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AN EVALUATION OF THE USE OF THE DRY-WEIGHT-RANK AND THE COMPARATIVE YIELD BIOMASS ESTIMATION METHODS IN PARAMO ECOSYSTEM RESEARCH

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Resumen
Se evaluó la aplicabilidad de una combinación de dos métodos para estimar la biomasa general y la composición botánica, en una vegetación natural paramuna en el Parque Nacional Natural los Nevados (Cordillera Central de Colombia). El primer método («comparative yield») determina la biomasa general, destruyendo parcialmente la vegetación de los cuadrantes de muestreo y el segundo («dry weight rank») determina la composición botánica con base en el peso seco, sin destruir la vegetación. Estos métodos, inicialmente desarrollados para pajonales forrajeros en Australia, se adaptaron para ser utilizados en el ecosistema paramuno. Como resultado se obtuvo una estimación de la biomasa aérea de 2864 g peso seco. m^{-2} (desviación stándard 48) en la cual, la gramínea Calamagrostis effusa contribuyó con el 70%.
Puede concluirse que el método de producción comparativa es útil para estimar la biomasa en el ecosistema paramuno, siempre y cuando se utilicen las adaptaciones mencionadas. Por otra parte la estimación de la composición botánica con este método dio resultados más satisfactorios que con el método «dry weight rank», el cual presenta demasiados problemas debido a la complejidad de los pajonales del páramo.

Abstract
The use of the combination of the semi-destructive comparative yield method for overall biomass estimation and the non- destructive dry-weight-rank method for studying botanical composition on a dry weight basis in an undisturbed páramo vegetation in the Los Nevados national park (Colombian Central Cordillera) was evaluated. These methods, developed for Australian production grasslands, were adapted for use in the páramo ecosystem. The average above ground biomass in the area was estimated as 2864 g dryweight. m-2 (sd.48), of which the bunchgrass Calamagrostis effusa contributed with ca 70%.
When used with some adaptations, the comparative yield method seems suitable for biomass estimations in the páramo ecosystem. The here presented estimation of botanical composition with this method gave better results than dry-weight-rank method, which had too many shortcomings for use in the complex páramo grassland ecosystem.

Introduction

The most widely used method to estimate above ground biomass in grasslands is the destructive sampling of plots and subsequent extrapolation to establish the yield of vegetation quadrats (Cochran 1963; 'TMannetje, 1978). The optimum quadrat size is that size that provides the smallest confidence interval of the mean for a given labour cost. When the vegetation structure becomes more complex, the optimum quadrat size and cost will increase if the same confidence interval is to be maintained (Wiegert, 1962).

The vegetation structure of neotropical equatorial alpine grasslands (páramos) is one of the most complex among the grasslands in the world (Cleef, 1981). The dominant growth forms of the páramos in the Colombian Central Cordillera are stemrosettes (*Espeletia hartwegiana* subsp *centroandina*), constituting an emergent (up to 5 m) vegetation layer above high (up to 1 m) growing bunchgrasses (*Calamagrostis* spp., *Festuca* spp), and dwarf shrubs (*Pernettya* spp., *Bacharis* spp.). An additional lower vegetation layer may be present with ground rosettes (*Hypochaeris* spp.) sedges (*Carex* spp.) and short-growing grass species (*Calamagrostis* spp., *Agrostis* spp.). Almost bare spots are common (Salamanca, 1991). Due to this spatial heterogeneity and complex structure, optimum quadrat size for destructive sampling will be high. For accurate biomass measurements of páramo vegetation, a less destructive and faster method, which takes into account the spatial heterogeneity, may be favourable. In the present study we evaluate the usefulness of a combination of two methods to estimate biomass and composition of Australian production grasslands, adapted for and applied in a relatively undisturbed páramo vegetation.

The comparative yield/dry weight rank method

In the semi-destructive comparative yield method for estimating total above ground grassland biomass (Haydock & Shaw, 1975), a series of sampling units (standard quadrats) is selected subjectively and marked to construct an ordinal scale over the total range of dry matter yields within a study area, using the following procedure: First, a sampling unit with the highest dry matter yield of the area under investigation (class 5) and a sampling unit with the lowest yield (not zero, class 1) are selected. Subsequently, a sampling unit in between 1 and 5 (class 3) and sampling units in between 3 and 5 (class 4) and in between 1 and 3 (class 2) are selected.

