B-60 Development of Evaluation Model for Carbon Sink (Abstract of the Final Report)

Contact person Masahiro Amano
Professor, School of Human Sciences
Waseda University
Mikajima 2-579-15, Tokorozawa, Saitama, 359-1192 Japan
Tel:+81-42-947-6740 Fax:+81-42-948-4314
E-mail:amano@waseda.jp

Total Budget for FY2002-FY2006 409,898,000Yen (**FY2006**; 77,358,000Yen)

Key Words Kyoto Protocol, Biomass Carbon, Soil carbon, Model, airborne laser altimetry

1. Introduction

This Report examines existing as well as new mensuration techniques to evaluate carbon sequestration by promoting afforestation/reforestation and deforestation (ARD), forest management under Articles 3.3 and 3.4 of the Kyoto Protocol (KP), and CDM/JI sink project under article 12 and 6 as well as to establish a reporting system for IPCC (UNFCCC) Inventory report under Article 5. The focus is on how afforestation/reforestation and forest management are being interpreted, promoted and implemented under Articles 3.3 and 3.4 of the KP across the nationwide. Information used in this report was obtained from administrative sector and research fields as to the approaches and progress each was making with respect to the development of useful forest sequestration programs.

The KP of the United Nations Framework Convention on Climate Change requests to establish a specific national inventory of carbon pools in forest sector for KP. The carbon pools include litter, dead wood, and soil, as well as aboveground and belowground biomass. Furthermore, soil and dead organic matter carbon dynamics should be evaluated when forest management such as thinning and clear-felling is operated.

2. Research Objective

Methods to evaluate accuracy of estimation of carbon uptakes of forest biomass using forest resources statistics and methods to improve the accuracy were discussed. As a method of cross check, a hybrid model to estimate forest growth was developed.

The objectives of the soil research are 1) to review basic data on pools and processes of soil and dead organic matter dynamics for making the national inventory under the Convention, 2) to develop a model for carbon dynamics in the soil and dead organic matter, which can evaluate the effect of forest management defined on these pools.

Objectives of CDM research are to clarify the effect/leakage that the afforestation and reforestation projects under CDM cause for the surrounding area, to clarify the measurement method of effect/leakage through the analysis of the occurring process, and to show the guideline for avoidance and the reduction of a negative effect/leakage.

The main objective of developing a model to evaluate carbon sequestration by forests during the first commitment period is to examine the strategy for implementing silvicultural practices for efficient carbon uptake in FM plantation forests during the first commitment period. The subsequent objective is to investigate the relationship among (1) the amount of carbon to be sequestered in FM plantation forests during the first commitment period, (2) harvesting & thinning volume during the first commitment period and (3) the total area of FM plantation forests.

In Japan, a total carbon uptake in forests under the Article 3.3 & 3.4 activities is capped up to 13.0 (million t-C year^{-1}) by the Marrakesh Accords. The Forest Agency regards the forests under the Article 3.4 activities (FM forests) as (1) plantation forests implemented silvicultural practices such as weeding, pre-commercial thinning and thinning since 1990 (FM plantation forests) and (2) natural forests managed such as protection forests, forest reserves and natural parks (FM natural forests).

This objective of this study is to develop a carbon sink accounting model based on ecological approach. This is intended to contribute to account carbon sinks for the Kyoto Protocol and the possible full carbon accounting. The input parameter of the model are environmental and forestry data with a scale of 1 km grid. Testing this model with carbon flux data (Takayama site), it reproduced the time-series data very well and we succeeded in dividing photosynthesis level into understory vegetation and others.

3. Result and Discussion

(1) To develop models for evaluating Japanese forests under Kyoto Protocol conditions

1) Measuring forest biomass by utilizing Remote Sensing

a. Development of Forest Carbon Monitoring Methodologies using Airborne Laser Profiling

Methodologies for scaling forest biomass and forest carbon sequestration with airborne laser profiler over an extensive range was developed in three steps for possible use in the Kyoto Protocol forest carbon accounting and reporting. In the first phase of accuracy evaluation, the airborne-laser estimates of biomass of and carbon sequestered by a 500 hectare tract of the Tomakomai National Forest turned out to be consistent with those obtained by the conventional ground mensuration, yield tables and tower measurement of CO_2 flux, with the sole exception of national forest inventory registering only 60% of the ground truth timber stock measurements.

