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Comparison of Whittaker and Modified-Whittaker plots to estimate species richness in semi-arid grassland and shrubland

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Abstract

Biological diversity and species richness have been declined throughout the world as a result of human activities. Measuring species richness is important in rangeland conservation to evaluate the status and trends of native plant species, detecting non-native species invasion and monitoring rare species. However, heterogeneity in plant distribution makes inventories difficult. In this study two methods of measuring species richness, Whittaker and Modified-Whittaker plots, were compared to see how well they captured the species diversity. This was carried out on grassland and shrubland vegetation types using three replicates in Salook National Park in Esfaraien, Iran. The result of this study showed that there is a significant difference between the two methods in estimating species richness for both vegetation types where greater species richness was found in Modified-Whittaker plot. The regression model for species-area relationship was significant for both methods in each vegetation type but explaining more variation (91%) in Modified-Whittaker plot. There was no significant difference between the two methods according to the sampling time except for 1 m^2 sub-plots; however, the Modified-Whittaker plot is more convenient for establishing and measuring in the field.

Keywords: Nested sampling techniques; Plant diversity pattern; Species-area curves; Biodiversity

1. Introduction

Maintaining or increasing plant species diversity is an important goal of habitat managers in arid and semi-arid ecosystems (Fulbright 2004). Species richness is the simplest way to describe community and regional diversity (Grime 1979; Barbour *et al.* 1987). Estimation of species richness of local communities is an important step for investigations in community ecology and rangeland management (Ives *et al.* 2000; Nijs and Roy 2000; Cam *et al.* 2002, Collins *et al.* 2002; Tavili *et al.* 2009). Detecting local species richness is important in rangeland sampling particularly for detection of palatable species. Also, it is possible to find rare species for conservation purpose, and early detection of exotic and invasive species which are important to range management for restoration efforts (Stohlgern *et al.* 1998). Variation in species richness over space and time has been the major interest to range managers for monitoring vegetation changes particularly in arid and semi-arid rangelands (Gifford *et al.* 1998; Dupre´ and Diekmann 2001).

Literature shows that different plot designs have been used to study vegetation as they may greatly influence the conclusions. The traditional method is releve` analysis which is closely associated with a procedure for describing and classifying vegetation that has a long history of development and use among European plant ecologists engaged in phytosociological studies (Knapp 1984). In this method a small area is lay out initially and the

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species presence is recorded. Then the sample area is progressively enlarged to twice the size and this continues until no more species recorded. This method like other nested design gives the species richness and the species-area curve. However, it is time consuming and sometimes difficult to establish in tall vegetation (Knapp 1984). A method of nested sampling has been widely used as an appropriate method for comparing community diversity. It samples the vegetation in multiple spatial scales (i.e. nested quadrat sizes of 1 m^2, 10 m^2, and 100 m^2 within a 1000 m^2 area). This method also named Whittaker plot (Whittaker 1977). Then, Stohlgren *et al*. (1995) proposed a modified version of Whittaker plot as they believed the original Whittaker plot had several deficiencies. In Modified-Whittaker plot the shape and spatial distribution of sub-plots in the main plot has been changed to overcome the problem of autocorrelation. Also, this nested sampling approach captures a significantly higher percentage of total species richness than other techniques (Shackleton 2000; Anderson and Hoffman 2007).

While comparison of different nested sampling plots has been the subject of many studies in different vegetation types (Stohlgren *et al*. 1995; Stohlgern *et al*. 1997; Stohlgern *et al*. 1998; Shackleton 2000; Leis *et al*. 2003; Barnett and Stohlgren 2003; Keeley and Fotheringham 2005; Anderson and Hoffman 2007), little is known about their applications for vegetation in arid and semi-arid areas of Iran (Pilehvar *et al*. 2001). Accordingly, the purpose of this study is to compare two common nested vegetation sampling designs (Whittaker vs. Modified-Whittaker plots) to estimate species richness for a semi-arid grassland and shrubland in the Salouk National Park in the northern Khorasan province.