A large number of sampling units (scored quadrats) is selected at random in the area, of which dry matter yield is given a score on the scale of the standard quadrats. Depending on the relative difference between the scale units, intermediate scores are allowed. Finally the five standard quadrats are harvested and the material oven dried. With the biomass of these five quadrats and the scores of the randomly selected quadrats total biomass can be estimated (Haydock & Shaw, 1975).

Both the selection of the standard quadrats as the assignment of scores is based on visual parameters as density, height and woodiness of the vegetation. An initial training period is necessary to calibrate visual selection and scoring with actual dry weight and to minimise differences in scoring by different investigators (testing of scores by harvesting and weighing, Friedel, *et al.*, 1988).

Botanical composition on a dry weight basis can be estimated with the non-destructive dry-weight-rank method ('TMannetje & Haydock, 1963). In this method, a large number of quadrats are selected at random in an area. In each an estimate is made of the species with highest rank on a dry weight basis, by means of the mentioned visual parameters. Similarly the species with the second and third rank are identified. For each species the load of first ranks is multiplied by 8.04, second ranks by 2.41 and third ranks by 1.00 (sensu 'TMannetje & Haydock, 1963). Summing the resulting products gives a species-score, which is then expressed as a percentage of summed species-score of all species. This percentage represents the botanical composition. 'TMannetje & Haydock (1963) have shown that the mentioned multipliers can be applied to any type of grassland.

The two methods, including the multipliers, have been applied in grasslands all over the world, and have been tested and improved by different authors (Friedel *et al.*, 1988; Kelly & McNeill, 1980).

Adaptations to the paramo ecosystem

In this study the comparative yield/dry-weight-rank combination was adapted to estimate overall above ground biomass (including litter, adult stemrosettes were excluded) and botanical composition of an undisturbed páramo vegetation (Caño de Agua Leche, Los Nevados National Park, Colombian Central Cordillera at 4100 m alt., 4 48'N, 75 24'W). In an area of 3 ha with a relative homogeneous distributed vegetation five standard quadrats (1 m2) were selected and marked. Next the whole area was divided in a systematic transect-line pattern. While walking along all transects, 50 quadrats were randomly selected by throwing (blind-eyes) a hoop (diam.100 cm). By this procedure all points in the area had the same change to be sampled. Each quadrat was given a score on the standard quadrat-scale, with a precision of 0.25 (1.00, 1.25, 1.50, 1.75,...5.00). Although 50 quadrats should suffice to minimise confidence limits (Friedel et al., 1988), two independent data-sets of 50 were analysed to obtain a better idea about the stability of the results.

Average scores of the comparative yield method of the 2 data-sets were 3.28 and 3.18, with standard deviations of 0.88 and 1.04 (range: 1-4.75), reflecting the heterogeneity of the vegetation. The scores approximate to a normal distribution ($p<0.05$).

After harvesting and drying (24 hr at 105 C), the yield of the 5 standard quadrats was weighed. Total yields (dead and living, incl. litter) amounted to 234, 808, 1788, 4275 and 9462 g DW.m-2. After a logarithmic (ln) transformation of these values, the function $\ln Y = 4.68 + 0.91 * Qc$ described the relation between standard quadrat class (Qc) and ln yield (ln Y), ($R2 = 0.99$, $p<0,01$). This function could be applied to the s ores of the scores quadrats to calculate average dry weight.m-2 of the area:

$$\ln B = \frac{\sum_{i=1}^{50} (0.91 * Sci + 4.68)}{50} \quad (1)$$

where: B= Average above ground biomass of area (g DW.m-2)
Sci = Score of scored quadrat i on range 1-5
The average above ground biomass of the data-sets 1 and 2 was 2836 and 2891 gDW.m-2 respectively (average of both sets: 2864 g DW.m-2, sd=48).

