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Evaluating the level of agreement between human and time-lapse camera observations of understory plant phenology at multiple scales

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ABSTRACT

The growing popularity of digital-repeat photography in field research is seeing traditional field efforts being assisted and even replaced by low-cost cameras. The efficiency of using cameras is obvious, but there is an assumption that they capture the same information as observations made by humans. This paper aims to determine the level of agreement between these two methods of interpreting understory vegetation phenology. We compared daily phenological observations made by low-cost cameras with those made by personnel during field visits every 10 days. Phenophases were defined as the non-spectral, physical developmental stages of Canadian buffaloberry (*Shepherdia canadensis*) and alpine sweetvetch (*Hedysarum alpinum*). The relationship between observation methods was quantified using a weighted kappa statistic at three spatial scales ranging from individual plants to areas up to 6 ha. Agreement between the camera observations and those made by field personnel was nearly perfect (Kappa > 0.9) for both the vegetative and reproductive phenology of both study species at all spatial scales. The level of agreement was found to be more variable early in the season when plant growth is more rapid. Overall there was a slight bias in the image interpretations to underestimate the rate of development. Time-lapse photography was found to be an analogous replacement for field visits; however, some plant species are more suitable for observation by camera than others. Spatially, it was determined that observations of a single plant are all that is required to capture the phenology of the surrounding region in excess of 6 ha. This analysis was carried out over a single growing season in the in the Rocky Mountains of western Alberta, Canada.

1. Introduction

A fundamental premise of scientific research is that repeated observations of natural phenomena can be used to identify patterns, trends, and changes over time and space (MacArthur, 1972). Traditionally these observations have been obtained manually by individuals in the field. Over time, however, this effort has transitioned towards the use of automated digital sensors (Crimmins and Crimmins, 2008). The benefit of this technology is primarily for the acquisition of consistent, high-quality datasets at substantially reduced costs and effort (Sonnentag et al., 2012). For instance, digital-repeat photography has been broadly applied in ecosystem research, with a critical focus on vegetation phenology (Schwartz, 2013, Inoue et al., 2014): the study of the periodic life-cycle phases of plants which include leaf-out, flowering, and senescence (Badeck et al., 2004). Applications include observing rates of vegetation development as a bioindicator of climate change (Richardson et al., 2009b, Nagai et al., 2014), carbon flux calculations (Ahrends et al., 2008; Ide and Oguma, 2010), and species habitat assessment (Proulx and Parrott, 2008, Bater et al., 2011a, Coops et al., 2012, Nijland et al., 2013).

Imaging sensors capture vegetation phenology by either recording structural changes during leaf and flower development, or collecting the spectral information reflected by the plants as a measure of overall image 'greenness' (Richardson et al., 2007). The latter method is the most common and is used to bridge phenological observations on the ground with satellite imagery to evaluate phenology at the ecosystem scale, also known as *land-surface phenology* (Schwartz and Reed, 1999, Beaubien and Hall-Beyer, 2003, Richardson et al., 2013). As a result, ground-level camera observations (near-surface remote sensing) are typically made of the forest canopy or the vegetated land cover which is directly observable by satellites (Inoue et al., 2015). Beneath the canopy, near-surface remote sensing is less prevalent, though it is becoming increasingly important in a variety of applications. An improved understanding of the relationship between forest tiers provides further insight into monitoring vegetation spectral-dynamics via satellite (Miller et al., 1997), differences in phenological timing (Richardson and O'Keefe, 2009; Ryu et al., 2014), ecosystem structure (Kudo et al., 2008; Nijland et al., 2014), and wildlife habitat quality (Tuanmu et al., 2010; Bater et al., 2011b). Assessments of habitat quality sometimes use phenology as a proxy for the amount of available

Abbreviations: MODIS, Moderate Resolution Imaging Spectroradiometer; NDVI, Normalized Difference Vegetation Index; FOV, Field of View.

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nutrition on the landscape by relating a specific phenophase to forage quality; particularly when the appearance of a phenophase equates to a readily available food-source, such as fruit (Hebblewhite et al., 2008; Nielsen et al., 2010). This method of near-surface phenological monitoring requires direct visual inspections of plant-level phenology to validate camera imagery and to collect biomass samples for nutritional analysis (Coogan et al., 2012; Nijland et al., 2013).

For this study, the effort to observe understory vegetation phenology is motivated by our involvement in an ongoing grizzly bear (*Ursus arctos*) research program where we are working to monitor critical habitat for this species in Alberta, Canada (https://friresearch.ca/program/grizzly-bear-program). These animals strategically exploit a wide variety of understory plants that provide variable nutrition at differential times of the growing season (Nielsen et al., 2003). Alpine sweet vetch (*Hedysarum alpinum*) is a herbaceous legume with a nutrient-rich perennial taproot that offers quality forage preceding spring green-up, and after autumn senescence (Coogan et al., 2012). Canadian buffaloberry (*Shepherdia canadensis*) is a widespread diaceous shrub that fruits in late summer (Hamer and Herrero, 1987). The ensuing objective of this research is to eventually scale the nutritional development of these plants from the plot level to a much larger region using satellite remote sensing. In general, extending localized understory phenological observations to the broader area is difficult for reasons that include environmental gradients and micro-climate, as they tend to alter phenology over space (Fisher et al., 2006). Phenotypic and genetic variation can also alter the rate at which plant species respond to environmental cues (Macdonald and Chinnappa, 1989, Richardson and O'Keefe, 2009). As a result, spatially characterizing the phenology of a specific plant species in the forest understory is complex, and represents a significant research challenge (Tuanmu et al., 2010).

