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INTEGRATION OF NPP SEMI MECHANISTIC - MODELLING, REMOTE SENSING AND CIS IN ESTIMATING CO_2 ABSORPTION OF FOREST VEGETATION IN LORE LINDU NATIONAL PARK

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ABSTRACT

Net Primary Production, NPP, is one of the most important variables characterizing the performance of an ecosystem. It is the difference between the total carbon uptake from the air through photosynthesis and the carbon loss due to respiration by living plants. However, field measurements of NPP are time-consuming and expensive. Current techniques are therefore not useful for obtaining NPP estimates over large areas. By combining the remote sensing and GIS technology and modelling, we can estimate NPP of a large ecosystem with a little ease. This paper discusses the use of a process based physiological sunshade canopy models in estimating NPP of Lore Lindu National Park (LLNP). The discussion includes on how to parameterize the models and how to scale up from leaf to the canopy. The version documented in this manuscript is called NetPro Model, which is a potential NPP model where water effect is not included yet. The model integrates CIS and the use of Remote Sensing, and written in Visual Basic 6.0 programming language and Map Objects 2.1. NetPro has the capability of estimating NPP of Cs vegetation under present environmental condition and under future scenarios (increasing [CO_2], increasing temperature and increasing or decreasing leaf nitrogen level). Based on site-measured parameterisation of V_{aM}* (Photosynthetic capacity), /Jj (Respiration) and leaf nitrogen ONi), the model was run under increasing CO_2 level and temperature and varied leaf nitrogen. The output of the semi-mechanistic modelling is radiation use efficiency (?). Analysis of remote sensing data give Normalized Difference Vegetation Index (NDVI) and related Leaf Area Index (LAI) and traction of absorbed Photosynthetically Active Radiation (/M>AK). Climate data are obtained from 12 meteorological stations around die parks, which includes global radiations, minimum and maximum temperature. CO2 absorbed by vegetation (Gross Primary Production, GPP) is then calculated using the above variables and parameters with the following equation:

$GPP = \sum_{1}^{365} e f_{APAR} PAR$. Forty five percent of GPP is used as plant respiration for estimating NPP, while ecosystem respiration is set as a function of temperature for estimating NEE. Under present condition, the net absorption of CO> by the vegetation of Lore Lindu National Park (NPP) is 1330.31 gCm"^{2}year"' and at double CO_2 and temperature increased of 3.5 "C, it increased by 23 %, reaching 1638.80 gCm'^{2} year'^{1}.

Key words : NPP Semi-mechanistic model, photosynthesis, carbon sequestration, net primary-production, tropical forest

INTRODUCTION

The global carbon balance has become an issue of great concern during the last decade due to its impact on climate. IPCC (2001) has implicated that the increase in CO_2 concentration from 285 ppm in year 1780 to 360 ppm in year 2000 has resulted in 0.6 °C global average temperature increase and it is projected that in the year 2100, the increase will be up to 5.8 °C. The concern over this problem has resulted in international agreements (e.g., Rio 1992; UNFCCC 1994; and Kyoto 1997) to reduce CO_2 concentration in the atmosphere.

Net primary production (NPP) is an important quantitative characteristic of an ecosystem (Churkina *et al.* 1999). It refers to the net production of organic carbon by plants in an ecosystem usually measured over a period of a year or more. It is the difference between carbon gain through photosynthesis and carbon loss through respirations. It constitutes the total annual growth increment (both above and below ground) plus the amounts grown and shed in senescence, reproduction or death of short-lived individuals in a stand plus the amounts consumed by herbivores. Seasonal changes in NPP will influence seasonal changes in net ecosystem exchange (NEE; NPP-soil respiration), and it is a principal cause of seasonal changes in atmospheric CO_2 (Keeling *et al.* 1996).

