest for King Sejo during Josun Dynasty since 1468. Most of the original protected area of 2,286 ha was designated as an experiment forest of Korea Forest Research Institute (KFRI) in 1913 (FRI of the Government-General of Korea, 1932). The Kwangneung Natural Forest Reserve near Mt. Soribong in KEF with area about 1,200 ha has been protected from human activities. It mainly consists of unique old-growth forests composed of broad-leaved trees those are typical species of central cool-temperate forest sub-zone in Korea. About 841 native plant species have been recorded in this area (KFRI, 1994), and it is home to some endangered and rare plant species including *Cypripedium japonicum* Thunb. *C. macranthum* Sw. (Orchidaceae). Dominating tree species are *Quercus* spp., *Carpinus* spp., *Cornus* spp. *Acer* spp. and *Pinus densiflora* (Lee *et al.*, 1990; Oh *et al.*, 1991).

At the Kwangneung Natural Forest Reserve area, we have set the 100 m×100 m permanent plot(core plot) and a flux tower to monitor the changes in forest ecosystem and carbon/energy fluxes from 1998 to 1999. This area was registered as a long-term ecological research (LTER) site in 1998 (Oh *et al.*, 2000) and KoFlux site in 2002 (Kim *et al.*, 2002).

The aim of this paper is 1) to describe the site characteristics including climate and soil characteristics, and forest stand structure and living biomass to provide useful information and data for ecosystem studies in this area, and 2) to synthesize carbon budgets by each component of forest ecosystem components including living tree biomass, soil and litter layer.

II. STUDY AREA

The study area, which is the KEF(Kwangneung Experiment Forest of KFRI) is located at the west-central portion of the Korean peninsula (Fig. 1), and covers 2,240 ha. Topography is rugged and elevations range from about 90 m to 600 m, and the highest peak is Mt. Jukyeopsan (600.6 m, a.s.l.) and followed by

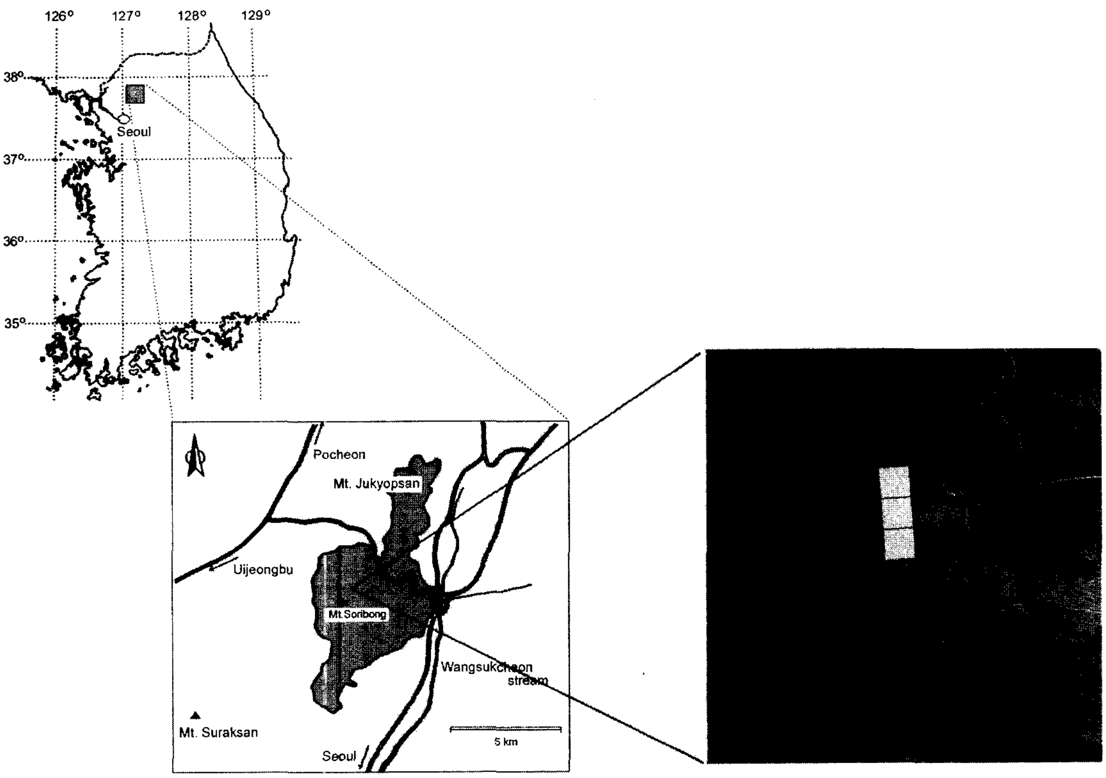

Fig. 1. Location of the study area, KEF, Korea (shaded area on the left), permanent plot and the flux tower (right) of DK site.