In the second phase, the applicability of airborne laser profiling to an extensive range was tested in the boreal forest zone of western Canada. The estimated S-N biomass distribution all across the boreal forest zone from the northern end of the Prairies to the Arctic Ocean based on a 600 km and 750 km laser profiling transects respectively at the south and north ends, revealed significantly less boreal biomass stock than has been normally reported or reputed. Repeated laser profiling of a five year interval over the southern transect revealed drastic decrease in biomass also against the general belief of its being a carbon sink. The decrease was primarily due to a major forest fire which burned the central portion of the transect, but widespread dieback of broadleaved species at the southern end of the transect also contributed to some extent. Furthermore, it also suggests northward shifting of the boreal forest zone.

The third and final phase was laser profiling of entire Ehime Prefecture for landuse classification and timber stock assessment as a practicality test for application in the Kyoto Protocol carbon accounting. The greatest discrepancy found between the laser estimates and the government landuse statistics was in forest area and amounted to 10% of the total prefecture area. Even greater discrepancy was found in standing timber stock with the government figure from the national inventory registering only half the amount of the laser estimate. Some part of the discrepancies can be resolved as a difference in definition and demarcation, but substantial discrepancy remains in timber stock unless persistent underestimation in the national inventory is dissolved.

b. Improvement of forest inventory book utilized by LiDAR

The objective of the present study is to develop a transparent and verifiable model of volume estimation for conifer plantations using remote sensing. The model is to be independent from observation, that is, ground truths are not necessary for parameter fitting and model construction.

To achieve it, the estimation process is divided into two steps; direct measurements of physical parameters of stands, and stand carbon storage estimation by an external model. As an external model, we adopt the iso-height curves in the stand density chart, which can estimate a stand volume from a stand height and a density, directly measurable parameters by the laser scanner. In the present study, firstly, the iso-height curves are created from the external inventory data. Then, the stand heights and densities are directly observed by means of the airborne remote sensing. Finally stand carbon storage are estimated by the observed stand heights and densities using the iso-height curves. The experiment has been taken place in Tomakomai National Forest, Hokkaido, Japan. We found that the new iso-height curves predicted the stand carbon storage very well. This method will contribute the implication of the remote sensing technology to forest management by sharing the concept and values with foresters.

c. The mechanism of relationship between the biomass change of land surface ecosystem and the climate change

Examining the mean values for all vegetation types over the first 10-year period, the vegetation carbon storage (VC) is 677.4 PgC, the soil carbon storage (SC) 1,852.2 PgC, the gross primary production (GPP) 158.7 PgC year $^{-1}$, the net primary production (NPP) 91.2 PgC year $^{-1}$, and the net ecosystem production (NEP) 3.9 PgC year $^{-1}$ for the total land surface. In these model results, although the value of VC is almost the same as the results from other models, the values of SC and NPP are relatively larger than those of other estimations (see, e. g., Field et al. 1998[(1)], Ito 2002[(2)]). The soil carbon storage (SC) values estimated by previous plot scale field investigations, on average, are about 1,730 PgC (Ito 2002[(4)]). Other representative values are 1,567 PgC (IGBP-DIS 2000[(3)]), and 1,500 PgC

(IPCC 2001[4]). The value of NPP is generally half that of the value of GPP. In the model results, the values of NPP in cold climate regions were generally more than half of the values of GPP. The estimated values of respiration from the vegetation in the cold regions were generally small, and the values of NPP for the regional vegetation estimated by the model became relatively large.

To investigate the impact of deforestation on the land surface climate and the carbon balance in the Asian tropical region, a control simulation and a vegetation change impact experiment were performed using a global climate model that includes the BAIM2.

