2012.4.13　昼ゼミ

Influence of stand, site and meteorological variables on the maximum leaf area index of beech, oak and Scots pine

R. Bequet, V. Kint, M. Campioli, D. Vansteenkiste, B. Muys, R. Ceulemans

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原　悠子

はじめに

- My interest is about Recent research of LAI.
  LAIに関して、近年どのような研究されているか。

- LAIを決定する要素を分類して挙げていてわかりやすい。

- 落葉広葉樹2種と常緑針葉樹1種を対象に比較していることが面白い。

Introduction

- Prediction of forest growth and productivity is important.
  森林の成長・生産力の予測は重要

LAI

- LAI is correlated with forest productivity.
  LAIは森林生産と相関関係がある
  (LAI determines intercept light and the total photosynthesis uptake. LAIは受光量を決め、総光合成量を決める)
- LAI also controls radiation extinction, rainfall interception and evapotranspiration.
  LAIは、光の減衰、林地への降雨量、蒸発散量を決定
- LAI can be used to scale up to regional level.
  LAIデータはより広い範囲へとスケールアップさせることができる

Introduction

This paper focuses on the Maximum LAI (LAI_{max}).

From previous studies

- LAI is sensitive to site quality, stand structure and management practices(Warning et al.; Gower et al.; Breuer et al.), and meteorological variables(Meier and Leuschner; Duurdma et al.).

LAI値は地位、林分構造、施業、気候に影響される

→We used multivariate empirical models of LAI_{max} based on stand, site and meteorological variables.

経験的変量モデルを使用(立木、サイト、気象を変量とする)

Materials and Methods

- Species
  - European beech (*Fagus sylvatica* L.)　(10sites)
  - Pedunculate oak (*Quercus robur* L.)　(10sites)
  - Scots pine (*Pinus Sylvestris* L.)　(14sites)
- Experimental site

  Flanders, Belgium　(temperate maritime climate：温暖海洋性気候)
  - All stands are homogeneous and mature.
  - Stand basal area (m^2ha^{-1}): 16-38 (pine), 16-31(oak), 22-33(beech)
  - Stand density index: 295-749 (pine), 240-554(oak), 367-534(beech)

Materials and Methods

- LAI measurement

  by Digital hemispherical photography (魚眼レンズを利用したデジカメ撮影による) at 16 points each site.

  analysis : using Hemispher program (Swiss Federal Research Institute)

  March-November , 2008 a weekly during bud break, and then every 3 weeks (Beech and Oak)

  2 times in summer (Pine) (because pines does not significant fluctuations over the growing season.)

Materials and Methods

- Stand variables
  - Stand structure: density, basal area, tree volume, SDI, dominant height
    立木密度、断面積合計、体積、林分密度指数、上層木樹高

    Stand and tree structure(1):Measured on the dominant model tree (DBH, height)
  - Stand age(2) and tree growth(3): tree ring analysis
  - Phenology(4): bud break and leaf-off vegetation
- Site variables
  - Soil characteristic(土壌特性), N-depositoin(窒素沈着), site index(地位指数)
- Meteorological variables
  - temperature (maximum, mean and minimum)(気温), precipitation(降水量) and radiation (光量)

Materials and Methods

- Statistical analysis
  - Repeated measure ANOVA combined with a tukey(p<0.05).
  - Identify the key predictors (separately and in combination of stand, site and meteorological variables) of LAI_{max} per tree species.

Result

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Table 1 Overview of maximum leaf area index (*LAI*) and of the predictor variables of the multiple linear regression models

