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Climate Change Impacts on Forest Ecosystems: Research Status and Challenges in Korea

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기후변화에 따른 산림생태계 영향: 우리나라 연구현황과 과제

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ABSTRACT

Recent global warming seems to be dramatic and has influenced forest ecosystems. Changes in phenology of biota, species distribution range shift and catastrophic climatic disasters due to recent global warming have been observed during the last century. Korean forests located mainly in the temperate zone also have been experienced climatic change impacts including shifting of leafing and flowering phenology, changes in natural disasters and forest productivity. However, little research has been conducted on the impact of climate change on forest ecosystems in Korea which is essential to assess the impact and extent of adaptation. Also there is a shortage in basic long-term data of forest ecosystem processes. Careful data collection and ecological process modeling should be focused on characteristic Korean forest ecosystems which are largely complex terrain that might have hindered research activities. An integrative ecosystem study which covers forest dynamics, biological diversity, water and carbon flux and cycles in a forest ecosystem and spatial and temporal dynamics modeling is introduced. Global warming effects on Korean forest ecosystems are reviewed. Forestry activity and the importance of forest ecosystems as a dynamic carbon reservoir are discussed. Forest management options and challenges for future research, impact assessment, and preparation of mitigating measures in Korea are proposed.

***Key words* : Global warming, Adaptation, Carbon sequestration, Forest management, Research challenges**

I. INTRODUCTION

The earth's climate has warmed by 0.6 ± 0.2°C over the past 100 years with about a 31% increase of carbon dioxide content in the air, compared with that of the pre-industrial era (IPCC, 2001). Besides many recent worldwide natural disasters due to catastrophic weather events, Korea has also experienced frequent disasters; i.e., a big forest fire in the east-coastal region in 2000, severe drought in spring of 2001, heavy rainfall accompanying landslides by typhoon Rusa in 2002, a warm winter in 1988, etc. By mid-year 2006, two extreme weather events were recorded; the heaviest snowfall in Busan on March, and the hottest air temperature in April at 40 cities since the beginning of Korean meteorological measurements in 1904 (KMA, 2006). The annual mean temperature of Korea has risen about 1.5°C since 1912, and the Korean climate has warmed about 0.9°C assuming that the urbanization effect is about 30%. In particular, low temperatures in winter

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increased more than summer highs, and the intensity of precipitation (the amount per event) increased while precipitation frequency decreased (Kwon, 2003).

IPCC (2001) predicted that CO_2 concentration in the air will be in the range of 540 to 970 ppm and globally averaged surface temperature will rise by 1.4-5.8°C in the year 2100. These projected changes are considered to be very rapid and to be non-uniform in time and space. The IPCC models projected spatially different patterns of mean temperature increase and annual precipitation change by regions, a decrease in diurnal temperature range in many areas (with nighttime lows increasing more than daytime highs), a general decrease of daily variability of air temperature in winter, and increased daily variability in summer for Northern Hemisphere land areas. Moreover, the amplitude and frequency of extreme precipitation events is very likely to increase, leading to more frequent floods, landslides with loss of life, property damage, loss of infrastructure and settlements, human health impacts, etc. (IPCC, 2001).

The impacts of global warming on forests can, in turn, influence the global climate system by feedback mechanisms involving changes in albedo, evapotranspiration, concentration of greenhouse gases, etc. Furthermore, forests directly affect climate on local, regional and continental scales by influencing ground temperature, surface roughness, cloud formation and precipitation. Thus forestry and land management activity has the potential for mitigation of warming impacts and reduction of CO_2 emission at the same time.

However, it seems that very few researches on climate change impacts and ecosystem processes have been conducted with actual long-term data for the forest ecosystems in Korea. Major limitations, potentials of recent activities and future challenges on the research field are needed to be addressed to face up to upcoming changing climate.

This paper discusses general aspects of the observed and predicted impacts of global warming on forest ecosystems, the role of forest ecosystems on the global carbon cycle, forest and forestry-related options, proposed Korean forest policies and research programs, and future challenges.

