SENSITIVITY ANALYSIS OF BIOME-BGC MODEL FOR DRY TROPICAL FORESTS OF VINDHYAN HIGHLANDS, INDIA

Manoj Kumar[a]* and A. S. Raghubanshi[b]

[a]Ecosystem Analysis Laboratory, Department of Botany, Banaras Hindu University, Varanasi- 221005, India.
[b]Institute of Environment & Sustainable Development, Banaras Hindu University, Varanasi- 221005, India.
* E-mail: bhu.manoj@gmail.com

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ABSRACT:

A process-based model BIOME-BGC was run for sensitivity analysis to see the effect of ecophysiological parameters on net primary production (NPP) of dry tropical forest of India. The sensitivity test reveals that the forest NPP was highly sensitive to the following eco-physiological parameters: Canopy light extinction coefficient (*k*), Canopy average specific leaf area (SLA), New stem C : New leaf C (SC:LC), Maximum stomatal conductance ($g_{s,max}$), C:N of fine roots (C:N_{fr}), All-sided to projected leaf area ratio and Canopy water interception coefficient (W_{int}). Therefore, these parameters need more precision and attention during estimation and observation in the field studies.

1. INTRODUCTION

There are various types of models that may be used in ecosystem analysis. Ruimy et al. (1994), categorized the NPP model into three groups: (1) statistical models (Lieth, 1975), (2) parametric models (Potter et al., 1993) and (3) process models (Foley, 1994). Traditional types of models are regression models, which are based on empirically derived statistical relationships. Such models may be used for predicting stand development under stable conditions and in regions where the built-in relationships were derived. Naturally, such models are not so useful for incorporating changing growth conditions and for spatial extrapolation. Moreover, such models remain descriptive and do not offer much explanatory power for ecosystem analysis. For this, so-called process-based models must be deployed. These models simulate ecosystem development as a result of ecophysiological processes described mechanistically and usually incorporate the effect of environmental change on ecosystem functioning and are able to quantify effects of, e.g., change in climate, elevated CO_2, nitrogen deposition and land use scenarios (Cienciala and Tatarinov, 2006).

Sensitivity analysis is the study of how the variation (uncertainty) in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of the model (Xu et al., 2004). It can be used to examine which variables/parameters have the largest effect on the model output. Sensitivity analysis determines what level of accuracy is necessary for a parameter to make the model sufficiently useful and valid. If the sensitivity tests reveal that the model is insensitive to a particular factor, then it may be possible to use an estimate rather than a value with greater.

For ecological analysis Biogeochemical (BGC) model is most preferred. BIOME-BGC (Running and Coughlan, 1988; Thornton, 1998) is such model which employs a simplified biochemical model of photosynthesis, environmentally regulated stomatal conductance, and explicit calculations of respiration for various plant pools to calculate NPP. It is a process-based model requiring a considerable number of ecophysiological and site parameters. Therefore, application of this model requires parameterization, including sensitivity analysis of model output to the input data.

Parameters	Symbol
Allocation current growth proportion	cg
Allocation new coarse root C : new stem C	CRC:SC
Allocation New fine root C : New leaf C	FRC:LC
All-sided to projected leaf area ratio	$LAI_{all:pro}$
Annual fire mortality fraction	m_f
Annual leaf and fine root turnover fraction	m_l m_{fr}
Annual live wood turnover fraction	m_w
Annual whole-plant mortality fraction	m_t
autotrophic respiration	Ra
Boundary layer conductance (projected area basis)	g_{bl}
C:N of dead wood	C:N_{dw}
C:N of fine roots	C:N_{fr}
C:N of leaf litter, after retranslocation	C:N_{lit}
C:N of leaves	C:N_{leaf}
C:N of live wood	C:N_{lw}
Canopy average specific leaf area (projected area basis)	SLA
Canopy light extinction coefficient	*k*
Canopy water interception coefficient	W_{int}
Carbon	C
Cuticular conductance (projected area basis)	g_{cut}
Vapor pressure deficit	VPD
Fraction of leaf N in Rubisco	N_R
Gross primary productivity	GPP
Leaf Area Index	LAI
Leaf water potential: complete conductance reduction	LWP_f
Leaf water potential: start of conductance reduction	LWP_i
Litter fall as fraction of growing season	T_{lf}
Maximum stomatal conductance (projected area basis)	$g_{s,max}$
New live wood C : new total wood C	LWC:T WC
New stem C : New leaf C	SC:LC
Nitrogen	N
Ratio of shaded SLA:sunlit SLA	$SLA_{shd:su}$
Transfer growth period	T_t
Vapor pressure deficit: Complete conductance reduction	VPD_f
Vapor pressure deficit: Start of conductance reduction	VPD_i

