조경학석사학위논문

Impacts of plant community composition on net primary productivity at restored forests in Caldas, Colombia

2014년 2월

서울대학교 대학원
생태조경·지역시스템공학부 생태조경학 전공
김 윤 정

Impacts of Plant Community Composition on Net Primary Productivity at Restored Forests in Caldas, Colombia

지도교수 이 동 근

이 논문을 조경학 석사학위논문으로 제출함

2013년 10월

서울대학교 대학원

생태조경·지역시스템공학부 생태조경학 전공

김 윤 정

김윤정의 석사학위논문을 인준함

2013년 12월

위 원 장 ____________(인)

부 위 원 장 ____________(인)

위 원 ____________(인)

Abstract

Impacts of plant community composition on net primary productivity at restored forests in Caldas, Colombia

Supervised by DongKun Lee
The Graduate School, Seoul National University
Yoonjung, Kim

As productivity in forest restoration has drawn attention to offer maximum efficiency of carbon sequestration, global afforestation and reforestation generally seeks maximum productivity in their plantation activities. Represented global A/R projects including AR CDM and REDD are therefore tended to be planned with one or two industrial species. On the other side, the call for biodiversity is treated as significant issue in line with carbon sequestration. Though global projects, only focused on biodiversity, were not activated yet like AR CDM and REDD, many ecologists and residents of project site had been protested for existed plantation method which only considering carbon sequestration. Specifically, mono-plantation with only industrial species was criticized, because it standardize global forest landscape, destruct local biodiversity, and have short maintenance time.

To reduce such side-effects of mono-plantation with industrial species, REDD+ and REDD++ were suggested. The modified version of global afforestation and reforestation projects had forced practitioners to seek new restoration mehtod of multiple-species plantation. Furthermore, it suggests native species to be planted. Therefore newly created forest landscapes are supported to have multiple species

including native trees. Nonetheless to say, modified version of forest restoration method would promote more higher standards for biodiversity. However, there were arguments whether species richness plant, and also plantation with native trees would offer similar range of productivity as mono-plantations do. Previous studies, aimed to solve this question, illustrated different results, but there were researches demonstrated high productivity of multi-plantation.

Therefore, this study questioned whether there are viable relationship between net primary productivity and adopted forest strata having different community composition. Moreover, this study estimates net primary productivity in each forest strata to assess multi-species plantation's competitiveness compared to mono-plantation. In the mean time, because there are known environmental variables affecting net primary productivity, this study attempted to analyze each variable and adopted restoration mehod's influences to net primary productivity.

To evaluate net primary productivity, NASA-CASA model was used. Since, characteristics of forest strata were important in this study, to calculate temperature and water influences reflecting forest strata, this study implemented latest suggestions of relevant studies, and used its algorithm different to previous NASA-CASA. To assure existed relationship between plant diversity and net primary productivity, one-way ANOVA test was performed. As for influences of environmental variables and species number, linear regression analysis was accomplished.

The result illustrated that there were relationship between species number and net primary productivity satisfying $P<0.01$. Moreover, results of regression analysis shown high significance between species number and net primary productivity. Specifically, Five years variation of net primary productivity was highly correlated with species number. However, net primary productivity in 2008, representing initial stage of restored site after plantation, shown lower values of significance than NPP in 2012.

This study discovered that multi-plantation site can have higher productivity than mono-plantation. Multi-species plantation, planted with pioneer/intermediate/final species with combination of industrial and native trees, had highest values of net primary productivity. In line with that, plantation with three industrial species also shown more increased productivity than nearby mono-plantation.

To satisfy local resident's needs in forest restoration, mono-plantation with industrial species is no longer supported in REDD+ and REDD++. Along with this study's result, there are also other researches supporting multi-plantation's competitiveness. Therefore, the result of this study can be used as a rationale to promote ecological forest restoration in global afforestation and reforestation activities, and it can also be implemented to support optimum forest strata model.

❑ Keywords : Forest restoration, Multi−species plantation, NASA−CASA, MODIS, AR CDM

❑ Student Number : 2012−21132

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Ⅰ. Background and research objective

Forest sequester and store more carbon than any other terrestrial ecosystem and is an important natural 'brake' on climate change(Holly. K. Gibbs et al., 2007). Over 60% of the terrestial above-ground carbon and about 45% of the soil carbon are being stored in forest(Tans et al., 1990). Recognizing the prominent role of forest biomes in global ecology and the global carbon cycle, international society urgently seeks solutions for slow deforestation(Dixon et al., 1993).

Tropical and subtropical deforestation has been a theater of large-scale corruption and illegal activity circumventing regulation designed to control logging(Callaham and Buckman., 1981). In addition, agriculture has expanded in concert with logging through both spontaneous settlement after logging and government-planned agricultural projects(Kummer et al., 1994). Relevant researches discovered that tropical deforestation released of the order of 1-2 billion tonnes of carbon per year during the 1990s, roughly reaching 15-25% of annual greenhouse gas emissions(Malhi and Grace, 2000; Houghton. 2005).

To conserve carbon stocks of the forest, global society seeks Afforestation and resforestation through clean development mechanism(AR CDM) and Reducing Emissions from Deforestation and forest Degradation(REDD) in developing countries. Those methods are commonly seen as a significant, cheap, quick and win-win way to reduce greenhouse gas(GHG) emissions(CIFOR, 2008).

However, many ecologists had been argue that the way to build plant community from those restoration activities may not be sufficient to support local ecosystem's ecological regeneration. That is, because of the operational cost of restoration activities, plant restoration community tended to be planted as a monoculture. Unfortunately, monoculture, planting trees with one or two species, having low biodiversity, has numerous known side effects. Scherr et al.(2004) assumed “the recent rapid expansion of fast growing monoculture plantation has resulted in a groundswell of community opposition in a number of tropical countries, as this type of reforestation does not provide many of the traditional forest goods used by communities and few of the ecological services” Lesica and Allendorf(2009) also argued that monoculture contains low regenerative potential which is crucial to support any future biomass increases. Moreover, Rodrigues(2009) asserted that monoculture with exotic fast growing species, tended to be maintained only 15 years without sufficient regenerative activities.

For that reason, because of those known side-effects of monoculture, global society now seeks REDD+ which intended to seek multi-species plantation aimed for not only carbon stocks, but also forest’s overall ecological functions including biodiversity and productivity. To discuss, ecologists pointed out forest restoration with high plant richness would increase local biodiversity. Hutson and Gilbert(1996) attested that mixed species community influenced small animal’s abundance including bird species. Groombridge and Jenkins(2002) assumed that flora has species diversity ten times more than terrestrial fauna, and it affects terrestrial fauna’s life cycle. For that reason, plant richness had been used by many ecologists including Swift et al.(2004), Costanza et al.(2007), and Henry et al.(2009) to estimate biodiversity.

However, there were debates whether multi-plantation would be effective to enhance forest’s productivity or not. When considering the fact that productivity is the main issue for afforestation and reforestation, forest restoration with multiple species should pose highest productivity like monocultures do. Referring previous relevant studies, Neem et al.(1994, 1996) approved positive relationship between plant diversity and net primary productivity in microcosm ecosystem. Tilman et al.(1997) also shown positive relationship in grassland ecosystem. On the other hand, researchers include potvina et al.(2011) and Yuanbin Zhang et al.(2011) illustrated no particular relationship between species richness and productivity, but they rather estimated more productivity in mono-plant community than multi-plant community. In line with that reflecting debates across last decade, Loreau et al.(2001) concluded that the nature of relationship between community composition and productivity remains unclear.

On the other hand, there are debate whether planting trees with only industrial species would be optimum choice for local ecosystem. Supporters of multi-species community composition argues effects of native species(Kelty, 2006). Diverse ecological trait of native species and industrial species have potential to provide more various ecological benefits to local ecosystem.

Therefore, to support optimum forest restoration for global afforestation and reforestation, it is unavoidable to detect differences in forest productivity depends on applied community composition including mono & multi species and native & industrial species. That is, impacts of such plant community composition to forest productivity should be analyzed to support effective forest restoration scheme.

Thus, this study aims to evaluate impacts of plant community composition to net primary productivity at restored forest in Caldas, Colombia. Specifically, this study attempted to evaluate reasonable algorithm among suggested calculation algorithms for net primary productivity which reflects plant community's differences in large scale. In addition, this study analyzed differences in net primary productivity based on four community compositions including mono/multi and native/industrial species. Furthermore, this study evaluated community composition's influences to ne t primary productivity compared to other environmental variables affecting NPP.

Ⅱ. Materials and Methods

1. Research flow

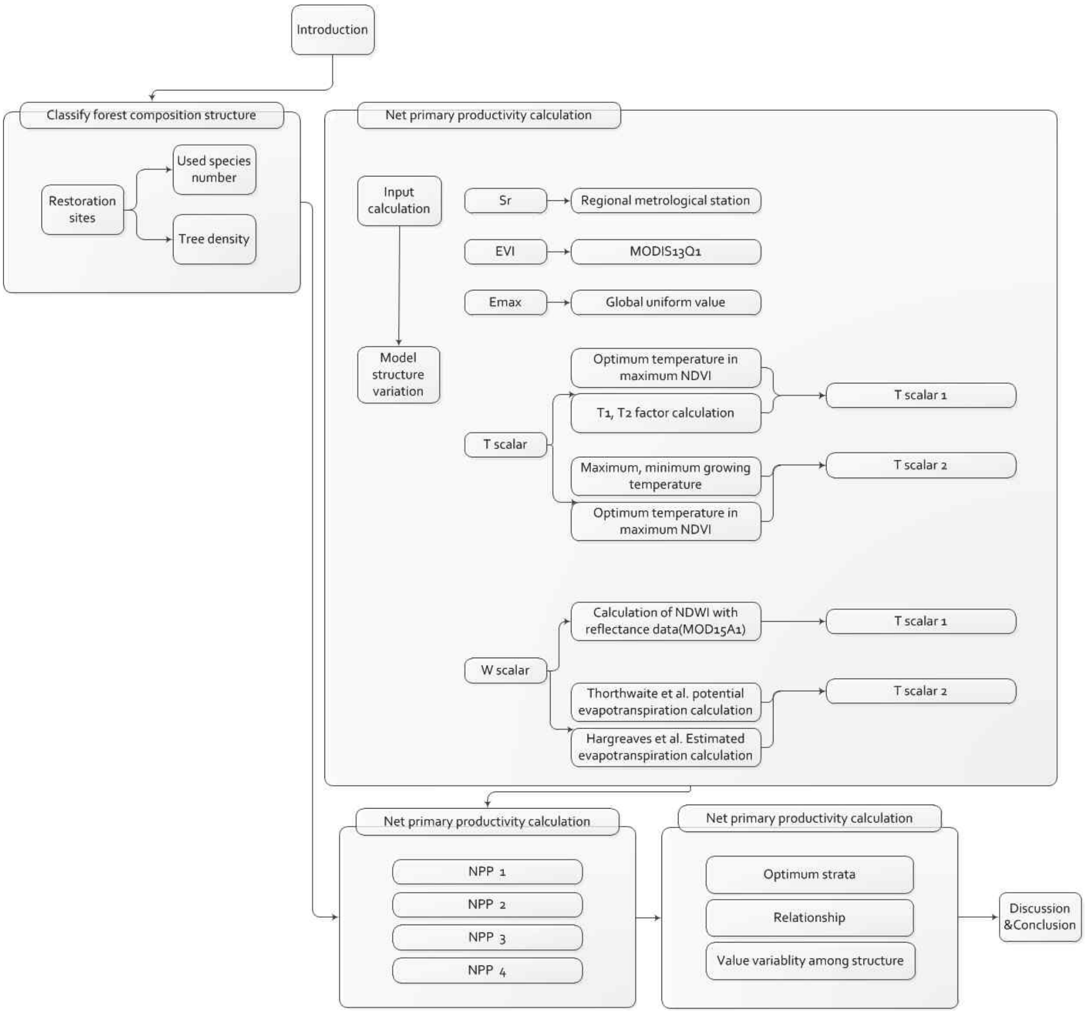

Figure 1. Research flow

2. Study sites and restoration methods

Study site was located in Caldas, Colombia. In early 2000, the sites had chosen to be restoration sites with primary purposes, focusing carbon sequestration. Four different forest stand model was implemented for reforestation. Each four forest stand model was adopted in large scale, so each model had minimum of 650m^2 area(Figure 2). The past land use of study area were composed of pasture field or agricultural field with remnant shrubs. For plantation, existed shrubs were excluded.