II. GLOBAL WARMING EFFECTS ON FOREST ECOSYSTEMS

Over the past 100 years, the Earth's surface temperature has risen by 0.6 ± 0.2°C with 1998 being the warmest year. Precipitation increased by 5-10% over the mid- and high latitudes of Northern Hemisphere continents (IPCC, 2002). Many studies showed ecological responses to changes of regional climate, particularly increases in temperature. Such observed changes include:

1) Changes in timing of biological events (phenology)
2) Changes in species distribution ranges
3) Increased frequency and intensity of outbreaks of pests and diseases
4) Changes in species composition of communities
5) Changes in the structure and functioning of ecosystems including streamflow, water temperature and water quality

As a result of many long-term phenological data sets, especially in Europe and North America, it is evident that phenological trends respond to climate change. Common changes in the timing of spring activities include plant leaf unfolding, flowering, breeding or arrival of birds, spawning of amphibians, appearance of butterflies, etc. In Mt. Gyebangsan, the degree of leafing for 3 tree species including *Quercus mongolica* was observed and compared with the spring temperature (Lim and Shin, 2004). The relationship of leafing and spring temperature was very close. Leafing time of several tree species became 5-7 days earlier by 1°C increase in United Kingdom (Sparks and Carey, 1995). Root *et al.* (2003) using more than 10 years of data, analyzed observations on species and global warming, and estimated means of phenological shifts separately for invertebrates, amphibians and birds, and for trees and other plants. Means, except for trees, clustered around an earlier shift of 5 days per decade, but trees were 3.0 ± 0.1 days per decade. Mean shifts at latitudes from 50 to 72° were 5.5 ± 0.1 days/decade earlier while at latitudes from 32 to 49.9° were 4.2 ± 0.2 days/decade. Menzel and Fabian (1999) reported that the growing season expanded 3.6 days/decade during the past 50 years. These results indicate that many species have some capacity to respond rapidly to climate changes by altering the timing of life-history events. However, timing of life-history events depends on factors besides temperature, and a shift in phenology may disrupt important correlations with other ecological factors. Plant-animal interactions such as pollination and seed dispersal depend on synchrony between species. For many systems, species will respond to climate change at similar rates and maintain synchrony (Buse and Good, 1996), whereas for other species the loss of synchrony may have detrimental effects. In the Netherlands, warmer springs have resulted in a mismatch between the time of peak availability of insects and the peak food demands of nestling Great tits (Visser *et al.*, 1998).

Climate is an important determinant of geographic range for many species. Recent northward movements of species' range boundaries consistent with warming have been observed in birds (Thomas and Lennon, 1999), mammals (Payette, 1987), and butterflies (Dennis, 1993, Parmesan *et al.*, 1999). Parmesan *et al.* (1999) examined changes in the northern range boundaries of 52 species of European butterflies over the past 30-100 years, and found that 34 species shifted northward, 1 species southward and 17 species unchanged.

Air temperature in mountain regions changes with elevation at about 1°C per 160 m and changes with latitude at about 1°C per 150 km (IPCC, 1996). Grabherr *et al.* (1994) surveyed montane plants on 26 mountain communities in the Swiss Alps and compared species distributions to historical records. The rate of upward shift was estimated to be 1-4 m per decade. These movements were slower than the 8-9 m per decade expected based solely on the change in mean temperature over the last 90 years. In Korea, using the scenario of climatic warming 2°C by 2100, the shifts of the potential ranges of the several native trees including *Camellia japonica* which is an evergreen broadleaved tree, *Quercus mongolica* and *Abies nephrolepis* were predicted based on the thermal ranges of the species (Lim and Shin, 2005). The predicted changes of distribution ranges were dramatically toward northward in latitude, and toward the top of the mountains. Distribution ranges of the trees in the warm temperate forest zone, such as *Camellia japonica* were predicted to expand about 2 times, and extend 100m higher in elevation (Lim and Shin, 2005). Trees of the cool-temperate forest and sub-alpine forest zones were predicted to become confined to half of the current potential ranges. Since forests in Korea are located mainly on the mountainous area, altitudinal shifts of the distribution ranges are also important factor. Thus the vegetation in the sub-alpine zone will be mostly vulnerable. Priority should be given to the conservation of the high mountains vegetation and species of the habitat ranges in anticipation of significant global warming. Kong (2005) suggested some plant species vulnerable to global warming using a climatic indicator of high summer temperature in Korea. The author mentioned the further research on bioclimatic ranges and adaptation abilities of plant species would be required to assess the possible impacts of climatic warming.