It is possible that the continuous deforestation in the tropical rain forest area could induce a continuous decrease in the land surface uptake of carbon dioxide from the atmosphere. Consequently, this gives impetus to a tendency for the atmospheric carbon dioxide concentration to increase, even if bare soil surface conditions are not produced after the deforestation. In the Asian tropical region, it was concluded that the impact of deforestation on the carbon balance was greater in the tropical rain forest, than that in the tropical seasonal forest.

2) Development of models to estimate carbon uptakes by forest biomass

Based on analysis of the Kyoto protocol, the Marrakech accords and IPCC Good Practice Guidance for LULUCF, definition of forests and accounting methods under Article 3.3 and 3.4 were discussed, and Forest Sinks Estimation Model was developed for accounting and reporting under the Kyoto protocol.

Considering rules on definition of forest, Japanese forest planning system and condition of Japanese forests, it was suggested that definition of forest that minimum area is 0.3ha, minimum tree crown cover is 30%, minimum height is 5m at maturity and minimum width of forest is 30m for Japanese reports. Analyzing changes of Landsat TM images in two point of time did not give good results for identification of AR and D under Article 3.3. On the other hands, a systematic sampling for land use and land-use changes with 500 m grids on ortho photos and SPOT images could identify ARD adequately, and the result showed that the method is appropriate for Japanese report.

Because Japan has forest registers for all stands and they are updated every five years at least, “Stock change method” is suitable for estimating carbon sinks. For sinks under Article 3.4 Forest management, an estimation method by ratios of forest management land (FM ratios) was developed. A trial of the method with forest registers of Ehime prefecture in 2005 and 2006 indicated that forest sinks were 343 K t-C/yr and forest sinks under Article 3.4 forest management were 167 K t-C/yr 1n 2005.

Integrating methods developed in the project, Forest Sinks Estimation Model was developed (Figure 1). The model was used for National Inventory Report under UNFCCC and Report on Japan’s Assigned Amount under the Kyoto protocol.

3) To develop a model for evaluating carbon budget of forest soil

Data on carbon accumulation in soil and dead organic matter were collected from previously published reports and summarized. Changes in organo-chemical constituents in decomposing litter were studied for obtaining suitable parameters predicting carbon dynamics. The CENTURY model was selected among several famous carbon dynamics models and adjusted to Japanese forest sector by climate data and soil-vegetation map.

The average soil carbon stocks in Japanese forests were 9.0 kg m^{-2} in nation-wide level but the variation of soil carbon stocks among prefectures was wide. Litter decomposition rates of red pine and beech were mainly controlled by the decomposition rates of lignin and cellulose. The parameters of CENTURY model were adjusted to follow biomass accumulation of Japanese tree species and changes in carbon stocks of soil and dead organic matter under forest management systems. After the modification we named the model as CENTURY-jfos. Using the model, changes in carbon stock in dead wood, litter, and soil carbon pools were calculated. The model parameters were provided for each prefecture and for each predominant tree species to simulate carbon dynamics accurately. The effects of forest management such as cutting and thinning were also examined for applying articles 3.3 and 3.4 in Kyoto Protocol.

Carbon stock in soil of Japanese forests was higher than those in temperate forests located in Europe and North America but carbon stock in litter in Japan was smaller than the other temperate forests. It is difficult to find the relationship between chemical processes of organic matter and model structure in CENTURY model. However, CENTURY-jfos has enough accuracy to describe carbon stock changes in Japanese forest for reporting Kyoto Protocol.