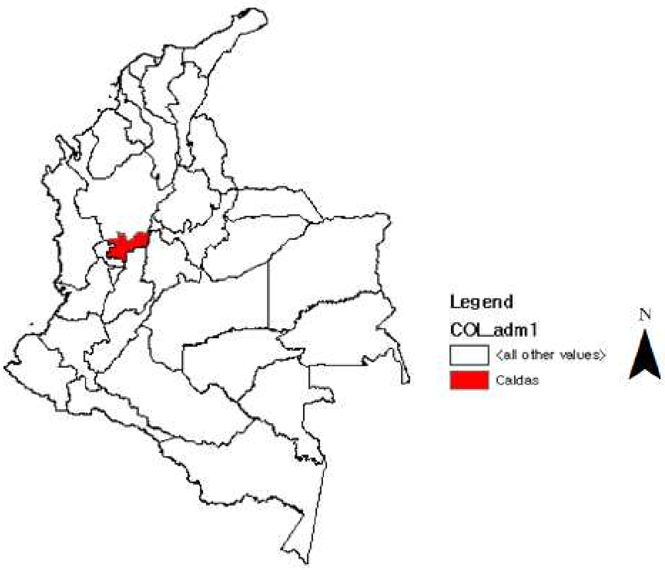

Figure 2. Location of Caldas in Colombia

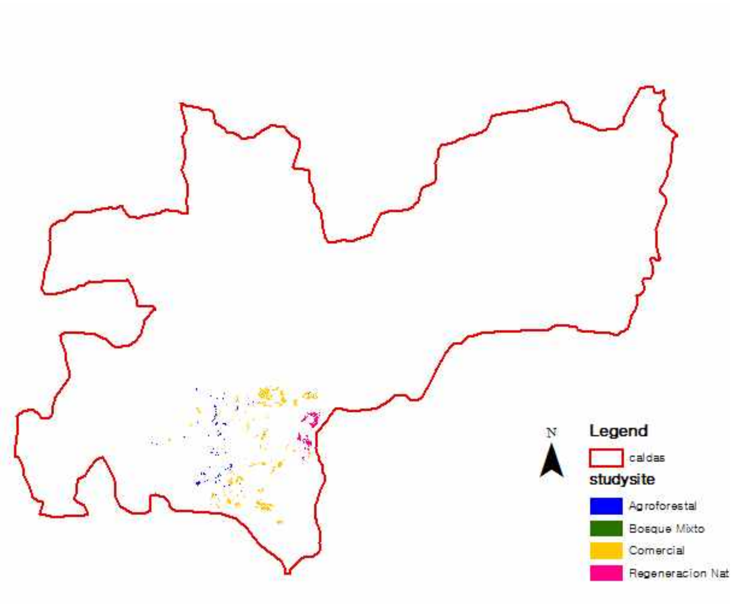

Figure 3. Study site of large scale restoration in Caldas

First stand model was comprised of one species strata, including industrial species of *Alnus acuminate, Cordia alliodora, Cupresus lusitanica, Eucallyptus grandis, Pinus patula* and *Pinus tecunumanit*, which reflect mono-plantation sites. Second stand model had three species strata, including species of *Cordia alliodora, Pinus tecunumanitt,* and *Pinus patula*. Third and Fourth strata had more than 10 species for restoration, and third strata were planted with pioneer species, intermediate species and final species supporting later succession(Table 2). Native species and industrial species were combined in third strata, but fourth strata's planted species were only limited to native species(Table 3). Entire plantation field were initiated in 2002, and finished its plantation in 2007-2008. Though it had extra plantation in need, area for supplement plantation was small.

Strata	Number of species	Tree density(trees/ha)
mono(Commercial)	1	1100
multi_1(Agroforestal)	3	600
multi_2(Bosque Mixto)	n>10	1458
multi_3(Regeneration Nat)	n>15	Dense

Table 1. Planting strata

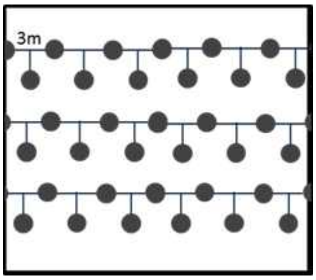	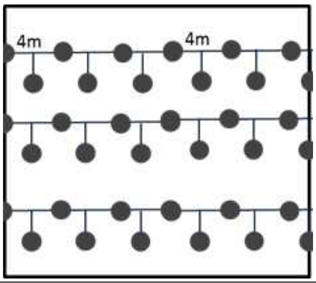	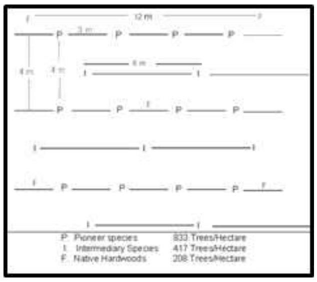
mono	multi_1	multi_2

Table 2. Planting distance

Strata	Species
multi_3	*Pinus patula*
	Pinus tecunumanii
	Cordia alliodora
	Alnus acuminate
	Eucalyptus grandis
	Cupressus lusitanica
	Tectona grandis
	Ginelina arborea
	Quercus humboldtii
	Cedrela Montana
	Fraxinus chinensis
	Juglans neotropica
multi_4	*Freziera canescens*
	Weinmannia mariquitae
	Polylepis sericea
	Miconia sp.
	Brimme;;oa gpidptoo
	Tibouchina grossa
	Ageratina sp.
	Vallea stipularis
	Oreopanax sp.
	Gaiadendrum punctatus
	Miconia salicifolia
	Ruagea sp.
	Bocconia frutescens
	Citharexylum subflavescens
	Podocarpus deifolius
	Croton magdalenensis
	Verbesina arborea

Table 3. Species by tree stand model in the project

2. Net primary productivity

The study calculated net primary productivity with modified NASA-CASA(Carnegie-Ames-Stanford Approach) algorithm. According to Porter et al.(1993), NASA-CASA effectively managed to produce NPP on the basis of light-use efficiency. The CASA is structured, for given area, the Amount of Photosynthetically Active Radiation absorbed annually by green vegetation(APAR) multiplied by the efficiency that radiation is converted to plant biomass increment equals the net primary productivity.

For each of 250m × 250m grid cells, NASA-CASA calculates APAR as the product of solar surface irradiance(Sr) and the fraction of photosynthetically active radiation by green vegetation. Specifically, for calculating FPAR, NASA-CASA uses EVI(Enhanced Vegetation Index). Moreover, NASA-CASA calculates maximum light use efficiency, determined using a calibration with field data of formal researches, and scalars representing the availability of water and suitability of temperature. For that reason, net primary productivity is represented as:

$$NPP = Sr \ EVI \ \varepsilon max \ T \ W$$

Where, Sr refers to solar radiation of project sites. EVI represents plant's FPAR. εmax is maximum light use efficiency. T scalar and W scalar define project site's temperature and water pressure on plant species.

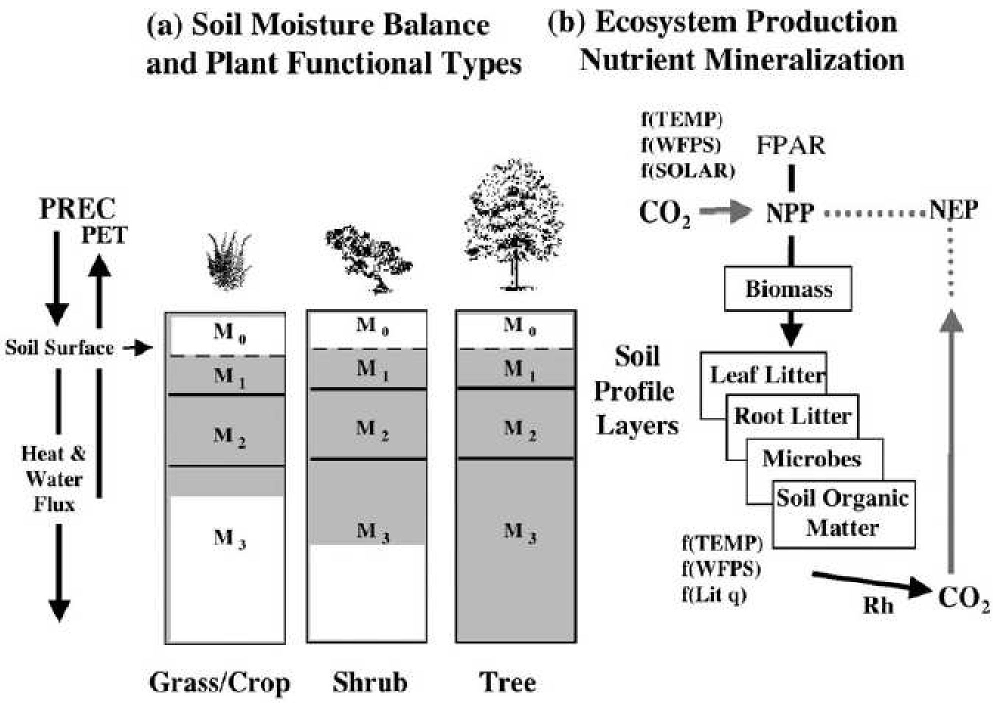

Figure 4. Schematic representation of components in the NASA-CASA model (R. Crabtree et al., 2009)

1) Light use processes of plant

(1) Solar radiation

Regional solar radiation were obtained through regional meterological stations. Two stations were located inside of study site, solar radiation tended to be ranged from 460 mj/m^2 to 532 mj/m^2.

(2) APAR(EVI)

According to Potter et al(1993), net primary productivity derived from EVI shown highest similarities with field based NPP. EVI, therefore, represented as an optimum vegetation index to calculate NPP, modeling plant's FPAR(Fraction of Photosynthetically Active Radiation absorbed by the vegetation).

NPP calculated within EVI managed to reflect 250m fine-scale green vegetation's responses compared to generated 1km NPP from CASA model according to Potter et al.(2003)'s results. Considering the fact that even though global afforestation and reforestation are commonly practiced among large site scales, 1km is often hard to reflect plant composition differences in forest restoration. To solve scale problems, Potter et al.(2007) attempted to calculate NPP with Lantsat TM/ETM imagenary which have scale of 30m × 30m. However, from experimental research, 30m results shown lower credibility compared to 250m scale results with EVI. Regarding those issues, currently, except field based experiments or eddy covariance calibrated results, FPAR estimation within EVI is assessed to have most smallest scale in NPP calculation.

According to Jiang et al.(2008), compared to NDVI, EVI has its advantage on atmospheric correction schemes. There are almost nine yearly time-series EVI since 2000. In this study, EVI was therefore used to synthesize fraction of photosynthetically active radiation absorbed by the vegetation.

Moreover, to convert FPAR values to APAR(Amount of Photosynthetically Active Radiation absorbed annually by green vegetation), maximum light utilization efficiency were multiplied. According to Potter et al.(1993), εmax was determined with globally uniform value of 0.389 g C MJ^{-1}.

2) General Temperature and Water effects in productivity

To produce multiple results with previously suggested variables by former researchers, we attempted to use different algorithms on T and W scalar. T and W refer to temperature and water influences on net primary productivity.