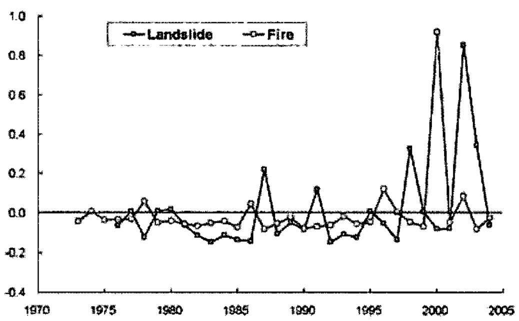

Fig. 1. Changes of forest area disturbed by landslide and forest fire in Korea. Y axis is anomaly standardized as $(X_i - X_{mean})/(X_{max}-X_{min})$. Forest fire areas were from KFS (2005a) and landslide area from internal data of Korea Forest Service.

Other montane habitats may also be showing the effects of climatic change. Dieback of montane trees (Hamburg and Cogbill, 1988; Fisher, 1997) is consistent with the effects of warmer climate. We feel that the alpine and sub-alpine forests are vulnerable to global warming and that communities should be monitored and conserved.

Fig. 1 shows a recent increase of forest area disturbed by forest fire and landslide in Korea. It is possible that these extreme climate-related events were driven by erratic conditions associated with early stages of ongoing global warming. The recent tendency of frequent climate-related disturbances is worldwide (IPCC, 2001). We plotted landslide area in Korea against annual precipitation, and we can find the high limitation line (Fig. 2). However, the plotted landslide area in 2002 was out of the trend line due to destruction by heavy rainfall that accompanied typhoon Rusa. The typhoon impacted the same area previously burned by a big forest fire in 2000, and showed an amplified effect.

The changes in disturbances would be important in sense of adapting to anticipated climate change and maintaining the forest as a carbon reservoir. Carbon stored in forest ecosystems could be lost as forests transit from one type to another under a changing climatic condition. Moreover, the raised air temperature accelerates soil respiration rate and may contribute to enhanc-

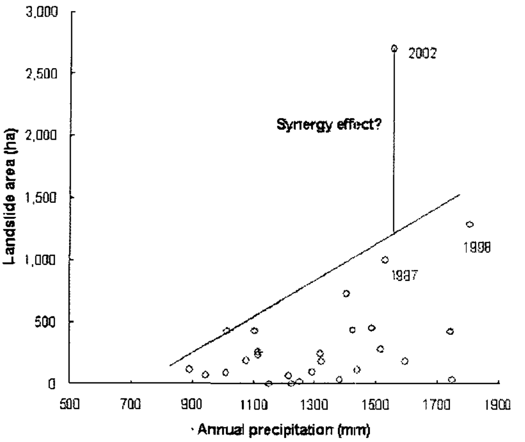

Fig. 2. Relationship between annual precipitation and landslide area in Korea. In 2002, typhoon Rusa with heavy rainfall destroyed the previously damaged area by a big forest fire in 2000.

ing the greenhouse effect. Using a process-based simulation model, changes of species composition and biomass were simulated for central cool-temperate forest zone in Korea. It was predicted that biomass production would be increased and *Pinus koraiensis* and *Quercus mongolica* would be replaced with *Q. serrata, Carpinus laxiflora* and *C. tchonoskii* in a 1°C warmer climate. However, biomass production would be decreased in a 2°C warmer climate (Fig. 3; J. H. Lim, unpublished data).

