INTRODUCTION

In order to advance our understanding of montane vegetation dynamics in the American West, we must refine the tools we utilize to identify ecosystem changes over time. At the highest elevations, the multi-decadal life cycles of tree species require monitoring techniques that are able to resolve these extended time scales of change. Decadal scale observations help to detect vegetation growth trends and when applied, forest management policy can thus reflect a greater understanding of the changing nature of their managed resources. In particular, photography has become an increasingly reliable and important tool used to identify change across decades.

To fill a gap in long term evaluation of change at higher elevations in the central Sierra Nevada, this study uses repeat-photography analysis to identify vegetation change trends over the last century (1897-2008). Historic photographs, concentrated in the high country of the Sierra Nevada Mountain Range in Yosemite National Park, California, USA and the surrounding area, provide visible benchmarks for a qualitative assessment of arboreal growth in sub-alpine and alpine vegetation zones. These data expand vegetation change analysis and provide a digital baseline for future repeat-photography study of growth trends.

In California, close to 50 percent of the state's 7,000 vascular plant species occur in the Sierra Nevada Mountain Range, more than one-ninth of these are endemic, and 200 are considered rare (SNEP 1996). In these mountains, plant species evolved to inhabit diverse communities found along a steep elevation gradient, across a relatively short horizontal distance (Johnston 1970; Beniston 2003).

In the Central Sierra Nevada, since the 19th century, anthropogenic pressures have increased on montane systems in the form of development, resource extraction, and management policy (SNEP 1996; Potter 1998; Fites-Kaufman *et al.* 2007). Rapid industrialization of resource extraction and development expansion of the 20th century produced unprecedented changes to montane environmental systems which compound our need to understand how species adapt and change over time (SNEP 1996; IPCC 2001; Beniston 2003). Coupled with rapid shifts in climate, as seen within the last half century (SNEP 1996; van Mantgen and Stephenson 2007; Beckage *et al.* 2008; Malmsheirmer *et al.* 2008; Marston 2008), these anthropogenic driven stresses on Sierra Nevada vegetation communities will play an increasingly important role in mountain ecosystems. Given that these recent shifts in climate have taken place over only the last 20-50 years, at an accelerated rate than previously recorded in this region, *how* we detect and monitor vegetation change over time has become an important component to our greater knowledge of ecosystem dynamics (Vale 1987; Klasner and Fagre 2002; Kull 2005).

Historic Data Gaps

The most important areas of future research are those centering on relationships between agents of change and vegetation.

-Fites-Kaufman *et al.* (2007) in
Montane and Subalpine Vegetation of the Sierra Nevada and Cascade Ranges

The complexity of human experience in mountain systems requires multi-faceted change detection research methods across multiple disciplines. Before detailed biological studies of Sierra Nevada ecosystems, the earliest of which date back to the 1930's and 1940's (UCBerkeley 2008), there are few visible and/or landscape scale records to establish benchmarks for long term change detection (SNEP 1996;). John Muir traversed the Sierra Nevada Range chronicling biologic and geologic diversity throughout the late 19th and early 20th centuries (Johnston 1970; NPS 2008). Despite these records we lack a detailed, visibly descriptive record to compare current vegetation growth against. Even within the last 20 years of detailed field study, Fites-Kaufman *et al.* (2007) have noted that site and point scale projects have been over emphasized and landscape scale study has been lacking. There is obviously a need to bridge these gaps between varying scales of study in alpine and subalpine ecosystems.

To fill these gaps, field observations, palynology (pollen), and dendrochronology (tree ring) analysis have been utilized to expand our understanding of vegetation growth across decades and centuries (Vale 1987; Schweingruber 1988; Prentice *et al.* 1991;

Briffa *et al.* 2003). Historic data from these techniques include annual individual growth estimates, historic species ranges, and proxy precipitation and temperature estimates over decades, centuries and millennia (Vale 1987; Schweingruber 1988; Prentice *et al.* 1991; Briffa *et al.* 2003). And while these techniques provide substantial quantitative tools, they lack a detailed qualitative assessment necessary for local and regional investigation of vegetation change(s). Specific location of individual trees, density of forest stands, and range fluctuations of arboreal species are all difficult to determine across extended timelines from narrative, palynology, and dendrochronology.

To establish growth trends along extended timelines, it is important to be consistent in the methods utilized. Recent detailed field observations and studies do not necessarily bridge the gap between historic data retrieved from palynology or dendrochronology and what is observed today. Both of these methods rely on current location of individuals/species, or describe presents/absence, which negates forest/individual health or distribution of species ranges across entire landscapes. Thus, the advent and application of photographic analysis across the previous century provides visual details of individual growth, distribution, and forest stand health unattainable with other methods (Bass 2004). Historic photographs remain unchanged, literal snapshots in time that can be examined and re-examined to address differing research needs across multiple disciplines. Bridging the digital divide (discussed below) has made the storage, retrieval, and analysis of these historic images even easier.

Research Objectives

The objectives of this study are to detail ecosystem change trends in alpine and sub-alpine communities of Yosemite National Park, California, over the last one hundred years (1897-2008) through repeat-photography assessment. A rich photographic history in the upper reaches of Yosemite provides the opportunity to conduct a qualitative assessment of landscape change since the 1890's. The use of repeat-photography, at ~80 different sites across a study area of over 250 km^2, provides a time series of photographs which is used to assess and identify growth trends. No other repeat-photography assessment in this part of the Sierra Nevada Mountains, specifically focused on vegetation change, has spanned such a wide temporal range.

In order for long term assessment of vegetation dynamics to be successful, this study provides repeatable monitoring locations to support future research efforts in Yosemite National Park. The photographic data set was originally discussed in Vale (1987) and Vale and Vale (1994) and was expanded in this 2008 study to 1) add an additional 20+ years of photographic data to the set, 2) expand total temporal reach from ~80 to over 100 years, and 3) provide accurate easily repeatable co-ordinates and meta-data for future study. Five growth trends, including growth and density of Krummholz and forest stands, increased incursion of tree growth into meadows, expansion of forest patches, and a reduction of forest clearings, were tested based on qualitative assessment of photograph triplets taken at each site. It is hypothesized that conclusions reached by other recent studies from the Sierra Nevada and the American West will be seen to continue in the Tuolumne region. Others have concluded that increases in mean temperatures and increased variation in precipitation along with a history of fire suppression policy in the Sierra Nevada, though complex, has produced noted growth of forest stands, expanded range of arboreal species upslope, and increased new growth into meadows (Vale 1987; SNEP 1996; McKelvey *et al.* 1996; Grace *et al.* 2002; Millar *et al.* 2004; Fites-Kaufman *et al.* 2007). Additionally, by increasing accuracy and repeatability, this project has the potential to expand observed trends and establish a baseline for future research. Future applications of repeat-photography at the sites utilized for this study are suggested and discussed. The addition of a quarter century of growth beyond the previous repeat-photography study will provide an update to regional ecosystem change and vegetation growth trends in this area of the Sierra Nevada Range.