

Short communication

A non-destructive and rapid method to estimate biomass and aboveground net primary production in arid environments

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Abstract

We present the calibration of a fast and non-destructive method to estimate aboveground plant biomass measuring vegetation cover. We double-sampled vegetation cover and aboveground biomass in the Patagonian steppe using 150 plots for shrubs and 50 plots for grasses. We performed simple linear regressions between vegetation cover and biomass for the dominant species and life forms (shrubs: *Mulinum spinosum*, *Senecio filaginoides*, and *Adesmia campestris*; grasses: *Poa ligularis*, *Stipa speciosa*, and *Stipa humilis*). All regressions were significant ($p < 0.01$) for green and total biomass. Whereas all grass species had similar slopes, shrub slopes differed among each other with *S. filaginoides* and *A. campestris* having the steepest slopes for green and total biomass, respectively ($p < 0.05$). Life-form calibrations showed steeper slopes for shrubs than for grasses ($p < 0.05$). Our regressions are a basis for a non-destructive, rapid, and inexpensive way of estimating green biomass, aboveground net primary production (ANPP), and forage availability. Our life-form equations very likely could be used to estimate biomass and ANPP in other arid ecosystems dominated by tussock grasses and shrubs.

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1. Introduction

The study of aboveground net primary production (ANPP) has been a central theme in ecology. Estimates of ANPP have been used to address a broad range of questions, from

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forage availability for livestock to estimates of the global carbon balance. ANPP is the rate at which aboveground biomass is produced or energy is fixed per unit of area and time, and it is expressed in weight or energy units (e.g. $\text{g m}^{-2}\text{yr}^{-1}$ or $\text{kJ m}^{-2}\text{yr}^{-1}$) (Sala and Austin, 2000). Plant biomass is the quantity of vegetation mass or energy accumulated, and it is expressed in weight or energy per unit of area (e.g. g m^{-2} or kJ m^{-2}). Although closely related, ANPP and biomass represent different concepts the former being a flow and the latter a state variable.

Different methods have been developed to estimate ANPP depending on the rate of biomass turnover of the ecosystem (Sala and Austin, 2000). In grasslands and steppes with fast biomass turnover, one of the best methods to estimate ANPP is to harvest biomass at the peak of the growing season (Sala and Austin, 2000; Singh et al., 1975). Modifications to this method include several biomass harvests throughout the growing season that increase fieldwork (Sala and Austin, 2000; Singh et al., 1975), decrease some kind of errors while increasing others (see Biondini et al., 1991; Sala et al., 1988). Cost and repeatability over time were recognized as the main disadvantages of biomass-harvest techniques. Main costs were heavy manual fieldwork to collect samples, and specialized and time-consuming manual laboratory work to process samples. In addition, harvests cannot be repeated over time in exactly the same place, leading to confusions between time and space variability. As an alternative to harvest techniques, biomass can be estimated using variables that correlate with it, such as vegetation cover (Sala and Austin, 2000). The line-interception method (Canfield, 1941), which records the length of canopy overlap with a transect laid out on the ground, has been widely used in grasslands and steppes. Vegetation cover has been used as a surrogate of biomass because of its low cost and repeatability.

Here, we report on a calibration at species and life-form levels between vegetation cover and biomass for a semiarid steppe. We double sampled vegetation cover and biomass for the same experimental units in the Patagonian steppe in early summer, when the peak of green biomass occurs. The Patagonian steppe covers an area of 500,000 km^2 at the southern end of South America and has vegetation closely related to other cold deserts. Our calibration could be a useful tool for ecologists and natural-resource managers because it provides a simple and parsimonious way to estimate the dynamics of biomass, forage availability, or ANPP.

2. Materials and methods

The study area is located close to Río Mayo, Chubut (Argentina), at 45° 41'S and 70° 16'W, at an elevation of 500 m above sea level. Long-term mean annual temperature is 8.1 °C, and mean annual precipitation is 152 mm, falling mainly in fall and winter. Vegetation is typical of the Occidental District of the Patagonian steppe (Soriano, 1956) with 50% of vegetation cover, and ANPP evenly divided between shrubs and grasses (Jobbágy and Sala, 2000). Dominant shrubs are *Mulinum spinosum* Pers., *Adesmia campestris* Rowlee, and *Senecio filaginoides* DC.; dominant grasses are *Stipa speciosa* Trin. and Rupr., *S. humilis* Brot., and *Poa ligularis* Steud.; and forbs contribute with more than 20 species (Golluscio and Sala, 1993). Vegetation height for grasses and shrubs is on average 18 cm (Adler et al., 2004) and 50 cm (Vrsalovic, pers. comm.), respectively.

