METHODS

This study uses repeat-photography to identify vegetation growth trends in the sub-alpine and alpine vegetation zones. In order to advance the length of time between paired photographs to capture vegetation growth trends, as well as provide a more detailed description of each site for future monitoring, the photograph sites used and analyzed by Vale (1987) and Vale and Vale (1994) were identified and rephotographed. Vale compared vegetation visible in the 1980's to historic scenes from photographs captured around the turn of the 20th century from the USGS archives. For this 2008 study, photographs captured at each site were analyzed as part of photo triplets: 1) historic USGS photographs taken between 1897-1939, 2) photographs taken by Vale 1984-89, and 3) photographs captured in 2008 (Table 2). The greatest time span of these photograph triplets is 111 years, while the average of the entire data set is 100 years.

Table 2. Photograph Triplets used to identify vegetation change trends
These photograph sets were utilized for this project, including various photographers supplied by the USGS, T. Vale in the 1980's and N. Wasserman in 2008.

Source	Photographer	Photo Year(s)	Cited in text as
USGS	Various	1897-1939	"c1900"
T. Vale	T. Vale	1984-89	"c1985"
N. Wasserman	N. Wasserman	2008	"2008"

Locating repeat-photography sites

Each repeat-photography site was described in Vale (1987), Vale and Vale (1994), as well as within USGS photo captions of the historic photographs. From these general locations and descriptions, topographic features within each photo were reviewed against USGS 1:24,000 scale topographic maps and approximate vantage point(s) were identified.

These approximated locations were then taken to Yosemite during the summer of 2008. Location of exact photo vantage point relied heavily on repeat-photography field methods utilized by the U.S. Forest Service and described by Hall (2002). These include the use of orientation lines, ridgeline alignment, and the identification of foreground features to properly align camera height and field location (Hall 2002). Once each photo location was identified and camera/ tripod set up, the site was recorded using a hand-held Magellan eXplorist 210 Global Positioning System (GPS) unit. The hand held unit was used to record latitude and longitude (WGS84 datum), as well as elevation, direction, and GPS accuracy. Ninety-two percent of sites located were logged with <10 m accuracy, while one-third of the sites were identified to within three meters (Appendix A).

Photographs were captured digitally using a Nikon D60 DSLR camera and Nikon Nikkor 18-135mm (f/3.5-5.6G) DX lens in JPEG format (RBG, 3872x2592px, 300ppi, ~4.5megabytes each) set on a Slik Sprint Pro tripod. Each photo site was bracketed ±1 and ±2 exposure compensation at both f5.6 and f18 in order to record proper exposure, detail, and light composition. In most cases f5.6 provided reliable composition, sharpness, color, and contrast necessary for analysis (Appendix B). Upon review, one frame from each bracketed set was selected, cropped and coupled to their historic pair, and used for all analysis. No digital color or contrast enhancement/correction was applied to any photograph. Low resolution images are included within this text though higher resolution images were used for analysis. A complete set of images, at higher resolution than printed herein, along with an interactive mapping feature are available at http://www.ridgelinephotography.com/Yosemite.htm.

Photo Analysis

Previous work done on this topic by Vale (1987) and Vale and Vale (1994) produced five notable trends apparent in alpine and sub-alpine vegetation zones for this region of the Sierra Nevada. Review of photo triplets for this study was conducted with these trends as a base for analysis. Categories for photo analysis were taken from Vale (1987) and Vale and Vale (1994) include detection of:

1. Change(s) in Krummholz stand height and density
2. Change(s) in forest at the upper forest line
3. Change(s) in tree growth into meadows
4. Change(s) in density of local patches of forest
5. Change(s) of growth patterns of trees on domes and rock slopes

Each 2008 photo was visually compared to its c1985 and c1900 pair separately, though in some cases no c1985 photo was available and thus the 2008 photograph was compared to c1900 photos only (Appendix C). In most cases, increase/decrease in the number of individual trees (forest stand density) vs. increased/decreased branch/foliage growth within stands (coverage) was indistinguishable, and thus an assessment of overall 'density/cover' was conducted. The net result is evidenced by fewer or reduced spaces between trees, less exposed rock or slope between stands, visibly fuller and healthier looking individuals, and a more homogenous and dense forest stand as seen from a distance.

In general particular attention was paid to overlap between photos to avoid 'double counting' features or events. Forest stands, slope faces, and meadow edges (for example) if pictured in two or more adjacent pictures taken by the same photographer and in the same year were only recorded once. If a similar vantage point or field of view was taken in different years, these were included as separate events. A value of *increase* ("+"), *decrease* ("-"), *no change* ("/"), or *not visible/not applicable* ("nv") was assigned to a subset of criteria within each of these categories.