2. Materials and methods

2.1. Study area

The study area was located at Salook National Park (57°06´ 57°16´ E, 37°08´ 37°15´ N) in the north east of Iran in Khorasan province. It has 6000 ha area with 1080-2900 m above sea level (a.s.l) and the average annual temperature and precipitation are 12 ºC and 280 mm, respectively. This study was carried out on two vegetation types (grassland and shrubland). The dominant species were *Bromus tomentellus* and *Stipa barbata* in grassland and *Artemisia siberi* in shrubland. The other important species in grassland were *Centaurea rhizontha, Salvia nemorosa, Cirsium rivensis, Phlumis cancellata, Agropyron thrichoforum,* and *Rubia tinctoria*. Some species such as *Amygdalus lyssioides, Scariola orientalis, Asperula arvensis, Stipa barbata,* and *Noea macronata* were also abundant in shrubland.

2.2. Plot designs and vegetation sampling

At each vegetation type three Whittaker and Modified-Whittaker plots were established randomly by overlaying them. In both methods the size of the main plot was 1000 m^2 (20 x 50 m) but sub-plots were differently nested in the main plot (Fig. 1). In Whittaker plot the 1 x 1 m sub-plots were overlaid on the 2 x 5 m sub-plots, which, in turn, were overlaid on the 10 x 10 m sub-plot. In contrast, in Modified-Whittaker plot ten 0.5 x 2 m (1 m^2) sub-plots systematically spaced along the inside border, two 2 x 5 m sub-plots in alternative corners, and a 5 x 20 m sub-plot in the plot centre. The presence of species, their covers, and the litter and bare ground cover were estimated in each 1 m^2 and then the cumulative plant species were recorded in the 10 m^2, the 100 m^2 sub-plots, and the 1000 m^2 main plots. The field sampling was carried out by a team of four persons for establishing the main plot and sub-plots and recording the species. The sampling time including the time for plot establishment and recording species was also measured.

2.3. Data analysis

The count data (number of species) were transformed prior to analysis using $Y' = (Y+1)^{0.5}$ because of non-normal distribution (Sokal and Rohlf 1995). Thereafter, the number of species recorded in the 1 m^2, 10 m^2, and 100 m^2 sub-plots of both methods were compared with a paired t-test (Sokal and Rohlf 1995). A regression model ($S = a + b \log P$; S, the number of species and P, the plot area) was performed firstly to estimate the number of species in each 1000 m^2 plot based on the cumulative species recorded in the sub-plots and secondly to evaluate which method conformed better with established species-area theory. For the former the expected values of species richness for both methods were compared to observed values recorded in the main plot using Chi-square test. Here, the method with the smallest differences between observed and expected values would be more useful in estimating species richness. For the latter, the method with higher coefficient of determination (R^2) would be more accurate in estimating the species richness. We also applied t-test for comparison of sampling times for establishment of the main plot and sub-plots. All statistical analyses were performed using MiniTab ver. 13 (Anon. 1998).

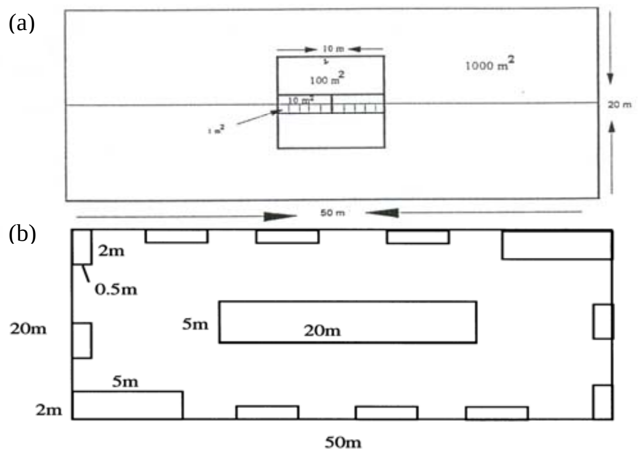

Fig. 1. The layout of (a) Whittaker and (b) Modified-Whittaker plots used in this study

3. Results

A total of 184 species were recorded in this study with the dominant family of Gramineae, Compositeae, Legominoseae, and Labiateae. In both grassland and shrubland there were significant differences between the two methods in estimating the total number of species in all sub-plots (Fig. 2). In all cases, the greatest species richness was found in Modified-Whittaker plot.

For both methods the regression between the cumulative species richness in sub-plots and the plot area was significant (Table 1) which resulted to calculate the expected species richness for the main plot (1000 m^2) of each method. Here, the difference between the expected species richness with observed one (recorded in the field) in the main plot was significantly smaller for the Modified-Whittaker plot in both vegetation types (Table 1).

