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Assessment and Comparison of the Visual Survey Method for Estimating Acorn Production in Holm Oak (*Quercus ilex ssp. ballota*) Open Woodland of Southwestern Spain

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We assessed the accuracy of a visual survey method for quantification of acorn production in Holm oak in two plots located in the Huelva province of southwestern Spain during three acorn dissemination periods from 2007 to 2010. At the end of September during each period, visual surveys were used to estimate acorn numbers. Four seed traps were placed beneath the crowns of the same trees at the north, south, east, and west positions to determine acorn weight and number on a fortnightly basis during the mast seeding period (October to January). The accuracy of the visual survey was assessed by linear regression and correlation analysis. The results indicated a significant positive correlation of the two methods during all the three time periods. The resulting regression equations allowed estimation of acorn production based on visual surveys. These results suggest that the visual survey method is a simple and precise method that can be used to predict acorn production in Holm oak landscapes.

Keywords acorn production, Mediterranean landscape, visual surveys

Seed production plays an important role in the long-term sustainability of natural and dehesa (agrosilvopastoral) ecosystems of the Mediterranean region. Dehesas are socially and economically important, and acorns are important fodder for livestock and historically were a staple food for some human populations. Annual and individual variations in acorn production influence the regeneration and management of oak forests (Alejano et al., 2011). The two most important species of oaks in this region are the Holm oak [*Quercus ilex* ssp. *ballota* (Desf.) Samp.] and the cork oak (*Quercus*

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suber L), species that are very tolerant of water stress (Olarieta et al., 2012; Carevic et al., 2010; Hódar, 2002). In Mediterranean ecosystems, *Quercus* species are subjected to drought from May to September, when temperatures are high and precipitation is rare. Dehesa ecosystems typically have an annual precipitation of about 400 mm. Studies of acorn production in these ecosystems may provide insight about how these ecosystems will respond to forecasted climatic changes, in which temperatures will increase and precipitation will decrease (IPCC, 2007).

There have been many estimates of acorn production in other species of *Quercus*, such as species in North America (Koenig et al., 1994b), Asia (Shimada and Saitoh, 2006), and Spain (Alejano et al., 2008). All of these studies have reported considerable variation in acorn production among years, species, and even trees of the same species. Acorn production can be estimated by indirect techniques, based on climatologic data or pollen count (Fernández-Martínez et al., 2012; Rodríguez-Estéves et al., 2008; García-Mozo et al., 2007), or by direct techniques, which include counting acorns in marked branches (Espelta et al., 2008), visual surveys of standing acorns in the crown, and acorn collection in seed traps or containers. This last technique involves distributing seed traps beneath the crown and counting the number of acorns that fall into a trap (Rodríguez-Estévez et al., 2008; Vázquez, 1998). Most studies of acorn production, especially in Spain, have used seed traps because this technique is effective for estimating the reproductive rates of different species, and for assessment of mast-fruiting periods, acorn size, and the presence of pests (Zulueta and Cañellas, 1989). Notwithstanding these advantages, this is an expensive and labor-intensive methodology because seed traps must be manufactured, kept in place, and checked regularly.

Visual surveys have also been used to evaluate acorn production of Holm oak. For example, the number of standing acorns in a tree crown can be counted during a fixed period of time before dissemination (Graves, 1980). This method has been used in studies of the influence of pollen on acorn production (García-Mozo et al., 2007), the effect of silvicultural treatments on acorn production (Perry and Thill, 2003), and the reproductive synchrony of American oaks (Liebhold et al., 2004). However, few studies have compared acorn count results from visual surveys and traps. Visual surveys are clearly less expensive, but can only be used to estimate acorn production when compared with previous estimates from acorn traps (Greenberg and Warburton, 2007). Visual surveys quantify the acorn crop prior to fall, so there must be an estimate of the number of acorns that disappear before fall due to predation. These surveys are useful because quantification is predictive, and counting can begin in the summer or even earlier (Greenberg and Parresol, 2002).

In the present study, we compared acorn counts derived from visual surveys and collection in traps in 34 trees in two dehesa plots during three periods of dissemination and used these results to develop a model that allows estimation of acorn production based on visual survey.