Variable name	Unit	Beech					Oak					Scots pine				
		Mean	SD	Min	Max	CV (%)	Mean	SD	Min	Max	CV (%)	Mean	SD	Min	Max	CV (%)
Response var.																
Maximum LAI	$m^2\ m^{-2}$	3.56	0.30	3.17	4.18	8.5	2.64	0.30	2.35	3.25	11.5	1.99	0.22	1.67	2.27	11.0
Predictors																
Stand age	year	90	28	68	147	31.2	77	23	54	121	29.7	69	7	61	81	10.5
Dominant height	m	31.6	2.2	26.6	33.8	6.9	25.3	4.4	16.1	30.1	17.4	21.3	3.8	15.0	25.9	17.7
Tree density	stems ha^{-1}	218	95	88	403	43.6	241	113	69	442	46.9	442	189	196	717	42.7
LW/EW_prev	$\mu m\ \mu m^{-1}$						2.25	0.99	0.72	4.16	44.0	1.34	0.35	0.82	1.92	25.8
Clay	%	19.19	8.28	8.61	29.5	43.2	14.18	7.49	6.52	24.4	52.8	5.81	2.89	3.37	11.33	49.8
Nitrogen	%	0.10	0.02	0.05	0.12	21.8	0.13	0.03	0.06	0.17	24.4	0.08	0.04	0.05	0.14	43.8
Organic matter	%	4.01	1.04	2.24	5.42	26.0	4.39	1.59	1.89	6.46	36.2	2.81	1.56	1.11	4.95	55.6
C/N ratio	mol mol^{-1}	23.5	2.5	19.4	27.4	10.5	18.74	3.9	9.9	23.9	21.1	21.5	6.1	14.3	32.0	28.4
N-deposition	scale	7.02	1.46	5.00	9.00	20.9	6.95	1.61	5.10	9.00	23.1	6.92	1.36	5.00	9.00	19.7
Site index	m	34.7	4.9	27.6	40.6	14.2	29.7	4.2	23.2	35.0	14.1	23.8	4.7	15.8	30.4	19.7
Tmin Apr-May_curr	°C	7.5	0.4	7.1	8.1	5.4	7.5	0.5	6.4	8.1	6.3	6.7	0.8	6.1	8.1	11.4
Prec Apr-Jun_curr	mm day^{-1}	1.92	0.05	1.86	2.00	2.4	1.96	0.14	1.82	2.12	6.9	2.16	0.21	1.86	2.34	9.5
Prec Jul-Aug_prev	mm day^{-1}	2.80	0.30	2.50	3.18	10.7	3.09	0.32	2.50	3.34	10.5	3.60	0.53	2.50	4.05	14.8

LAI_{max}: beech 3.2-4.2 m^2m^{-2}　oak 2.4-3.3 m^2m^{-2}　pine 1.7-2.3 m^2m^{-2}

Stand variables

Site variables

Meteorological variables

Result

Table 2 Best multiple linear regressions for maximum leaf area index (in m^2 m^{-2}) with different groups of predictor variables (stand, site and meteo) and with all predictors together (Best combination) for each of the three species

	Predictor group	Model performance		Predictors				Constant	
		adj. R^2	rRMSE (%)		*B*	*β*	*P*	*B*	*P*
Beech	Stand	0.855	3.36	Tree density	0.004	1.126	<0.001	−0.283	0.711
				Dominant height	0.097	0.700	0.003		
	Site	0.506	6.96	Clay	0.029	0.780	0.016	2.285	0.001
				Nitrogen	7.705	0.526	0.072		
	Meteo	0.574	6.37	Tmin Apr-May_curr	0.591	0.788	0.007	−0.877	0.495
	Best combination	0.958	2.17	Tree density	0.003	1.031	<0.001	2.240	0.020
				Dominant height	0.055	0.394	0.011		
				Prec Jul-Aug_prev	−0.399	−0.394	0.050		
Oak	Stand	0.906	4.35	Stand age	0.014	1.037	<0.001	1.348	<0.001
				LW/EW_prev	0.101	0.331	0.020		
	Site	0.506	9.92	N-deposition	0.134	0.708	0.021	3.152	<0.001
				Organic matter	0.096	0.499	0.075		
	Meteo	0.390	10.59	Prec Apr-Jun_curr	1.516	0.677	0.032	−0.377	0.777
	Best combination	0.906	4.35	Stand age	0.014	1.037	<0.001	1.348	<0.001
				LW/EW_prev	0.101	0.331	0.020		
Scots pine	Stand	0.800	10.5	Dominant height	−0.050	−0.866	0.001	3.054	<0.001
	Site	0.954	7.9	Clay	−0.063	−0.883	0.001	1.581	<0.001
				N-deposition	0.079	0.472	0.006		
				C/N ratio	0.012	0.343	0.015		
	Meteo			None					
	Best combination	0.954	7.9	Clay	−0.063	−0.883	0.001	1.581	<0.001
				N-deposition	0.079	0.472	0.006		
				C/N ratio	0.012	0.343	0.015		

similar

Result

Deciduous species　Similar between beech and oak

LAI_{max} was in mid-July. 落葉樹2種の最大のLAI は7月中旬

- beech: the best predictor is stand variable with tree density and dominant height (R^2=0.86) and + previous summer precipitation (R^2=0.96)
  （Meteorological variable）
  - Positive relations :tree density, dominant height, soil fertility, spring minimum temperature
  - Negative relation: the previous year summer and Autumn precipitation.
- Oak: the best predictor is stand variable with stand age and LE/EW ratio (R^2=0.91)
  - Positive relation with stand age, previous year LW/EW ratio, soil fertility and spring precipitation