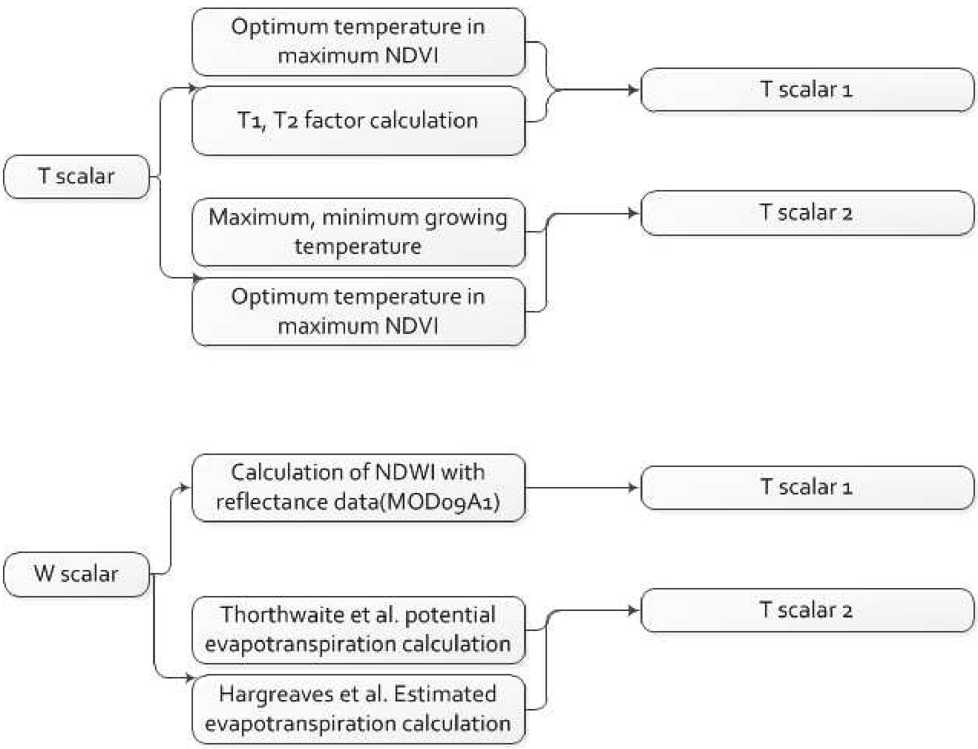

Figure 5. Proposed calculation methods for T and W scalar

(1) Modification of NASA-CASA model

Even though, NASA-CASA simulates net primary productivity with fine scale than previous CASA model, it is limited to reflect vegetation characteristics of plant community. According to Potter et al.(1993)'s study, CASA model evaluated water scalar with Thorthwaite(1953)'s formular and its relationship with soil texture, his study hypothesized site's water responses with soil water balance. CASA and NASA-CASA model, therefore, simulated water balance with soil profile, that is a function of the seasonally accumulated heat flux influencing both precipitation(PPT) and potential evapotranspiration(PET). Moreover, CASA and NASA-CASA estimates temperature scalar with NDVI(Normalized Difference Vegetation Index) derived from AVHRR. Potter et al.(1993) assumed that the AVHRR NDVI of greenness has been closely correlated with canopy greenness, that is computed from the ratio of visible and near-infrared radiation reflected from the canopy as detected by the AVHRR satellite sensor. However, when considering the fact that AVHRR NDVI assess plant canopy's greenness with scale of $4km \times 4km$, it was difficult to reflect study site's vegetation characteristic of planted district.

Therefore, in this study, aiming to get NPP values based of plant strata, attempted to obtain temperature and water scalar in different algorithms to NASA-CASA. To do so, latest suggestions from researches of Wang Lin et al.(2007) and Gao et al.(2013) were implemented in model's algorithm. For that reason, temperature and water scalar were calculated using following equations.

(2) T scalar

For temperature influences, this study used not only historical NASA-CASA algorithms of Porter et al. (1993), but also suggestions of Wang Lin et al.(2007) and Gao et al.(2013).

As documented in Porter et al.(1993) and Field et al.(1995) T scalar should represent plant's temperature stress at very high and low temperature. Porter et al.(1993) and Field et al.(1995)'s temperature scalar approach considers plant's optimum growing temperature as mean monthly temperature having highest NDVI values. For that reason, this study compared monthly NDVI values to obtain optimum mean temperature for plant's growing process.

Within the calculated optimum temperature, T1(x) and T2(x), the two temperature stress terms serve to depress Ɛ at very high and very row temperatures and to depress Ɛ when the temperature is above or below the optimum temperature(Potter et al., 1993).

T1(x) = 0.8 + 0.002Topt(x) - 0.0005(Topt(x))2

T1(x) is ranged from 0.8 and 0℃ to 1.0 at 20℃ to 0.8 at 20℃ to 0.8 at ℃.

T2(x) = C/{1+e[0.2(Topt(x)-10-T(x,t)]}/[1+e[0.3(-Topt(x)-10+T(x,t))]]

Topt refers to mean temperature having highest NDVI values. C is a constant.

On the other hand, because Potter et al.(1993) and Field et al.(1995)'s method to assume temperature's effect did not considered plant's minimum and maximum growing temperature range, suggestion proposed from Wang

Lin et al.(2007) and Y. Gao et al.(2013)'s T scalar calculation method were used.

Therefore, T scalar was calculated as:

$$T(x) = \frac{(T-Tmin)(T-Tmax)}{(T-Tmin)(T-Tmax)-(T-Topt)^2}$$

Tmin and Tmax were plant's growing temperature thresholds. Topt refers to monthly mean temperature having highest NDVI.

(3) W scalar

NDWI(Normalized diffrence water index) were used to assess water influences to net primary production. NDWI is sensitive to changes in liquid water content of vegetation canopies(Bo-cai Gao, 1996). Unlike proposed methodologies in CASA model to calculate water responses in soil, calculation of W scalar with NDWI reflect plant's leaf area's water possessions.

Therefore, it is more focused on the relationship between atmospheric water contents, green leaf area, and its impact on net primary productivity. NDWI is calculated with MOD09A1 surface reflectance data, used two bands were NIR(841-875nm) and SWIR bands, respectively.

$$W(x) = \frac{1+NDWI}{1+NDWI_{max}}$$

Furthermore, for other previously suggested approach to calculate W scalar, Thornthwaite(1957) and Hargreaves et al.(1985)'s methods were implemented using Hijmans et al.(2005)'s world precipitation and temperature data.

Potential evapotranspiration was estimated through thorthwaite's methods, and estimated evapotranspiration was calucalated through Hargreaves et al.(1985)'s methods. To have W scalar, PET and EET were used as:

$$W(x) = 0.5 + EET(x)/PET(x)$$

Specifically, as an alternative if solar radiation data, relative humidity data and/or wind speed data are not able to find, reference evapotranspiration, EET (mm d^{-1}), can be estimated using the Hargreaves equation (Hargreaves and Samani, 1985). The Hargreaves equation is therefore for daily computation is given by:

$$EET = a + b * \frac{1}{\lambda} * 0.0023 * (\frac{Tmax + Tmin}{2} + 17.8) * \sqrt{Tmax - Tmin} * R_a$$

where Tmax(°C) is the maximum daily air temperature, Tmin(°C) is the minimum daily air temperature, Ra (MJ m^{-2} d^{-1}) is the solar radiation. The parameters a (mm d-1) and b are calibrated coefficients, determined on a monthly or yearly basis by regression analysis or visual fitting. An unadjusted version of Hargreaves equation (given by default) is given with a=0 and b=1.

As for Thornthwaite(1957)'s calculation method, following equation was used. Thornthwaite method used temperature to derive the PE values. The method states that:

$$PE = 1.6 \left(\frac{10T}{\sum_{i=1}^{12} (\frac{T}{5})^{1.514}} \right)^{m} * \left(\frac{\frac{h}{12}}{\frac{D}{30}} \right)$$

where T is the mean monthly air temperature (°C), h is daylength, m is a cubic fraction of an empirically determined heat index and D is the number of days in the month.

Thornthwaite stated that over a moist vegetation essential to the PE model the Bowen ratio is constant. It follows from this that any parameter that will successfully approximate the sensible heat flux will also give a measure of the evaporation flux. It follows from the above reasoning that the application of the method is limited to areas where PE conditions are fulfilled.

4) Evaluating influences of restoration model to NPP

(1) Assessing environmental variables affecting NPP

According to previous studies, including studies of Lieth et al.(1978), Leemans and Cramer.(1991), Neem et al.(1994), Costanza et al.(1998), and so on, net primary productivity is affected by site-specific environmental variables of temperature, precipitation, soil texture, soil moisture, and soil texture. To analyze whether adopted species number in plant strata had effect on net primary productivity, this study analyzed each environmental variables in study site(Table 4).

Environmental variables	Scale	Reference
Monthly mean temperature	1km × 1km	Hijmans et al.(2005)
Annual precipitation		
Soil texture		Panagos P. et al.(2012)
Elevation		

Table 4. Assessed environmental variables

(2) Estimating influences of species number in NPP differentiation

To assess differences among the four adopted strata, the 256 random points were created, and each points were spatially divided based on soil texture classification. Study site had three types of soil texture, therefore 256 random points of plant strata were divided in three spatial data(Figure 6).

The results of net primary productivity and species number were analyzed using one-way ANOVA. The results having $P<0.01$, using SPSS 21.0, were assessed to have differences in net primary productivity according to species number. To estimate each assessed environmental variables and species number's impact on net primary productivity, linear regression analysis were performed. For each variables, results having $P<0.01$ were analyzed to have major influence to NPP.

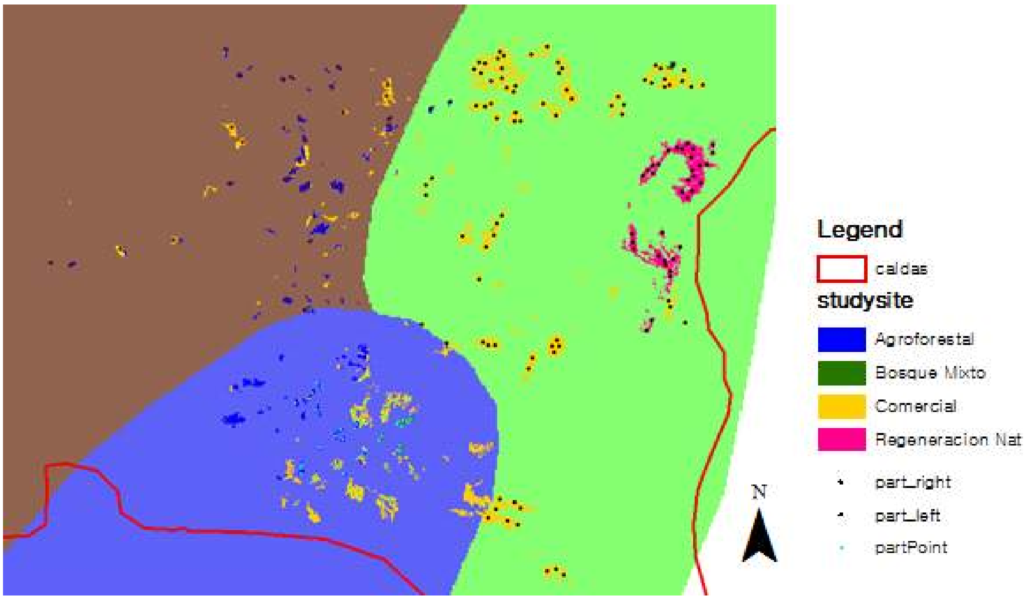

Figure 6. Spatial distribution of random points

5) Comparing results to field-data

To verify estimated NPP values, previous global NPP estimations were reviewed. Scurlock and Olson(2001)'s study offer best NPP values around the world, including the nearby points of study site, to get spatial NPP distributions based on landuse type. The study compared results of NPP with Scurlock and Olson(2001)'s study.

6) Comparing results with MOD17

Even though, MOD17 had different scale to calculate NPP, the study compared results with MOD17. However, because MOD17 calculated NPP values in more large scale, the study attempted to show diffrences among results from two different calculated mechanism between MOD17 and this study's suggested model.

Ⅲ. Literature Review

1. Afforestation and reforestation(AR) in the Clean Development Mechanism

Under agreement at the seventh session of the Conference of Parties to the UN Framework Convention on Climate Change in Marrakesh(COP7) industrialised countries will be able to meet a part of their emission reduction commitments under the Kyoto Protocol by financing reforestation and afforestation activities(AR) in developing countries though the clean development mechanism(UNFCCC, 2001).

Definition of AR, afforestation and reforestation, is not clearly identified among researchers and practitioners. However, according to Smith(2002), "AR comprises human induced conversion of non-forest land through planting, seeding and/or human induced promotion of natural seed sources" This definition, primarily focusing on COP7, emphasize the plantation's role in forest restoration.