III. FORESTS AS A CARBON RESERVOIR AND IMPORTANT MITIGATION OPTIONS

Terrestrial ecosystems play a critical role in modulating the global carbon cycle by exchanging CO_2 with the atmosphere. And forest ecosystems are a major reservoir of carbon, containing 80% of all the carbon stored in land vegetation, and about 40% of the carbon residing in soils. Since 1980, the average increase rate of the atmospheric carbon was about 0.4 %/year (i.e. in 1990s annual rate of atmospheric CO_2 increase were

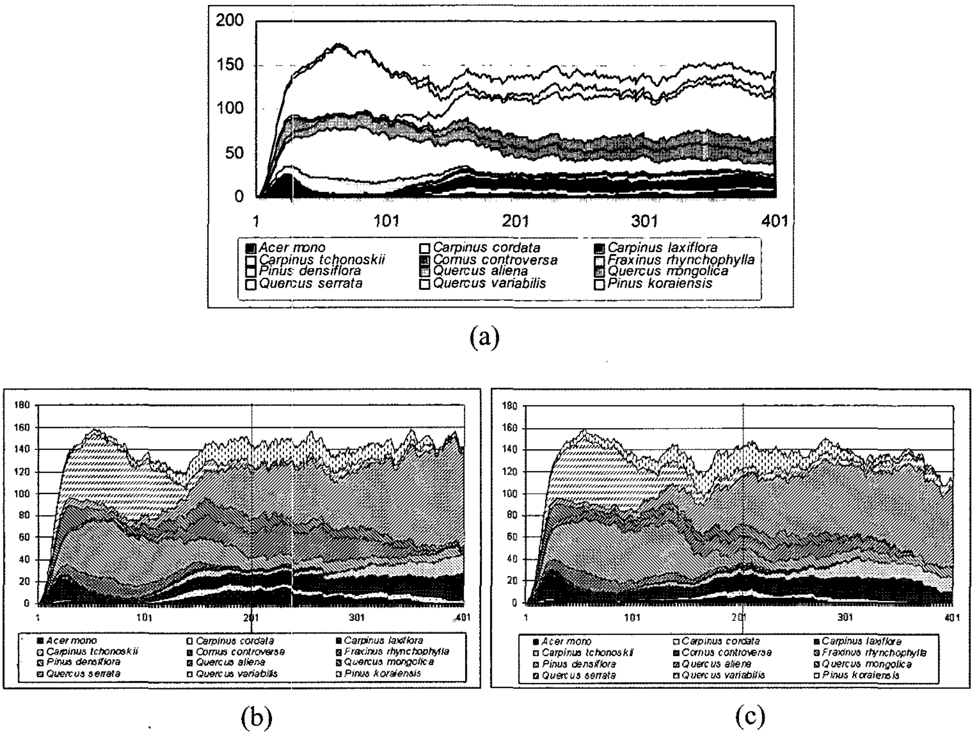

Fig. 3. Simulated changes of forest composition and biomass changes for the central temperate forest zone of Korea. It was assumed that the first of running year is 2001, and hereafter transient warming is undergoing (a) without changes, (b) 1°C increase per 100 yrs., (3) 2°C increase per 100 yrs.

from 0.9 to 2.8 ppm/yr.), mainly due to CO_2 emissions (IPCC, 2001). Most of the emissions were due to fossil fuel burning, and the rest, 10-30%, was predominantly due to land-use change, especially deforestation.

Globally, the estimated carbon stock of terrestrial vegetation is 540-610 GtC, and the amount is similar to 750 GtC in the atmosphere, less than half of 1,580 GtC in soils and organic matter, and much smaller than 40,000 GtC in the ocean (UNEP/GRID-Arendal, 2005). However, the amount of annual exchange with the atmosphere is about 121 GtC through GPP (Gross Primary Productivity) which is about 20% of the total carbon stock in the vegetation. Much of this carbon removed from the atmosphere each year by plants is returned to the atmosphere as a result of the respiration of other organisms (including soil microorganisms, animals and humans; heterotrophic respiration), fire, timber harvest, etc. And the amount of carbon in terrestrial biosphere including living and dead plants and soils is increasing in mass and enhancing its carbon stock by 1.4 ± 0.7 GtC per year (IPCC, 2001). With losses from deforestation of about 1.6 GtC per year, the remaining terrestrial biosphere should be accumulating 3.0 GtC per year. This accumulation of carbon in terrestrial biosphere is partly as a result of higher concentration of atmospheric CO_2 and increased nutrients input, but also due to the re-growth of intensively managed or previously cleared forests, especially in temperate forest region.