Tropical forests are important sink of CO2, representing 59 % of the global carbon pool in forests (Dixon *et al.* 1994). Although the area of tropical forests is only 22 % of the global forest area, they account for 32 - 43 % of the world's potential terrestrial NPP (Melillo *et al.* 1993; Field *et al.* 1998).

Because conventional measurements (periodical destructive harvesting) of NPP of all ecosystems at all times are impractical, models are needed to estimate NPP. The model discussed in this manuscript is based on Farquhar and Caemmerer (1982), June (2002) and De Pury and Farquhar (1997). Most part of the model equations are mechanistic and some are semi mechanistic. When using such models in estimating NPP, prediction of environmental effects to NPP become more reliable. This manuscript contained theoretical background in developing the models, at leaf and canopy level; parameterisation and integrating remote sensing (RS) technology for data input and Geographical Information System (GIS) for display. Parameterisation of model was conducted using photosynthesis system ADCLC4AM. The model is run to answer the following question:

(i). How much CO_2 is absorbed by vegetation in a protected forest like Lore Lindu National Park ; (ii). How would changes in temperature, light, and CO_2 concentration in the atmosphere affect the absorption?

Model parameters and estimated NPP of Lore Lindu National Park are presented. Integration of the model with remote Sensing data and GIS are done using Map Object 2.1 and Visual Basic 6.0 in an application software NetPro.

MODELLING NET PRIMARY PRODUCTION (NPP)

Plant Photosynthesis and Net Primary Production

Plants fix carbon dioxide from the atmosphere during the process of photosynthesis. All the carbon fixed during photosynthesis is called gross primary production (or gross primary productivity in terms of rate, for example, tonnes of carbon per hectare per year, usually called GPP). Some of the fixed carbon is used by the plants themselves for metabolic processes (largely respiration) and in this process, carbon dioxide is returned to the atmosphere. The carbon that is not used in respiration remains on the plant and adds to the biomass of the plant. This is net primary production (NPP).

NPP represents the net new carbon stored as biomass in stems, leaves or roots of plants. It is the difference between the carbon assimilated during photosynthesis by plant leaves and carbon consumption through respiration by leaves, stems and roots. It is a quantitative measure of plant growth and carbon uptake. The knowledge of NPP distribution provides information on the productivity of croplands, forest and grasslands and thus helps improve management strategies for sustainable development of natural resources. At the national scale, NPP allows the estimation of the contribution of landmass to the global carbon budget which is important in global change studies.

In agricultural system and forestry, NPP is usually defined as the increase in the standing biomass plus losses through litterfall and through consumption by herbivore. There are three main ways of estimating net primary productivity - first involves the estimation of biomass production and second through the measurement of gas exchange and modelling or third through CO2 flux measurement using surface tower over forest canopy or agroforestry system or using mast installed with instrument directly measuring CO2 fluxes over short type of vegetation like grassland or crop.

NPP modeling and data requirements.

An attractive approach for estimating *NPP* was firstly proposed by Mont'ith (1972; 1977), in which he determined *dC/dt* (carbon accumulation over time;wnen time = 1 year dC/dt = NPP) as a product of the efficiency of the canopy *(e,* mol CO_2 mol"^{1} PAR or in unit gC MJT^{1}), fraction of photosynthetically active radiation, PAR *(/APAK)* absorbed by the canopy and the daily PAR reaching the top of the canopy *(PAR)* as:

$$\text{NPP} = \sum^{365} e f_{APAR} PAR \qquad (1)$$

The original approach of Monteith considered the value of *e* as a constant and based on net CO_2 absorption (determined through increased in biomass). On reality, *e* changes through time due to the changing climatic and plant variables like Leaf Area Index, nitrogen level, and water status. In order to make the model to be responsive to the changing environmental condition, or to be used for a climate change prediction effect, *e* has to be mechanistically or semi mechanistically modelled using the approach introduced in June (2002).

The outline of the semi-mechanistic model to produce the *e* value introduced in this manuscript is shown in Figure 1.