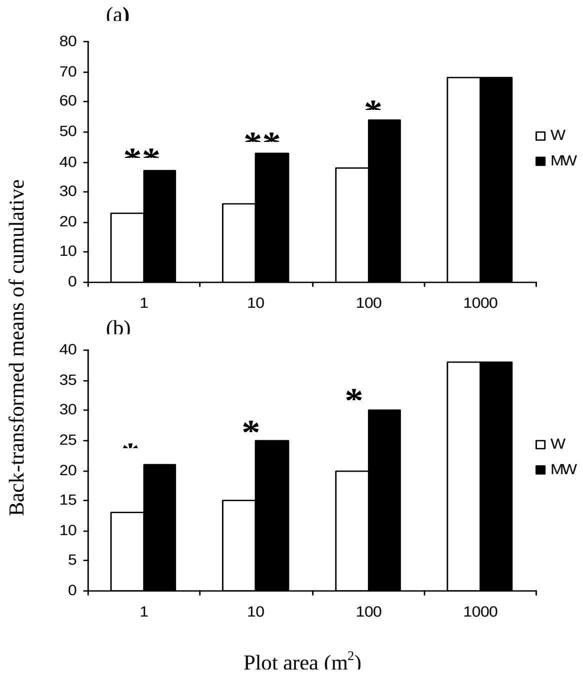

Fig. 2. The mean number of species recorded by sub-plots and main plot in the Whittaker (W) and Modified-Whittaker (MW) methods in (a) grassland and (b) shrubland. Paired t-test significant level are shown only for each sub-plot (* P<0.01 and *** P<0.001) as the main plots are the same for both methods

Table 1. Observed and expected species richness in Whittaker and Modified-Whittaker plots for two vegetation types

Vegetation type	Method	Regression Model	R^2	F	Expected species richness	Observed species richness	Chi-square
Grassland	Whittaker	S = 21.5 + 7.5 LogP	83.1%	34.49**	44	68	13.1***
	Modified-Whittaker	S = 36.2 + 8.5 LogP	91.1%	71.40***	61.7	68	
Shrubland	Whittaker	S = 12.5 + 3.5 LogP	69.3%	15.83**	23	38	9.44**
	Modified-Whittaker	S = 20.8 + 4.5 LogP	79.9%	27.89**	34.3	38	

Once again a regression was used but on all data (including sub-plots and the main plot) to see which method can produce a better model to estimate the species richness from plot area. In both studied areas we found a significant relationship between the species richness and plot area for both methods (Fig. 3). However, the Modified-Whittaker plot conformed a better model by explaining more variations (95% and 89% in grassland and shrubland, respectively). Combining two data sets showed that both methods resulted in significant relationship between species richness and plot area but more variation has been explained by Whittaker plot than Modified-Whittaker plot (Fig 3c).

Comparison of sampling time required for each method using t-test showed that there was only difference between two methods in 1 m^2 sub-plot in both grassland ($t = 20.78^{**}$) and shrubland ($t = 13.39^{**}$) where greater time was required for establishment of modified-Whittaker plot.