Activities such as the establishment of mono-specific or multi-species plantations for wood and non-wood products appear to be compatible with this definition, as are both industrial and community-based plantations. The definition also, apparently, is compatible with the establishment of estate crops, such as oil palm. Two points, particularly significant for forests and local communities, should be highlighted. First, plantations established after cutting down forests would not qualify under this definition.

Plantations would however qualify if established on grasslands, agricultural lands or degraded forest land with less than 10% canopy cover. Secondly, Assisted Natural Regeneration (ANR) of forests is included. In this aspect, the definition differs from the definition of AR put forward by the

International Panel on Climate Change(IPCC, 2000).

AR activities in clean development mechanism catalyze forestry plantations, oil palm plantations, and renewable energy. According to J. Smith(2002), majority of Forestry plantation in AR CDM is dominated by industrial species including palm plantation. Plantation of fast growing species in developing countries are rapidly growing, because of its asset to have higher rate of carbon sequestration and high yields(Sedjo, 1997).

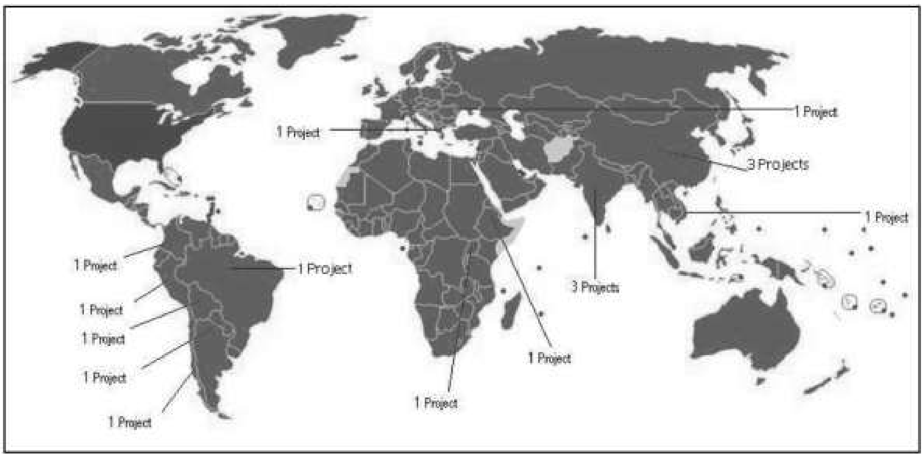

Figure 7. The location of 17 registered AR CDM sites(J. Smith, 2002)

Top priority in industrial forestry plantations thorough AR CDM activities is cost-effectiveness(Smith, 2002). Afforestation and reforestation activities are commonly requiring land use change of previous land. Often, crop land or pasture are selected to be a site for AR. When cost-effectiveness is not satisfied in such land use change, AR is not socio-economically beneficial to local residents. Furthermore, leakage of carbon sequestration should be considered to promote longer term carbon sequestration(Hardner et al., 2000).

The relationship between industrial forestry plantations and natural forests is more complex than appears at first glance, particularly in region rich in timber(Barr, 2000). In Indonesia, for example, in 1999 only 8% of the 100 million cubic metres consumed by the processing sector came from plantations, most of the rest being obtained by cutting down natural forests(Barr, 2000).

Moreover, CDM activities dominated with industrial species is criticized by many ecologists. Standardization of forest landscape, low biodiversity of mono-industrial species plantation, and short maintenance time of ecosystem are suggested as negative points to AR CDM(Anon, 1992).

2. Ecological forest restoration in global AR

Deforestation and forest degradation began 20,000years ago, and restoration has, in some way, been practiced for centuries, but only recently has it started to receive society's attention(Cairns and Heckman, 1996). Even though, forest restoration lately started, Sean McNamara et al(2006), Rodrigues et al(2009), Rodrigues et al(2011), Jeffrey D. Corbin et al(2012) researched undergone forest restoration projects in global afforestation 、 reforestation activities.

Rodriguet et al(2009) demonstrated that amongst conducted restoration projects during 1982~today, consideration on species diversity and succession stage contributed on self recovery. For the initial stage of tropical forest restoration, restricted exotic fast-growing species ,without knowledge on ecological processes, were planted. In this stage, ecological processes responsible for forest maintenance were largely ignored, and criteria for the selection of species were not established yet. During 1982~1995 years, native species became widespread in forest restoration, but only focusing a small number of fast-growing species(maximum 30 species) planted in high density(Barbosa et al., 2003). As advanced knowledge on plant community was discovered, from 1985, near reference plant composition was used to rehabilitate the degraded forest. However, after 2000, the species composition in forest restoration no longer expected to just "copy" the existed near forest, but it attempted to build basic ecological process of forest. For that reason, restoration projects were started to consider multiple species, the natural process for self-recovery, and also genetic and plant species diversity became more important issues to cope with.

McNamara et al(2006) illustrated mixed native species plantings in

Vietnam. The main agenda in forest restoration of Vietnam was soil and water resource's rehabilitation. Because, few native species were able to tolerate degraded soil, much early plantation development in Vietnam focussed on monocultures of fast-growing exotic species of *Eucalyptus, Acasia and Pinus*(Nghia and Kha, 1998; Kha et al., 2003). This study composited fast-growing species *A. auriculiformis* with other 6 species to establish mixed plantation in afforestation.

Rodrigues et al(2011) conducted research on large scale reforestation in tropical forest. Developing countries, where 26 of the 34 global biodiversity hotspots are located, were particularly important biomes to rehabilitate. In tropical forest, for prolonged restoration, it is necessary to create self-perpetuating forests that truly support ecosystem functioning and adaptive evolution, as well as ongoing supply of ecosystem to people(Loreau et al., 2001). The researchers suggested number of species based on forest type to be planted. Highly adopted plant diversity was assisted.

3. Enhancement of biodiversity in forest restoration

Forest rehabilitation efforts through ecological restoration fundamentally aim to obtain ecosystem services which forest offers. Jordan(1987) asserted the major goal of ecological restoration is the reestablishment of the characteristics of an ecosystem, such as biodiversity and ecological function, that were prevalent before degradation. Thus, there is a widespread assumption that ecological restoration will increase provision of ecosystem services.

However, many restoration practices often focused on one ecosystem service, that is carbon sequestration. Rey Benas et al.(2009)'s study assessed eighty-nine restoration activities throughout the world. According to this study, among the ecosystem services, provision service was main ecosystem function rehabilitated. On the other hand, biodiversity was rarely restored as reference ecosystem do.

In line with that, stephens and Wagner(2007) asserted that currently half of the global forest plantations are for industrial purposes prevailing by monoculture. Monoculture, widely used in plantation activities, have a common belief that it will influences biodiversity in negative way(Wagner et al., 1998). According to Wagner et al.(1998), increasing yield of monoculture will decreases biodiversity. Moreover, there are argument that single species forests will further contribute to land simplication in areas that were once highly diverse forests(Lamb, 1998).

The recent rapid expansion of fast growing monoculture plantations has resulted in a groundswell of community opposition in a number of tropical countries, as this type of reforestation does not provide many of the traditional forest goods used by communities and few of the ecological services (Scherr et al., 2004). Monocultures are also perceived to have largely negative impacts on the local environment especially for biodiversity conservation(Cossalter and Pye-Smith, 2003).

Then, what are the ecological restoration methods influencing biodiversity in positive way? Ecological restoration draws on decades of cumulative understanding of ecology, biology, climate and soil science, and attempts to pull the relevant parts together to reconstruct or repair the ecosystem (Simmons et al., 2007). Moreover, of greatest importance is the ecological process during restoration (Gattie et al., 2003).

Forest ecosystems house a major portion of terrestrial biological diversity (Carnus et al., 2003) and their declining area is frequently associated with the loss of species, conservatively estimated at 1,000 to 10,000 times the rate prior to human intervention (Pott, 1997). Biodiversity is defined by the United Nations Convention on Biological Diversity (United Nations, 1992) as “the variety among living organisms from all sources including diversity within species, between species, and of ecosystems.”

It is generally accepted, by conservationists and land managers alike, that the conservation of forest biological diversity at all levels is essential to maintaining the health of forest ecosystem(Hartley, 2002). That is, through species composition planning and management, adapting species diversity and seeking habitat heterogeneity, plantation forest could also have potential to enhance forest’s biodiversity(Hartley, 2002).

Specifically, instead of monoculture, forest composition communities is better to be restored with multiple species with native species, increase emphasis on retaining areas of native vegetation, and spatially and temporally juxtapose exotic and native stands within a landscape(Hartley, 2002).

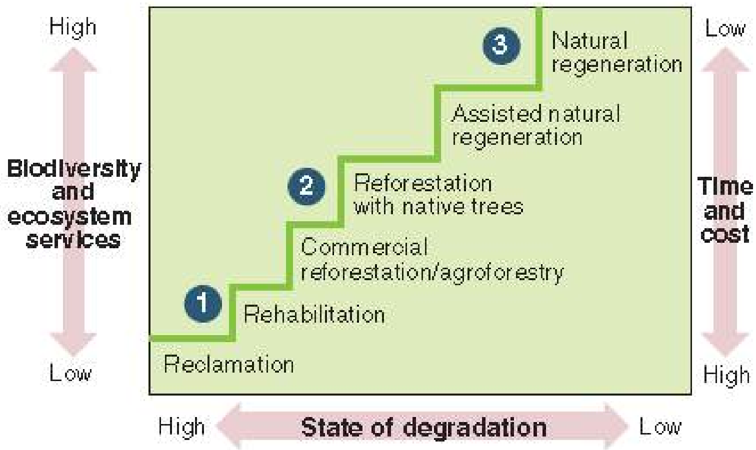

Figure 8. The restoration staircase for biodiversity and ecosystem services(R. L. Chazdon, 2008)

In addition, even though fast-growing, short-lived species with low-density wood are favored by many reforestation projects designed to provide carbon offsets, but long-term carbon sequestration is promoted by growth of long-lived, slow-growing tree species with dense wood and slow turnover of woody tissues that is also be effective to biodiversity(Chazdon, 2008).

Groombridge and Jenkins(2002) approved the relationship between plant species diversity and terrestial fauna. Kier et al.(2005) estimated world's eco-regions with plant diversity values reaching the conclusion that high biodiversity value meet high plant diversity. For that reason, plant species diversity historically long been used as biodiversity indices by various ecologists such as Swift et al.(2004), Costanza et al.(2007), Henry et al.(2009) to represent biodiversity.

4. Productivity and biodiversity

Historically, the question of whether the productivity of a plant community is dependent upon its species richness has received much attention, both by agronomists and ecologists. The former have mainly focused on "low number systems", i.e. chiefly systems with one to three species (Swift and Anderson, 1993), while the latter have usually been interested in more diverse communities. The working hypothesis in these studies is that more diverse communities are more productive because different species are complementary in their use of resources, which allows multispecific mixtures to exploit the environment more completely.

Trenbath(1974) attempted a test for two-species mixtures compared with monocultures. This study reviwed data for 344 experiments which did not include grasslegume associations, he found that in most cases, the yield of the mixture fell between those of the two monocultures. The biomass of mixtures in some instances was lower than that of the least productive monoculture, and the mixture overyielded the most productive monoculture in 24% of cases, but very few were statistically significant. In line with these results, Wilson(1988) reviewed data on plant competition, found that mixtures overyielded the most productive monocultures in only two cases out of 17.