Table 1: List of abbreviations

Previously, sensitivity analysis for BIOME-BGC (BioGeoChemical Cycles) model has been conducted by White et al. (2000) and Tatarinov and Cienciala (2006) for temperate biomes. Reassessment of model sensitivity for dry tropical forest of India is needed because effect of parameters for different combinations of site and eco-physiological parameters may differ. Therefore, the aim of the present study is (i) to collect ecophysiological and site parameters for dry tropical forest of India from available literature and observations and (ii) to reveal the effect of ecophysiological parameters on NPP and also identify critically sensitive input parameters.

2. MATERIAL AND METHODS

2.1 BIOME-BGC model description

The BIOME-BGC version 4.1.2 was provided by Peter Thornton at the National Center for Atmospheric Research (NCAR), and the Numerical Terradynamic Simulation Group (NTSG) at the University of Montana (available online at http://www.ntsg.umt.edu.). The model is used for this study along with MT-CLIM (Mountain Microclimate Simulator). BIOME-BGC (Thornton 1998, 2000) is a biogeochemical model that simulates the storage and fluxes of water, C and N in terrestrial ecosystems using a daily time step and at different ecological scales (Churkina et al., 2003). The model requires daily weather data including radiation, maximum and minimum temperatures, precipitation and daytime VPD. It also requires information describing the soil properties (Table 2) and eco-physiological traits of vegetation (Table 3). Allometric relationships are used to initialize plant and soil C and N pools based on the leaf pools of these elements. BIOME-BGC estimates NPP on the basis of GPP and Ra (i.e. NPP).

Parameters	Value	Sources
Number of meteorological year	25	This study
Number of simulation years	25	This study
First year for simulation	1986	This study
Constant atmospheric CO_2 (ppm)	390	This study (LiCor – 6400)
Effective soil depth (m)	0.15	Singh and Singh 1991
Sand percentage by volume in rock-free soil (%)	69.0	Singh and Singh 1991
Silt percentage by volume in rock-free soil (%)	27.0	Singh and Singh 1991
Clay percentage by volume in rock-free soil (%)	04.0	Singh and Singh 1991
Site elevation (m)	172	This study
Site latitude (◦ N)	25	This study
Wet + dry atmospheric deposition of N ($KgN/m^2/yr$)	0.0001	Pathak et al. 2009
Symbiotic + asymbiotic fixation of N ($KgN/m^2/yr$)	0.0004	Pathak et al. 2009

Table 2: Model input parameters for site characteristics

2.2 Sensitivity analysis

Sensitivity analysis was performed as documented in Cienciala and Tatarinov (2006), "output variables (y) to input parameters (x) (or the effect of parameter x on the variable y), $\Delta y/\Delta x$ was calculated as a ratio of output variable change to parameter change (both in %)". A negative ratio would mean a decrease in variable with an increased parameter value and vice versa (Cienciala and Tatarinov 2006). As for the absolute quantity ($|\Delta y/\Delta x|$), the parameters were ranked in terms of their effect on the modeled variable as (i) parameters with a strong effect ($|\Delta y/\Delta x|$ larger than 0.2), (ii) parameters with a medium effect ($|\Delta y/\Delta x|$ between 0.1 and 0.2) and (iii) parameters with low effect ($|\Delta y/\Delta x|$ less than 0.1).

2.3 Study area

The study area is located on the Vindhyan Plateau in the Marihan range of East Mirzapur Forest Division of Uttar Pradesh, India, at 24 18 - 25 55 N and 82 32 - 83 45 E. The total forest area in this block is 10360 ha. The climate is tropical and characterized by monsoon conditions. There are three seasons: rainy (mid June - Sept.), winter (November - February) and summer (March - mid June). The mean monthly temperatue varies from 17.5 C (January) to 37.5 C (May) and total annual rainfall averages 821 mm, of which 86 % occurs in the rainy season. The potential natural vegetation is northern tropical dry deciduous forest (Champion and Seth, 1968). The details about dominated species of study area were described by Singh and Singh (1991).