Soribong-peak (533.1 m, a.s.l.).

Most of the lower part of the KEF has been replanted artificially as botanical garden, exhibition forest or experimental forests. However, the old-growth deciduous natural forest near Soribong-peak in the KEF designated as Kwangneung Forest Reserve for Research, and protected from forest management activities, human disturbances and civilian access except for research. In this area, we have established 3 ha permanent plot (100×300 m, core plot is 100×100 m in the central part of the plot, Fig. 1) and a flux tower, and the site was registered as the KEF site of KLTER (Korean long-term ecological research) network (Oh *et al.*, 2000) and the DK site of KoFlux network (Kim *et al.*, 2002). The site location is 37°45' 25.37" N, 127°9' 11.62" S with elevation of 340 m a.s.l. The terrain has a valley-like topography with a~10% slope with the aspect of east (90±45°) dominantly.

The weather observation station of Jungbu Forest Experiment Station is located at the central part of KEF area with elevation about 110 m a.s.l., and its climatic data are shown in Figs. 2 and 3. As the climate of Korea, it is continental climate, except for August when it is oceanic climate. During the summer time characterized by wet monsoon it is hot and humid with frequent rain showers, while it is cold and dry in winter. Seasonal changes are gradual but distinctive; spring and autumn are relatively short while summer and winter are rather long.

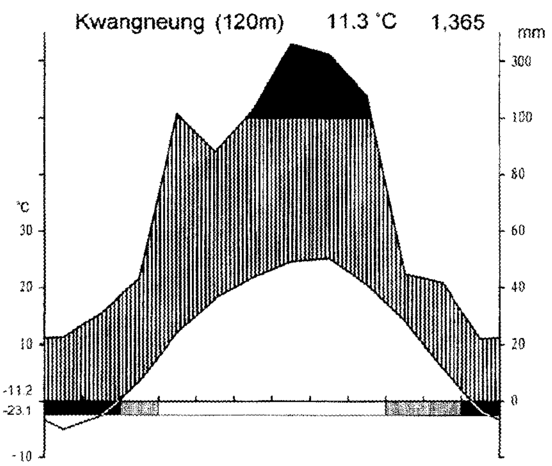

Fig. 2. Climatic diagram of the KEF region. Data were obtained from the weather observation station of Jungbu Forest Experiment Station of KFRI from 1964 to 1993 (FRI Korea, 1994).

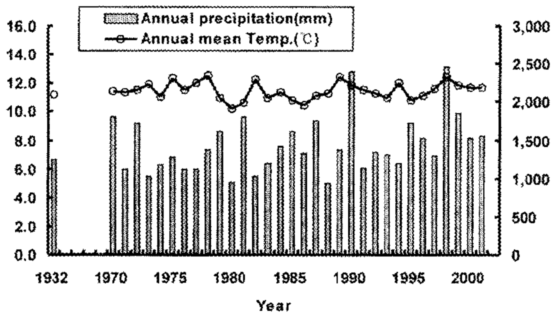

Fig. 3. Changes in mean annual temperature and annual precipitation of the KEF region. Data were obtained from the weather observation station of Jungbu Forest Experiment Station of KFRI and KFRI (1932).

Annual mean temperature of the KEF is about 11.3°C, and annual precipitation is 1,365 mm. Annual mean temperature is about 0.5°C lower than the Seoul weather observation station that is located about 30 km south from the KEF. However, the mean coldest month, January air temperature is about -5.0°C and this is 1.6°C lower than that of Seoul. It infers that KEF has longer period of snow cover and shorter growing season than Seoul. The difference of seasonal pattern of climate may influence on the vegetation growth and energy flux of the ecosystem.