Experimental Plots

The study was conducted in two experimental plots in the province of Huelva, south-western Spain, on a flat area at 288 m a. s. l. The 3 collection periods were 2007–2008, 2008–2009, and 2009–2010. The first plot is located on "El Campillo" farm in the municipal district of San Bartolomé de la Torre (hereafter SB), with an area of 2.7 ha and 36 trees per hectare. The second plot is located in "Huerto

Ramírez" farm (hereafter HR), in the municipal district of Villanueva de los Castillejos, with an area of 2.8 ha and 69 trees per hectare. Both areas have typical Mediterranean climate, characterized by hot and dry summers with 3–4 months of scarce or no precipitation. Annual precipitation typically ranges from 400 to 600 mm, and mostly occurs between October and April. Data from the nearest weather station (Gibraleón town; UTM huse 29: 671800 x, 4142595 y) indicated that the mean minimum daily temperature in the coldest month (January) is 4.2°C, and the mean maximum daily temperature in the warmest month (July) is 32.7°C.

Seed Trap Estimation of Acorn Production

Acorn production (AP) was estimated by placing four rubber seed traps (0.45 m diameter on the top) beneath the crown of a tree at the north, south, east, and west positions, and three-quarters of the distance from the stem to the edge of the crown. Acorns were weighed and counted immediately after each fortnightly collection from October to January, during each of the three seed dissemination seasons. Sixteen trees in SB and 18 trees in HR (samples stratified by diameter) were selected for measurement of acorn production. Acorn production was expressed as fresh mass per square meter of crown projection (g/m^2). Preliminary investigation indicated no significant differences in acorn water content among trees, months, years, and locations, allowing use of fresh mass rather than dry mass.

Acorn Visual Estimation of Acorn Production

Visual surveys (VS) were performed in both plots before acorn dissemination in 54 trees in HR (18 of which were selected for AP) and 34 trees in SB (16 of which were selected for AP). As a general rule, a VS must be performed before acorn fall (Graves, 1980). Thus, VS was performed during the last week of September in the first two years and the first week of October in the third year. For the VS of each tree, two observers randomly selected one side of the crown of each tree and counted all apparently viable mature acorns on the crown in 15 seconds; these results were added, yielding a 30 sec acorn count. All surveys were performed by the same observers during all three periods to avoid bias.

Statistical Analysis

Regression analysis and calculation of Pearson's correlation coefficient were used to assess the relationship of AP and VS. Data were log transformed to increase linearity and decrease the correlation between the mean and variance. Following regression analysis, the Durbin-Watson coefficient (DWC) was used to determine autocorrelation of the residuals. A DWC near 2 indicates no correlation, a value greater than 2.5 indicates a negative correlation, and a value less than 1.5 indicates a positive correlation. The presence of correlated residuals indicates violation of an important assumption of least-squares regression. All statistical calculations were performed with SPSS (version 14.0). The criteria used to perform and interpret the statistical analyses were based on Sokal and Rohlf (1995).

Figure 1 shows the results of acorn production obtained by the AP and VS methods. The first year of the study (2007–2008) had the lowest correlation ($r^2 = 0.532$; $y = 0.996x + 0.625$; $F = 30.87$, $p < 0.01$, $DWC = 1.55$). The correlations were greater