Moreover, Kelty(1992) suggested rationale that why mixture of species can be more productive than that of monoculture. According to this rationale, mixture of species have three reasons to provide more productivity. The rationale proposes that species rich plantations are able to more efficiently access and utilize limiting resources because they contain species with a diverse array of ecological attributes. As a consequence, more diverse plantations should have higher net primary production, and in a

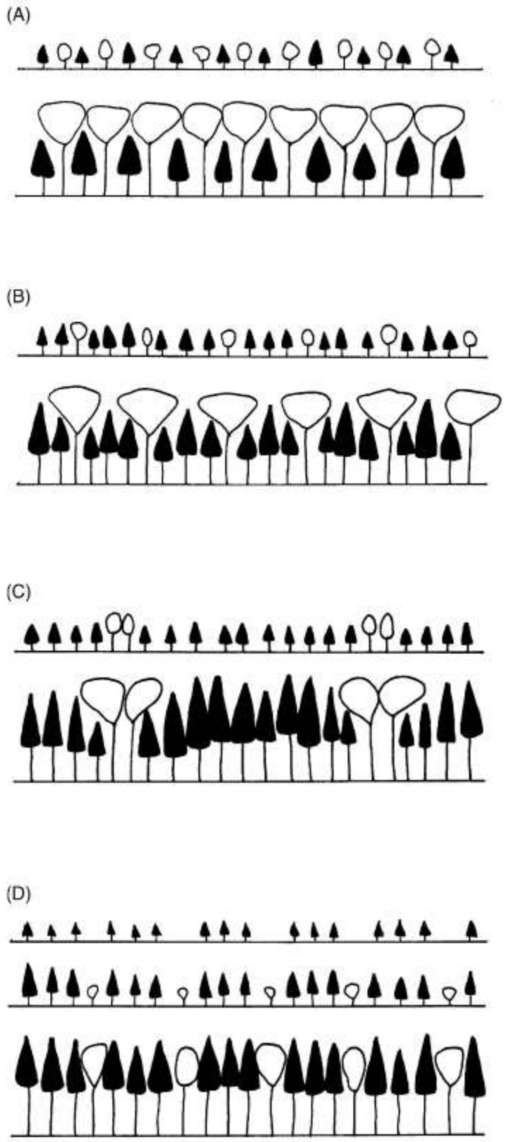

Figure 9. Application of mixed species plantation with two species (Kelty, 2006)

well-managed plantation, this should translate into larger timber volumes. Moreover, the hypothesis suggests that plantations which use combinations of species that improve the growing conditions (i.e. nitrogen-fixing trees) for other species may facilitate increases in overall production of a mixed stand. Alternatively, the sampling effect hypothesis proposes that more diverse plantations demonstrate increased production because they have a higher chance of containing species that are ‘‘overyielding’’ and highly efficient in their use of limiting resources. That is, one or two species within the community are largely responsible for any increase in production. Determining which of these mechanisms achieve productivity increases in mixed species stands may encourage more diverse plantations to be established.

Furthermore, referring Kelty(2006)’s assumption, one advantage of multiple species is ability to produce multiple products on varying rotations. There may also be a more predictable advantage for mixtures in the timing of production of commercial or subsistence products. Generally, the largest financial problem that forest landowners face when establishing plantations is the length of time from the large initial investment of site preparation, planting, and control of competing vegetation to the economic return in forest products at the end of the rotation. The management of many monocultures includes early thinnings undertaken as soon as a usable product can be harvested, but some species that are valuable as solid wood products at large diameters have little or no value when small. Growing multiple species in a plantation can give more options for providing periodic income throughout the rotation.

4. Native species and its succession in forest restoration

Unlike, typical artificial forest restoration, natural regeneration in the forest area tended to be performed under sequence of succession. Succession, often viewed as a natural recovery process or natural modification system in ecosystem, is researched among various ecologists. Furthermore, native species, originally found in regional ecosystem, is not likely to use in AR CDM, but because it contains potential to restore orginal regional ecosystem's characteristic, it is recommended to plant among researchers and practitioner.

Recent studies demonstrated that "plantation can facilitate or catalyze forest succession(Parrotta et al., 1997)" The studies of Yu et al.(1994) for china and Kuusipalo et al.(1995) for indonesia indicated that succession drawn by plantation was tended to occur in sites where anthropogenic influences is scare. Furthermore, enhanced structural complexity due to plantation observed to catalyze forest succession. Structural complexity is easy to differentiate understory microclimate conditions, influencing vegetation turnoff inside of regional plant community. When change structural complexity due to plantation changed micro-climate conditions, such as amount of absorbed solar radiation in leaf area, then dominant species would have chanced to be modified based on species characteristic.

To know about the questions such as 1) Plantation is possible to catalyze forest succession and natural regeneration with native species? 2) What are the conditions and methods to catalyze forest succession through plantation? International organizations such as World Bank, USDA forest service, and IUFRO held conference in 1996. Below results were showing forest restoration's optimum method in terms of forest succession and using native species(Parrotta et al., 1997).

1. Relative to unplanted (control) sites, plantations have a marked catalytic effect on native forest development (succession) on severely degraded sites (such as mined lands and badly eroded areas) and on sites dominated by grasses and ferns which otherwise preclude colonization by forest species.

2. The relative catalytic effect of plantations increases with increased site degradation and from drier to wetter sites, and generally decreases with increasing distance from remnant native forest stands (seed sources). Further research is recommended to develop techniques for accelerating natural forest succession on drier sites.

3. Structural complexity of the planted forest is an important determinant of subsequent biodiversity enrichment due to the importance of habitat heterogeneity for seed-dispersing wildlife and microclimatic heterogeneity for seed germination. This suggests that broadleaf species yield generally better results than conifers, and that mixed-species plantings are preferable to monocultures. Future studies in this area are needed to assess the influence of overstory (planted) species architecture and phenology on understory microclimate heterogeneity (spatial and temporal patterns), and aspects of forest floor and soil development that influence recruitment of native forest species, under a variety of site and landscape conditions.

4. Wildlife, especially bats and birds, are of fundamental importance as seed dispersers in tropical regions. Their effectiveness in facilitating plantation-catalyzed biodiversity development on degraded sites depends on the distances they must travel between seed sources (remnant forests) and plantations, the attractiveness of the plantations to wildlife (ability of plantations to provide habitat and food), and the condition of the forests from which they are transporting seeds. Additional research is needed under

a variety of ecological conditions to better understand the dynamics of animal seed dispersal in degraded landscapes, to develop appropriate plantation designs to encourage seed transport from remnant forest stands, and to determine the range of distances between seed sources and rehabilitation sites over which seed dispersal by animals is likely to be effective.

5. Larger-seeded forest species are far less likely to colonize degraded sites than smaller-seeded species due to seed dispersal limitations, and therefore require management interventions (e.g., enrichment planting) to facilitate their establishment, particularly where forest restoration is a major objective. Further studies are recommended to develop low-cost techniques for establishing large-seeded species either at the time of plantation establishment, or as enrichment plantings at appropriate stand ages.

6. Regarding silvicultural management options, the workshop examined the effects of site preparation alternatives (mechanical, fire, chemical), understory management practices, and plantation thinning regimes on both the planted trees and the species-rich native forest understory they foster. Due to the complexity of interactions among the many factors involved, however, specific recommendations are dependent on initial site conditions, the goals of plantation management, and the relative importance of the planted trees for timber or biomass, the regenerating understory, and other socio-economic and environmental goods and services provided by the rehabilitating forest system. The issue of `trade-offs' between overstory productivity and understory development was identified as an important topic for further study, requiring experimental studies to determine the effect of plantation understory regeneration on overstory growth and nutrient cycling processes during the course of stand development.

7. There was a broad consensus that the `catalytic plantation' approach is a promising tool for degraded land rehabilitation in a variety of contexts. Given the growing recognition in the scientific and development communities, among policy-makers, and in the private sector of the need to incorporate biodiversity rehabilitation and conservation in land-use planning and forest management, this approach is attracting broad interest as an economically and socially viable means for integrating social, economic and environmental land management goals. The potential applications discussed included `restoration' plantations in riparian areas and on other critical sites (such as steep eroded slopes); plantings designed to foster development of mixed native forests for a variety of locally used and valued species; and alternative management strategies for long-rotation timber plantations, short-rotation fuelwood or fiber plantations, and agroforestry systems.

5. Calculation of net primary productivity

According to Field et al.(2005), terrestrial net primary production (NPP), the time integral of the positive increments to plant biomass, is the central carbon-related variable summarizing the interface between plant and other processes. It describes both the removal of carbon from the atmosphere and the potential delivery of carbon to herbivores, decomposers, or humans interested in food or fiber. Therefore, NPP is the net flow of carbon from the atmosphere into plants and, at steady state, the net flow of carbon from plants to heterotrophs and storage pools in the soil.

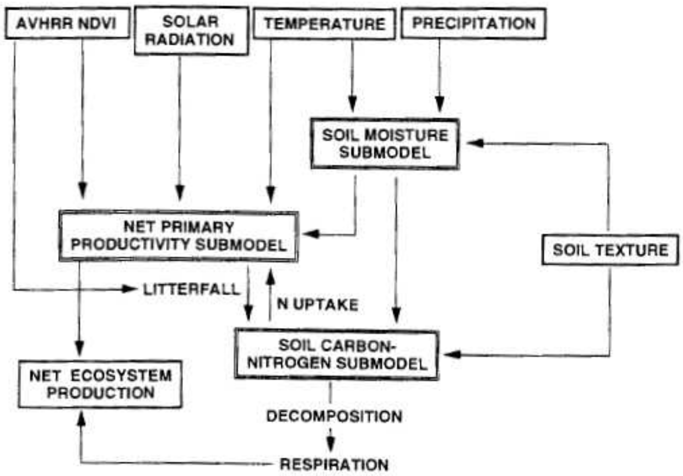

Figure 10. CASA model integration framework
(Potter et al., 1993)

Measurement of NPP is historically suggested by researchers such as potter et al. and field et al. Potter et al.,(1993) suggested calculation method with remote sensing data, MODIS images with temperature and water scalars. According to his theory, plant's photosynthetic activities can be measured with remote sensing's spectral data. Moreover, Field et al.(1995)'s research asserts NPP with GPP(Gross primary production). In terms of Gas exchange, researcher describes NPP as the sum of GPP and Ra(autotrophic respiration).

Suggestions of calculation model is called CASA(Carnegie-Ames_Stanford approach). In this model, the very fundamental approach was to illustrate optimal metabolic rates for major ecosystem biogeochemical processes and to adjust the spatially uniform variables using unitless scalars related to the effects of air temperature, predicted soil moisture, litter substrate quality, soil texture and land use(Potter et al., 1993). Though combining plant's light use processes, CASA reflects plant's growing mechanism.

Ⅳ. Results

1. Temperature and water scalar from suggested algorithms

1) Temperature and Water influences on productivity

(1) Temperature scalar

To produce a net primary productivity for each restoration sites, we produced T scalar map based on two calculation approaches. First T scalar was estimated considering maximum and minimum temperature threshold, and second approach considered maximum NDVI values. Those two results illustrated temperature influence in productivity.

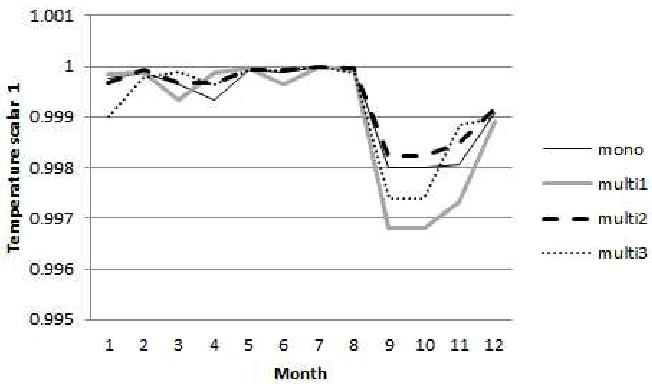

Figure 11. Temperature scalar 1

Setting minimum and maximum temperature thresholds of plants to 0℃ and 40℃, multi 2 site with ten species illustrated higher temperature susceptibility. Whereas, multi 1 site shown minimum temperature influences(Figure 11).

On the other hand, referring plant's responses relevant to NDVI, temperature scalar 2 illustrated that multi 2 site had lowest susceptibility, and multi 3 site with more than 12 species shown highest susceptibility to temperature in regard to productivity(Figure 12).

