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Vertical point sampling with a digital camera: Slope correction and field evaluation

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A B S T R A C T

Vertical point sampling with a digital camera (VPSC) is a promising new forest sampling method that can be used to improve existing sampling protocols or rapidly assess forest structure over large areas. Previous research into VPSC has not accounted for the potential bias that can result from implementing this method on sloping terrain. Here, we present a modified method of conducting VPSC on sloping terrain that maintains unbiased estimates by implementing an automated computer program to adjust for slope at each sample point. This updated method is easily implemented and includes minimal alterations to the existing VPSC protocol, though there will likely be some situations where it is impractical or unnecessary. To address this, we quantified the bias incurred for ignoring slope altogether by conducting a field study in two separate forest types: mixed conifer and mixed deciduous. The coniferous plots showed no slope-related bias whereas the deciduous plots displayed bias on steeper slopes. This difference in bias between forest types is likely due to the difficulty identifying deciduous tree tops in the digital photographs. The lack of discernible bias on the lesser slopes and in the conifer forests was largely due to the slope-related bias being overwhelmed by the unavoidable variability inherent in VPSC. Overall, the slope-related bias should be negligible, regardless of forest type, provided the majority of the sample points fall on slopes of approximately 35° or less. These results further support the use of VPSC as a useful new method of monitoring forest conditions, conducting forest inventories, or assessing wildlife habitat.

1. Introduction

Vertical point sampling (VPS) is a method by which trees are sampled with probability proportional to their squared-height (Hirata, 1955; Grosenbaugh, 1958). This method is analogous to horizontal point sampling (i.e., prism cruising in forestry) where trees are sampled with probability proportional to their squared diameter (Bitterlich, 1948; Grosenbaugh, 1958). In contrast to the wide-spread use of horizontal point sampling, VPS has rarely been used in practice, primarily due to the difficulty in implementing this procedure and to the perceived lack of usefulness of the resulting estimate of "height-squared per unit area." Recently, Ducey and Kershaw (2011) developed a method by which VPS can be quickly conducted using a digital camera. This new method alleviates many of the difficulties that arise when carrying out VPS using traditional methods. Additionally, Ducey and Kershaw (2011) show that the resulting estimates of height-squared correlate strongly with various stand-level attributes that are often time-intensive and difficult to obtain, including biomass, cubic volume, and Reineke's stand-density index (Reineke, 1933). The relationship between height-squared and these additional forest attributes makes VPS useful in ratio estimation or double-sampling schemes (Oderwald and Jones, 1992; Schreuder et al., 1993; Husch et al., 2003).

Digital cameras are increasingly popular tools for measuring different aspects of forests, trees, and crops (Clark et al., 2000; Mesas-Carrascosa et al., 2012; Murakami et al., 2012). Incorporating digital cameras into vertical point sampling greatly increases the speed, efficacy, and applicability of this method. The ubiquity and low cost of digital cameras makes vertical point sampling with a camera (VPSC) a useful tool for foresters, forest ecologists, or private land owners to rapidly assess forest conditions over a broad spatial extent or estimate aspects of forest structure that are otherwise resource intensive to obtain.

A remaining issue when conducting vertical point sampling with a camera is the effect of sloping terrain on the resulting

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estimates. In VPSC, a vertical photo of the canopy is taken at a randomly selected sample point and the number of tree tops appearing in the photo is tallied. On sloping terrain, the trees located uphill from the sample point appear "taller" in the resulting image, while downhill trees appear "shorter." This distortion leads to an expanded inclusion area for trees on sloping terrain that increases the probability that these trees are sampled.

In this study, we investigate two methods of accounting for sloping terrain when conducting VPSC. First, we present a method by which a novel, automated computer program is used to directly adjust for the slope at each sample point and maintain unbiased estimates. Secondly, we investigate the bias incurred for ignoring slope by conducting a field study in two separate forest types: mixed conifer and mixed deciduous. From these results we provide general recommendations as to when the slope-adjustment procedure should be followed, and when sloping terrain can be ignored with minimal bias.