III. MATERIALS AND METHODS

3.1. Plot survey for the analysis of forest stand structure and biomass estimation

Inside the 3 ha permanent plot, a 1 ha core plot was established in 1998 to assertain the forest stand structure and species composition. The core plot was divided into 100 sub-plots (10 m×10 m) by digging PVC pipes

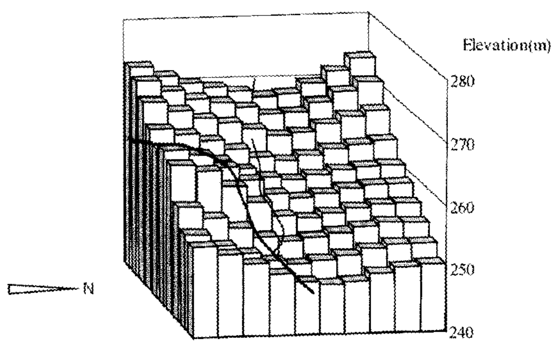

Fig. 4. Topography and channeling of the permanent plot.

at each corner to make it easy for survey. Topographical feature and stream channels of the core plot are shown in Fig. 4. Species name, DBH, and height of all the trees and shrubs larger than 2 cm in DBH were measured from 1998 to 1999. Forest stand structure of the DK site was analyzed by height distribution of trees. These plot data were used for estimation of the amount of biomass and carbon contents in living trees at DK site.

3.2. Site characteristics and LAI measurement

The study area is topographically rugged and micro-environments of sites, soil characteristics, and soil moisture content are heterogeneous. In the 1 ha core plot, volumetric soil moisture contents at 100 sample points and seasonal changes in LAI(leaf area index) at 14 sample points were measured (Fig. 5). Volumetric soil moisture contents of soil layer from 0 to 20 cm were measured using TDR sensors (HydroSense soil water measurement system, Campbell Sci. Inc.) on a sunny day of July, 2002.

LAI is defined as one-half the surface area of leaves per unit ground surface (m^2/m^2, Kucharik *et al.* 1998, Welles and Cohen 1996). There are several indirect and non-destructive methods to measure LAI, such as using LAI-2000 (Li-Cor Inc.), hemispherical photography, line quantum sensors, leaf laser and so on (Welles and Cohen 1996), and each has it's own advantages and shortages.

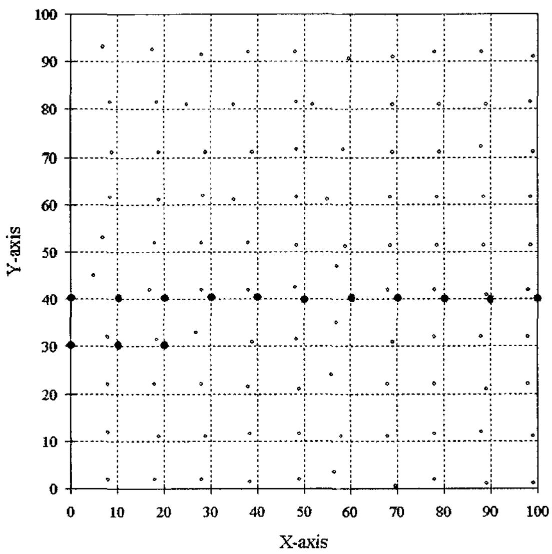

Fig. 5. Location map of the measuring points for volumetric soil moisture contents (small circle) and seasonal changes of LAI (filled circle).

We applied hemispherical photography method, because it is easy to use in forest and keep canopy images may be reanalyzed when a better model for LAI estimation becomes available. To estimate LAI at each sample point, we took hemispherical photographs at 1.2 m height using a fisheye lens digital camera (Nikon Coolpix-950) mounted on a SLM2 Self Leveling Mount (Delta-T Devices Ltd., UK). Therefore, the LAI measurements in this study do not include shrub and herb layer lower than 1.2 m in height. Each digital image was analyzed within range of 30 degree from the zenith angle using HemiView Canopy Analysis Software ver. 2.1 (Delta-T Devices Ltd., UK) to estimate LAI.

Distributions of LAI in the 1 ha core plot were estimated by the measurements at each corner of the 10 m×10 m sub-plots (121 points) on July, 2002. Then LAI of 4 directions were analyzed for each point image to assign into each sub-plots. Four observations from 4 points were averaged to estimate LAI of the sub-plot. Seasonal changes in LAI were measured at 14 points located systematically as shown in Fig. 5. Spatial interpolation was conducted using the spline interpolation method in the Spatial Analyst extension module (version 2.0) on the ArcView GIS software (version 3.2) environment (Environmental Systems Research Institute, Inc.).