3. RESULT

Sensitivity analysis for eco-physiological parameters revealed that SLA, $g_{s,max}$, W_{int} and $LAI_{all:pro}$ exert a strong negative effect on NPP, while *k*, SC:LC and C:N_{fr} showed positive effect (Table 3). C:N_{lit}, N_R, CRC:SC and C:N_{leaf} showed positive medium effect on NPP (Table 3). Input parameters like $SLA_{shd:su}$, T_t, VPD_i, m_t, LWP_f, FRC:LC, T_{lf}, VPD_f etc. had low sensitivity to model output value of NPP (Table 4). m_l m_{fr}, LWC:TWC, g_{cut} has produced almost negligible effect on the sensitivity of the model.

4. DISCUSSION

For dry tropical forest observed *k* had a high positive impact on NPP. The value of *k* depends upon intercepted photosynthetically active radiation (PAR) and LAI (Lagergren et al. 2005). LAI has major influence on BIOME–BGC since it controls canopy radiation absorption, water interception, photosynthesis, and litter inputs to detrital pools (White et al. 2000). Increased specific leaf area (SLA) resulted in higher LAI (LAI = SLA × leaf carbon) without altering photosynthetic capacity, increasing water stress and thereby reducing NPP (White et al. 2000). SC:LC allocation ratio has a high positive effect on NPP of dry tropical forest. This is due to the redistribution of biomass into the woody compartment with a low turnover rate (Tatarinov and Cienciala 2006). Maximum stomatal conductance ($g_{s,max}$) showed a negatively high sensitivity to NPP; this was in contrast to the report of European temperate managed forestry (Tatarinov and Cienciala 2006). Increases in $g_{s,max}$ reduced NPP by increasing water stress. Increased $C:N_{fr}$, reduces root nitrogen requirements and diverts nitrogen to increased photosynthetic capacity which promotes higher NPP for most biomes (White et al. 2000).

Fraction of leaf N in Rubisco of dry tropical forest showed positive sensitivity to NPP similar to major natural temperate biomes (White et al. 2000) and for beech and small or medium spruce species (Tatarinov and Cienciala 2006). This effect follows from the fact that maximum rate of carboxylation in the model is proportional to N_R (Tatarinov and Cienciala 2006). The effect of the $C:Nl_{leaf}$ was similar to the report of Tatarinov and Cienciala (2006) for beach species which was in contrast to White et al. (2000), who found, that the increase of $C:N_{leaf}$ decreased NPP in all woody biomes. Such an ambiguous effect of $C:N_{leaf}$ might be due to the trade-off between the increase of photosynthesis and foliage respiration with an increasing foliage nitrogen content (Tatarinov and Cienciala 2006). VPD_i and VPD_f showed low negative effect on NPP. This negative relation with NPP was due to increased VPD which causes closure of stomata resulting in inhibition of photosynthesis (Jarvis 1976; Stewart 1988). Fire mortality also had a low negative effect on NPP, which primarily occurs in summer season in dry deciduous forest, i.e., it is affected by fire mortality for a shorter time (Tatarinov and Cienciala 2006).

