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Predicting annual grassland productivity from community-level mean traits: how does a rapid method based on botanical survey perform?

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Abstract. Because methodology used to assess functional structure of the community has to be adapted to the objectives of the study and the processes of interest, two simpler methods for measuring cumulated weighted mean values of three traits are compared, and the ability of the functional descriptors to predict the annual aboveground production tested on a set of 28 grassland plots. The non-destructive method, applied once a year and based on botanical survey to assess the species abundances, provides cumulated weighted mean (CWM) values that are highly correlated to values resulting from the reference method, that is from species hand sorting of biomass sampled all along the year to assess annual productivity. Statistical models predicting annual production using the CWM of leaf traits and plant height showed good to very good fits, are highly significant, with r² of 72.4 for the reference method and 63.7 for the simplest one. This latter is thus considered highly valuable for studying links between functional structure and processes.

Keywords. Temperate permanent grassland – Functional diversity.

Prédire la production annuelle de biomasse à partir des traits moyens de la communauté : intérêt d'une méthode simplifiée d'observation botanique

Résumé. *Dans un contexte d'analyse des relations entre structure fonctionnelle des communautés et fonctionnement de l'écosystème, les méthodes utilisées pour estimer les descripteurs fonctionnels doivent être adaptées aux processus d'intérêt étudiés. Deux méthodes simplifiées d'estimation de la valeur moyenne des traits de communauté ont été testées ainsi que la capacité de ces variables à prédire la production annuelle de biomasse de 28 parcelles de prairie permanente. La méthode simplifiée non destructive par observation visuelle de points quadrats avec une mesure annuelle pour évaluer les abondances spécifiques a conduit à des valeurs de traits moyens très fortement corrélées aux valeurs de la méthode de référence basée sur le tri pondéral des espèces dans les repousses successives de biomasse tout au long du cycle annuel. Pour ces deux méthodes, les valeurs moyennes de traits foliaire et de hauteur des plantes apparaissent comme des variables explicatives de la production annuelle de biomasse dans des modèles très significatifs et à forts R², validant l'emploi de la méthode simplifiée.*

Mots-clés. *Prairie permanente – Diversité fonctionnelle.*

I – Introduction

Herbage production of semi-natural multispecies grasslands is a key process that still need to be explained in more details and predicted. Previous works have provided evidence of the usefulness of plant functional traits and their diversity at the community level to predict grassland properties and services, including production (Diaz *et al.,* 2007). Reliable implementation of this approach requires first selecting appropriate descriptors of the functional structure of plant communities among the variety of indices that have been proposed so far. Moreover, the methodology used to estimate these indices has to be adapted to the question and the scale at which processes are studied (Lavorel *et al.,* 2008). Among the available indices, community weighted mean (CWM) of a trait is defined as the mean of the values recorded in a community weighted by the relative abundance of the species bearing those values. It is considered as an informative index because it relies on the hypothesis that the most abundant species drive the processes. In the calculation of CWM, standardized methods have been defined for traits measurement. For species relative abundances, the reference method is based on their contribution to the total biomass. However, direct estimation of such contribution is destructive and time consuming, particularly when measurement have to be realized all along the year as it is required for properly estimating such annual production. Here, we aim at testing the performance of simpler methods, using measurements realised once a year at the moment of active growth. One is based on botanical survey where the relative abundance of species is visually estimated, the other on hand sorting of species biomass. Questions are: (i) do estimates of CWM differ between the methods?; and (ii) is there any effect of the method on the relationship between the community-level functional descriptors and annual aboveground production? These questions are treated using a set of 28 grassland plots differing for functional structure and productivity.

II – Materials and methods

1. Study site and measurements

This study was based on a long-term experiment located on upland (850 m asl) on a semi-natural grassland in Auvergne, Theix, France (45°43'43'' N, 03°1'21'' E), belonging to the SOERE Acbb[1]. Measurements were carried out in 2011 on 28 plots, i.e.7 management treatments applied since 2005, with four plots per treatment. Treatments include cattle grazing at high or low stocking rate, sheep grazing at low stocking, control not used (abandon), and three treatments under cutting differing by the level of fertilizer. The community is dominated by tall grasses such as *Festuca arundinacea* Scherb*.*, *Alopecurus pratense* L*.,* with other species including smaller grasses (*Poa pratense* L.*, Lolium perenne* L.), forbs (*Taraxacum officicalis, Achillea millefolium* L.*)* and legumes (*Trifolium repens* L.). These species are characterized by high Ellenberg indicator values for N, which indicates a high level of soil fertility at this site.