3.3. Biomass estimation

For all the trees larger than 2 cm in DBH, species and DBH in the plot were measured as described above. And then, the total biomass of each tree including below ground biomass was estimated by the equations driven by Lim (1998). For the trees whose gravities of woody parts is high, including *Quercus* spp., *Carpinus* spp., *Fraxinus* spp. and *Acer* spp. (mostly broad-leaved trees), the equation B=0.1673 $D^{2.393}$ (R^2=0.964, p<0.001) was applied, where, B is total biomass including below ground parts (dry matter, kg), and D is DBH (cm). For the trees whose gravities of woody parts is low, including *Pinus* spp. and *Cornus* spp., the equation B=0.086 $D^{2.393}$ was used.

3.4. Synthesis of carbon budgets

To estimate the amount of carbon in living tree biomass, we converted the biomass data from the ground survey data at the plot into carbon content by simply multiplying by half (IPCC, 1996). Data of the carbon content in the soil layer and litter layer were obtained from other ecological research works that have been carried out at the DK site, such as the "Biodiversity and Forest Ecosystem Changes" project of KFRI. Some carbon flow data were obtained from other papers (Doh, 2001, You, 1994). However some unknown components are still remained, such as coarse woody debris.

IV. RESULTS AND DISCUSSION

4.1. Forest stand structure and biomass of DK site in KEF, Korea

Forest stand structure and biomass of the core plot of the DK site are summarized in Table 1. Total stem density was 1,473 trees/ha, basal area was 28 m^2/ha, and biomass was 281.2 tons/ha. Woody plants lager than 2 cm in DBH in the 1 ha core plot comprised 33 species. The number of *Quercus serrata* trees was only 70, however the basal area and biomass were more than half of the total amount of the plot. This is because *Q. serrata* is shade intolerant and dominates the upper layer of the canopy of forest with maximum height of 30 m and maximum DBH of 110 cm (Table 1), and few trees were found beneath the canopy layer (Fig. 6).

Carpinus laxiflora dominated just underneath the canopy crown of *Q. serrata*. Some trees of *Acer mono*,

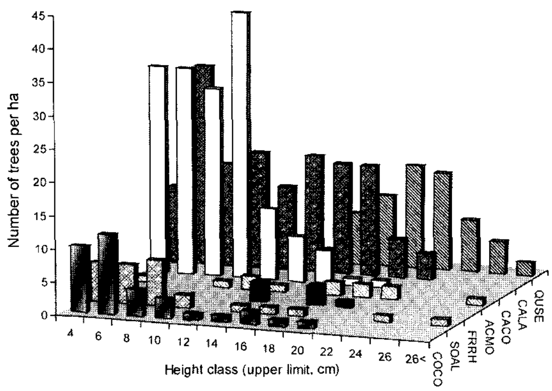

Fig. 6. Major species distribution by height class at the KEF permanent plot (QUSE: *Quercus serrata*, CALA: *Carpinus laxiflora*, CACO: *Carpinus cordata*, ACMO: *Acer mono*, FRRH: *Fraxinus rhychophylla*, SOAL: *Sorbus alnifolia*, COCO: *Cornus controversa*).

Sorbus alnifolia, Cornus controversa, Celtis jessoensis and *Prunus mandshurica* var. *glabra* were found at the canopy layer and near the valley. In the middle layer of the forest, *Carpinus cordata* was dominant, and accompanied with *C. laxiflora, C. controversa, Acer pseudo-sieboldianum* and *Sorbus alnifolia. Euonymus*

Table 1. Stem density, DBH, height, basal area and biomass of the KEF permanent plot