Result

Conifer

- Pine: the best predictor is site variables (R^2=0.95)

  stand variable (R^2=0.80)(fairly well)

- Positive relation with spring radiation
- Negative relation with dominant height and soil fertility (expect for N-deposition)

Results

Table 3 Best multiple linear regressions for maximum leaf area index (in $m^2\ m^{-2}$) for all three tree species together (except Model 2* only for Pedunculate oak and Scots pine)

	Model performance			Predictors				Constant	
	adj. R^2	rRMSE (%)			B	β	P	B	P
Model 1	0.602	18.14		Dominant height	0.059	0.455	0.018	0.084	0.887
				Clay	0.037	0.438	0.027		
				C/N ratio	0.029	0.244	0.062		
Model 2*	0.587	12.32	☆	Stand age	0.018	0.714	<0.001	0.613	0.074
				LW/EW_prev	0.223	0.455	0.007		
Model 3	0.528	18.46		Dominant height	0.095	0.738	<0.001	0.255	0.564
Model 4	0.373	21.07		Site index	0.070	0.628	<0.001	0.658	0.195

- Models1.2.3: Depend on similar key predictors(☆) as the species-specific models
- Model3 is best correlation based on single predictor.
- Dominant height was the main predictor (single(model3) or with some other predictor (model1)).
- No meteorological variable was shared by all species.気象は複数樹種のモデルにはあてはまらない！

➢ Positive relation: dominant height, stand age, previous year LW/EW ratio and soil fertility(except for C/N ratio)

Results

Table 4 Proportional deviations (%) of the modelled leaf area index (*LAI*) compared to the measured LAI in four beech and two Scots pine experimental sites across Europe

Site	Country	Species	Years tested	LAI	Stand age	Canopy height	Tree density	Modelled LAI		
				$m^2\ m^{-2}$	Years	m	stems ha^{-1}	Stand	Comb	Meteo
Hesse	France	Beech	1997–2007	5.7–8.2	30–42	14	2,617–4,445	80%	50%	7%
Collelongo	Italy	Beech	2004–2008	5.4–6.6	113–117	21.5	825–830	−7%	3%	−25%
Hainich	Germany	Beech	2001–2007	5.5–6.6	230–236	25	344	−30%	−20%	5%
Sorø	Denmark	Beech	2001	5	85	25	283	−34%	−20%	1%
Hyytiälä	Finland	Scots pine	2004–2008	2.0–2.2	43–47	14–17	1,273	7%	na	na
Loobos	The Netherlands	Scots pine	1996, 2000, 2005–2008	1.5–2.1	86–98	15–18	360	10%	na	na

Three different multivariate LAI models were tested: the stand model, the best combination (*comb*) model and the meteorological model

na not applicable, *source* CarboEurope-IP database

Species-specific models of out side of Belgium. (Beech and Pine)

- Succesfully model is Collelongo.
- Hainich and Soro was underestimated with the stand model.
- Hesse is young and densely stand so the model not work well (overestimate).

✓ The meteorological model worked well (Beach).

✓ The stand model predicted very well. (No significant meteorological model.)

