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Field validation of 1930s aerial photography: What are we missing?

D.M. Browning [a,*], S.R. Archer [a], A.T. Byrne [b]

[a] School of Natural Resources, University of Arizona, P.O. Box 210043, Tucson, AZ 85721, USA
[b] Department of Environmental Science & Policy and Biology, Clarkson University, 8 Clarkson Avenue, Potsdam, NY 13699, USA

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ABSTRACT

Aerial photography from the 1930s serves as the earliest synoptic depiction of vegetation cover. We generated a spatially explicit database of shrub (*Prosopis velutina*) stand structure within two 1.8 ha field plots established in 1932 to address two questions: (1) What are the detection limits of panchromatic 1936 aerial photography?, and (2) How do these influence *P. velutina* biomass estimates? Shrub polygons were manually digitized on 1936 imagery and linked to 1932 field measurements of *P. velutina* canopy area. Aboveground 1932 *P. velutina* biomass was estimated using a site-specific allometric relationship for field-measured canopy area. Shrub canopy detection limits on the 1936 imagery were comparable to those reported for contemporary imagery. Based on a conservative shrub size detection threshold of 3.8 m^2, 5.8% of *P. velutina* biomass was missed. Spatial resolution (0.6 vs. 1.0 m) did not influence detection limits, but the overall accuracy of shrub cover estimates was greater on 1.0 m images. Presence of the sub-shrub *Isocoma tenuisecta* may also have significantly influenced estimates of *P. velutina* canopy area. These analyses illustrate the importance of standardizing aerial photo interpretation protocols, accounting for uncertainty estimating shrub biomass, and caution species-specific interpretations for historic aerial photography.

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1. Introduction

Changes in land cover and land use play a pivotal role in driving global change (Pielke et al., 2002; Vitousek, 1994). Historical perspectives enable researchers to elucidate trends and patterns of change and to disentangle interactions among factors influencing change trajectories (Foster et al., 2003). Aerial photography is useful for making quantitative multi-temporal assessments of land cover change. The synoptic nature and length of record provide the ability to map and monitor resources over large areas at decadal time scales. Commercial aerial photography in the United States was first available after World War I (Lillesand and Kiefer, 2000) and is the earliest source of remotely sensed imagery capturing land surface characteristics. As such, early aerial photography serves as the baseline for the longest time series of imagery and is broadly accessible through archival outlets [e.g., U.S. National Archives and Records Administration (NARA); Rango et al. (2008)].

A valuable component of the historic record, early aerial photography provides an important source of baseline assessments for studies of land cover change and an effective way to monitor long-lived plant species in a manner not generally possible in plot or experimental studies (Archer, 1996; Archer and Bowman, 2002; Fensham and Fairfax, 2002). The earliest aerial photography available in the southwestern United States was acquired in the mid-1930s as part of agricultural surveys conducted by the Agricultural Stabilization and Conservation Service and Soil Conservation Service (Rango et al., 2008). Because early aerial photos provide a basis from which to gauge the rate and extent of land cover and land use change, insights regarding detection limitations are relevant for land managers as well as members of the remote sensing, landscape ecology, forestry, and the ecosystem/global change modeling community. Land use and land cover change analyses based on remotely sensed imagery requires prudent evaluation of accuracy and performance (Rindfuss et al., 2004). However, there are no published records documenting the detection limits and accuracy of vegetation cover estimates derived from early aerial photography due to paucity of spatially explicit field data coincident with photo acquisition.

* Corresponding author at: USDA-ARS, Jornada Experimental Range, P.O. Box 30003, MSC 3JER, New Mexico State University, Las Cruces, NM 88003-8003, USA. Tel.: +1 575 646 2961; fax: +1 575 646 5889.
E-mail address: dbrownin@nmsu.edu (D.M. Browning).

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One of the most striking land cover changes in grasslands and savannas (hereafter "rangelands") worldwide over the past 150 years has been the proliferation of trees and shrubs (hereafter "woody plants") at the expense of perennial grasses (Archer, 1995; Van Auken, 2000). Rangelands occupy ca. 40% of the global land surface (Bailey, 1996), contribute 30–35% of the terrestrial net primary productivity (Field et al., 1998), and are inhabited by more than two billion people (Safriel and Adeel, 2005). This land cover change in rangelands thus has ramifications for terrestrial carbon, nitrogen, and hydrologic cycles, land surface–atmosphere interactions, and rangeland and human health. Although regarded as having had a significant impact on the North American terrestrial carbon sink (Houghton, 2003; Pacala et al., 2001), the lack of detailed or spatially explicit historical records on this shift in land cover has hindered quantitative assessments.

An improvement in our ability to accurately estimate vegetation biomass across large areas is required to reduce uncertainty in terrestrial carbon pool estimates (Schimel et al., 2006). Time series analysis of repeat aerial photography or a combination of aerial photography and satellite imagery is one tool for addressing shortfalls in the historic land cover record (Asner et al., 2003). However, the utility of aerial photography for quantifying trends and patterns of woody plant cover in rangelands depends upon a variety of factors, including photo scale, atmospheric haze, spatial resolution or cell resolution size, and film development and digital image processing protocols (Fensham and Fairfax, 2002; Fensham et al., 2002). These factors can be assessed in modern photography (e.g., Fensham and Fairfax, 2007; Robinson et al., 2008). In contrast, historical photography, the baseline on which rates, patterns and trajectories of change are based, is not typically amenable for validation. Thus, we are forced to assume that detection limits in early images are comparable to those in more recent images. How robust is this assumption?