We simultaneously estimated vegetation cover and biomass in randomly selected 20 × 100 cm plots located inside an enclosure for large herbivores. Shrub individuals, relative to grass individuals, are bigger and have lower density, and we expected larger

variance in cover and biomass in our 0.2 m² plots. Therefore, we randomly located 150 plots for shrub and 50 plots for grass calibrations. In order to increase the range of grass-cover we reduced cover in 10% intervals from 0% to 90% for different plots. We achieved the desired grass-cover reduction by randomly removing portions of individuals. We removed wedges of different sizes from each tussock. For example, we used wedges with a 36° angle in all the individuals belonging to a plot where we wanted to achieve a 10% reduction in cover.

We evaluated vegetation cover with two parallel lines per plot, each of 100 cm length, placed 5 cm from the border, where we recorded green and dead interception per species. We considered the interception of the aboveground portion for both grasses and shrubs. Then, we harvested aboveground biomass, sorted it in the laboratory, oven-dried it at 70 °C and finally weighed it. We sorted shrub biomass into four categories (green leaves, current and previous-year twigs, and dead), and grass biomass into three categories (green, recently dead, and old-dead leaves). We considered (A) green biomass as green leaves for grasses (Jobbágy and Sala, 2000) and as green leaves and current twigs for shrubs (secondary growth was not considered, Fernández Alduncin et al., 1991), and (B) total biomass as the sum of all biomass categories. We estimated life-form biomass per plot as the sum of biomass per species within each life form. We harvested biomass in December when the peak of green biomass occurred.

We performed linear regression analysis between vegetation cover and aboveground plant biomass per species and life forms, for green and total biomass, and tested significance with ANOVA. We forced equations through zero because (i) without cover there is no biomass, (ii) the sampling included the no cover-no biomass point for all species and life forms, and (iii) intercept terms were not statistically different from 0 (Quinn and Keough, 2002). We compared slopes (1) among species with the Tukey–Kramer test for multiple unplanned comparisons (Sokal and Rohlf, 1995), and (2) between life forms with the test for equality (Sokal and Rohlf, 1995). Finally, using an independent set of 50, 5 m-interception lines located near our current work, we compared species and life form equations with averaged values of ANPP estimated using a destructive harvest technique.

3. Results

All the relationships between green cover and biomass for individual species were significant ($p < 0.01$), and r^2 ranged between 0.53 and 0.85 (Table 1a, Fig. 1a and b). *S. filaginoides* had the highest slope, *M. spinosum* an intermediate value, and the three grasses with *A. campestris* the lowest slopes ($p < 0.05$, Table 1a). The linear regressions for both life forms, grasses and shrubs, were also significantly different ($p < 0.01$). The slope of the cover-biomass relationship was 2.9 times steeper for shrubs than for grasses ($p < 0.01$; Table 1a, Fig. 1c). The slope was steeper for shrubs because they are taller and consequently have a higher biomass per unit of area. The r^2 was higher for grasses than for shrubs, probably because slopes were similar among grass species, whereas they significantly differed among shrub species (Table 1a, Fig. 1a and b).

All the regressions relating total cover to total biomass (live + dead) per species were significant ($p < 0.01$), and r^2 ranged between 0.67 and 0.90 (Table 1b). On average, cover-biomass slopes were 7.5 times higher for total than for green biomass. The higher slope for total biomass was due to the addition of woody parts for shrubs, and of recently and

Table 1

Parameters for the regression equations relating cover and biomass for individual species and life forms for (a) green biomass and (b) total biomass