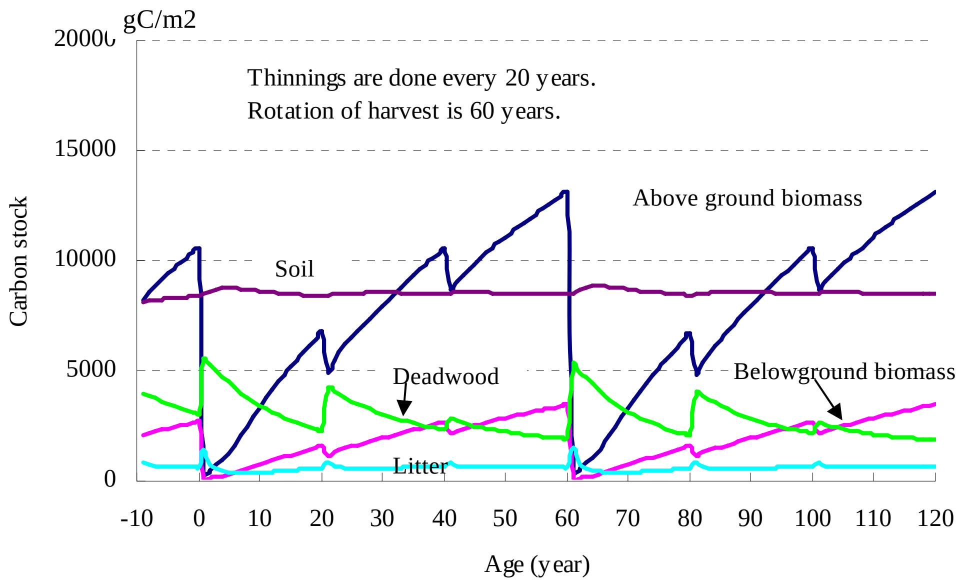

Fig. 1 Changes in carbon stocks in biomass, soil, and litter in Japanese cedar forests using the CENTURY-jfos model.

The average and variation of carbon stocks in soil, litter, and dead organic matter in Japanese forests were summarized. CENYURY-jfos was developed for accounting carbon stock changes in litter, dead wood, and soil pools in Japanese forest sector. The model was used in the national report of Kyoto Protocol.

4) To develop a model for evaluating carbon budget of timber sector

We developed a simulation model to investigate the carbon stock effect by utilization of HWP (Harvested Wood Products), and estimated the amount of carbon stock and emission in the building, furniture, paper and paper board sections after 2013 according to the three IPCC guideline approaches. When the amount of the productions (buildings, furniture, paper) were stable and wood usage would remain in the present state, not much absorption would be expected in the stock change and production approaches, and the emission over 10 million t-C would be the results in the atmospheric flow approach.

We incorporated the modules for evaluation of the energy saving effect and fossil fuel substitution effect to the model (Fig. 2). The total amount of reduction in carbon emission by three effects would be 12 million t-C/yr (average over 2013-2017), on condition that 70% of building construction starts was wooden construction, 70% of newly produced furniture was made by wood, and all wood and paper waste were used as energy source.

Based on the energy use (carbon emission) for producing materials, the effect of carbon emission reduction by substituting common materials used in housing with three stories or less, nonresidential buildings, office furniture, and aluminum sashes by wooden materials was estimated. Considering carbon stock along with carbon emission, contribution by substituting the other materials was quantitatively evaluated.

The substitution in the buildings lower than three stories were found to be very effective since a difference of the amount of the materials and energy use between a wooden constructed house and a house of other construction was significant. The amount of carbon emission reduction by substituting other materials in furniture by wooden material was not large, but the carbon stock increased significantly by the substitution. Substitution of aluminum sashes by wooden sashes was not effective in terms of carbon stock, but effective for carbon emission reduction.