Results

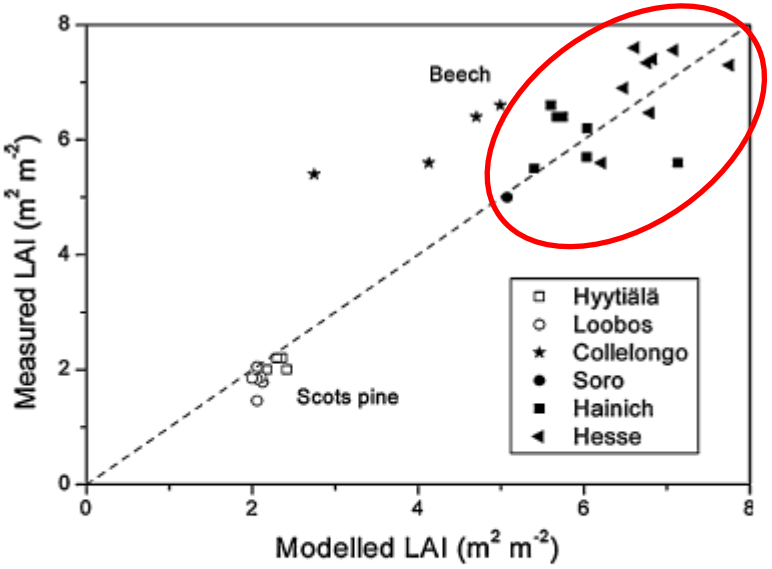

Fig. 3 Scatter plot of the measured leaf area index (LAI) and the modelled LAI based on multiple regression models. The measured LAI corresponds to data of the CarboEurope-IP database of experimental sites of beech (*full symbols*) and Scots pine (*open symbols*). The modelled LAI were done with the best performing models per species, namely the meteorological model for beech and the stand model for Scots pine. The *dashed line* indicates the 1:1 relation

Discussion

- Previous studies reported similar LAI_{max} values.
- Stand variables: LAI_{max} is positively linked to age. Stabilize or decline slowly with as become older (ex. Battaglia et al.).
  - LAI_{max} related to dominant height(model 1 & 3) and height is correlated to stand age. → LAI_{max} linked with age.

  (Pine: negative correlation with dominant height, site index and clay content . It was not expected.　The increase in dominant height was strongly correlated to site quality. Pine tends towards more open crowns because of intraspecific and related mortality (Ford 1982).) 種内間競争と枯死率に関係して林冠が開く
  - Pine and beech: no correlation between LAI_{max} and stand density.

  Better sites developed quicker and were already harvested leading to a more open canopy and a lower stand LAI than the poor site.

  ⇔Oak: good correlation.
  - Tree density of Beech was strong predictor about $LAI_{max.}$
  - The dominant's tree's DBH is not important for LAI_{max}.
  - Oak: bud burst and increasing in LAI depend on LW/EW ratio of the previous year.

Discussion

- Site variables:
  - site index correlated to stand productivity and growth(model4) and hence to site quality.
  - Clay content is predictor of LAI_{max} support leaf expansion (Clay keeps water and be a good indicator of soil fertility).
  - LAI_{max}*C/N: positive (this study) or negative relation (Meier and Leuschner 2008) in the scots pine.

→better site developed quicker and were already harvested leading a more open canopy stand than in the poor site..

- Meteorological variables

Positive relationship between precipitation or soil water availability and LAI.

- Oak: Higher precipitation was a consequence of a higher number of leaves.

⇔Beech: higher summer precipitation indicate decreasing in LAI.

(Low precipitation: leaf size increased and SLA decreased)

Discussion

- Models: (with similar studies)
  - Remarkable: One model per site simulate with 10 %. (in spite of different the stand, site , meteorological conditions and LAI measurement technique (hemispherical photography or litter collection).) 立地、地位指数、気候、測定方法が異なるにも関わらず、10%の制度で測定可能。
  - The meteorological model performed very well for the central European site. (less well for the Mediterranean site)

  Models based on forest structure and site quality be less applicable than models based on meteorological variables.→need to investigate the model for other climate regions.

  Pine and Oak showed a strong model to estimate LAI_{max} based on growth of the previous year and stand age.

  Species-specific model not appear to have similar predictors.

  Different growth strategies (e.g. hydraulic balance, deciduous vs. conifers) and management explain the weaker generic model performance. 成長戦略と施業がモデルの精度に影響する

Conclusion

- Beech and oak: LAI_{max} be explained by stand characteristics and tree growth variables.

→productivity depends on management and practices.

- Pine: leaf area development was more sensitive to site quality and climate factors.
- All three tree species: more dominated by stand characteristics and tree growth variable.

- 樹種によって、LAIの決定要因の働きかた(Positive or Negative)が異なることが興味深い。
- LAIを決定する要素は多様である。(林分・土壌・気象 環境に大きく分類され、そのなかをさらに細分化した指標)
- N沈着・CO_2増加といった、生育環境の変化で、LAI_{max}も変化するのではないか。