Species/life form	Slope (g m ⁻² percentage ⁻¹)	r ²	Vegetation cover range (percentage)
(a)			
<i>Mulinum spinosum</i>	274.7 ^a	0.85	0–0.71
<i>Senecio filaginoides</i>	421.7 ^b	0.71	0–0.36
<i>Adesmia campestris</i>	81.9 ^c	0.74	0–0.63
<i>Poa ligularis</i>	87.7 ^c	0.53	0–0.19
<i>Stipa speciosa</i>	69.3 ^c	0.80	0–0.26
<i>Stipa humilis</i>	77.3 ^c	0.79	0–0.06
Shrubs	227.3 ^A	0.64	0–0.79
Grasses	78.1 ^B	0.72	0–0.32
(b)			
<i>Mulinum spinosum</i>	871.3 ^{mn}	0.67	0–0.75
<i>Senecio filaginoides</i>	1087.2 ^{mo}	0.82	0–0.89
<i>Adesmia campestris</i>	1625.2 ^p	0.80	0–0.76
<i>Poa ligularis</i>	532.6 ^q	0.79	0–0.43
<i>Stipa speciosa</i>	580.1 ^{oq}	0.76	0–0.36
<i>Stipa humilis</i>	612.3 ^{noq}	0.90	0–0.26
Shrubs	1225.4 ^M	0.74	0–1.0
Grasses	596.3 ^N	0.86	0–0.67

Slope, coefficient of determination (r²), and the observed range of the independent variable, for the linear regression set to the origin between biomass and vegetation cover. All equations were statistically significant at $p < 0.01$. Sample size was 150 for shrubs and 50 for grasses. Different lowercase or uppercase letters mean different slopes among species ($p < 0.05$) or life forms ($p < 0.01$).

old-dead material for grasses. *A. campestris* total cover-biomass slope was 20 times steeper than the relationship for green biomass because this species has a large woody structure, although its annual production per plant is low (Fernández Alduncin et al., 1991, Table 1). Consequently, *A. campestris* had the steepest slope among species ($p < 0.05$, Table 1b, Fig. 1d and e). Cover-total biomass regressions per life form were also statistically significant ($p < 0.01$; Table 1b, Fig. 1f). The slope for shrubs was twice as steep as the slope for grasses (Table 1b). The vegetation cover range was wider for shrubs than for grasses, and for total than green biomass (Table 1).

In order to evaluate the accuracy of our equations, we used an independent data set of vegetation cover that consisted of 50, 5 m-interception lines to estimate ANPP in the same location where we did the calibration. We obtained an estimate of ANPP of 57 g m⁻² yr⁻¹, which was similar to the 15-year average reported for the site of 56.2 ± 14.8 g m⁻² yr⁻¹ (Jobbágy and Sala, 2000). The cost of estimating vegetation cover with the line interception method was much lower than estimating biomass using the harvest method. In the case of the last example, we used three field sampling days and 800 laboratory hours to classify, dry, and weigh 10 kg of biomass. In contrast, we used only two field sampling days and 8 hours of data entry to process the vegetation-cover data set.