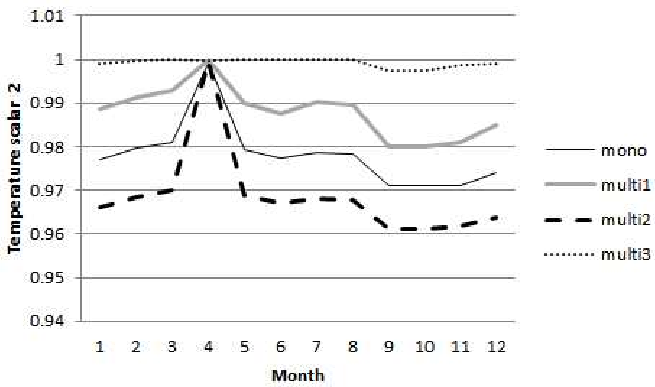

Figure 12. Temperature scalar 2

strata	differences among T scalar
mono	0.254007
multi1	0.132479
multi2	0.369447
multi3	0.943768

Table 5. Discrepancies between temperature scalar

However, even though results shown variation among susceptibilities of each plant composition strata, differences between values were subtle. According to Table 5, multi 1 site had minimum range of discrepancies up to 0.132479. On the other hand, multi 3 site illustrated highest discrepancy of 0.943768.

(2) Water scalar

Water scalar, also shown variabilities among two different calculation approaches. Water scalar 1 was estimated measuring plant's water possession status to calculate NDWI(Figure 13). Water scalar 2 was suggested by calculating the response ratio between actual evapotranspiration and potential evapotranspiration rate estimated from monthly mean temperature(Figure 13). Therefore, scalar 1 represented plant's leaf area's water susceptibility based on spectral reflections of remote sensing data, but scalar 2 illustrated water balance to plant based on temperature responses.

Water scalar 1 and 2 uniformly illustrated that plant composition strata having highest water susceptibility was multi 2 site with three species. While, two scalar shown different results for plant composition strata having lowest water susceptibility. That are, water scalar 1 illustrated that multi 3 site were the lowest, on the other side, water scalar 2 shown that mono plantation site had lowest water influences.

Water scalar 2 tended to have constant values of '1', because based on ratio calculation of EET and PET, months within precipitation that is higher than potential evapotranspiration were assumed to have no restrictions in water influences. That is, when EET exceeds PET, NPP is no longer

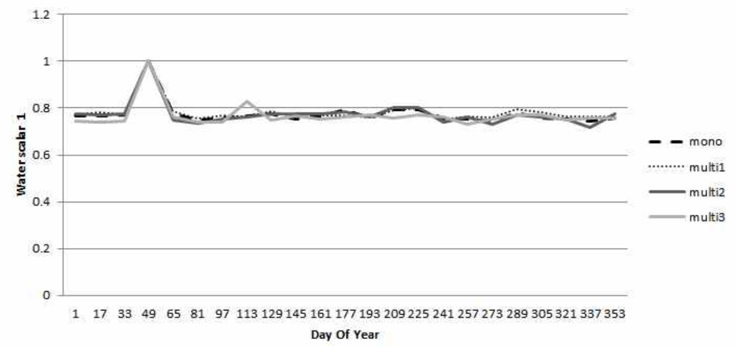

Figure 13. Water scalar 1

restricted by soil moisture, and W equals 1(Field et al., 1995).

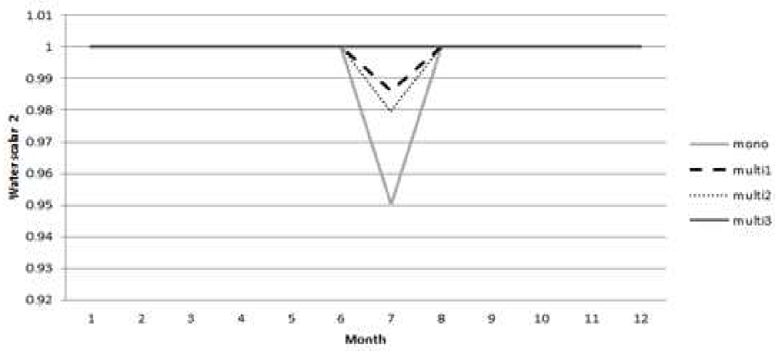

Figure 14. Water scalar 2

2. Differences of estimated productivity among four algorithms

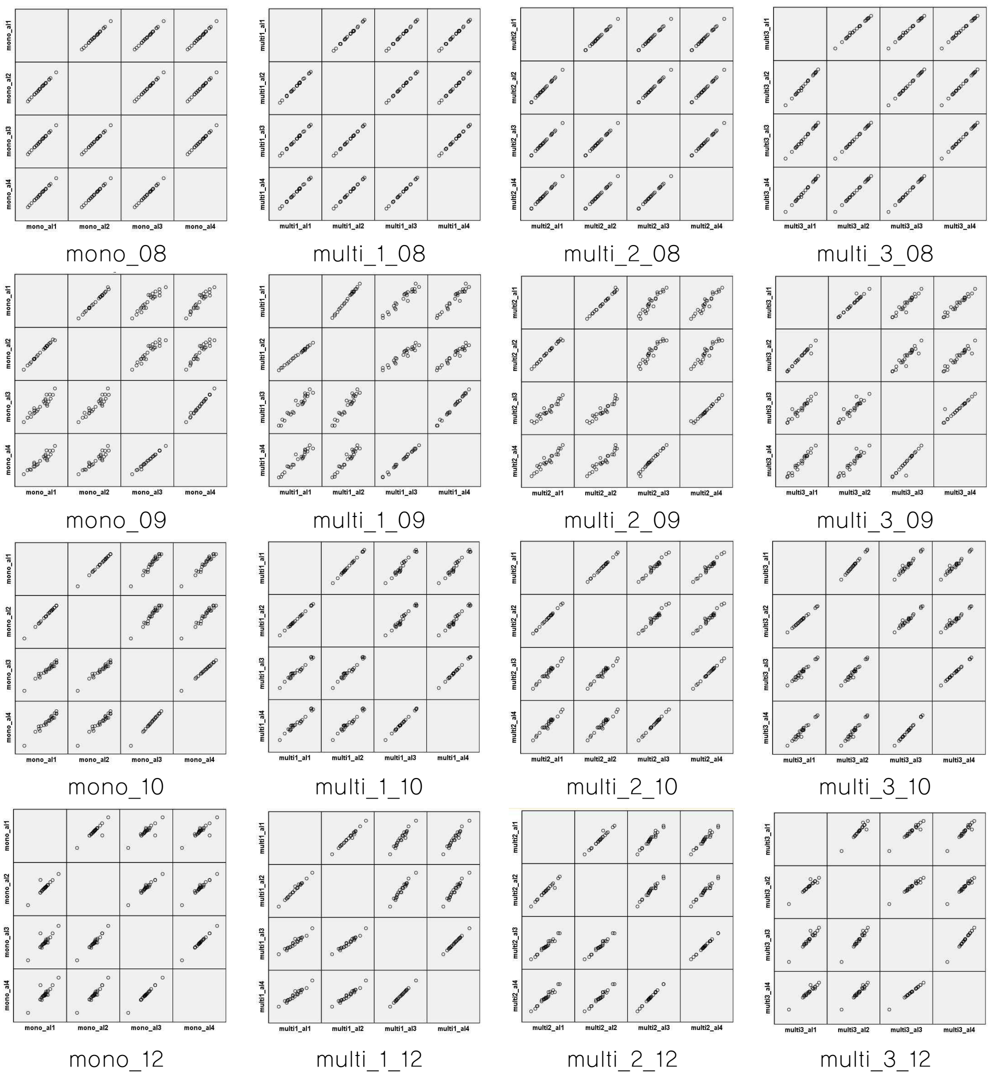

Figure 15. Scatter plots of adopted algorithms

The results shown that variations among utilized four model structure have slight discrepancies. That is, every NPP from 2008 to 2012, calculated from suggested four algorithm showed not much differences between values. Pearson Corelation analysis illustrated $p<0.001$ similarities. Scatter plot in Figure 15 illustrated its correlations.

3. Net primary productivity

Calculated net primary productivity is illustrated in Figure 16. Yearly summed NPP is shown in Figure 17. The results showed that calculated NPP values using vegetation index was ranged between 1630 to 2128gC $m^{-2}yr^{-1}$. The ranking among NPP values had changed from 2008 to 2012.

According to results, highest growth was shown in multi2 community composition which included at least ten industrial and native species within study area. Multi1, having two or three industrial species, had shown constant higher values from 2008 to 2012. However, mono community composition, planted with one industrial species, showed lower NPP values compared to multi1 and multi2. In the mean time, multi3, consisted with only native species, showed lowest NPP from 2008 to 2012. However, increased rate of NPP was moderate compared to other community composition. According to Figure 17, multi3 planted with only native species shown higher growth rate of NPP than mono planted with one industrial species.

Comparing multi1 and multi2, multi1 showed constant high NPP rankings. However, in 2012, multi2 planted with combination of more than ten industrial and native species showed higher NPP than multi1 planted with two or three industrial species.

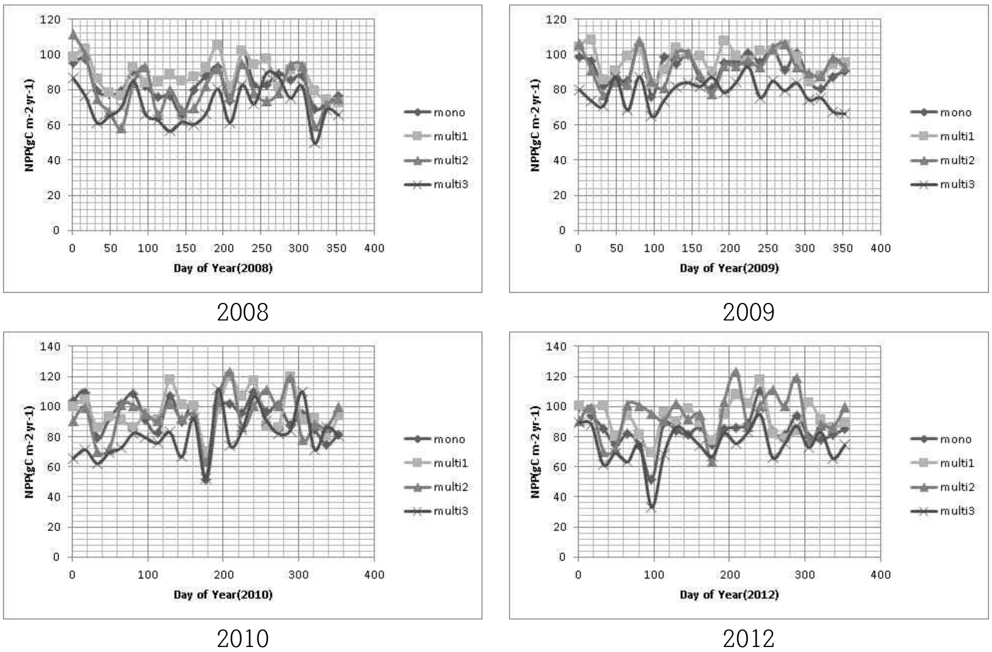

Figure 16. Calculated net primary productivity

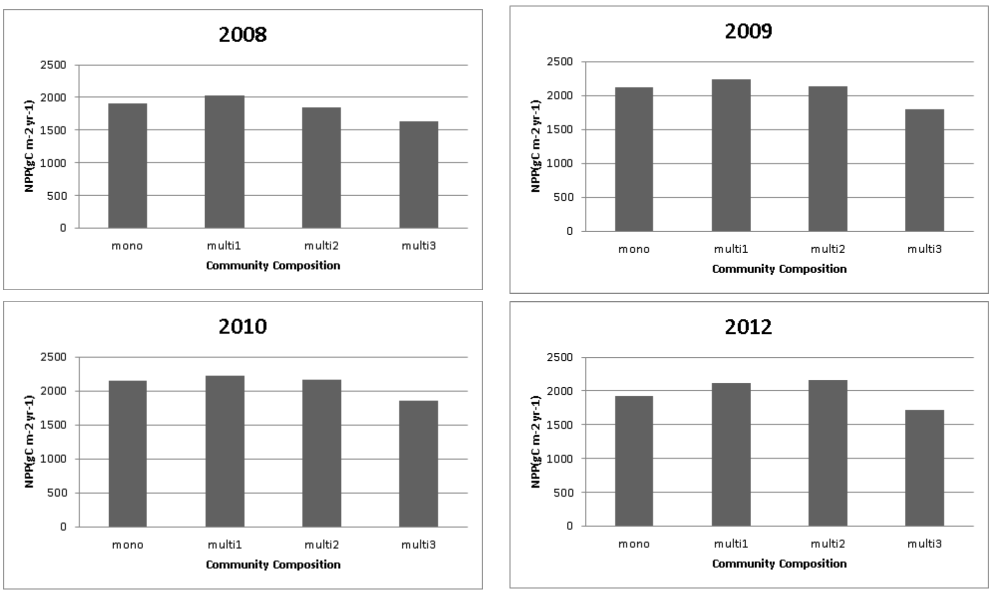

Figure 17. Yearly summed NPP from 2008 to 2012

4. Evaluating a valid relationship between net primary productivity and plant community composition

Performed one-way ANOVA test were illustrated in Table 6 and 7. For one part of random points, point were closed located between forest strata of mono and multi_3 sites. Net Primary Productivity of 2008 and 2012 illustrated highest P value which satisfying P<0.01.