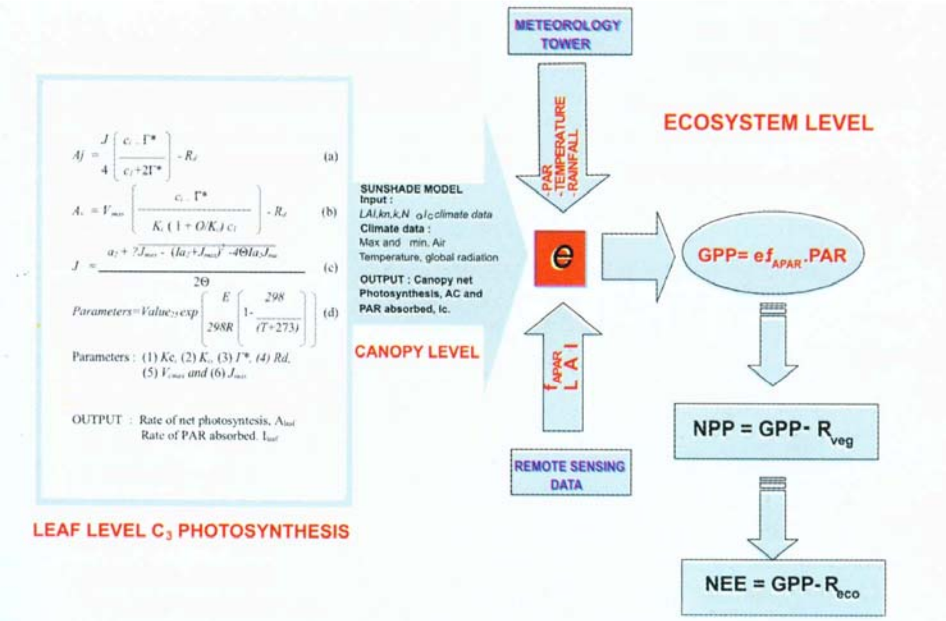

Figure 1. Structure of the model showing the flow of data from the leaf scale to canopy and to ecosystem. Equations (a) and (b) showing the effect CO_2 concentration on leaf assimilation rate; Equations (c) showing the light effect; equations of (d) showing the temperature effects on model parameters at the leaf level. Main output of the model at the leaf scale is the value of ***e*** which is scaled up to the ecosystem level to calculate NPP and NEE (Farquhar *et al.* 1980; De Pury and Farquhar 1997; June 2002, 2006; Hunt Jr. *et al.* 2002).

__Defenitions of symbols used in Figure 1 :__

Θ	curvature factor of the light response curve
Γ*	CO_2 compensation partial pressure in the absence of dark respiration (μbar)
A	the net CO_2 assimilation rate (μmol m^{-2} s^{-1}), subscript ***c*** represents canopy, ***leaf*** represent ***leaf***.
a_2	quantum yield (in terms of incident PAR) of electron transport at low light
A_j	RuBP-regeneration limited rate of CO_2 assimilation (μmol m^{-2} s^{-1})
A_v	Rubisco-limited rate of CO_2 assimilation (μmol m^{-2} s^{-1})
c_i	partial pressure of CO_2 in the leaf (μbar)
E	activation energy for carboxylation, oxygenation, respiration and rubisco activity (J mol^{-1})

I	light intensity incident on leaf surface (nmolm"^{2} s"^{1})
J	rate of actual electron transport (^imol m"^{2} s"^{1})
•/ma*	maximum electron transport rate (^imol m^2 s"^{1})
K_e	Michaelis-Menten constant for carboxylation by Rubisco (|.ibar)
Ka	Michaelis-Menten constant for oxygenation by Rubisco (mbar)
O	ambient partial pressure of oxygen (mbar)
R	universal gas constant, 8.3144 J mol^4 K"^{1}
Rt	dark respiration of leaf which continues in the light (nmol m"^{2} s"^{1})
T	leaf temperature (°C)
K™«	maximum rate of Rubisco activity in the leaf (umol m"^{2} s"')
&„	nitrogen extinction coefficient
k	light extinction coefficient
Af_0	leaf nitrogen concentration on top of canopy (mmolm"^{2})
^c.kai	Total PAR absorbed by the canopy and leaf (umol m"^{2} s"')
NPP	Net Primary Production
GPP	Gross Primary Production
NEE	Net Ecosystem exchange
Rveg	Respiration by vegetation (0.45 GPP)
Reco	Respiration of ecosystem (as a function of temperature)