We implemented the simple non-destructive method of species contribution to the partial or total biomass and the time-consuming destructive methods as follows:

Non-destructive method based on quadrat points (QP): in May, the plant species composition was estimated within each of the 28 plots by a QP method (Daget and Poissonet, 1971). At 40 points located along transects, a pin was moved downward the vegetation and all the species that hit this pin were listed and scored. For each species, its relative abundance, expressed in percentage, was calculated as sum of scores of that species divided by the sum of scores attributed to all species.

Destructive method based on biomass measurements: the aboveground production has been estimated in 2011, using 4 sampling areas per plot, 0.6*0.6 m^2 each, clipped (5.5 cm heigth) all along the year before each grazing or cutting events. In mowed and abandoned treatments the aboveground biomass has been cut in May, July and October, whereas it was cut in April, May, June, September, November in grazed treatments. Initial standing biomass at the beginning of the regrowth period in February was removed; sampling areas were moved within the plot at each clipping date, and, in grazed plots, sampling areas were protected from animal by enclosure (0.6*0.6m).

[1] SOERE ACBB : Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement : Agro-écosystèmes, Cycles biogéochimiques et Biodiversité.

In the laboratory, a representative sub-sample of the clipped biomass (by mean, 19.5% of the total) was selected for species hand sorting. Each species material sorted from the sub-sample and the rest of the sample were oven-dried (60 °C, 48 h) and weighed. Doing so we obtained for each plot at each sampling date, the best assessments of the aboveground production between two successive dates, and the associated contribution of each species. The annual herbage production (g DM m^{-2} y^{-1}) was then calculated as the sum of all sampling dates. The species relative abundances at the community level were calculated at the annual scale, taking into account the species contribution in biomass at each sampling date.

Plant traits: a plant-traits database of the dominant species of the experimental site has been built since 2006 (data not shown). Three main traits, ie, leaf dry matter content (LDMC), specific leaf area (SLA) and reproductive height (RepHt) have been measured according to Cornelissen *et al*., (2001) in each plot. A mean trait value has been calculated for each species at the treatment level, using values measured at the plot level.

Plant trait values at the community-level: community weighted mean (CWM) was calculated for each of the three traits in each of the 28 plots, following Lavorel *et al.* (2008):

$$\text{CWM} = \left(\frac{1}{\sum p_i}\right) * \left(\sum p_i * trait_i\right),$$

where p_i is the relative abundance of species i to the community and $trait_i$ is the trait value of species i.

Three sets of CWM were derived. One based on species relative abundance provided by the quadrat point method (QP hereafter), one based on biomass measurements at annual scale (An_Biom hereafter), and one based on biomass measurements in May (May_Biom hereafter).

2. Statistical analyses

We first assessed the differences in CWM estimates between the different methods of measurement of species abundance. To do so, Pearson's correlations were used. In addition, three Anova (one for each trait) were performed in order to test for the effect of treatment, method, and treatment x methods interaction on CWM values. Data were Log transformed when necessary and the Shapiro-Wilks test was used to check for the normality of the residuals. Second, we compared statistical models relating the annual above ground biomass and the CWM values estimated from the different sampling methods. We used a step-wise forward and backward regression procedure to emphasise the best predictors (among CMW of LDMC, SLA, RepHt) of the annual aboveground production. The procedure was used successively with CWM calculated by QP, An_Biom and May_Biom methods.

III – Results

CWM values resulting from the different methods (Table 1) are significantly correlated (Table 2). For the three traits, correlation appears much higher between quadrat point (QP) and Annual biomass methods, than between quadrat point (QP) and May_biomass methods.