Broad FOV cameras that acquire spectral indices such as NDVI and *greenness* do not directly observe the structural changes of individual plants. Studies examining the linkages between camera phenological metrics and the structural properties of vegetation remain elusive (Yang et al., 2014). To our knowledge, attempts to extend the phenological observations of single understory plant-camera pairings to the broader area is absent from the literature. The rapid adoption of repeat digital photography in ecosystem phenology research necessitates ongoing assessment of the limitations and utility of the imagery collected (e.g. Keenan et al., 2014; Vartanian et al., 2014). Despite their consistent and objective observations, cameras produce imagery that still requires field validation and post-hoc interpretation by human observers so as to extract meaningful data. There is a need to compare interpretations of camera imagery with traditional direct field observations to ascertain how closely they agree. The manner and scale in which plant phenology is recorded with digital cameras can affect overall confidence in the dataset (Vartanian et al., 2014).

The objective of this study was to evaluate the level of agreement between phenophase observations made in-person during field visits and those interpreted from imagery collected by digital cameras. Observations were made of the structural-physical changes in the vegetative (green-leaf) and reproductive phenology of *S. canadensis* and *H. alpinum*. The agreement between the two methods were compared across three spatial scales: 1) individual plants, or *plant-scale*, 2) plants occurring within a 10 m radius plot, or *neighborhood-scale*, and 3) plants occurring within a 250 m^2 plot analogous to the ground resolution of a satellite sensor image pixel, or *pixel-scale*. We hypothesized that there would be no significant difference between the two phenological observation methods, though the relative merits of cameras (enhanced observation frequency; limited visual perspective) versus humans (unrestricted visual interpretation; limited revisit frequency) might lead to results that vary with scale. In all, 55 plants were observed daily using cameras, and close to 4000 phenological observations were made by field personnel during near-weekly visits over a single growing season.

2. Methods

2.1. Study area

The study area is located along the eastern slopes of the Rocky Mountains in Alberta, Canada (Fig. 1). The landcover of this region is comprised of deciduous aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white spruce (*Picea glauca*) mixed forests at lower elevations. The upper-foothills and mountains are dominated by mature lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and sub-alpine fir (*Abies lasiocarpa*) conifer forests.

A total of 37 observation plots were distributed over 650 km along five elevational transects to obtain a variation of growing environments and temperature regimes (between latitudes 49.9°N and 54.4°N). Twenty three of these plots were *neighborhood-scale* (10 m radius or 0.031 ha) while the remaining 15 plots were *pixel-scale* (250 m × 250 m or 6.25 ha). This ground coverage of pixel-scale plots relates specifically to the image pixel size of the Moderate Resolution Imaging Spectroradiometer (MODIS), which is a popular spaceborne platform for phenological observation of vegetation (Soudani et al., 2008; Badeck et al., 2004; Zhang et al., 2003). The pixel-scale plots were comprised of a variety of spatially homogeneous forest stand-types (deciduous, coniferous, and mixed) with low local topographic complexity.

2.2. Camera network observations

A digital camera network of 55 Wingscapes PlantCams® (6 MP) was distributed throughout the study area. Each unit incorporates a weatherproof casing which contains a built-in intervalometer and lithium (AA) batteries that provided ample seasonal duration. 2560 × 1920 pixel resolution JPEG images (~1 MB) were recorded to 4 GB SD cards. Image compression through *lossy* formats such as JPEG could affect phenotyping accuracy, but this resolution is ample to

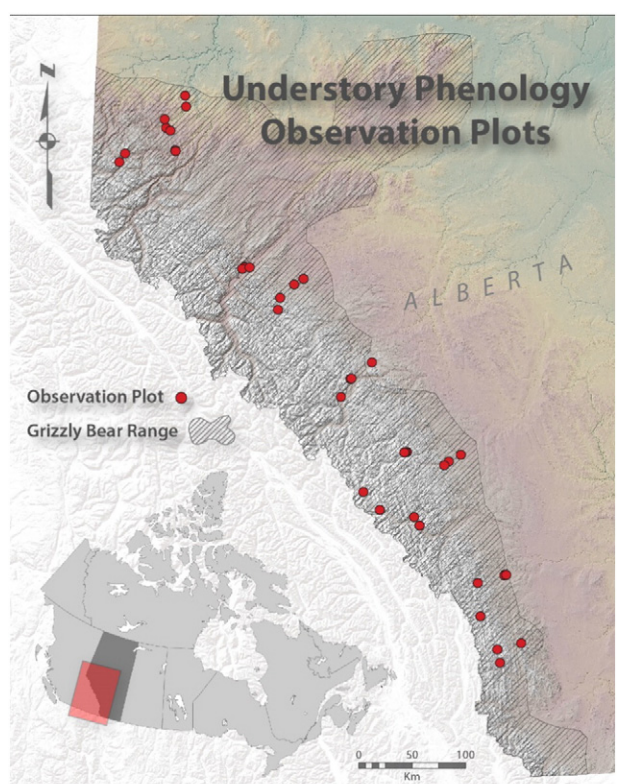

Fig. 1. Study area extent and observation plot locations throughout the Rocky Mountains of western Alberta, Canada. Highest plot elevation: 1800 m, lowest: 800 m.