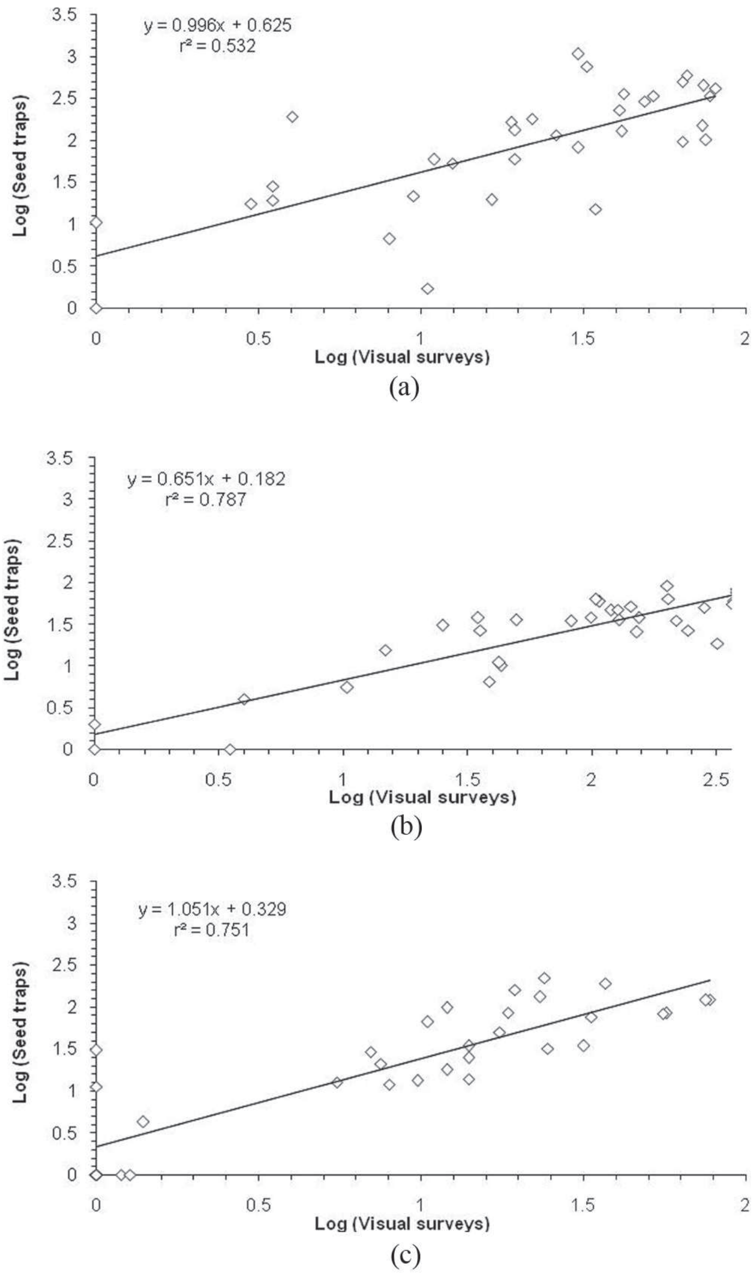

Figure 1. Relationship between visual surveys and seed traps (fresh weight; g FM/m^2) of acorn production in holm oaks. (a) 2007–2008 period ($F = 30.87$, $p < 0.01$, DWC: 1.55); (b) 2008–2009 period ($F = 35.11$, $p < 0.001$, DWC: 1.52); (c) 2009–2010 period ($F = 34.88$, $p < 0.001$, DWC: 1.50). Variables were log transformed.

during 2008–2009 ($r^2 = 0.787$; $y = 0.651x + 0.182$; $F = 35.11$, $p < 0.001$, DWC = 1.52), and 2009–2010 ($r^2 = 0.751$; $y = 1.051x + 0.329$; $F = 34.88$, $p < 0.001$, DWC = 1.50). The three DWC values indicate no autocorrelation of the regression residuals (Figure 2).

Our results indicate a significant and positive relationship of the estimates of acorn production based on the VS and AP methods. Koenig et al. (1994a) reported that visual estimation allowed accurate estimation of acorn production following regression analysis with data from seed traps. Recent investigations that compared seed trap and visual survey methods in North American *Quercus* species also showed positive correlations of these methods (Perry and Thill, 1999; Koenig et al., 1994a).