2. Overview of vertical point sampling

In vertical point sampling, the radius of the inclusion area of each tree is selected to be a fixed proportion of its height, rather than a fixed proportion of its diameter (Hirata, 1955). This situation results in the inclusion area of each tree being proportional to the height squared of the tree (Grosenbaugh, 1958). A "Height Squared Factor" (HSF) is selected to control the number of trees tallied per sample point (analogous to the basal area factor, or BAF, when conducting horizontal point sampling). This HSF determines the size of the sampling area for each tree: a larger HSF means that trees have smaller inclusion areas and are sampled less often; a smaller HSF means that trees have larger inclusion areas and are sampled more often.

Ducey and Kershaw (2011) recently developed a method by which a digital camera can be used to conduct vertical point sampling. This new method allows the individual to use a photograph to identify those trees whose inclusion areas overlap a randomly selected sample point (i.e., those trees that should be tallied). Their method involves:

1. Taking a vertical photograph of the canopy at a randomly selected sample point.
2. Overlaying a rectangle on the photograph, with the dimensions of the rectangle corresponding to a pre-determined HSF.
3. Counting the number of trees tops that appear in the rectangle.
4. Multiplying this count by the corresponding HSF to obtain an estimate of height-squared per unit area.

Due to the geometry of vertical photographs, this method samples trees with probability proportional to their squared-height, and thus it is a simple way of conducting VPS. In order to simplify the geometry of this situation when dealing with sloping terrain, the method used throughout this study alters the above procedure by digitally overlaying a circle (as opposed to a rectangle) on the photograph and counting the number of tree tops located within this circle (Fig. 1). The desired HSF dictates the diameter of the overlaid circle, with a larger HSF corresponding to a smaller circle and *vice-versa*.

To understand how this photo-counting methods succeeds in implementing VPS, note that the vertical projection of a rectangular photograph can be visualized as a 4-sided inverted pyramid. By drawing a circle on the resulting image, we are projecting a cone up through the image. If the top of a tree is visible within the superimposed circle, then this is an indicator that the sample point falls within the circular inclusion area of that tree, and the tree should be tallied. Under this method, the outside boundary of a given tree's inclusion area is the collection of points where the top of a tree is at the outer edge of the cone (Fig. 2). For all such points, the distance from the camera to the tree is equal to $h \cdot \tan\theta$, where θ is half of the opening angle of the cone and h is the height of the tree. Thus, the inclusion area is a circle with radius proportional to the height of the tree, and with area proportional to the squared-height.

An important assumption with all vertical point sampling methods is that each tree has a single well-defined top that can be readily identified. In certain stands and for certain tree species this assumption is justified, though in practice it can often be difficult to identify the exact location of the "top" of the tree due to the presence of foliage or to decurrent growth forms (Fig. 1). The benefit of VPSC compared to other VPS methods is that the photos can be scored by multiple individuals and stored for later verification, thus potentially reducing the bias incurred by inaccurate estimation from any one individual. Importantly, any bias incurred by misidentifying tree tops is irrelevant in ratio or regression sampling as long as the individual is consistent in their counting preferences across all of the photographs.

2.1. A modified HSF for a circular inclusion area

Overlaying a circle on the photos alters the calculation of HSF from what Ducey and Kershaw (2011) give for a rectangular inclusion area. When overlaying a circle, the inclusion area for a tree on flat terrain is likewise a circle, equal in area to the cross-section of the cone at the point where the top of the tree intersects the cone (Fig. 2). By rewriting the radius, *r*, of this inclusion area in terms of the height, *h*, of the tree and the angle, θ, that defines the cone, the inclusion area on flat terrain is:

$$A_{flat} = \pi(h\tan\theta)^2. \quad (1)$$

If a single sample point is selected in a sampling region of area $\widetilde{A}$, the probability that this tree is included (counted) is equal to this above inclusion area divided by the total area. To estimate the total height-squared per unit area (τ), we can use a Horvitz–Thompson estimator (Horvitz and Thompson, 1952), where the summation is over the v trees counted in the photo at that point:

Fig. 1. Identifying tree tops in vertical photographs. Circles, rather than rectangles, are superimposed over the vertical photos in the modified VPSC protocol. Deciduous (left) and coniferous (right) stands each provide unique challenges to identifying tree tops.