The model used is a *C^* photosynthesis model. It is chosen due to the fact that €3 plants dominate 95 % of earth vegetation. It is shown in the model that the responses of C_3 leaf photosynthesis to light, temperature and CO_2 concentration can be described by the biochemical properties of just two steps in the process, the carboxylation reaction (shown by K_{cmax}) and the regeneration of the acceptor for carboxylation (shown by $J_{,mu}$). This mechanistic model, has been widely validated as an accurate predictor of photosynthetic carbon uptake by leaves with variation in environmental conditions. The scaling up to canopy to estimate NPP is done using sun-shade model (De Pury and Farquhar 1997; June 2002). In the simulation, supply of CCK (fj) into the leaf is modelled as 0.7 of ambient CCK (c_a). This is a condition where water is not a limiting factor and vapour pressure deficit is around 12.5 mbar. 7_{max} is taken as 2.1 F_{cmax}. To run the model the following groups of data are needed: (1) Fixed parameters of leaf and canopy photosynthesis for €3 plants (Table 1); (2) Photosynthetic parameters based on measurements (Table 2) ; (3) Hourly climate data of maximum and minimum air temperature and global radiation. These hourly data are generated from daily data.

Ra was determined by extrapolation of a linear regression at the lower end of the PAR response curve (at PAR = 0-100 ^mol m"^{2} s"^{1}) (Figure 2) and F_{cmM} was estimated from the lower end of the q response curve at q around 100 jibar (Table 2).

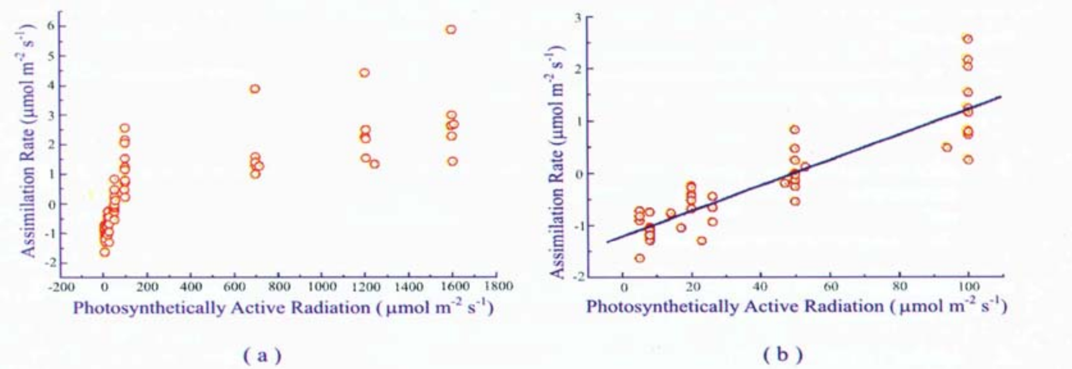

Figure 2. PAR response curve of several tree species in Lore Lindu National Park (a) and the resulting extrapolation of the curve at the lower end of PAR (0-100 μmol m^{-2} s^{-1}) R_d = - 1.20 μmolm^{-2}s^{-1} (R^2=0.899), Quantum Yield for assimilation (a_2) = 0.02 molmol^{-1} (b).

