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Double Sampling Methods in Biomass Estimates of Andean Shrubs and Tussocks☆

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ABSTRACT

The natural Andean vegetation environment is the most important resource available to local pastoralist economies. Knowledge of its attributes is vital in assessing ecosystem properties and improves management decision making. However, there is a lack of research on models that estimate species and life-form biomass for the Puna. We developed a series of models that facilitated the estimation of biomass while avoiding the direct harvesting of the most representative Puna steppe plant species in Jujuy, Argentina. The models thus developed are useful tools in the evaluation of changes in ecosystem dynamics through time and space. Allometric equations were developed for the dominant shrubs (*Baccharis boliviensis*, *Fabiana densa*, *Parastrephia quadrangularis*, *Tetraglochin cristatum*, *Ocyroe armata,* and *Adesmia* sp.) and tussock grasses (*Jarava ichu*, *Festuca crysophylla,* and *Cenchrus chilense*). A field record of the maximum diameter, perpendicular diameter, and height of each plant; number of individuals per plot; and tussock grasses and shrub cover across all vegetation communities was undertaken. Linear regressions including plant measures demonstrated a good fit ($R^2 > 0.7$, $P < 0.001$) to the biomass for individual plants and surface area. The predictive equations developed allow for the rapid and accurate estimation of shrub and tussock biomass. This is essential to monitor the effects of grazing for impact assessment of the different management practices and vegetation dynamics.

Introduction

The Puna, or Altiplano, is a high-altitude Andean ecosystem present in Bolivia, Chile, Peru, and Argentina, where it covers 10,000 km^2 (Alonso and Viramonte, 1987). The plant communities consist mainly of shrub-steppe, with tussocks, short grasses, and dicotyledonous herbs (Cabrera, 1971; Ruthsatz and Movia, 1975). These constitute the main available forage for livestock. This livestock is composed mainly of sheep *(Ovies aries)*, llamas *(Lama glama)* (Göbel, 2001; Wawrzyk and Vilá, 2013), and wild vicuñas *(Vicugna vicugna)* (Borgnia et al., 2010; Vilá, 2012; Arzamendia and Vilá, 2014). Native vegetation is the only source of forage, and its seasonal and interannual variability and availability impacts the livestock productive system. Shrubs are also a fuel source, while tussocks are employed as construction material (Genin et al., 1995). Plant biomass is a crucial vegetation attribute that is strongly linked to climate and water availability, as well as other ecosystem properties, such as nutrient cycling, and above-ground net primary, secondary, and livestock production and land degradation (Singh et al., 1975; McNaughton et al., 1989; Fernández et al., 1991). Thus, it is vital to have suitable methods in place to assess above-ground plant biomass, as this is indispensable for carrying capacity estimation and overgrazing avoidance management.

Previous work in the Puna has focused on botanical composition, vegetation units, and cover (Cabrera, 1971; Ruthsatz and Movia, 1975; Bonaventura et al., 1995; Arzamendia et al., 2006). To date there is no published research on models that estimate species and life-form biomass from this area.

Given its accuracy, direct harvest is a widely used method for evaluating vegetation biomass, but it is expensive in both time and resource requirements (Sala and Austin, 2000; Pucheta et al., 2004). Nondestructive techniques, also known as *double sampling methods,* allow for biomass estimates to be calculated from diverse vegetation species

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using allometric equations, augmented through recourse to dimension data obtained in the field (Sala and Austin, 2000; t'Mannetje, 2000).

In this article, we develop a set of predictive models of aboveground biomass; these are then used to estimate North Argentinean Puna shrub and tussock biomass. In turn, these models provide a rapid assessment indicator of environmental disturbances caused by management practices and long-term climate changes, such as duration and intensity of droughts, and for studies of vegetation dynamics.

Methods

Study Site

The study site is located in Santa Catalina (21°56′47.47″S, 66°3′7.32″ W) northwestern Jujuy Province, Argentina. The elevation ranges between 3 700 and 3 800 meters above sea level, and the area covers approximately 14 000 hectares. The climate is cold and dry, presenting an annual average temperature of 7.7°C and a mean annual precipitation of 375 mm, concentrated mainly over the summer wet season (Buitrago, 2000). At the western edge of the study area, steep mountain slopes describe a rough terrain of rocks and shallow soils. The general slope within the study area is oriented toward the East, where the Santa Catalina River flows. The river runs through flat ground, and this area then presents more developed soils and a markedly lower percentage of rock cover.

Phytogeographically, the study site is classified as Andean-Patagonic Domain, Puna Province, with the dominant plant formation being a shrub-steppe (Cabrera, 1971). Dominant shrubs are *Baccharis boliviensis* and *Fabiana densa,* which occur on slopes and foothill areas; *Parastrephia quadrangularis, Tetraglochin cristatum, Baccharis incarum,* and *Ocyroe armata,* which are found on moderate slopes, as well as flat and riparian areas. Dominant tussock grasses are *Jarava ichu,* present on slope and flat areas, and *Festuca crysophylla* and *Cenchrus chilense,* located on flat, riparian, and/or humid areas.