Species	Basal Area ($cm^2 \cdot ha^{-1}$)	Biomass ($kg \cdot ha^{-1}$)	DBH(cm)		Height (m)		Density
			Mean±SD	Max.	Mean±SD	Max.	($trees \cdot ha^{-1}$)
Quercus serrata	141,555	148,528	48±17	110	19±4	30	70
Carpinus laxiflora	65,352	56,086	18±15	52	11±5	22	153
Carpinus cordata	21,956	14,928	10±7	54	7±3	20	176
Acer mono	10,994	10,308	30±17	59	16±7	28	12
Fraxinus rhynchophylla	7,499	6,651	33±9	50	16±2	20	8
Sorbus alnifolia	5,649	4,858	10±13	50	8±6	29	27
Euonymus oxyphyllus	3,199	1,100	3±1	16	4±1	11	530
Cornus controversa	2,466	1,728	6±6	38	7±4	19	39
Cornus kousa	1,935	1,048	6±4	17	5±2	9	45
Styrax japonica	1,797	782	4±2	12	5±2	9	100
Acer pseudo-sieboldianum	1,574	720	4±3	13	5±2	10	89
Styrax obassia	1,130	574	5±3	15	5±2	11	36
Celtis jessoensis	998	856	11±14	35	7±9	23	4
Prunus mandshurica var. *glabra*	763	608	9±1	31	9±8	19	5
Others (19 species)	13,158	12,481					179
TOTAL	280,025	261,255					1,473

oxyphyllus were the dominant species at the shrub layer and comprised about a third of total number of trees (530 trees/ha) found at the plot, however the biomass was only 3.2 tons/ha.

The major cause of succession in the natural Kwangneung Experiment Forest is gaps created by the deaths of trees. There are some large *Q. serrata* trees greater than 100 cm in DBH. Most of the forest canopy gaps are formed by standing dead trees and broken large branches. And sometimes they created by broken or uprooted single trees or several trees caused by heavy rain or storms. The mean and maximum sizes of a gap are reported to be 92 m^2 and 524 m^2, respectively, with mean gap age of 4.3 years (Cho, 1992). The major disturbance is canopy gaps created by death of overstoried trees, and the area occupied by canopy gaps was estimated to be 4.6% of the total forested area in the KEF (Cho, 1992).

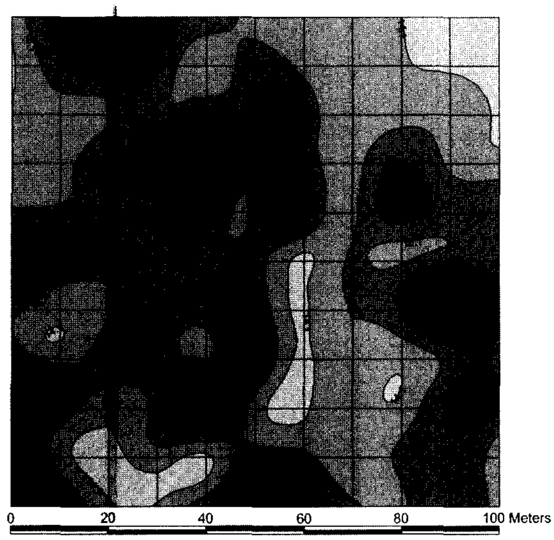

Fig. 7. Volumetric soil moisture distribution (%) of the permanent plot.

4.2. Soil characteristics and LAI

Parent rock type of the DK site is granite gneiss. Soil type is slightly dry or wet brown forest soil (alfisols in USDA system), and the depth is from 38 to 66 cm. Soil texture is loam or sandy loam, with the ratio of sand 46% in surface layer, and 50% in subsurface layer, and the ratio of silt 8% in surface layer and 13% in subsurface layer. Soil pH was from 4.2 to 5.0 in surface layer, and from 4.8 to 5.2 in subsurface layer (Lim *et al.*, 2002).

Soil moisture (SM) contents are spatially variable due to the topographical feature and the course of stream. Mean volumetric soil moisture contents of the plot and standard deviation was 19.9±5.3%, with the maximum 46%, and minimum 12%. Spatial distribution pattern of SM contents of plot is shown in Fig. 7. The SM content near or in the valley and concave area was higher than on the slope or ridge areas (please compare this map with Fig. 4).

Spatial distribution of the plot LAI is presented in Fig. 8. Because the forest is an old-growth stage, there are several gaps created by tree falls in the plot. Those gaps make the forest canopy structure heterogeneous. Mean LAI and standard deviation of the plot was 3.76 ±0.82, maximum 6.15, and minimum 2.53. However, several years after the gap formation, new trees under the canopy could be able to grow up vigorously, and LAI of the site would be recovered. Fig. 9 shows the relationship between basal area of trees and LAI, and no linear relationship was found between them.