To scale up the model result for the whole national park, input data (LAI and /APAR) derived from NDVI (Normalized Difference Vegetation Index) observed from satellite images (Landsat TM) are used as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (2)$$

$$LAI = \mathbf{12.74}\ NDVI + 1.34 \quad (r^2=0.74) \qquad \text{(Ibrahim 2001)} \qquad (3)$$

$$f_{APAR} = 1.075\ NDVI - 0.08 \qquad \text{(Ochi and Shibasaki 1999)} \qquad (4)$$

where NIR and RED is the amount of reflected light of visible near infrared, and red wavelengths, respectively; /APAR is fraction of absorbed photosynthetically active radiation. Both equations (3) and (4) are developed for tropical forest.

MODEL DEVELOPMENT WITH STUDY CASE LORE LINDU NATIONAL PARK

NetPro Model is a prototype of potential net primary production model where water deficit effect is not included yet. The model integrates the use of Remote Sensing in obtaining Leaf Area Index (LAI) through a relationship with NDVI. The mathematical equations showing the linear regression between LAI with NDVI and LAI with /APAR were obtained from tropical forest area. The LAI is used as input to the photosynthesis model, while the f_{APM} is used as input for Eq. (1) to estimate

Table 1. Fixed photosyiithetic parameters for C_3 plants and canopy parameters

Parameters		Value	Sources
r*	CO: compensation partial pressure in the absence of dark respiration (|*bar) (at 25	42.75	Bemacchi *et al.* (2001)
E	activation energy for carboxylation, oxygenation, respiration, rubisco activity and COi compensation point (J mol'")	79430,36380, 46390, 65330,37830	Bemacchi *et al.* (2001)
K,	Michaelis-Menten constant for carboxylation by Rubisco (Pa)	40.49	Bemacchi *et al.* (2001)
K_a	Michaelis-Menten constant for oxygenation by Rubisco (Pa)	27840	Bemacchi *etal.* (2001)
R	universal gas constant (J mol'" K"^{1})	8.3144	Goudriaan (1977)
P«	canopy reflection coefficient for diffuse PAR	0.036	Goudriaan (1977)
K,	diffuse and scattered diffuse PAR extinction coefficient	0.715	Goudriaan (1977)
pH	reflection coefficient of a canopy with horizontal leaves	0.041	Goudriaan (1977)
*'	beam and scattered beam PAR extinction coefficient (for random orientation of leaves)	0.69/sinp	June (2002)
N,,	Base level of nitrogen not associated with Photosynthesis (mmol N m'")	29	Antene/a/. (1995)
X.	ratio of rubisco capacity to leaf nitrogen content	1.63	June (2002)
Pi	the leaf reflection coefficient for PAR	0.10	De Pury and Farquhar (1997)
T,	the leaf transmissivity to PAR	0.05	De Pury and Farquhar (1997)
0,	curvature factor of the light response curve	0.7	June (2002)

Note: 4-i/ip is sun elevation.

Table 2. Plant photosynthetic parameters and variables needed for the model and conditions of measurement to obtain them (June 2002)

Parameters/variables	Methods of measurement and estimation	
	at PAR (μmol m^{-2} s^{-1})	at CO_2 (μmol m^{-2} s^{-1})
a_2 (mol mol^{-1})	0, 20, 50, 100	350
R_d ((μmol m^{-2} s^{-1})	0, 20, 50, 100	350
V_{cmax} (μmol m^{-2} s^{-1})	1000	100
J_{max} (μmol m^{-2} s^{-1})	2.1 x V_{cmax}	
Leaf Nitrogen (mmol m^{-2})	Sampling and Laboratory analysis	
LAI (Leaf area index)	Remote sensing derived NDVI	
Climate data (global radiation, minimum and maximum temperature)	Interpolated from 12 meteorological stations around LLNP with data from year 2001 to 2005.	