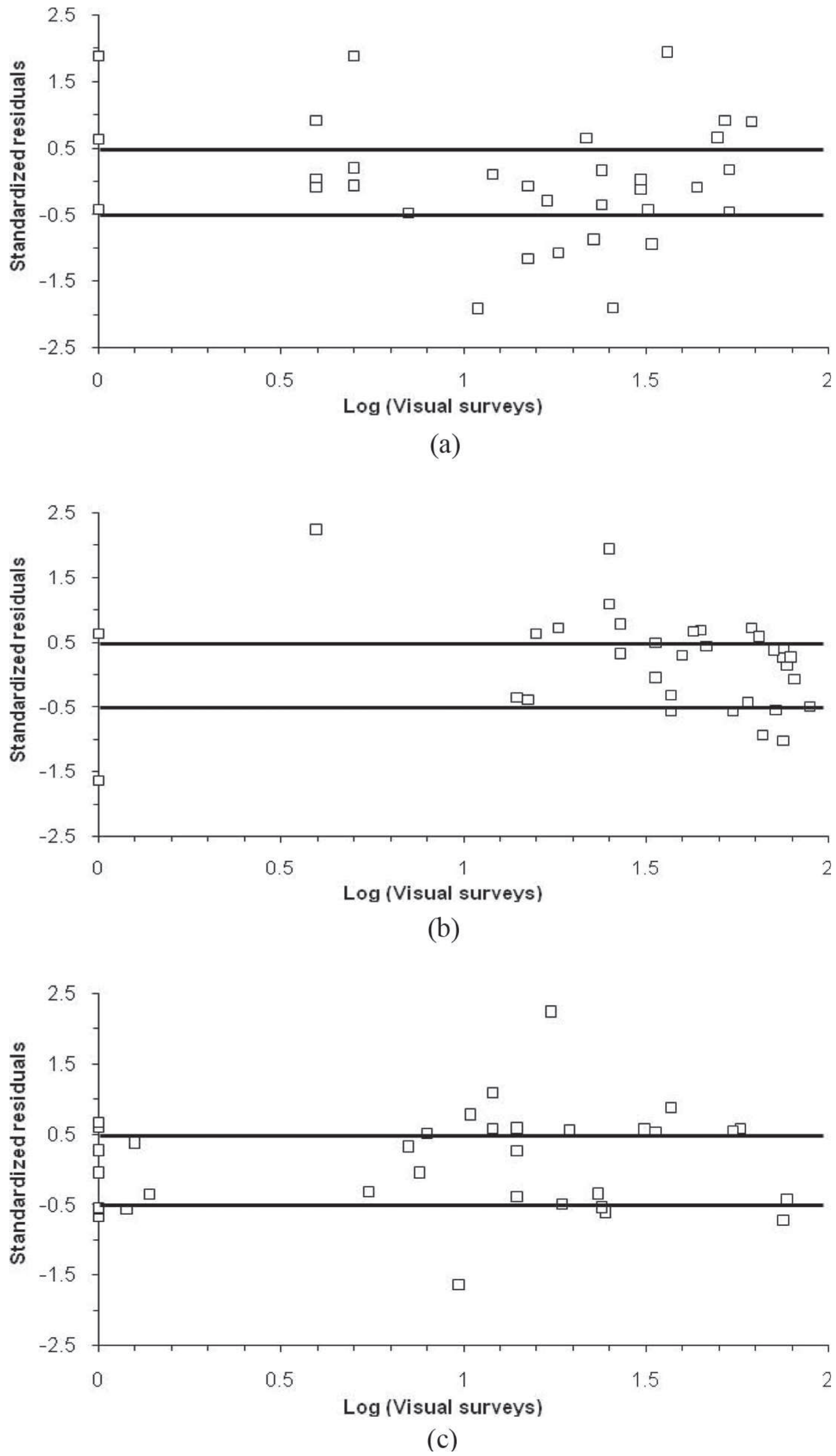

Figure 2. Standardized residuals of regression's equation of acorn production estimated between visual surveys and seed traps (fresh weight; $g\,FM/m^2$) containers in holm oaks. (a) 2007–2008 period; (b) 2008–2009 period; and (c) 2009–2010 period. Values between –0.5 and 0.5 are expected.

Taken together with our results, this indicates that visual surveys are valid techniques for estimation of acorn production by oak trees.

Our results also indicated no autocorrelation of the residuals in the regression analysis based on calculation of the DWC. Nonetheless, the presence of points on the regression line where no acorns were visually counted but were collected in seed traps might have been caused by errors in the VS due to the small number of acorns in some trees. A VS is greatly influenced by factors at the time of sampling, such as the position of the observer in relation to sunlight and the unique characteristics of each tree crown, and these may affect the count and cause significant error when productivity is low (Perry and Thill, 1999). It should also be noted that we observed an increase in positive residuals when the acorn count was high. This suggests that the VS method is a less effective estimator when comparing trees with high acorn yields, because the number of counted acorns depends on the sampling time (Koenig et al., 1994a). However, it is completely reasonable to think that these residuals are highest in areas where several acorns were counted, a fact that was inferred from the clustered points located in the high zone of the regression (values close to 2). The high presence of negative residuals seemed to occur in trees where several acorns were visually counted but few or no acorns were collected. This was likely due to seed predation by wildlife species that feed on acorns (Senar and Borras, 2004; Avilés et al., 2002).

As previously noted, the results of our VS method of acorn production were significantly correlated with production based on AP measurements from seed traps. The VS method is clearly simpler and less expensive than the AP method. In the open woodland forests of the Mediterranean region of southwestern Spain, acorns are an important source of animal fodder. Thus, use of the VS method to estimate acorn production in agroforestry research of these ecosystems will allow more rapid assessment of acorn production and, in conjunction with seed trapping, will also allow estimations of acorn loss due to predation. This will provide better approximations of the real value of acorn production per tree, which, with other technical and scientific criteria, is needed for sustainable forest management. Improved acorn management is needed to sustain livestock production in the arid and semi-arid highlands of southwestern Spain, and land managers need access to efficient tools for estimation of acorn production.

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