We estimated the amount of wooden waste and carbon emission reduction by using the wooden wastes for energy production. The potential for carbon emission reduction was estimated as 3% of base year emission. We also investigated advantages and disadvantages of the various methods of bioenergy conversion such as mixed combustion, gasification, liquefaction. We clarified that heat value of wood pellet fuel was calculated from the results of elemental analysis. Gasification efficiency was higher in the Japanese cedar wood among other species and

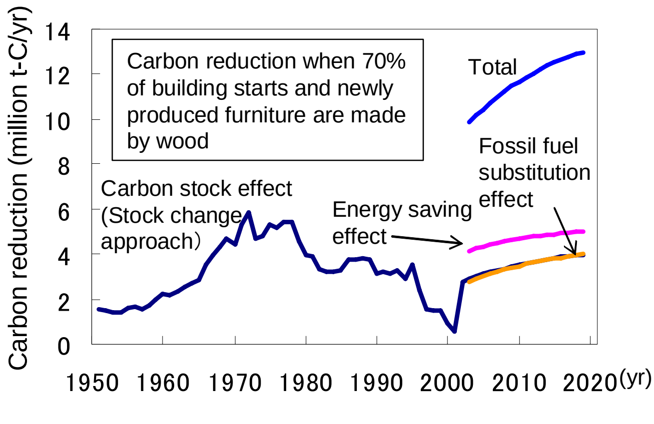

Fig. 2 “Carbon stock effect”, “Energy saving effect”, and “Fossil fuel substitution effect” when proactively utilize wood estimated by the simulation model.

the efficiency was improved by steaming during the process of gasification.

5) To develop a methodology to establish AR-CDM project

In some cases we can expect to be sequestered carbon in artificial forests about 10 tC/ha/yr at good sites. The value of *Eucalyptus globulus* in Manjimup, Australia may be exceptional, then above ground carbon accumulation reached about 16 tC/ha/yr and these values might be the upper limit of industrial plantation with fast growing tree species. Carbon accumulation of rehabilitating forests was not always lower than that of industrial plantation. Selecting the suitable tree species for the purpose of forests and for the site condition may be one of the most essential factors to success establishing and preserving forests. From the allometric relationship between DBH and above ground biomass in all sample trees we measured and census data (mean DBH, actual tree density, age) in various species planted in the tropics, the predicting formula of carbon sequestration with age was presented and the formula might be useful in Project Design Document (PDD) description of A/R CDM at the various site which a investor or government will be in the planning.

Research Method

Concepts of leakage, the process in which it occurs, and the method to quantify the leakage were clarified. Leakage is categorized by leakage drivers or land use changes and/or other local people’s activities. Prototype of an evaluation model for predicting and monitoring leakage was developed. The evaluation model involves 3 major steps of 1) clarifying an implementation manner of AR-CDM project, 2) clarifying land utilization pattern and changes of it, and 3) identifying and quantifying leakage. Quantifying in step 3) varies depending on magnitude of leakage and availability of data. Prototypes of leakage evaluation model were developed. They need to be simplified and more concrete following discussion and rules that will be clarified in UNFCCC before the First Commitment Period.

6) To develop a national model to evaluate Japanese forests under Kyoto Protocol

The purpose of this study was to predict the likely amounts of carbon sequestration on a national scale for Japan in the Article-3.3 and 3.4 planted forests of the Kyoto Protocol during the first commitment period. For the Article-3.3, the land use change from forests to other land uses and the contrary land use change from 1976 to 1995 were identified using the national statistics. Next, the time series changes in the areas were extrapolated from 1995 to 2012, the end of the first commitment period, using the power series and logarithmic functions fitted to the observed land use change areas, respectively. For the Article-3.4, regression models were developed to predict the forest areas that had undergone silvicultural practices, employing silvicultural subsidies and forest workers’ wages as predictor variables. Then the time series changes in the predictor variables were provided by extending their recent trends, with the result being that the forest areas that have undergone silvicultural practices were predicted on the basis of the three scenarios of the variables. Thus, the Article-3.4 forest area was calculated considering overlaps of silvicultural practices over fixed stands. Furthermore, these Article-3.3 and 3.4 areas were converted into the amount of carbon sequestrations by multiplying them by coefficients such as a volume table, biomass expansion factor, and others. As a result, the Article 3.3 forests would release approximately 0.76 Mt-C/yr during the first commitment period. And the Article-3.4 planted forests would sequester 11.55-12.26 Mt-C/yr during the first commitment period. These amounts cover approximately 85% of the carbon sequestration goal by land-use change and forestry activities capped under the Marrakesh Accords. This 85% seems to be sufficient for achieving the goal, considering the additional carbon uptake by FM natural forests. In addition, if FM planted forests were restricted to the practiced stands with Ry≦0.85, the total carbon uptakes amount to 10.40-10.81Mt-C/yr that cover approximately 75% of the carbon sequestration goal. In this case, it is important to provide a sufficient silvicultural subsidy to last until the end of the first commitment period and to implement silvicultural practices on the forest stands that have not undergone such practices since 1990 to achieve the goal.