Cell resolution or photo grain size imposes constraints on the ability to distinguish landscape elements with remotely sensed imagery. Understanding these limitations is key to devising appropriate analytical methods to achieve study objectives (Woodcock and Strahler, 1987). The importance of spatial scale and the interactions between scale of measurement, discrete versus continuous depictions of landscape parameters, and spatial autocorrelation structure within an image has been recognized. Strahler et al. (1986) proposed a framework for exploring a range of natural resource applications with remote sensing models based upon the relationship between the size of analytical elements or image objects (e.g. shrub canopies) and cell resolution size. They used the term "H-resolution" to represent situations in which the targets of interest are larger than the cell resolution size (e.g., shrub canopies in fine spatial resolution aerial photography). Image objects are functionally defined by H-resolution pixel groups with similar appearance, tone, and structure (Hay et al., 1997). In H-resolution images, objects are discernable and spatial arrangement can be explored. Alternatively, the term "L-resolution" denotes situations in which target image objects are smaller than the cell resolution size (e.g., shrub canopies in moderate spatial resolution satellite imagery) and detection of individuals is not possible (Strahler et al., 1986). Both L- and H-resolution information exist in a given image (Woodcock and Strahler, 1987), thereby presenting a case for multi-scale analytical approaches and clear definition of object-based research goals (Hay et al., 2003). Our analysis of 1936 panchromatic digitized imagery was based on the H-resolution model, wherein we specify one target, canopies of the dominant woody species (*Prosopis velutina* Woot.), to determine detection limitations of 1936 photography and validate aerial photo-based depictions of *P. velutina* canopies and landscape-scale estimates of shrub cover.

These objectives were addressed in Sonoran Desert grasslands of the southwestern U.S.A. where shrub encroachment has been well-documented (Brown, 1950; Browning et al., 2008; Glendening, 1952; McClaran, 2003). In 1932, two 40 m × 440 m plots were established on the Santa Rita Experimental Range in southeastern Arizona and the location of all shrubs and cacti within the plots were noted and their canopies measured (Glendening, 1952). This provided us with the unique opportunity to compare 1932 field maps of shrub canopy to cover maps derived from 1936 digital aerial photography. Specifically, we (1) validated estimates of shrub canopy cover at two scales of observation: *i*) individual *P. velutina* canopies and *ii*) total cover of all shrubs; (2) quantified the size of *P. velutina* plants below the detection limits on 1936 panchromatic imagery; (3) classified omission errors (*P. velutina* plants present in 1932 but not recognized on 1936 photography) attributable to *i*) detection limits, *ii*) spatial co-registration, and *iii*) species identification errors; and (4) translated detection limits to *P. velutina* biomass missed with the historic aerial photography. In addition, we (5) quantified the effect of image spatial resolution on detection limits and cover estimates by evaluating geometrically corrected digital imagery at two cell resolution sizes commonly used in studies of land cover change (0.6 and 1.0 m).

2. Methods

2.1. Study site

The study was conducted on the 21,514-ha Santa Rita Experimental Range (SRER) 45 km south of Tucson, Arizona (31° 49′ 58″ N, 110° 52′ 24″ W) along the western edge of the semi-desert grassland region of the Sonoran Desert as defined by Brown (1994). We focused on two 1.8 ha (40 m × 440 m) study plots at 1070 m elevation. Established in 1932 by Dr. William McGinnies in a mesquite savanna, the vegetation in these plots was representative of the semi-desert grasslands within the southwestern U.S.A. The McGinnies plots were situated on soils of late Pleistocene age with a sandy clay loam subsurface texture (Batchily et al., 2003). *P. velutina* (Woot.) was the dominant shrub. Other shrub species in the area included *Celtis pallida* Torr. and *Acacia gregii* Gray, and the sub-shrub *Isocoma tenuisecta* Greene, a species intermediate in growth form and longevity between herbaceous plants and true shrubs (Table 1). See McClaran et al. (2003) for detailed descriptions of geomorphology, vegetation, and climate.

Aerial photo validation was based on an exhaustive 1932 census of woody plant canopies within the two 1.8 ha plots situated ca. 60 m apart from each other (hereafter referred to as 'North' and 'South'). In the 1932 survey, corners of 10 m × 10 m subplots were marked with re-bar, and the location of all shrubs and cacti was mapped by species using a telescopic alidade and plane table and their canopy diameter recorded (Glendening, 1952). Sub-shrubs such as *I. tenuisecta* were not mapped. In 2006, we mapped subplot corners with a Global Positioning System (Leica GS20) using the Universal Transverse Mercator (UTM) projection, North American Datum 1983, while applying a 0.5 m horizontal positional accuracy threshold.

2.2. 1932 Field measurements

Shrubs locations in the 40 m × 440 m plots were incorporated into a geographic information system (GIS) by scanning and spatially registering 1932 scaled, hand-drawn survey maps to a Cartesian coordinate system in ArcMap (v.9.0 Environmental Science Research Institute Inc., 2004). Shrub locations on the geocoded 1932 field maps were digitized as points located at the bole of the largest stem. Because our objectives were to quantify the cover of true shrubs, cactus locations were not digitized. Field measurements of canopy diameter in North–South direction were