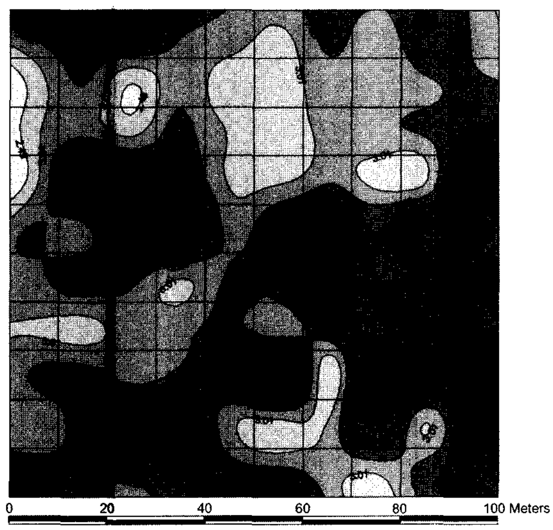

Fig. 8. Spatially interpolated LAI distribution of the permanent plot.

Seasonal changes of LAI at the core plot of DK site is shown in Fig. 10. Bud burst begins usually at early or mid April, and leaf senescence occurs at early November in DK site. The observed maximum LAI was 3.65 on July, and decreased a little in August due to heavy rainfall and insects, especially by *Mecorhis ursulus* (Attelabidae) which cut the oak shoots after laying their eggs in acorns.

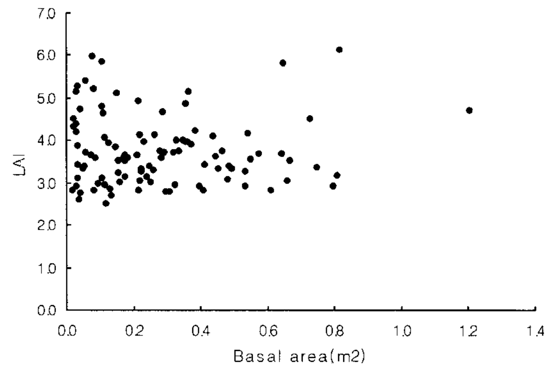

Fig. 9. Relationship between basal area and LAI.

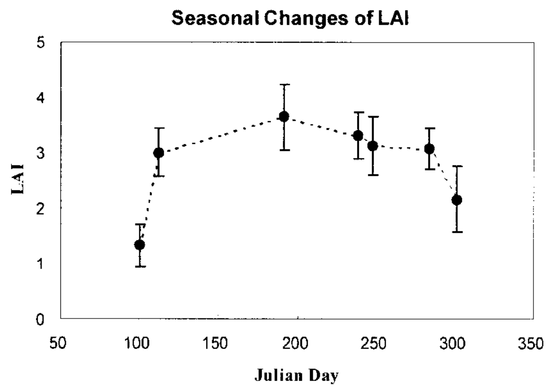

Fig. 10. Seasonal changes of LAI at the DK site. Vertical bars represent the ranges of standard deviation.

4.3. Carbon budgets of the DK site

The amount of carbon contained in living biomass was estimated 136.0 tons C/ha in DK site. This amount is relatively high when compared with the 35-years old *P. koraiensis* plantation in the KEF which has 109.4 tons/ha (54.7 tons C/ha) of above-ground biomass (Lee *et al.*, 1998). This is because the stem gravity of the *P. koraiensis* tree is lower than hardwoods, and the plantation forest was not fully stocked yet. This amount of biomass is also much higher than the 178 tons/ha (89 tons C/ha) estimated at the natural forest of Piagol in Mt. Chirisan (Kim *et al.*, 1982). However, when we compare with the data of old-growth natural forests in temperate region, this value is close to them, such as 251 tons/ha (125.5 C tons/ha) at the 100 to 150 years-old *Fagus* forest in Japan (Kawahara *et al.* 1979), and from 200 to 600 tons/ha (from 100 to 300 tons C/ha) in old-growth forests reported by Whittaker and Marks (1975).

You (1994) estimated primary productivity in living tree stem of the natural KEF was about 3.0 tons/ha/year (1.5 tons C/ha/year). This value is much lower compared with that of a cool-temperate region of 5 to 20 tons/ha/year (Kira and Shidei, 1967). It is widely acknowledged that biomass accumulates with time and reaches maximum at the steady state. Thus primary productivity is low or oscillating below/above zero at the old-growth stage. Annual leaf litter production in DK site was about 5.6 tons/ha/year (2.8 tons C/ha/year, Kim *et al.*, 2003, in this issue). Except for the amount of consumption by herbivory, annual NPP was estimated about 4.3 tons C/ha/year.