Krummholtz formations

Review of Krummholz formations was broken into three sub-categories: Individual height, stand density, and individual tree branch/foliage health. Height was reviewed relative to foreground objects (usually rocks/boulders) and in some cases other vegetation in the area, though this was avoided if possible. In most cases qualitative growth of individual trees could be easily assessed, either taller/bigger, smaller, or the same. Visual increase in the number of individual trees and increase/reduction of gaps between trees was used to determine stand density (as previously mentioned). If individual trees could be discerned from the larger grouping, changes in size of branches and overall evidence of tree health - fuller, "bushier" branches vs. skinnier, thinner branches and foliage - was determined.

Tree line stands

Photographs including the tree line were reviewed against both the c1900 photo set and the c1985 photo set (when available) in order to assess growth at the tree line over differing time spans (25 yrs vs. 100 yrs.). As discussed, movement of the tree line can be difficult to detect due to the growth of saplings intermixed with dwarfed trees at the tree line ecotone. When compared relative to ridgelines, predominate rock features and other stationary objects, tree line movement was determined based on 1) increased density of the forest stand immediately at the tree line, along with 2) increased presence of tree growth beyond that line. These assessments were done on areas that theoretically could support tree growth, meaning where there was a visible continuation of soils on slopes or ridges and not in areas where abrupt steep slopes existed that do not/could not support tree stand growth. As with Krummholz formations, if individual trees could be identified, the health of these individuals was taken into consideration. There were few instances of this though, mainly due to the fact that most photographic scenes that included the tree line were from vantage points far afield from the tree line itself.

Meadows

In photo triplets that contained meadows, four criteria were assessed. First, was there evidence of any new tree growth in areas that previously did not contain trees? If there was an increase in trees in the meadow, a designation of "increase" or "+" was recorded. Second, was the original meadow edge (relative to ridgelines, foreground objects, etc) still visible or had tree invasion obscured/retreated from this edge? This helped to establish 'substantial' meadow invasion where the original meadow edge was completely obscured. Lastly, while assessing new growth into meadows, notice was taken of non-arboreal growth in the scene. The growth of grasses and non-woody vegetation, though seasonally variable, was included in review to help assess soil moisture as well as help define a base-line for future analysis. Inclusion of analysis of non-arboreal vegetation is not included in discussion but was noted during review of the photograph triplets.

Forest stands

Qualitative assessment of forest stands, not at the tree line and distant from meadow edges, was based on visual evidence of stand density, included the reduction/expansion of non-meadow forest clearings, the increase/decrease of forest patches, and increased/decreased branch and foliage cover. In most cases it was difficult to determine whether there were more/fewer individual trees present *and/or* if there was increased/decreased cover of branches and foliage. Thus, forest stands were assessed for their density and cover. During the review of photograph triplets that contained forest stands, it was noted that there were large areas of tree die-off. Die-off was characterized by visible concentrations of de-foliated and/or snags within a continuous forest stand. Discoloration of individuals or forest canopy towards browns and grays helped to identify these areas.

Domes and rocky slopes

Though containing thinner stands of trees, domes and talus/rocky slopes were visible in many photo scenes and included in review. Two criteria were used to describe these areas. First, a general analysis of increased/decreased individual trees and the presence/absence of clearings were conducted (previously discussed as stand 'density'). Visually, increases in the number of trees on domes and rocky slopes could be qualitatively assessed fairly easily. In particular, new growth was visible where seasonal snow patches once existed, the spaces between individuals was reduced, and evidence of stand expansion was apparent for smaller patches of trees. Second, were young tree saplings visible? Saplings, normally a quarter the size or less of surrounding trees could be important in establishing growth rates as well as providing evidence for cycles of germination in the region.

Snow patches

In the case of visible patches of snow, size relative to surrounding landmarks, ridgelines, and prominent boulders was assessed. Each patch was reviewed against their historic partner(s), and a designation for the entire scene was concluded. This analysis and inclusion of data is designed for future study and did not result in conclusive discussion in this study.

Eighty-eight percent of the photo sites used by Vale (1987) and Vale and Vale (1997) were identified and rephotographed for this study. Those sites excluded were either not locatable, too far afield, or contained minimal usable scenery. Combined, the located photograph sites were found across over 900 m (3,000 ft) of elevation across an area 250 km^2. The location of these sites would not have been possible without the work presented in Hall (2002) and should be consulted if future repeat-photography projects are attempted or designed. In Yosemite National Park and the surround area, repeat-photography has allowed assessment of vegetation change across over one hundred years of landscape change.