Reduction of fossil fuel use should be encouraged in order to decrease emissions into the atmosphere. Emissions by land-use changes should also be decreased, and carbon sequestration by replacement of fossil fuel-based energy and products with renewable wood based energy and products should be enhanced.

In 2000, the total estimated net accumulation of carbon in forest ecosystem was 11.3 million tC (forest growth was 12.3 million tC, and emission by timber harvesting was 1.0 million tC) in Korea. Annual accumulation rate per ha was about 1.9 tC (KFRI, 2005). Most of the Korean forest is 20-40 years old, and at the peak or just passed the full-vigor phase of fast growing when comparing stand age with the carbon absorption rate by species (KFRI, 2005). The rate of carbon sequestration in the mature phase is lower than the full vigor phase. However, the level of the long-term carbon stock depends on the balance between the impacts of harvesting events and the rate of forest regeneration. Periodic harvesting of old trees and replacement with young trees can lead to a lower long-term carbon stock than the case of avoided harvesting. Forest soil carbon is also an important carbon reservoir. Changes in forest soil carbon depend on a balance between the accumulation of dead biomass, its incorporation into the soil, and losses due to respiration and decay. The rates of litter input and decomposition can be influenced by management practice and change in climate (especially temperature and rainfall patterns) and will affect the rate of carbon loss or gain in forest soils. Any soil disturbance associated with forest management may release carbon to the atmosphere, and should be minimized to optimize soil carbon stocks.

Key components of forest ecosystems and their associated carbon pools are above- and below-ground living biomass, dead biomass, soil carbon, and the carbon associated with wood products. However, the potential of forestry activities to reduce the atmospheric carbon is not simply the sum of the impacts on these carbon pools. Another potential opportunity is to use wood products to reduce the consumption of fossil fuels. Sustainably harvested wood can substitute directly for fossil fuels in the form of renewable wood fuel (bioenergy), or indirectly as renewable wood products replacing, where appropriate, materials such as concrete and steel which involve high fossil fuel consumption in their production.

IV. ACTION PLAN AND RESEARCH PROGRAMS

It seems that regional changes in climate which are highly spatially heterogeneous, are more relevant in the context of ecological response to climatic change. Forest carbon management requires an in-depth assessment of numerous factors including site conditions, potential productivity, vulnerability to climate change and natural events, and the end-use of harvested wood. A number of options are available for maintaining or enhancing carbon benefits. To evaluated these options some principles can be applied; 1) maintenance or enhancement of long-term on-site carbon stocks in the forest, 2) minimization of disturbance to litter and soil, to avoid carbon emissions and soil degradation, 3) ensuring energy efficiency in forest management operations and in the conversion of harvested timber to products, 4) harmonizing carbon management with other objectives and with practical constrains.

KFS developed a forest policy plan in 2005, named

"Fundamental Plan for Carbon Reservoir Enlargement"(KFS, 2005b). It includes;

1) Mitigation of the atmospheric CO_2
- Ecological forest tending practices
- Afforestation and reforestation; marginal fields, urban area
- Restrain forest conversion to other land uses
- Forestry CDM (Clean Development Mechanism)/JI (Joint Implementation) projects preparing the future implementation of Kyoto Protocol
- Promoting forest bio-energy and woody products

2) Establishment of a national GHG (Greenhouse Gases) inventory and reporting system considering Kyoto Protocol
- Identification of Kyoto forests and their database construction
- Development of estimation and validation of GHG statistics in the forest sector
- Establishment of a carbon accounting system of woody products

3) Global warming adaptation measures
- Prevention, early warning and suppression system for forest fires
- Control and quarantine system of forest insects and plant pathogens
- Impact assessment of the projected global warming on forest ecosystems
- Maintaining forest productivity by silvicultural methods and soil conservation
- Adaptation strategy for conservation of forest biological diversity