NPP. PAR data is obtained from global radiation measured in the meteorology stations around LLNP. The source code of NetPro is written in Visual Basic 6.0. ArcView v. 3.3 with MapObjects 2.1 are used to display the resulting NDVI, f_{apar} and spatial LAI. Figure 3 shows the welcoming page of the application NetPro, while Figure 4 shows the Map display and calculation form.

Study site: Lore Lindu National Park

a. Site Information

The NetPro V. 1.0 is run for Lore Lindu National Park, Central Sulawesi The whole national park is located in Lat. 1° 107-1 °50S and Long. 119°50?- 120°20?E (Figure 5). Vegetation that occurs in TNLL includes species dominating the lower area (200-1000 m) such as *Mussaendopsis beccariana, Ficus sp., Myristica sp., Pterospermum sp., Canangium odoratum, Arrenga pinata* and species dominating the higher area (1000-2500 m, 90 % of TNLL) such as *Castanopsis argentea* and *Lithocarpus sp.* Other species includes *Podocarpus sp., Elaeorpus sp., Adinandra sp., Litsea sp., Callohylhim sp., Eucalyptus deglupta* and Palmae (Kartawinata 1985; Mogea 2002).

b. Software used and data input for NetPro

Sofware used for data preparation and to run NetPro includes Visual Basic 6.0, ERMapper 6.4, ArcView 3.3 and MapObject 2.1. Data input into NetPro v 1.0 includes (1) shapefile of polygon with different characteristics of NDVI, minimum

Figure 3. Welcoming page of NetPro v1.0

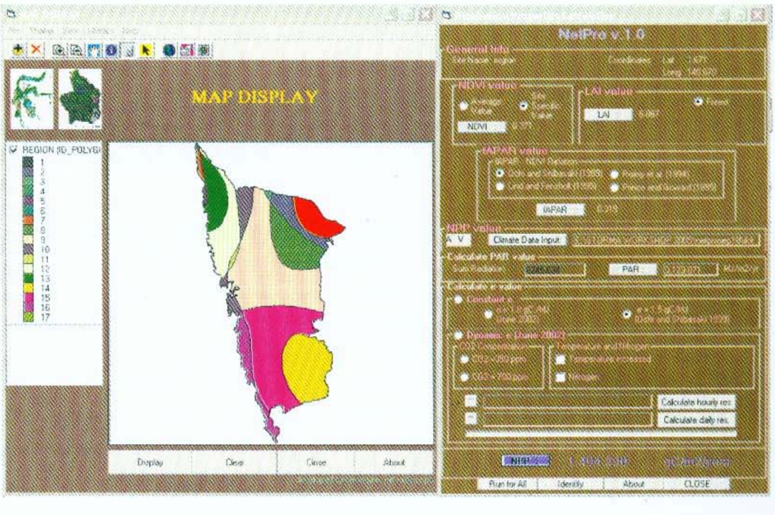

Figure 4. Map Display and Calculation Forms of NetPro. The display form shows the study case area in LLNP which is divided into polygons of certain value of averaged NDVI, global radiation and temperature.

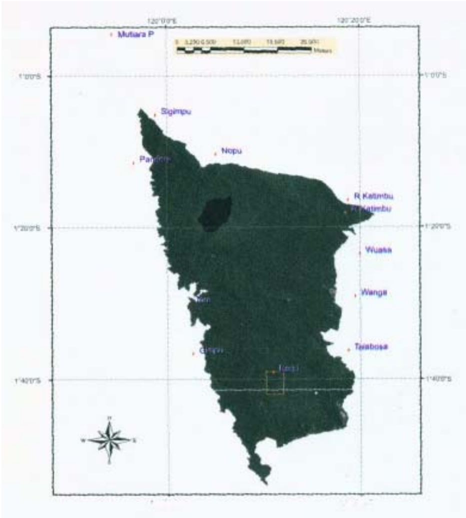

Figure 5. Lore Lindu National Park in Central Sulawesi, with red dots showing 12 meteorological stations around the park and red square shows the location the meteorological tower where direct measurement of CO: fluxes are conducted.

and maximum temperature and PAR classes of LLNP; (2) daily averaged climate data (Global radiation, maximum and minimum temperature) from year 2001-2005. NDVI is derived from Landsat TM 7 dated 21 August 2001. The climate data, global radiation and daily temperature are zoned into several polygons (Figure 6).