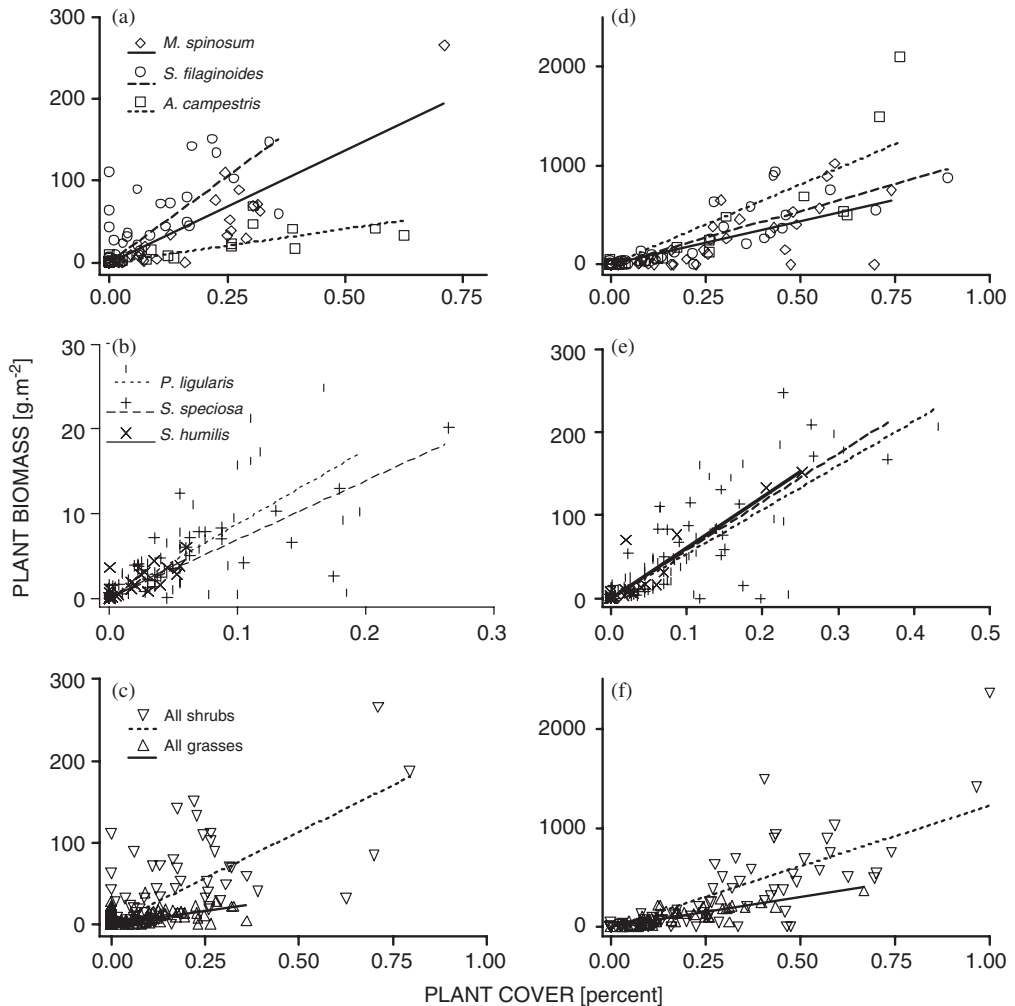


Fig. 1. Relationships between aboveground biomass and vegetation cover for species and life forms of the Patagonian steppe. (a), (b) and (c) for green biomass, (d), (e) and (f) for total biomass; (c) and (f) for life form and the rest for individual species. Straight lines represent the least-square regression set to the origin. For equations and analysis, see Table 1.

4. Discussion

The relationships developed in this paper between cover and biomass at the species and life form levels were all significant for green biomass as well as for total biomass. Therefore, cover is a good predictor of green biomass, ANPP, and total biomass. Cover may be a non-destructive, inexpensive, and fast method to estimate ANPP. ANPP could be estimated just by using green vegetation cover data measured at peak green biomass, in a way similar to the use of a single harvest to estimate ANPP (Sala and Austin, 2000; Singh

et al., 1975). Our method of removing portions of individuals was useful to increase the range of grass cover.

The use of vegetation cover as a surrogate variable for ANPP has the advantage of being non-destructive, compared to the harvest technique. ANPP could be estimated repeatedly in the same experimental unit assessing temporal response patterns. For example, the line interception method has the advantage that lines could be fixed to the experimental units (i.e. a string of wire fixed by stakes within a plot). Monitoring of cover on the same place over time combined with our equations, helped us to better understand the controls of variability on ANPP or test hypotheses about stability of ecosystems, avoiding confusions of time and space.

Work reported in this manuscript is unique because it developed a single method that can be used to estimate both shrub and grass production simultaneously for a relatively understudied region, the Patagonian steppe. Vegetation cover has been used as an estimate of biomass in arid ecosystems but this method has not been calibrated for the Patagonian steppe. Equations developed for other ecosystems presented parameters for a single species or single life form (i.e. Guevara et al., 2002; Williamson et al., 1987) or used allometric equations (which typically differ among life forms) that must be scaled with density to obtain ecosystem-level biomass (i.e. Adler et al., 2004; Johnson et al., 1988; Návar et al., 2004; Rittenhouse and Sneva, 1977; Williamson et al., 1987). More recently, remote sensing techniques combined measurements on leaf area index and photosynthetic absorbed radiation to estimate plant biomass. Spectrometers mounted on satellites and planes provided good answers at a global and regional scale (Jobbágy et al., 2002; Puelo and Lauenroth, 1998). However, the influence of bare soil color (Fensholt et al., 2004) and the similarity of species spectral signal (Elmore et al., 2000) difficult the identification of species, and decrease the effectiveness of spectrometer at the plot scale. Our method would be superior than the use of spectrometers when a detailed species or life-form response is necessary.

The relationships reported here for the different life forms could potentially be used in other arid ecosystems. The steepness of the cover–biomass slope for a life form should be determined by plant height because increasing plant height results in an increase in biomass per unit of surface. We suggest that our approach would work best in arid ecosystems with vegetation made up of tussock grasses and shrubs with plant height and physiological characteristic similar to the Patagonian steppe: e.g. the Puna in South America (Cabrera, 1994), the Great Basin in North America (Barbour and Billings, 1988), and the Turkestan, Takla Makan and Gobi deserts in central Asia (McGinnies, 1979).

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