The estimates of the biomass presented here were compared with the yield of two independently selected and harvested scored quadrats (scores: 2.75 and 3.25). With the regression equation their biomass was estimated as 1316 and 2074 g respectively. Actually they supported 1228 and 1966 g, an over estimation of 7%.

Dry-weight-rank estimates were also made in the previous selected scored quadrats. Ranks were assigned to 5 species and to 4 groups (dwarf shrubs, ground rosettes, sedges and short grasses were not ranked on species level). *Calamagrostis effusa* contributed 70% to total biomass of the area with data-set 1 and 74% with data-set 2 (table 1). For the other

Table 1. Load of first, second and third ranks per species, species scores and botanical composition (% of dry weight) of the overall biomass, as obtained by the dry-weight-rank method. Results of 2 data-sets of 50 scored quadrats.

	Data set 1					**Data set 2**				
Species/groups	**# 1st ranks**	**# 2nd ranks**	**# 3rd ranks**	**Species score**	**% dry weigh t**	**# 1st ranks**	**# 2nd ranks**	**# 3rd ranks**	**Species score**	**% dry weight**
Calamagrostis effusa	42	24	6	401.5	70.1	42	33	8	425.2	74.3
C. recta	5	13	6	77.5	13.5	5	0	1	41.2	7.2
Sedges	1	4	8	25.7	4.5	0	5	8	20.1	3.5
Short grass	1	2	4	16.9	2.9	0	0	2	2.0	0.4
Ground rosettes	0	1	4	6.4	1.1	0	2	10	14.8	2.6
Rosaceae	1	3	10	25.3	4.4	3	2	7	35.9	6.3
Lupinus microphyllus	0	0	1	1.0	0.2	0	2	4	8.8	1.5
Dwarf shrubs	0	2	4	8.8	1.5	0	5	6	18.1	3.2
Juvenile *Espeletia*	0	1	7	9.4	1.6	0	1	4	6.4	1.1
Total score				**572.5**	**100.0**				**572.5**	**100.0**

species differences between the two data-sets were considerable.

Another botanical composition estimation procedure was developed to be used with the comparative yield method. After harvesting the standard quadrats the yield was separated in the different species/groups, which were then subdivided in living and dead material. The contribution of a particular unit (e.g., *Calamagrostis effusa*, young leafs), expressed as a percentage of the total yield of a standard quadrat was determined. Subsequently, botanical composition was calculated as:

$$\%Vt = \frac{\sum_{a=1}^{5} \{\%Sc(a+x)*(\%Vt(a)*(1-x) + \%Vt(a+1)*x)\}}{100} \quad (2)$$

where %Vt = Contribution (%) of unit to the overall biomass in the area

%Sc(a+x) = Contribution (%) of score a+x to total number of scored quadrats
a = Integer part of score (1,2,3,4,5)
x = Fractional part of score (if a 4, x = 0.25, 0.5, 0.75; else x = 0)
%Vt(a) = Contribution (%) of unit to the yield of standard class a.
%Vt(+1) = Contribution (%) of unit to the yield of standard quadrat class a+1

This method resulted in a more detailed overall botanical composition than the one obtained by the dry-weight-rank method: to more species a contribution was attained and a subdivision per unit was made in living and dead standing crop (table 2).

Discusion and conclusions

Rigourous statistic testing was not possible due to of the small sample size, the lack of standard quadrat replicas and the application of the methods in just one páramo site. Moreover, data on biomass from other regions are not available so comparisons of the present overall biomass figures with the results of other methods can not be made. Nevertheless, some remarks can be made.

The comparative yield method seems suitable for páramo ecosystem research. Because of the big difference between the yields of different spots within the vegetation it is easy even for relative inexperienced observers to select the 5 standard quadrats covering the biomass range, and to score vegetation quadrats on this scale. This is suggested by the small diference between the two sets and by the accuracy of the estimated yield of the two sampled scored quadrats. A in-transformation of the yields allows the use of a linear regression model to describe the relation between yields and scores, but one yield per class is too few for statistical analysis. More replicas per class or more classes, possibly with a smaller quadrat size, would improve the significance. The variance of data-set scores was quite high, which reflects the inherent heterogeneity of the vegetation and its biomass. Analysing the distribution of the scores with respect to additional parameters (terrain factors, land use) recorded during the scoring of the quadrats could probably provide useful information about the distribution of the biomass over the area.