In the face of ongoing global warming, KFRI has established a research plan to understand forest ecosystem change mechanisms, to conserve forest biodiversity and to maintain health and productivity of Korean forests:

1) Development of scientific national carbon accounting system in the LULUCF (Land use, Land-Use Change and Forestry) sector
- Assessment of the Kyoto forests using GIS (Geographical Information System) and RS (Remote Sensing) technology
- Accurate estimation of carbon conversion factors by soil type
- Development of a monitoring system for carbon flows in woody products and assessment of their life-time

2) Enhancement of the carbon sink potential
- Assessment of effectiveness of forest policies on carbon sequestration
- Development of silvicultural techniques for carbon sequestration
- Provenance testing and selection of tree genotypes suitable for carbon sequestration
- Possibility and effectiveness of CDM projects for carbon emission credit
- Development of bio-energy production techniques and of log-house construction methods

3) Scientific understanding, and impact assessment of global warming on forest ecosystems
- Long-term monitoring of forest ecosystem changes
- Impact assessment of global warming on biodiversity, forest disasters, and productivity of forest ecosystems
- Scientific measuring and assessment of carbon, water and energy flows in forest ecosystems using flux towers and development of ecosystem models linked with GIS/RS

V. AN INTEGRATIVE FOREST ECOSYSTEM STUDY

Interdisciplinary forest ecosystem research by the union of long-term ecological research program of KFRI and flux research programs at the same site of Gwangneung forest resumed in 2004. This included the construction of one more flux tower (the second tower, ST) to better capture the heterogeneities of the site of complex terrain and to supplement the measurement at the main tower (MT). Researchers with widely varying expertise joined the projects including GIS/RS, soil sciences, forest hydrology, forest ecology and dynamics, stable isotopes, and ecosystem modeling. This represents the begging of true inter-disciplinary research at Gwangneung forest and therefore the site was designated as a 'Supersite' that became the center of three main research projects; 1) Long-term forest ecosystem studies (KFRI, 1997-present), 2) CarboKorea (an Eco-technopia project funded by Ministry of Environment, 2004-present), 3) HydroKorea (an 21st Century Frontier Research Program funded by Sustainable Water Resources Research Center, 2004-present).

The Gwangneung Supersite is located at the north of Seoul, Korea on valley-like terrain with a slope of around 10%. The major forest type is a natural broad-leaved forest of the cool-temperate forest zone. The dominant tree species of the canopy layer is *Quercus serrata* with a mean canopy height of about 16-22 m (Lim *et al.*, 2003). Major forest types near the ST are plantations of coniferous trees including *Abies nephrolepis, A. koreana* and *Pinus koraiensis.* Even in the broad-leaved deciduous forest, the species composition and biomass amount are spatially heterogeneous mainly due to the topographic position which creates differences in light conditions and soil moisture regimes. Therefore, we made several eco-plots of different forest types, and conducted research to estimate and model parameters such as the spatial distribution of LAI, biomass and carbon pools, soil moisture gradients, etc. We have monitored the changes of forest ecosystem elements including forest stand dynamics, biological diversity (including plants, invertebrates, vertebrates, fungi), soil texture and properties, litter fall and decomposition rates of leaves and woody debris, monthly pH of rain and SO_2 and NO_2 concentration in the air (Oh *et al.,* 2000).

At the flux towers, eddy-covariance (EC) systems (CSAT3 and CR5000, Campbell Scientific Inc.; LI-7500, Li-COR) are mounted at 20 and 40 m on MT and 40 m on ST. In addition, H_2O/CO_2 concentration profile systems (LI6262, Li-Cor; CR23X-TB, SDM-CD16AC, Campbell Scientific Inc.; vacuum pump, KNF Neuberger) were installed on both towers measuring concentrations at 8 different levels. Net radiometers (CNR-1, Kipp & Zonen) and quantum sensors (LI-190SA, LI-COR Inc.) were installed at the towers. Soil heat flux plates (HFT, Campbell Scientific Inc.) at two depths, air temperature/humidity probes (HMP-45C, Campbell Scientific Inc.) at five levels, soil temperature probes (TCAV, Campbell Scientific Inc.) and water content reflectometers (CS-615, Campbell Scientific Inc.) at several depths, cup anemometers and wind vanes at several heights are operational. These meteorological data are sampled every thirty minutes. To monitor the soil respiration continuously, our research team developed an automatic opening and closing chamber system (AOCC) based on an open-flow dynamic method (open-flow AOCC, Suh *et al.*, 2006,).