(2) The development of a model to evaluate carbon budget of forest ecosystem and to analyze uncertainties

The objectives of this topic are (1) developing of a biological model using forest inventory data, (2) estimating carbon sink in managed forest in Japan and (3) assessing uncertainty of carbon sink of managed forest.

A new biological model in which forest inventory data can be used for parameter was developed. Amount of thinning which is one of anthropogenic disturbances affecting on forest sink is modeled. Amount of final cutting is estimated by the cut of timber model which s developed in other topic of this project.

In order to verify the model precision, we compared results of this model with inventory data at test sites. Results of this model agreed with inventory data in quantitatively. Next, we assessed uncertainty of forest sink. As a result, the amount of the CO2 sink in managed forest in Ehime Prefecture of 2005 was 0.269Mt-C/yr by this model and the result was closed to the result based of inventory method. But the amount of growth was different from that obtained from yield table. At last, we assessed the uncertainty of the cut of timber. If the cut of timber raise 3%/yr from 2005, the amount of forest sink in 2012 will decrease 5% than BAU scenario.

From the comparison of model and inventory data, it is assumed that yield table which is based on inventory data may have issue. Because the yield table include effect of thinning and growth rise smoothly but there are many forests which are suit for thinning. From the calculation results, activation of forest caused CO2 emission because all carbon in biomass harvested is oxidized in the removal year in Kyoto protocol. In reality, carbon is stocked in forest products and activation of forestry may not discourage the carbon sink. So it is better to apply full carbon accounting to avoid this inconsistency.

References

(1) Field, C. B., M. J. Behrenfeld, J. T. Randerson, and P. Falkowski, 1998: Primary production of the biosphere: integrating terrestrial and oceanic components. Science, 281, 237-240.

(2) Ito, A., 2002: Soil organic carbon storage as a function of the terrestrial ecosystem with respect to the global carbon cycle. Japanese J. Ecol., 52, 189-227 (in Japanese).
(3) IGBP-DIS (International Geosphere-Biosphere Program, Data and Information Services), 2000: *Global Soil Data Products CD-ROM*. Oak Ridge National Laboratory, Oak Ridge, TN.
(4) IPCC (Intergovernmental Panel on Climate Change), 2001: *Climate Change 2001: the Scientific Basis*. Cambridge University Press, Cambridge, United Kingdom. 881pp.

Major Publications

1) E.R.G.Abraham, T.Kusakabe, H.Tsuzuki, and T.Sweda: J. For. Plann., 8, 9-16. (2002)
"Relationship between mean free path and leaf area in boreal forest canopies"

2) C.J. Williams, B.A. LePage, D.R. Vann, T.Tange, H.Ikeda, M.Ando, T.Kusakabe, H.Tsuzuki, and T.Sweda: Forest Ecol. Manag., 180, 287-301. (2003)
"Structure, allometry, and biomass of plantation Metasequoia glyptostroboides in Japan"

3) Mabuchi, K., Y. Sato, and H. Kida: J. of Climate, 18, 410-428 (2005a)
"Climatic impact of vegetation change in the Asian tropical region Part I: Case of the Northern Hemisphere summer"

4) Mabuchi, K., Y. Sato, and H. Kida: J. of Climate, 18, 429-446 (2005b)
"Climatic impact of vegetation change in the Asian tropical region Part II: Case of the Northern Hemisphere winter and impact on the extratropical circulation"

5) K.Ono, M.Hiraide, and M.Amari: Journal of Forest Research., 8, 191-198 (2003)
"Determination of lignin, holocellulose, and organic solvent extractives in fresh leaf, litterfall, and organic material on forest floor using near-infrared reflectance spectroscopy"

6) Noguchi K, Sakata T, Mizoguchi T, Takahashi M: Journal of Forest Research, 9, 261-264 (2004)
Estimation of the fine root biomass in a Japanese cedar plantation using minirhizotrons.