Although the composition of the standard quadrats was very diverse, the estimates of overall botanical composition with the comparative yield method resulted in detailed figures. Results of this kind, or even more precise, can be obtained using conventional methods, but that involves the destruction of far more quadrats and a considerably larger time investment.

The dry-weight-rank method for estimating botanical composition seems less appropriate in this vegetation, with its complex structure, especially as information on the living/dead ratios can not be obtained with this method. Due to the dominance of *Calamagrostis effusa* in almost all scored quadrats, the contribution of the other species to overall biomass was negligible. Of the 150 rank scores made in each data-set, 75 pertained to *Calamagrostis effusa* and 75 to all 8 other species/groups.

Table 2. Botanical composition (% of dry weight) of the five standard quadrats and of the overall biomass (results of 2 data- sets of 50 scored quadrats), as obtained by the comparative yield method.

Unit	Botanical composition of standard quadrats (%)					Overall botanical composition (%)	
	Standard Quadrat 1	Standard Quadrat 2	Standard Quadrat 3	Standard Quadrat 4	Standard Quadrat 5	Data-set 1	Data-set 2
Living							
Calamagrostis effusa young leaves *	1.0	1.6	2.6	2.5	2.2	2.3	2.2
C. effusa old leaves **		1.3	4.5	4.5	4.7	3.8	3.5
C. effusa sheath			5.0	12.4		8.1	7.9
C. effusa shoots	0.8				0.5	0.1	0.1
C. recta young leaves *				0.4	23.2	0.1	0.1
C. recta old leaves **				0.5	11.5	0.2	0.2
C. recta sheaths				1.8	11.7	0.7	0.5
Sedges	8.5	4.1			2.7	2.8	
Short grass	1.1					0.1	0.1
Ground rosettes	7.9	6.2	1.1	0.2		1.7	2.2
Rosaceae	3.0	0.5	2.8			1.3	1.2
Lupinus microphyllus		5.6	0.1			0.8	1.1
Other herbs1.00.50.30.3							
Dwarf shrubs	32.4	13.7	1.1	0.3		4.1	5.7
Juvenile *Espeletia*	2.2		0.2	0.2		0.3	0.3
Dead							
Calamagrostis effusa leaves	3.7		15.8	14.1		13.0	12.1
C. effusa sheaths				10.6	12.8	4.8	4.7
C. recta leaves			1.0			0.4	0.3
Sedges		17.4	1.7			2.9	3.8
Short grass	2.6					0.1	0.2
Juvenile *Espeletia*	1.0			0.1		0.1	0.1
Litter							
Calamagrostis spp	.32.7	41.8	42.7	54.4	33.6	45.6	44.4
Other	10.7	3.6	14.7	0.2		6.7	6.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Overall green leaves are defined as young leaves.
** Green leaves with yellow spots are defined as old leaves.

This is reflected in a low difference of the proportions of *Calamagrostis effusa* and high differences of the proportions of the other species between the two data-sets (Table 1). Both the results of the botanical composition obtained in the comparative yield method (summation of living and dead, litter excluded) and the results obtained in the dry-weight-rank method, show percentages of *Calamagrostis effusa* in the same range (CY:67% -set 1- and 62% -set 2-; DWR 70 and 74% respectively). All other species showed different contributions in the results of the two methods.

The comparative yield method, with the mentioned adaptations, could be a fast and reliable method of estimating biomass and composition of complex grasslands, if tested more intensively. The execution of the present study was ca. 24 hours, including harvesting, subdividing and weighing, which may be considered fast to obtain this kind of information

(Wiegert, 1962). When the sample set is increased as mentioned (more classes or more replicas per class) nonparametric regression and bootstrap analysis (Efron & Tibshirani, 1991) could be a recommendable test. An important additional reason for using it in threatened systems is that the methods requires less quadrats to be destructed than conventional methods. The dry-weight-rank method seems to have too many shortcomings to be practical in the páramo ecosystem.

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