A hydrological quantitative measurement system at a catchment was started in 1979 to understand hydrological processes. Long-term and specialized hydro-chemical measurements have been added focusing on the water cycle and some underlying processes that control chemical and physical behavior of elements and compounds in the natural environment. Standard instrumentation includes sensors for soil moisture, sapflow, rainfall, streamwater, soil water, stemflow samplers, stream gauges, streamflow weirs, throughfall measurement sites and groundwater observation wells. In addition, the radio transmission system helps to enhance the quality of observations by rapid data transmission and remote checking of instruments.

Through the integrated research at the Supersite a database management system is under construction for above- and below-ground measurements, flux data and GIS/RS data. Furthermore, effort will be given to understanding the mechanisms and processes in forest ecosystems to estimate parameters precisely and to develop models for estimation of CO_2 and H_2O dynamics in a forested complex terrain. Spatial and temporal up-scaling of the results is being conducted using various techniques including stable isotopes and GIS/RS-based ecosystem modeling. These systematic measurements are promising in building a foundation for the understanding of forest ecosystem processes in Korea and in developing models for prediction of global warming impacts on forest ecosystems, including forest dynamics, hydrology, carbon exchange, etc.

VI. FUTURE CHALLENGES AND SUGGESTIONS

Even though some phenological indicators of global warming have been monitored, researches and monitoring efforts in changes in species competition at ecotones and communities or ecosystems which are vulnerable to global warming are recommended. Also, basic experimental data and information of the physiological and genetic adaptability to changing environments are essential for parameterization as model inputs.

Assessment of adaptation and conservation of natural resources and management of carbon dioxide emission in the forest sector can be achieved. Well designed data sets and applicable models are essential for assessment of current status and prediction of forest ecosystem functions including water and carbon cycles. Current data of diverse components of forest ecosystems and their spatial distribution patterns are needed, as are forest ecosystem models including forest dynamics, carbon dynamics, and forest hydrology. Models to anticipate the impacts of a changing climate have to be developed in a form accounting for the complexity of terrain which is common in Korean forests.

적 요

최근의 지구온난화현상은 급진전하고 있으며 산림생태계에도 많은 영향을 미쳐 온 것으로 보인다. 지난 세기에 지구온난화와 함께 생물들의 생물계절, 종 분포범위 이동 및 급작스런 기상재해 등에 있어 분명한 변화가 있었다. 우리나라 산림은 주로 온대림지역에 위치하고 있으면서 잎과 꽃의 시기의 변화, 자연재해 및 산림생산성의 변화 등을 포함하여 기후변화의 영향을 받아왔다. 그러나 우리나라에서는 기후변화의 영향을 가늠하고 적응전략 수립에 필수적이라 할 수 있는 산림생태계의 영향에 관한 연구가 매우 미흡하였다. 아울러 산림생태계 프로세스에 대한 기초적이고 장기적인 자료도 부족하다. 우리나라 산림생태계 연구에 있어 하나의 장애물로 작용하였던 복잡한 지형조건을 가진 산림생태적 특성을 고려하여 주의 깊게 자료를 수집하고 생태계프로세스 모델을 개발하여야 할 것이다. 우리나라에서 산림생태계에 대하여 산림동태, 물과 탄소의 순환 및 플럭스 그리고 시공간적 동태모델링 등에 대한 통합적 연구를 소개하고 우리나라에서의 지구온난화에 따른 산림생태계의 영향에 대한 연구현황을 고찰하였다. 역동적으로 변화하는 탄소저장고로서의 산림생태계의 중요성과 임업활동에 대하여 논의하고 우리나라에서의 향후 연구방향과 영향평가 및 적응조치 수립을 위한 산림관리 옵션과 과제를 제시하였다.

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