		Sum of squares	df	Mean square	F	P value
NPP_08	Between Groups	107377.142	1	107377.142	41.138	.000
	Within Groups	263629.325	101	2610.191		
	Total	371006.467	102			
NPP_12	Between Groups	78269.661	1	78269.661	15.661	.000
	Within Groups	504781.113	101	4997.833		
	Total	583050.774	102			
NPP_var	Between Groups	2296.074	1	2296.074	.828	.365
	Within Groups	280067.928	101	2772.950		
	Total	282364.002	102			

Table 6. ANOVA 1

On the other hand, variation of Net primary Productivity had no significant relationship between changes in productivity from 2008 to 2012(Table 6). When considering the fact that multi_3 strata was comprised of only native species with seedling performances, the results were analyzed to be reasonable.

On the other hand, second performed analysis with three forest strata having different soil texture was shown relationship between productivity

		Sum of squares	df	Mean square	F	P value
NPP_08	Between Groups	17073.570	2	8536.785	6.404	.003
	Within Groups	71982.614	54	1333.011		
	Total	89056.184	56			
NPP_12	Between Groups	44239.531	2	22119.766	11.975	.000
	Within Groups	99743.341	54	1847.099		
	Total	143982.872	56			
NPP_Var	Between Groups	26658.798	2	13329.399	19.075	.000
	Within Groups	37733.820	54	698.774		
	Total	64392.617	56			

Table 7. ANOVA 2

and plant diversity(Table 7).

The result uniformly indicated $P<0.001$, that can be interpreted as viable relationship between plant strata and net primary productivity. Unlike Table 9, evaluated strata were commonly included industrial species for plantation. According to result, P-value was increased from 2008 to 2012. In 2008, though it satisfied $P<0.01$, P-value were shown 0.003, later in 2012, net primary productivity differentiation based on species number were shown more discrete P-value.

5. Influences of restoration method to NPP

To evaluate influences of restoration method differ in community structure for adopted four strata, this study performed linear regression analysis with assessed environmental variables. Table 8 shown the results of linear regression analysis matched the results with Table 6.

Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	285.271	111.251		2.564	.012
	Temp	3.740	12.250	.239	.305	.761
	Annu_Precp	.000	.001	-.529	-.771	.443
	Res_method	-3.299	2.125	-.284	-1.552	.124
	Elev	.001	.000	.544	1.843	.068
Independent variable: NPP_08						
Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	675.802	156.896		4.307	.000
	Temp	10.942	17.277	.557	.633	.528
	Ann_precp	.000	.001	-.356	-.461	.646
	Res_method	-6.182	2.997	-.425	-2.062	.042
	Elev	.000	.001	-.266	-.800	.425
Independent variable: NPP_12						
Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	390.531	112.270		3.479	.001
	Temp	7.201	12.363	.527	.583	.562
	Ann_precp	7.267E-005	.001	.095	.120	.905
	Res_method	-2.883	2.145	-.285	-1.344	.182
	Elev	-.001	.000	-1.005	-2.945	.004
Independent variable: NPP_Var						

Table 8. Linear Regression 1

According to Table 8, community composition(rest_method) in 2008 illustrated P-value of 0.124, and there were no other variables satisfying

P<0.05 or P<0.01. However, in 2012, influence of restoration method to npp shown high correlation of P<0.05, which means that adopted restoration method had influence on Net Primary Productivity after 5 years, since plantation had been completed. On the other hand, variable satisfying P<0.05 among 5 year's Net Primary Productivity variation was elevation.

Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	997.269	409.800		2.434	.018
	Temp	-26.759	14.038	-.834	-1.906	.062
	Annu_Precp	.001	.000	.927	2.309	.025
	Res_method	-2.472	1.441	-.206	-1.716	.092
	Elev	-.001	.001	-.344	-1.255	.215
Independent variable: NPP_08						
Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	841.542	503.157		1.673	.100
	Temp	-5.418	17.236	-.133	-.314	.755
	Ann_precp	.000	.000	.447	1.153	.254
	Res_method	3.072	1.769	.201	1.736	.088
	Elev	-.001	.001	-.306	-1.155	.253
Independent variable: NPP_12						
Model		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
1	(Constant)	-155.727	320.469		-.486	.629
	Temp	21.341	10.978	.782	1.944	.057
	Ann_precp	.000	.000	-.421	-1.142	.259
	Res_method	5.544	1.127	.543	4.920	.000
	Elev	.000	.001	-.053	-.209	.835
Independent variable: NPP_Var						

Table 9. Linear Regression 2

The results of Table 9 indicated that as for the variation of NPP from 2008 to 2012, restoration method was significant factor satisfying P<0.01.

There were none of values statistically affecting variation of NPP. Whereas, for NPP values in 2008 and 2012, restoration method illustrated no statistically significant impact, Otherwise, in 2008, annual precipitation was assessed to be significant factor to NPP.

6. Comparing results to field data and MOD17

Comparing the result of global Net Primary Productivity distributions in other formal researches, values of NPP tended to be estimated as Table 10. The values of NPP in 2008, were ranged between 1200 – 2100 gC m^{-2} yr^{-1}. On the other hand, this study's results had NPP ranged from 1630 to 2128 gC m^{-2} yr^{-1}.

Reference	Net Primary Productivity
Scurlock and Olson(2002)	1497-2780(gC m^{-2} yr^{-1})
The results	1630-2128(gC $m^{-2}yr^{-1}$)

Table 10. NPP of tropical forest in formal research and calculated value

Performed Pearson correlation analysis shown that results of NPP in 2008 is significantly correlated with MOD17 product satisfying P<0.01(Table 11). However, the results of this study tended to show more values of net primary productivity than MOD17.

		Modis_NPP_08	Result_NPP_08
Modis_NPP_08	Pearson Correlation	1	.377**
	P-value		.000
	N	189	189
result_NPP	Pearson Correlation	.377**	1
	P-value	.000	
	N	189	189
**. Correlation is significant at the 0.01 level (2-tailed)			

Table 11. Pearson Correlation between MOD17 and results

However, according to Figure 16, calculated value compared to MOD17 was tended to show slight higher values. That is, results were showing over estimated values than that of MOD17. However, MOD17 calculated NPP on more wide scale land use classification. Considering that restored forest in Caldas, Colombia tended to have relatively small area compared to MOD17's scale(1km × 1km), matching of values were showing different trend based on restored forest's area. Specifically, when all random points from whole restored forest, having area smaller than 1km × 1km, the results and MOD17 tended to show low matching of values(Fig 18). However, when considering that most of restored forest area was 250~300km × 250~300km(Fig 6), restored forest with forest area bigger than 1km × 1km was compared.

The results indicated that forest area bigger than 1km × 1km and MOD17's results were having similar values(Fig 19). The range of values were in between approximately 1100~1600.

The result indicated that this study's results were having more higher values of net primary productivity than MOD17. The results calculated with vegetation index tended to illustrate higher net primary productivity.

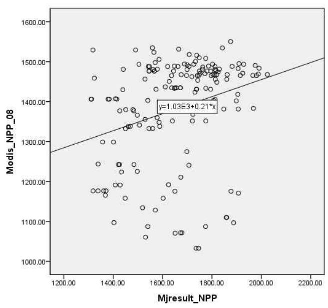

Figure 18. Compared range of results with MOD17(Not considering area)

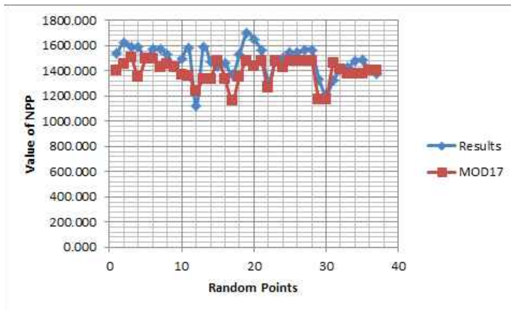

Figure 19. Compared results of forest area larger than 1km × 1km

Ⅴ. Discussion

Historically, the relationship between forest community composition and productivity had been supported by early researchers such as Odum(1953), MacArther(1955), and Elton(1958). Furthermore, they assumed that species richness community will generate higher adaptive potential for utilization of limited resources. To attest those hypothesis, and to figuring out optimum forest restoration community to sequestrate more carbon, many researchers conducted researches between forest composition strata and productivity. However, due to its difficulties to find actual restored forest by artificial plantation ,having different forest strata within project sites, it was hard to have results in the area of forest. Instead, experiments and researches were tended to be performed in grassland. This study, therefore, to figure out the impacts of restoration community to net primary productivity, adopted four different restored plant communities through clean development mechanism in Caldas, Colombia were assessed.

The results of four algorithm in model, assessing temperature and water influences to NPP, had produce slight differences of net primary productivity. Each four results had higher correlation with $P<0.01$. However, even though, their results had few differences, rank among forest composition type to NPP had slightest significant impact to final results.

Therefore, depends on methods to calculate temperature and water influences to net primary productivity, NPP rankings through restoration community were different. However, this study assumed that temperature and water scalar calculated via vegetation index were adequate to assess the final results. Specifically, the results indicating direct water and temperature influence in regard to vegetation canopy were assumed to reflect NPP differences depends on community composition, more adequately.

This is because, as for the water scalar, according to Potter et al.(2003) and Field et al.(1995), suggested CASA model assess water responses based on water balance between estimated evapotranspiration and potential evapotranspiration. Interactions between atmospheric water content, soil and plant were therefore estimated focusing on “evapotranspiration” However, calculated evapotranspiration using thronthwaite(1953)’s method was fundamentally drawn from monthly mean temperature. In line with that, estimated evapotranspiration was also drawn from values of monthly mean temperature and mean regional solar radiation. This means that even though the model should calculate water balance reflecting differences in plant canopy, with Potter et al.(2003) and Field et al.(1995)’s suggested algorithm, it was hard to have results considering canopy features.

On the other hand, second algorithm suggested by Bocai Gao(1996) and Wang Lin(2008), measure water responses more directly from canopy features. This is because, with second approach of model, water scalar is calculated depends on values of NDWI (Normalized difference water index). According to Gao(1996), NDWI is a more recent satellite-derived index from the NIR and short wave infrared (SWIR) channels that reflects changes in both the water content (absorption of SWIR radiation) and spongy mesophyll in vegetation canopies. It directly captures water status in vegetation canopy by using canopy reflectance values. Therefore, this approach is more apt to produce water scalar based on canopy feature in four restored community.

In line with that, temperature scalar calculated from vegetation index was also assessed to be more adequate to calculate NPP, reflecting differences in plant composition. Compared to suggested algorithm of Potter et al.(2003) and Field et al.(1995), results of Wang Lin et al.(2007) and Gao et al.(2013)

illustrated more specific results. This was because, optimum temperature for plant growth was calculated to community to community. Unlike Potter et al.(2003) and Field et al.(1995)'s results, calculated T scalar using NDVI had more high spatial resolution, because the results were came from vegetation index of MODIS. Compared to Potterr et al.(2003) and Field et al.(1995)'s results which have 4-km optimum temperature, vegetation index of MODIS calculated optimum temperature for every $250m \times 250m$. Therefore, further results were calculated within vegetation indexes.