Lim *et al.*(2002) estimated the amount of carbon stored in litter layer was 5.6 tons C/ha, and in soil from the surface layer to 30 cm in depth was about 92 tons C/ha by systematic sampling of 20 points with 10 m intervals at the core plot.

Estimated amount of carbon emission by soil respiration was roughly 2 to 6 tons C/ha/year according to the measuring instruments, i.e. soda lime and EGM2 by Doh (2001). Using these data we summarized carbon pools in a flow diagram for the DK site as Fig. 11. It was estimated that the total amount of carbon, except coarse woody debris, in DK site was more than 233.6 tons C/ha, and about 60% was stored in living tree biomass.

However, the NPP and soil respiration term are not firmly reliable, and changes year by year due to the changes in climatic conditions. Furthermore, soil respiration data were 3 times different between the two measurement methods, and the amount of coarse woody

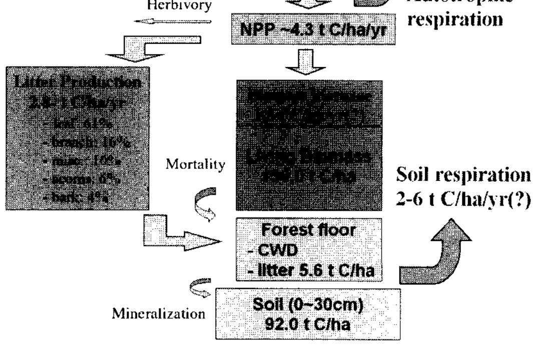

Fig. 11. Carbon budgets and flows at the DK site.

debris and decay rate are still unknown. Unknown terms and uncertain data should be filled and refined in the future works.

적 요

연구대상지인 광릉시험림은 한반도의 중서부에 위치하고 있으며 온대활엽수림대에 속한다. 광릉시험림 내 소리봉(533.1 m) 주변에 1 ha(100 m × 100 m) 면적의 영구조사지와 플럭스 타워를 설치하였으며 KLTER (한국장기생태연구 네트워크) 연구대상지인 동시에 KoFlux DK-site 연구대상지로 지정되어 있다. 영구조사지에 대해 개체목 위치도를 구축하고 임분의 구조와 토양의 물리적, 화학적 특성을 비롯한 임분구성요소(바이오매스, 토양, 낙엽 등)의 탄소수지를 분석하였다. 이 지역에서의 우점수종은 졸참나무, 서어나무이었으며 갈참나무, 까치박달 등이 함께 자라고 있다. 임분조사 결과 흉고직경 2 cm 이상인 입목의 밀도는 1,473본/ha 이었고, 바이오매스량은 261.2톤/ha, 흉고단면적은 28.0 m^2 이었다. 모암은 화강편마암으로 이루어져 있으며 토양형은 갈색산림토양에 속하고, 토심은 38~66 cm, 토성은 양토와 사양토, 산도는 표토층에서 pH 4.2~5.0, 심토층에서 pH 4.8~5.2로 나타났다. 지표로부터 1.2 m 높이에서 촬영한 반구사진(hemispherical photography)을 이용하여 엽면적지수(LAI)의 계절적인 변화를 측정한 결과 최대 LAI가 3.65이었다. 또한 토양수분함량 및 LAI의 공간적인 분포도를 작성하였다. 이 지역에서의 탄소저장량은 지하부를 포함한 입목에 총 136톤/ha, 낙엽층에 약 5.6톤/ha, 토양층 30 cm 깊이까지에 약 92.0톤/ha가 저장되어 있는 것으로 분석되어 총 탄소저장량은 236톤/ha 인 것으로 나타났다. 이상에서의 현지조사 및 관측 자료는 산림생태계의 구조와 기능 변화를 예측하기 위한 산림동태 모형을 비롯한 생물지화학적 동역학 모델의 적용에 필요한 모수와 자료로 활용될 것으로 판단된다.

REFERENCES

Cho, D. S., 1992: Disturbance regime and tree regeneration in Kwangneung natural forest. *Kor. J. Ecol.*, **15**, 395-410.