NDVI, Leaf Area Index (LAI), and /APAR resulting from image analysis for year 2001 are shown in Figures 7, 8 and 9. NDVI values are divided into 4 classes and based on the Equation of Ibrahim (2001), LAI ranges from 0 to 10.04. LAI values are used as input to Photosynthesis model to obtain *e* value. /APAR distribution (ranges from 0 to 65 %) is shown in Figure 9, where these values are used as input to the model to obtain NPP and NEE. Classes of average NDVI, temperature and global radiation are overlayed to form polygons with different characteristic of climate and NDVI.

c. Net Primary Production (NPP) and Net Ecosystem Exchange (NEE) of LLNP

The value of simulated *e* changes with changing environmental conditions such as changes in global radiation, temperature, atmospheric CO_2 concentration, and nitrogen level of the leaf, and therefore result in varied NPP and NEE values (Table 3).

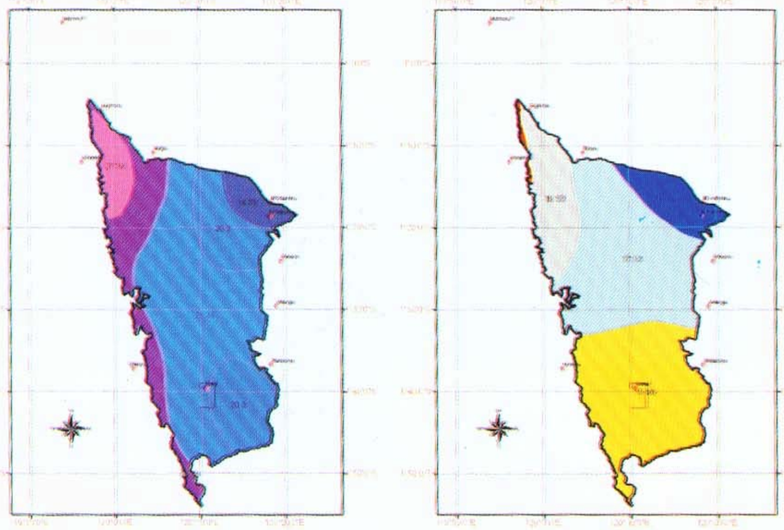

Figure 6. Zonation of average daily temperature (left) and global radiation (right). Data obtained from STORMA database 2001-2005.

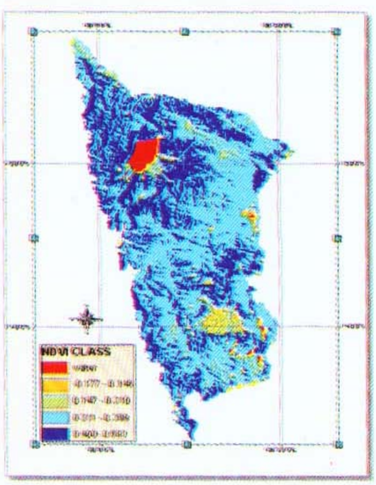

Figure 7. NDVI classes of the whole LLNP

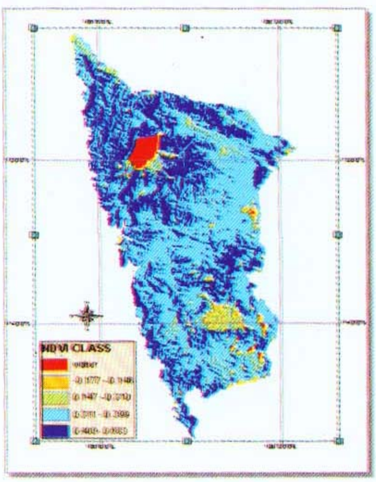

Figure 8. LAI classes of Lore Lindu National Park based on Eq. (3) of Ibrahim (2001) where $LAI = 12.74NDVI + 1.34$. Average value of LAI is 5.9.