Vegetation Sampling

Aiming to cover all vegetation communities at the study site, we randomly located 136 sampling plots, each 0.5 × 1 m. The size of sampling plots was selected on the basis of the range of plant sizes found in the field in preliminary studies. Sampling was performed during the dry season (September 2012, 2013) and during the wet season (April 2013, February 2014). Due to the intense rain storms and a river flood in summer 2013, the field work of that year was carried out in April, when the rains were less intense. In each plot, all individual plants were measured using a tape measure and registered, through classification into species and life-form (shrub or tussock). The parameters measured in the plants were the standards of this type of work (Assaeed, 1997; Hierro et al., 2000; Oliveras et al., 2014): total height, the vertical distance from ground level to the tallest living tissue (H, cm), maximum diameter (DIAM1, the maximum crown width above the ground, cm), and perpendicular diameter (DIAM2, cm) crown width at right angles to DIAM1. Each individual plant was measured and then cut at ground level and placed in a separate paper bag. Those shrubs whose crown exceeded the limit of the plot were harvested in total form. These were then dried at 60°C to achieve a dry weight. Finally, the dried samples were weighed (g) to the nearest 0.1 g. Shrub and tussock cover (sum of tussocks and shrubs crown area) was assessed through visual estimation of the sampling plots (Matteucci and Colma, 1982), thereby classifying cover into 10 incremental categories of 10%, between 0 and 100.

Data Analysis

Species-specific linear regression equations were developed using the plant dimension measures obtained in the field. The response variable was DW (dry weight), and the explanatory variables were H (height), DIAM1 (maximum diameter), and DIAM2 (perpendicular diameter). Variables were transformed into natural log (ln), thus ascribing to accepted normality and variance homogeneity assumptions (Quinn and Keough, 2002). Analysis was conducted using R statistical software (R Core Team, 2015).

The best allometric equations for each shrub and tussock species were selected according to the highest adjusted coefficients of determination (adjusted *R*-squared), significance (*P* value) of the regression coefficients and residual standard errors (Quinn and Keough, 2002). When several models presented similarly good fit to the data, the regression equation with the smallest number of parameters was chosen.

Data validation was performed through a linear regression between fitted and measured biomass ($g\ m^{-2}$) and by evaluating the confidence intervals of the equation parameters using bootstrap (10 000 replicates) (Crawley, 2007). These data were obtained by taking into consideration the dry weight sum of all individuals in the plot, thereby rendering a dry weight plot total. Models for each life-form, shrub, and tussock grasses were developed to simplify biomass-per-area estimations for use in wider-scale analysis.

Furthermore, our data were run in a model developed for Patagonic steppes by Flombaum and Sala (2007). This model had been developed for estimating biomass through recourse to specific species and life-form cover. The Flombaum and Sala (2007) model was deemed useful for other arid environments, such as the Puna, which is why it was applied to our data.

Results

A total of six shrub species and three tussock species were sampled during the dry and wet seasons. Shrub species were *B. boliviensis, F. densa, P. quadrangularis*, *T. cristatum, O. armata,* and *Adesmia* sp.; tussock species were *J. ichu, F. crysophylla,* and *C. chilense.* The sampled species were then modeled using at least one of the dimension measurements obtained in the field. We found that all the equations developed were statistically significant (Table 1 and Fig. 1).

Table 1
Summary statistics from shrub and tussock species.

Species	No.	Variable DW (g) mean (min-max)	H (cm) mean (min-max)	Diam1 (cm) mean (min-max)	Diam2 (cm) mean (min-max)
Baccharis boliviensis	60	97.10 (0.29-897.50)	30.55 (5.00-85.00)	33.93 (8.00-83.00)	27.42 (6.00-75.00)
Tetraglochin cristatum	36	96.59 (2.58-523.50)	22.42 (5.00-39.00)	31.08 (7.00-70.00)	24.94 (4.00, 58.00)
Festuca crysophylla	39	77.67 (1.00-1140.00)	42.45 (10.00-74.00)	42.56 (12.00-90.00)	32.49 (7.00-70.00)
Ocyroe armata	10	92.85 (194.2-420.50)	76.70 (45.00-114.00)	8.80 (49.0-9.70)	77.70 (45.00-134.00)
Jarava ichu	29	21.94 (0.32-183.20)	28.82 (9.00-58.00)	20.69 (5.00-70.00)	13.84 (5.00-52.00)
Parastrephia quadrangularis	36	192.10 (15.28-814.50)	34.67 (10.00-74.00)	51.44 (18.00-100.00)	40.50 (17.00-90.00)
Fabiana densa	16	29.26 (1.38-105.40)	21.11 (10.00-45.00)	20.67 (8.00-38.00)	14.89 (5.00-34.00)
Adesmia sp.	8	23.13 (1.00-74.43)	19.62 (3.00-31.00)	21.88 (10.00-32.00)	18.14 (5.00-30.00)
Cenchrus chilensis	9	58.76 (0.590-11.67)	63.89 (56.00-74.00)	10.00 (4.00-14.00)	6.44 (3.00-10.00)

DW, dry weight in g; H, height in cm; Diam1, maximum diameter in cm; Diam2, perpendicular diameter in cm.

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