CWM values are significantly affected by management treatment and also by method of assessment for two traits out of three. There is no significant effect of the interaction between treatment and methods (Table 3). However for LDMC the interaction is almost marginally significant. Annual biomass production in 2011, by mean at 566g/m², ranged from 236 to 986 g/m² across the whole data set. It was successfully predicted by linear models based on CWM as explicative variables (Table 4). The best fit was found for An_Biom with the CWM of the three traits selected (r^2 = 72.4, p<0.0001). The model for the QP method showed weaker but still good fit (r^2 = 63.7, p<0.0001), with the same three traits. Parameter estimates of these two models showed comparable values. The model using the May_biom method showed much weaker fit.

Table 1. Community weighted mean for three traits, LDMC (mg/g), SLA (cm^2/g) and RepHt (cm) in the 28 plots in 2011 for the different methods. Mean, minimum and maximum for CWM-QP method, CWM-An_Biom method, CWM-May_Biom method

Method	Quadrat Points			An_Biomass			May_Biomass		
Trait	LDMC	SLA	RepHt	LDMC	SLA	RepHt	LDMC	SLA	RepHt
Mean	239	230	74	242	242	82	245	247	81
Min/Max	207/294	179/287	55/99	203/281	197/330	49/107	200/281	186/337	51/113

Table 2. Correlation across methods used to calculate CWM for three traits: LDMC, SLA, RepHt

	LDMC		SLA		RepHt	
Methods (x-y)	r	*p* value	r	*p* value	R	*p* value
An_Biom-May_Biom	0.925	<0.0001	0.941	<0.0001	0.921	<0.0001
An_Biom-QP	0.831	<0.0001	0.863	<0.0001	0.871	<0.0001
May_Biom-QP	0.719	<0.0001	0.844	<0.0001	0.768	<0.0001

Table 3. Three separated ANOVA for testing the effect of Management Treatments and Methods on estimates of CWM for LDMC, SLA and RepHt

	LDMC			SLA			RepHt		
	df	F ratio	*p* value	df	F ratio	*p* value	df	F ratio	*p* value
Treatment (T)	6	41.07	<0.0001	6	20.76	<0.0001	6	26.73	<0.0001
Method (M)	2	1.43	0.248	2	4.5	0.015	2	8.76	0.0004
T x M	12	1.59	0.116	12	0.44	0.939	12	0.55	0.87

Table 4. Stepwise multiple regression models of annual above ground production (dependent variable) performed with CWM traits (explicative variables) values assessed with three different methods. For each fitted model, intercept, coefficient estimates (and standard error in bracket) of the selected variables, r-square and p value are reported

Method	Intercept	CWM-LDMC	CWM-SLA	CWM-RepHt	R^2	P value
An_Biom	382 *(421)*	-4.01 *(1.16)*	3.25 *(0.77)*	4.50 *(1.82)*	72.4	<0.0001
QP	-187 *(471)*	-3.24 *(1.25)*	4.39 *(1.08)*	7.01 *(2.35)*	63.7	<0.0001
May_Biom	736 *(449)*	-3.10 *(1.27)*	2.38 *(0.83)*	–	52.5	0.0001

IV – Discussion and conclusion

CWM of traits estimated from the different methods are tightly correlated. Correlation involving CWM_QP is higher with CWM_An_Biom than with CWM_May_biom. Difference could be link to the better ability of QP method to assess species contribution by covering larger area compared to biomass method, which, at each measurement time, explore a limited sampled area.

CWM estimations were affected by the method for two traits, and by treatment for all of them. No interaction between the methods and the treatments indicates that the methods produce unbiased estimate of CWM for SLA and RepHt traits (caution has to be taken for one trait LDMC as interaction is not far from significance) and this, whatever the grassland type (among those covered by the experimental set). Moreover, our result indicates that the three methods could be used for testing the effect of management treatments on functional descriptor (i.e. the functional response of communities).

Statistical models set with the annual aboveground production as response to the CWM of leaf traits and plant height showed good to very good fits. Most importantly, our results highlight that the QP method showed very similar performance to the An_biom method, which is expected to be the best method. We conclude that the much simpler, rapid and non-destructive method based on plant trait data and relative species abundances retrieved from botanical survey is highly valuable.

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