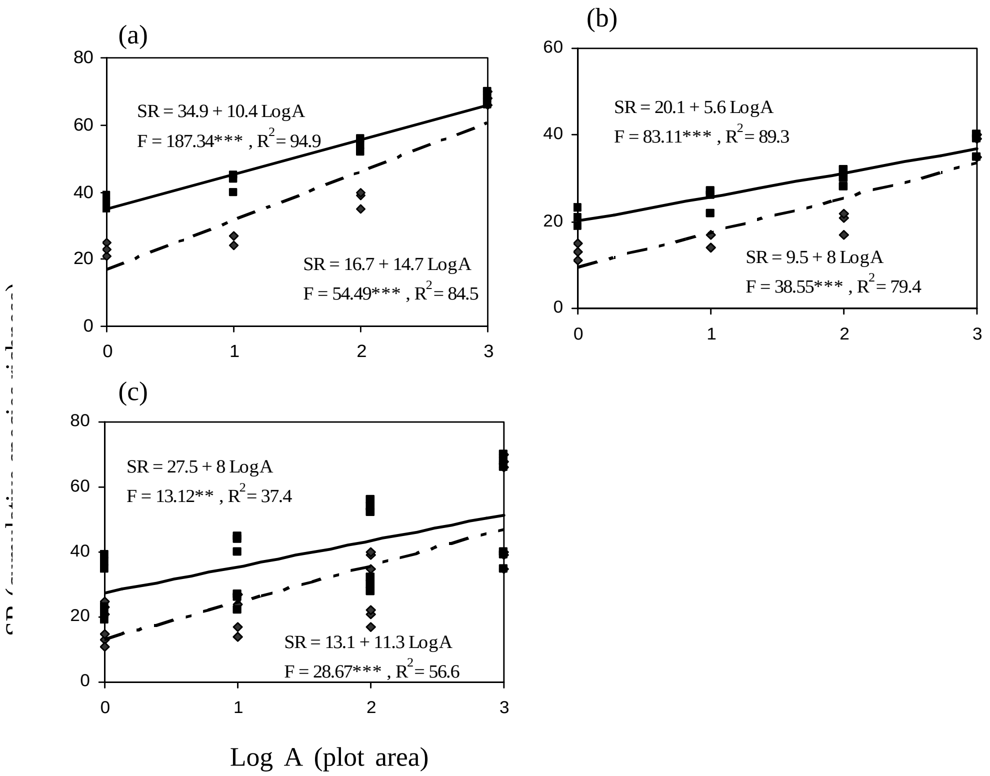

Fig. 3. The regression model for the relationship between cumulative species richness (SR) and plot area (Log A) for (a) grassland, (b) shrubland, and (c) combined grassland and shrubland (for sites) in Whittaker (dash line) and Modified-Whittaker (solid line) methods

4. Discussion and conclusion

Subplot in Modified-Whittaker methods showed significantly greater number of species. Similar results were found by Stohlgren *et al.* (1995) who applied these methods on 13 sites in forest and prairie vegetation type in Colorado. This is because of the spatial pattern of sub-plots in the main plot where sub-plots have less overlap than the sub-plots in the Whittaker method. As a result they are influenced less by spatial autocorrelation (Stohlgren *et al*. 1995). From this point of view, the systematic placement of the sub-plots makes the Modified-

Whittaker design easy to use in the field. Leis *et al*. (2003) found that modified Whittaker plot can produce data quality similar to contiguous quadrats but in less time on disturbed mixed-grass prairie. However, it was not found in our study probably due to different vegetation types. Another possible explanation for a difference in species richness between two methods may simply lie in the fact that the methods differ in the shape. In Modified-Whittaker plot sub-plots are rectangular with length to width ratio of 1:4 while sub-plots in Whittaker plot are square. Stohlgren *et al*. (1995) showed that Modified-Whittaker may show 30% or more increase in species richness over the Whittaker plot. However, Keeley and Fotheringham (2005) found no evidence of plot shape effect on the number of species recorded in nested vegetation sampling designs at the 0.1-ha scale or lower for Mediterranean-climate vegetation types.

One advantage of nested sampling design is to estimate the relation between species richness and plot area known as species-area curve. This relationship allows ecologists and range managers to estimate the number of native and exotic species in the larger, unsampled area where exhaustive sampling is not possible (Inouye 1998; Stohlgern *et al*. 1998). Also, it was used to identify the minimum area of sampling unit for plant communities based on the shape of the relationship (Knapp 1984). In this study both methods produced a significant regression model but strong species-area relationships were found in Modified-Whittaker plot for both grassland and shrubland as it showed greater value of coefficient of determination. This allows for better estimates of local species richness from a series of plots (Stohlgern *et al*. 1995; Stohlgern *et al*. 1998; Pilehvar *et al*. 2001). When we combined datasets of two vegetation types slightly a better model was found for original Whittaker plot. In all species-area relationships the regression lines showed that the greatest difference in the two methods is in the number of species recorded in the 1 m^2 sub-plots. Moreover, we found that the expected species richness in regression model was significantly close to the recorded species richness in the field for Modifed-Whittaker plot as similar to Stohlgren *et al*. (1995).

We suggest applying these nested sampling methods for semi-arid vegetation like in our study area as these methods have different sizes of plots to capture plants. Additional field tests are needed in other vegetation types of arid and semi-arid areas in Iran particularly to find appropriate sub-plot sizes. In this case, only Pilehvar *et al*. (2001) introduced a modified-Whittaker plot for forest of northern part of Iran. It is also recommended to compare the efficiency of nested sampling approaches with other sampling techniques used in rangeland vegetation sampling.

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