Doh, S. Y., 2001: Factors governing soil respiration in the hardwood forests of Mt. Nam, Kwangnung, and Mt. Jumbong, Korea. M. S. Thesis, Seoul Nat'l Univ., Seoul. 74pp.

IPCC. 1996: Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. IPCC/OECD/IEA.

Kim, J. H., Y. D. Park, D. S. Cho, S. D. Sung and B. M. Min, 1982: Community structure for the climax forest of the Piagol valley in Mt. Chiri. Report of Kor. *Nature Conservation Soc.*, **21**, 53-73.

Kim, J., W. Kim, C. H. Cho, B. C. Choi, B. L. Lee, D. Lee, E. W. Park, J. T. Lee, J.-H. Lim, J. H. Oh, J. I. Yun and C. S. Rho, 2002: KOFLUX: a new network of references sites for AsiaFlux/FLUXNET and CAMP/CEOP. Proceedings of the 2nd International Workshop on Advanced Flux Network and Flux Evaluation, 6-7p. Seogwipo, Korea.

Kim, C., J. H. Lim and J. H. Shin, 2003: Nutrient dynamics in litterfall and decomposing leaf litter at the Kwangneung Deciduous Broad-Leaved Natural Forest (*in this issue*).

Kim, J. H., Y. D. Park, D. S. Cho, S. D. Sung and B. M. Min, 1982: Community structure fo the climax forest of the Piagol valley in Mt. Chiri. Report of Kor. *Nature Conservation Soc.*, **21**, 53-73.

Kira, T. and T. Shidei, 1967: Primary production and turnover of organic matter in different forest ecosystems of the western pacific. *Jap. J. Ecol.*, **17**, 70-87.

Korea Forest Research Institute. 1932: General Description of Kwangneung Experiment Forest. Sanshusa Publ., Tokyo, Japan. 171pp.

Korea Forest Research Institute. 1994: Kwangneung Experimental Forest. Utkomunwhasa Press., Seoul, Korea. 910pp.

Kucharik, C. J., J. M. Norman and S. T. Gower, 1998: Measurements of branch area and adjusting leaf area index indirect measurements. *Agri. For. Meteorol.*, **91**, 69-88.

Lee, K. J., J. C. Jo, B. S. Lee and D. S. Lee, 1990: The structure of plant community in Kwnagneung forest (1): analysis on the forest community of Soribong area by the classification and ordination techniques. *J. Kor. For. Res. Soc.*, **79**, 173-186.

Lee, K. H., Y. G. Chung and Y. M. Son, 1998: Biomass of 35 years old *Pinus koraiensis* plantation in Pochon, Kyunggi-do. Kor. Soc. For. Measurements, **1**, 61-68.

Lim, J. H., 1998: A Forest Dynamics Model Based on Topographically-Induced Solar Radiation and Soil Moisture on the Kwangneung Experimental Forest. Ph.D. Thesis, Seoul Nat'l Univ., Seoul. 145pp.

Lim, J. H., J. H. Shin and J. S. Oh, 2002: Ecological site characteristics and carbon pools of the Kwangnung deciduous old growth natural forest, Korea. Proceedings of the 2nd International Workshop on Advanced Flux Network and Flux Evaluation, 57p. Seogwipo, Korea.

Oh, J. S., B. C. Lee, J. H. Shin, S. W. Oh and S. I. Kim, 1991: Community classification and stand structure of Kwangneung Natural Reserve Forest. *Res. Rep. For. Res. Inst.*, **42**, 36-56.

Oh, J. S., J. H. Shin and J. H. Lim, 2000: Long-term ecological research programme in Korea Forest Research Institute. *Kor. J. Ecol.*, **23**(2), 131-134.

Welles, J. M. and S. Cohen, 1996: Canopy structure measurements by gap fraction analysis using commercial instrumentation. *J. Exp. Bot.*, **47**, 1335-1342.

Whittaker, R. H. and P. L. Marks, 1975: Methods of assessing terrestrial productivity. pp. 55-118. *in* H. Lieth and R. H. Whittaker (eds.), Primary Productivity of the Biosphere, Springer-Verlag, New York.

You, Y. H., 1994: Nutrient Budget of Deciduous and Coniferous Forested Watersheds in Kwangnung. Ph.D. Thesis, Seoul Nat'l Univ., Seoul. 140pp.