7) K. Morisada, K. Ono, and H. Kanomata: Geoderma, 119, 21-32 (2004)
"Organic carbon stock in forest soils in Japan."

8) K. Morisada: Journal of Environmental Information Science,32, 25-32 (2004)
"The organic carbon stock of topsoil and its geographical distribution in Japan"

9) M. Takahashi: Journal of Forest Research 10, 239-241 (2005)
"Direct estimation of carbon mass of organic layer from dry weight."

10) Hiratsuka Motoshi, Toma Takeshi, Mindawati Nina, Heriansyah Ika, and Morikawa Yasushi: Journal of Forest Research, 10, 487-491 (2005)
"Biomass of a man-made forest of timber tree species in the humid tropics of West Java, Indonesia"

11) Mindawati Nina, Hendromono, Hiratsuka Motoshi, Toma Takeshi, Morikawa Yasushi and A. Ngaloken Gintings: Journal of Forestry Research, 1, 17-24 (2005)
"Tree trunk volume of Shorea species case study in Dramaga and Haurbentes research

forest in West Java, Indonesia”
12) T. Hiroshima: J. For. Res., 9, 2, 141-146 (2004)
“Strategy for implementing silvicultural practices in Japanese plantation forests to meet a carbon sequestration goal”
13) T. Hiroshima and T. Nakajima: J. For. Res., 11, 6, 427-437 (2006)
“Estimation of sequestered carbon in Article-3.4 private planted forests in the first commitment period in Japan”
14) Masahiro Amano and Roger A. Sedjo: RFF Reports, 59pp (2006)
“Forest Sequestration: Performance in Selected Countries in the Kyoto Period and the Potential Role of Sequestration in Post-Kyoto Agreements”
15) S.,Yamagata Y.,Krott M. : Forest Policy and Economics,4 ,65-77 (2002) “carbon sink by the forest sector-options and needs for implementation”
16) Alexandrov G ,Oikawa T, Yamagata Y, : Ecological Modeling, 148,293-306 (2002) “The scheme for globalization of a process-based model explaining gradation in terrestrial NPP and its application”
17) G.A.Alexandrov, Y.Yamagata:SCIENCE IN CHINA (Series C), 45,7,1-6 (2002)“Net biome production of managed forests in Japan”
18) G.A.Alexandrov, Y.Yamagata : SCIENCE IN CHINA (Series C), 45,Supplement,109-115 (2002) “Net biome production of managed forests in Japan”
19) Alexandrov,G.; Oikawa,T.:Climate Research, 19,3,265-270 (2002) “TsuBiMo: a biosphere model of the CO2-fertilization effect”
20) Alexandrov ,G.A., Oikawa,T. , Y.Yamagata : Tellus Series B-Chemical and Physical Meteorology,55,2,669-675 (2003)“Climate dependence of the CO2 fertilization effect on terrestrial net primary production”
21) Alexandrov G A, Yamagata Y: Ecological Modeling (2004)“A Peaked function for modeling temperature dependence of plant productivity”
22) Alexandrov,G.; Yamagata,Y. : Climatic Change, 67,39116,437-447 (2004)“Verification of carbon sink assessment: Can we exclude natural sinks?”
23) Alexandrov G.A., Y.Yamagata Oikawa T. and Saigusa N. : Agricultural and Forest Meteorology ,134,1-4,135-142 (2005)“Re-calibrationg TsyBiMo eith eddy-covarance measurements at Takayama“