Parameters	Type	Value	Sources
Year day to start new growth	Day of year	105	Singh and Kushwaha, 2005
Year day to end litterfall	Day of year	364	Singh et al., 1992
T_{lf}	Prop.	0.45	Singh and Kushwaha, 2005
m_w	$Year^{-1}$	0.70	White et al., 2000
m_t	$Year^{-1}$	0.048	Singh and Singh, 1993
m_f	$Year^{-1}$	0.005	Stipulated
FRC:LC	Ratio	1.0	Singh and Singh, 1991; Chaturvedi and Raghubanshi, 2011
Allocation of SC:LC	Ratio	2.2	Singh and Singh, 1991; Chaturvedi and Raghubanshi, 2011
Allocation of LWC:TWC	Ratio	0.1	DVM
CRC:SC	Ratio	0.4	Singh, 1990
Allocation current growth proportion	Prop.	0.5	Chaturvedi and Raghubanshi, 2011
$C:N_{leaf}$	KgC/KgN	20.3	Tripathi and Singh, 1992; Raghubanshi, 2008
$C:N_{lit}$	KgC/KgN	74.6	Singh, 1990; Singh et al., 1991
$C:N_{fr}$	KgC/KgN	48.2	Tripathi and Singh, 1992; Raghubanshi, 2008
$C:N_{lw}$	KgC/KgN	78.3	Tripathi and Singh, 1992; Raghubanshi 2008
$C:N_{dw}$	KgC/KgN	442.0	DVM
Leaf litter labile proportion	DIM	0.28	Singh et al, 1999
Leaf litter cellulose proportion	DIM	0.47	Singh et al, 1999
Leaf litter lignin proportion	DIM	0.25	Singh et al, 1999
Fine root labile proportion	DIM	0.30	DVM
Fine root cellulose proportion	DIM	0.45	DVM
Fine root lignin proportion	DIM	0.25	DVM
Dead wood cellulose proportion	DIM	0.76	DVM
Dead wood lignin proportion	DIM	0.24	DVM
Canopy water interception coefficient	LAI^{-1} d^{-1}	0.041	DVM
k	DIM	0.5	Maass et al., 1994
$LAI_{all:pro}$	DIM	2.0	White et al., 2000
SLA	m2/kgC	30.0	Chaturvedi and Raghubanshi, 2011
$SLA_{shd:su}$	DIM	2.0	White et al. 2000
N_R	DIM	0.08	Default value of DBF biome
$g_{s,max}$	m s^{-1}	0.006	This study
g_{cut}	m s^{-1}	0.00001	This Study
g_{bl}	m s^{-1}	0.08	This study
LWP_f	MPa	-1.8	Chaturvedi and Raghubanshi, 2011
VPD_i	Pa	930.0	This study
VPD_f	Pa	4100.0	This study

Table 3: Ecophysiological input parameters for model (*DVM = Default value of model for deciduous broadleaf forest (DBF) biome as White et al. (2000))

Parameters	Units	SI
k	(DIM)	0.40
SLA	(m2/kgC)	-0.36
SC:LC	(ratio)	0.34
$g_{s,max}$	(m/s)	-0.31
$C:N_{fr}$	(kgC/kgN)	0.29
W_{int}	(1/LAI/d)	-0.21
$LAI_{all:pro}$	(DIM)	-0.21
$C:N_{lit}$	(kgC/kgN)	0.18
N_R	(DIM)	0.15
CRC:SC	(ratio)	0.10
$C:N_{leaf}$	(kgC/kgN)	0.10
$SLA_{shd:su}$	(DIM)	0.09
T_t	(prop.)	0.08
VPD_i	(Pa)	-0.08
m_t	(1/yr)	-0.07
LWP_f	(MPa)	0.06
FRC:LC	(ratio)	-0.06
T_{lf}	(prop.)	0.04
VPD_f	(Pa)	-0.04
$C:N_{dw}$	(kgC/kgN)	0.03
g_{bl}	(m/s)	0.03
m_w	(1/yr)	0.03
LWP_i	(MPa)	-0.03
$C:N_{lw}$	(kgC/kgN)	0.02
LWC:TWC	(ratio)	-0.02
m_f	(1/yr)	-0.01
cg	(prop.)	0.00
g_{cut}	(m/s)	0.00
$m_l\ m_{fr}$	(1/yr)	0.00

Table 4: Sensitivity Index (SI) for Ecophysiological parameters

5. CONCLUSION

The study identified key eco-physiological parameters of a process model BIOME-BGC based on a detailed sensitivity analysis. Among the eco-physiological parameters *k*, SLA, SC:LC, $g_{s,max}$, $C:N_{fr}$, $LAI_{all:pro}$ and W_{int} showed the strongest effect on simulated NPP. Four ecophysiological parameter viz., $C:N_{lit}$, N_R, $C:N_{leaf}$ and CRC:SC had medium influence on simulated NPP value. Therefore these parameters need more precision and attention during estimation and observation in the field study.

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