In the mean time, the results calculated within vegetation index indicated that different forest community composition had different values to net primary productivity. According to the results, mixed plantation estimated to have more NPP growth rate compared to mono plantation. In line with the results of Tilman et al.(1997), mixed species plantation tended to have more optimum growth than mono-plantation. The researchers assumed that multi species plantation would promote more NPP. This is because, for new restoration site, multiple species with multiple ecosystem function would have more ecosystem function to adapt to environment. According to Kelty et al.(2006), Mixed-species plantations potentially have a very different role to play compared to objectives described above-as a part of the restoration of degraded lands.

Moreover, even though industrial species known for its fast growth rate, according to results, native species also had moderate growth. Compared to mono plantation with industrial species, community composition with only native species illustrated lower NPP values. However, when comparing the increased rate of NPP from 2008 to 2012, native species indicated modest growth rate. Furthermore, results showed that mixed plantation with native and industrial species had highest NPP values in 2012. Therefore, even though industrial species have higher growth, native species also estimated to have moderate growth.

Lamb(2005) asserted that Traditional monoculture plantations of exotic species mostly generate just financial benefits, whereas restoration using methods that maximize diversity and enhance biodiversity yields few direct financial benefits to landowners, at least in the short term. Furthermore, many ecologists emphasize benefits of community composition with multi species in planting. For example, according to Kelty et al.(2006)'s study, in the case of legume tree species growing in a lower canopy beneath Eucalyptus, the legumes can be removed for timber or pulp products (having already increased ecosystem N content, leaving the higher value Eucalyptus to grow to large diameters. Moreover, restored community with only one species had been highly criticized. Perley(1994) demonstrated that mono plantation had failure to consider public opinion, and this can be costly for foresters. In fact, because afforestation and reforestation through clean development mechanism are generally planted with mono-plantation, there are protests disagreeing with mono-plantation. Thus, when considering this study's results showing moderate growth of native trees and higher productive rate of multiple-species composition, clean development mechanism is required to consider multiple species plantation to promote not only carbon sequestration, but also multiple benefits including public consent.

In the mean time, from results of estimating community composition's impact to NPP, community composition had major impact compared to environmental variables. Specifically, in 2008, right-after plantation, plant community composition had low impact to NPP. However, in 2012, five years after plantation, plant community composition illustrated highest impact to net primary productivity. Environmental variables known to affect net primary productivity included precipitation, temperature, soil texture, and elevation. However, because this study assessed restored site, not naturally regenerated site, impact of those environmental variables was not significant. On the other hand, plant community composition had highest contribution to NPP. Therefore, the results demonstrated importance of community composition in forest restoration to promote carbon sequestration. That is, community composition itself was main factor to enlarge net primary productivity emphasizing the importance of community composition in global reforestation and afforestation. Projects including AR CDM and REDD, thus required to have appropriate planting guideline to promote productive environment via forest restoration.

Comparing results to field-data and MOD17, range of NPP was moderately agreeable. However, because MOD17 simulated net primary productivity in more large scale, some values showed incongruity. That is, differences in scale can resulted in different land use classification. Therefore, some restored forest can be classified as crop land or pasture in large scale. In line with that, large scale could not discern differences in community composition, because it calculated plant's FPAR(Fraction of Photosynthetically Active Radiation absorbed by the vegetation) without classification of community composition. This study, thus, need fine-scale field data to verify the results, but because there is problems in data availability, this study is required to research further in the field.

Currently, global afforestation and reforestation receive much attention than before. Forest restoration through afforestation and restoration is considered as cost-effective method to perform adaptation action to climate change. However, to promote more effective measure to climate change through forest restoration, the study demonstrated importance of community composition. Appropriate planting scheme is therefore required in clean development mechanism or REDD. Particularly, considering calculated net primary productivity among four community composition, this study accentuate the importance of mixed species plantation. Combination of industrial species or native species would promote more adaptive environment to plant growth, and also it offers diverse socio-economic benefits. These results encourage the use of variety of species across the tropics and call for more research into optimum community composition as an adaptation measure to climate change. The fine scale research on community composition and other ecosystem benefits across forest restoration in tropics remains to be explored.

Ⅵ. Conclusion

Afforestation and reforestation through global plantation projects such as CDM or REDD are effective measure to combat climate change. However, performing forest restoration thorough global plantation tended to focus on increasing forest area. Therefore, impacts of community composition in plantation to net primary productivity are required to be evaluated.

This study attempted to calculate suggested four algorithms of net primary productivity, and estimated NPP with vegetation indexes. Within relatively fine scale results, having 250m × 250m scale, the results demonstrated higher carbon sequestration of multi-species composition. Moreover, this study revealed competitiveness of native species when it mixed with industrial species.

Particularly, the finding of this results emphasizes the importance of community composition to net primary productivity. That is, when global afforestation and reforestation projects could promote adequate planting guidelines, it would available to promote more effective carbon sequestration.

Therefore, along with the results, it is important to promote ecological forest restoration in tropics in order to support productivity. Researchers had long been suggested plant composition measures to promote productive environment. When considering the fact that this study detected plant community composition's significance to productivity, global afforestation and reforestation projects are required to specify forest restoration guidelines to mitigate climate change.

국문 초록

조림 및 재조림 사업에 있어 산림의 생산성은 이산화탄소 흡수량을 최대화시키기 위해 주목받아왔다. AR CDM 혹은 REDD와 같은 교토의정서에 의해 발현된 산림의 조림 및 재조림 사업은 이러한 산림의 생산성을 극대화시키기 위한 방법으로 산림 면적을 늘리는데 주력하며 특히, AR CDM은 한두개의 생산수종(industrial species)으로 광역적인 복원 사업을 꾀하고 있다. 그러나 이러한 형태의 복원은 다수의 생태학자들에 의해 비판받아왔으며 생물다양성의 저하, 지역 생태계의 파괴, 산림 경관의 획일화와 같은 역효과들이 제시되어왔다.

이러한 역효과들을 완화하기 위해 기존의 연구자들은 대표적으로 수종의 혼합과 자연 수종의 활용을 제안한다. 그러나 이러한 주장을 두고 연구자들 사이, 과연 종의 혼합, 자연 및 생산 수종의 혼합과 같은 식물군집의 특성이 생산성에 영향을 미치는가에 대해 논란이 있어왔다. 다수의 연구자들은 적절한 수종의 혼합이 단수종보다 보다 더 많은 이산화탄소 흡수량 및 생산성을 도모할 수 있다고 제안한다. 그러므로 본 연구는 산림 생산성의 대표지표인 순생산성을 AR CDM 사업에 의해 조림 및 재조림된 군집 유형별로 분석하여 적용된 군집에 따른 순생산에의 영향을 평가하고자 하였다. 구체적으로 본 연구는 1) 순생산성의 분석을 위해 제안된 NASA CASA 모델의 알고리즘 중 본 대상지의 군집 유형이 광역적으로 구분되는 알고리즘의 도입 2) 적용된 군집 유형별 순생산성의 차이의 분석 및 군집 유형 특성과의 대조 3) 순생산성에 영향을 미친다고 알려진 환경변수와 군집 유형 특성이 순생산성에 미치는 영향력의 통계적 분석을 꾀하고자 하였다.

연구의 공간적 범위는 콜롬비아, 칼다스 지방이며 AR CDM 사업에 의해 산림복운이 완료된 곳이다. 연구의 시간적 범위는 2008년에서 2012년으로 복원이 완료된 후의 5년간의 기간을 평가 년도로 설정하였다. 순생산성의 평가는 MODIS 영상을 이용한 NASA CASA 모델이 활용되었다. 본 연구는 NASA CASA 모델의 물과 온도에 따른 광합성 효율에의 영향의 분석 방법으로 기존에 제안된 네가지의 알고리즘을 적용하였으며 이 가운데 식생지수를 활용한 방법의 결과를 대상으로 군집 유형별 순생산성의 차이를 분석하였다. 군집유형에 따른 생산성의 유의한 차이는 피얼슨 상관 분석, 일원배치분산분석을 통해 분석되었으며 환경변수와 군집유형에 따른 순생산성에의 영향은 선형회귀분석을 통해 분석되었다.

 연구 결과, 생산수종 및 자연수종이 혼합된 군집에서 가장 높은 순생산성을 분석되었다. 가장 낮은 순생산성을 보인 군집은 자연수종만으로 구성된 군집이었다. 특히, 생산수종과 자연수종이 혼합된 군집은 식재가 완료된 후 5년간 생산성의 높은 증가율을 보였다. 한편, 하나의 생산수종으로 구성된 군집의 경우 초기의 순생산성은 높았으나 점차 혼합 군집에 비해 낮은 생산성을 보임이 관측되었다. 생산수종만으로 혼합된 군집의 경우, 하나의 생산수종으로 구성된 군집보다 더 높은 순생산성 값이 도출되었다.
 온도, 강수량, 토성, 고도와 같은 순생산성에 영향을 미친다고 알려진 환경변수들과 군집유형의 순생산성에 대한 영향의 분석 결과, 초기에는 강수량과 같은 환경변수의 영향이 더 큼으로 분석되었다. 그러나 식재된지 5년뒤인 2012년에는 군집유형의 순생산성에대한 유의도가 가장 큰 것으로 분석되었으며 기타 환경변수들의 영향력은 낮음으로 분석되었다.
 본 연구의 결론은 다음과 같다. 첫째, 광역적인 조림 및 재조림 사업을 평가하는데 있어 제안된 NASA CASA 모델의 적용에 있어 식생지수의 활용이 보다 더 미세한 스케일의 결과를 도출할 수 있다. 식생지수의 활용은 광합성 효율에 대한 물과 온도에 대한 반응이 기존에 이용되어 왔던 토성에 따른 값 혹은 월평균 온도에 따른 잠재증발산량과 실증발산량의 차이로 계산되는 것이 아닌 식생 수관의 반사값으로 인하여 분석되게 된다. 따라서 기존의 방법이 식생의 특성을 전혀 고려하지 못했던 것에 비해 광역적으로나마 식생 반사값으로 인한 물과 온도에 대한 반응을 도출할 수 있다. 둘째, 본 대상지에 적용된 식생 군집유형 중 주로 수종의 혼합이 이루어진 대상지에서 높은 순생산성의 증가율을 나타내었다. 이것은 하나의 수종으로 식재된 군집과 비교할 때에 수종이 혼합된 군집에서도 경쟁력있는 순생산성을 도출할 수 있다는 것을 의미한다. 또한, 수종의 혼합이 이산화탄소 흡수뿐만이 아니라 부분적인 간벌을 통한 연료 및 목재로의 활용, 식이 식물로의 활용, 군집의 구조적 복잡성으로 인한 서식처 기능의 증대 등 보다 더 풍부한 생태계 서비스를 제공한다는 것을 고려할 때에 열대우림의 산림복원에 있어 수종의 혼합은 추천된다. 또한, 자연수종의 활용과 관련하여 자연수종만으로 이루어진 군집은 가장 낮은 순생산성을 보였으나 생산수종과 혼합된 자연수종 군집의 경우, 높은 순생산성을 보였으므로 지역의 생태계를 고려하여 자연수종과 생산수종의 혼합은 긍정적으로 여겨진다. 마지막으로, 식생군집유형은 순생산성의 값 및 증가 및 감소율에 가장 높은 유의도를 보였으며 이것은 이산화탄소 흡수량을 증가하는데 있어서의 식재 계획의 중요성을 설명해준다. 따라서 기후변화 대응을 목적으로 한 산림 복원 사업에 있

어 적절한 군집 구성 가이드라인의 설정이 필요하다고 할 수 있다.
본 연구의 결과는 향후 보다 더 효과적인 산림 복원 사업을 꾀하는데 있어 적절한 산림 군집 유형을 제안하는데 기초 연구로서 활용될 수 있다. AR CDM 혹은 REDD와 같은 사업이 광역 스케일을 대상으로 이루어진다는 것을 생각할 때에 MODIS 영상을 활용한 본 연구의 방법론은 구체적인 산림 복원 가이드라인을 설정하는데 있어 추후 활용될 수 있으나 현장 측정을 통한 미세 스케일에서의 연구가 향후 요구된다.

❑ **주요어 : 산림 복원, 혼합식재**, NASA-CASA, MODIS, AR CDM

❑ **학번** : 2012-21132

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