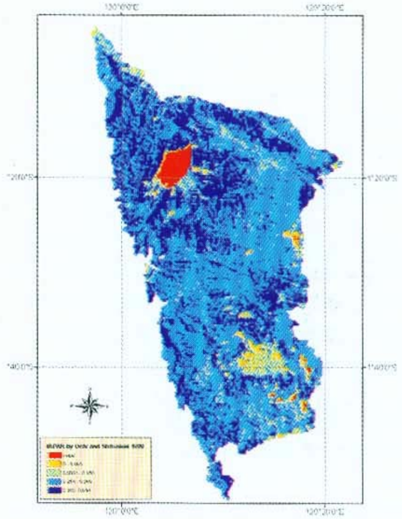

Figure 9. f_{APAR} classes of Lore Lindu National Park based on Eq. (7) of Ochi and Shibasaki (1999) where f_{APAR} = 1.075 *NDVI* – 0.08. f_{APAR} ranges from 0 to 65 % with blue color indicates higher absorption and orange indicates lower absorption.

Table 3. Simulated NPP and NEE values for study case area in Lore Lindu National Park. Simulation was run using f_{APAR} –NDVI relationship of Eq. (7) (Ochi and Shibasaki 1999) and LAI-NDVI relationship of Eq. (3) (Ibrahim 2001).

$[CO_2]$,ppm	LAI	ΔT, °C	Nitrogen, mmol m^{-2}	NPP, gC m^{-2} $year^{-1}$	NEE gC $m^{-2}year^{-1}$
350	5.9	0	95	1154	470
			145	1330	790
	5.9	3.5	95	1141	-196
			145	1272	44
700	5.9	0	95	1422	958
			145	1639	1351
	5.9	3.5	95	1461	386
			145	1629	692

CONCLUSIONS

This framework of model in estimating NPP using remotely sensed NDVI combined with semi-mechanistic modeling is first introduced by the author at the Scientific Meeting on Climate and Weather Prediction, Center for Climate and Atmospheric Science Applications, National Institute of Aeronautics and Space (LAPAN) in Bandung, Indonesia on 31th July 2002 where the proceedings was published in early 2003. The idea was then used by several undergraduate and post graduate students for thesis researches, using a constant value of radiation use efficiency *(e)* under the author's supervision for study sites in Sumatera and Sulawesi.

This research idea is further extended to include a mechanistic estimation of the radiation use efficiency, and in 2004 it was approved by The Integrated Research Award secretariat of The Indonesian Institute of Sciences to be funded for the period of 2004-2006. However with limited availability of budget during that period, the funding was then cancelled after being approved by the reviewer panel.

Through SEAMED BIOTROP DIPA2004, the development of the framework was realized and the prototype of the application software NETPRO is produced. Model parameterization was conducted in Lore Lindu National Park early 2005 supported by STORM A SFB 552 (Stability of Rainforest Margin) Project.

This work still needs improvement in display and modeling. It also needs inclusion of water effect, although application for Lore Lindu National Park the assumption that water is not a limiting factor can be used. To be applicable to different site and type of vegetation, site specific parameterization (V_{cmax}, *e)* and site variable measurement and estimation like leaf nitrogen, LAI, /APAR. climate data (diurnal global radiation, minimum and maximum temperature, diffuse radiation, vapour pressure deficit) are required. It is also important to develop relationship between NDVI and LAI and /APAR from different type of vegetation. Direct measurement of CO2 flux and *e* from *eddy correlation* and micrometeorology techniques for validation of model are needed.

Application of the model framework to other national parks in Indonesia will be an ongoing effort.

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