RESULTS & DISCUSSION

This study was able to identify, locate and photograph 88 percent of the photo scenes within the study area from the original work done by Vale (Vale 1987; Vale and Vale 1994). Fifty-two photo locations were identified above 2,450 m in the subalpine forest zone, and 31 were located above 2,900 m in the alpine zone. Evidence of vegetation change was analyzed between the three photo sets, c1900, c1985, and 2008. Based on 83 located and photographed scenes, five vegetation growth trends identified by Vale (1987) were documented and confirmed in addition to one new trend, reduction in snow fields. For each category at least two photo triplets are provided[*]. Discussions of results primarily compare photographs taken in 2008 to those taken c1985 unless otherwise noted. If no historic photograph was available, " - " is included in the associated table. In upper elevations of Yosemite National Park and the surrounding area, vegetation growth trends identified and discussed in the late 20th century (see Vale 1987) have continued through the beginning of the 21st century.

Changes in Krummholz stand height and density

Krummholz stands of mainly *Pinus albicaulis* in alpine environments above the tree line showed a general trend towards increased individual height and to a lesser extent increased density of stands, consistent with Vale's (1987) findings (Table 3).

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[*] The complete set of photograph triplets, at higher resolution than printed here, is available on the attached CDROM or at http://www.ridgelinephotography.com/Yosemite.htm

Krummholz stands were visible in 9 photo sets and reviewed against c1985 photos in all cases except photo #1 where no c1985 photo was available (Table 3). Of these, 67 percent (6 of 9) showed individual height increases and 55 percent exhibited increases in stand density (Figure 3). No change in stand density was detected in one third of those photographs reviewed (Figure 4). When foliage growth and health of individuals was visible, 60 percent showed evidence of increased coverage of individual branch and foliage growth while no change was detected in the remaining 40 percent. Compared to other data sets within this study, Krummholz formations comprised a small portion of photo sites and thus the conclusions presented should be noted with caution and further research in this area pursued. Krummholz stands found in the study area exhibited growth patterns consistent with trends identified by Vale (1987) and those found in other regional studies (Klasner and Fagre 2002; Millar *et al.* 2004).

Table 3. Krummholz Photo Analysis
Repeat-photography analysis of photo sets containing Krummholz formations. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Contains krummholz	Indiv height (+, -, /)	Stand density (+, -, /)	Indiv branches/foliage cover (+, -, /)
1	Tioga Pass	2985	x	y	nv	+	nv
5	Tioga Pass	2976		y	+	+	+
9	Gaylor Lake	3257		y	+	/	/
10	Gaylor Lake	3257		y	+	-	nv
13	Gaylor Lake	3257		y	-	/	/
14	Gaylor Lake	3257		y	+	/	+
59	Vogelsang	3097		y	+	+	nv
71	Parker Pass	3324		y	+	+	+
89	Mono Pass	2982		y	nv	+	nv

Figure 3. Results - Increased individual and stand Krummholz growth
Photo #71, from a view southeast through Parker Pass at 3,324 m, both height and increased branch/foliage cover of foreground Krummholz formations are visible.

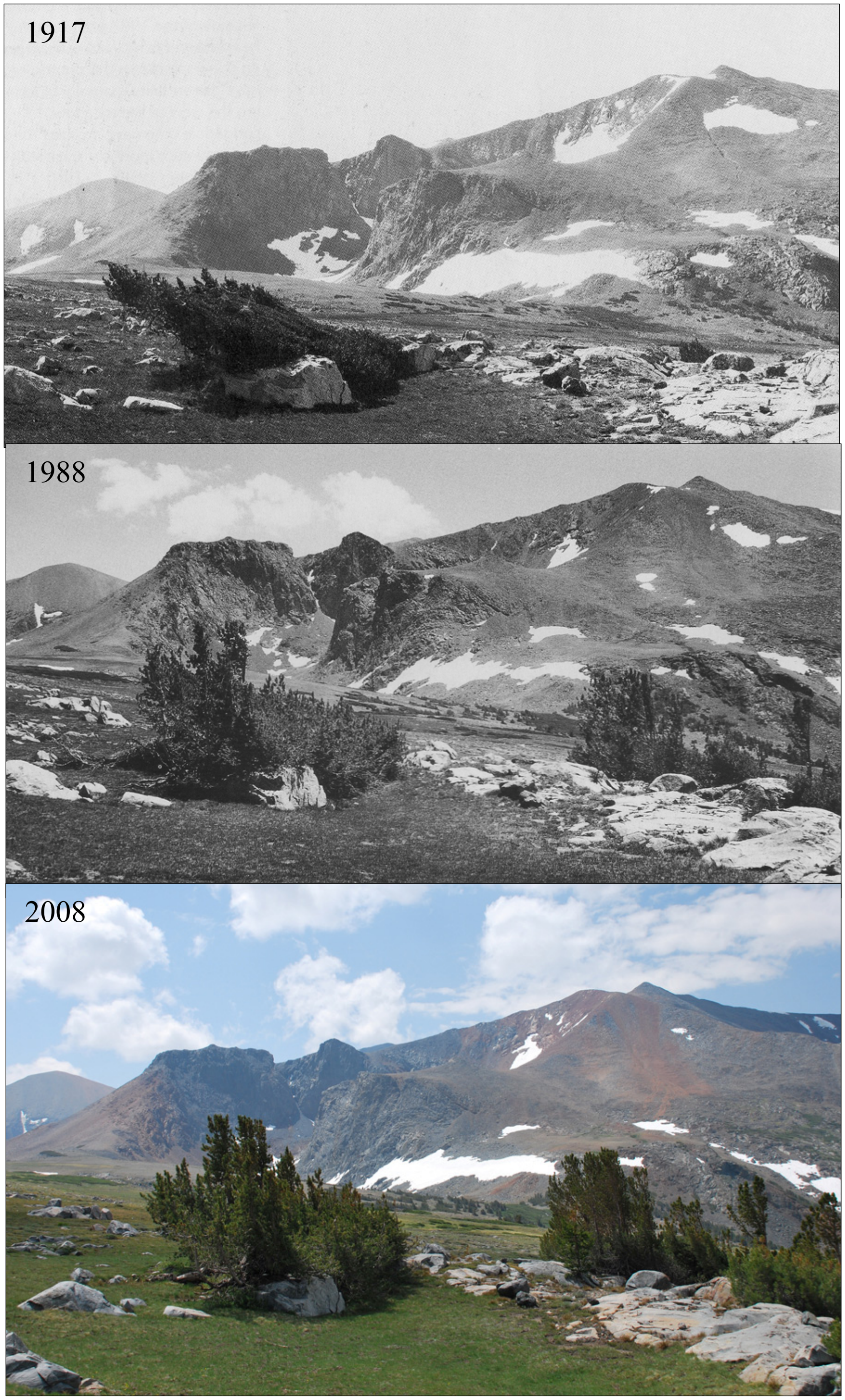
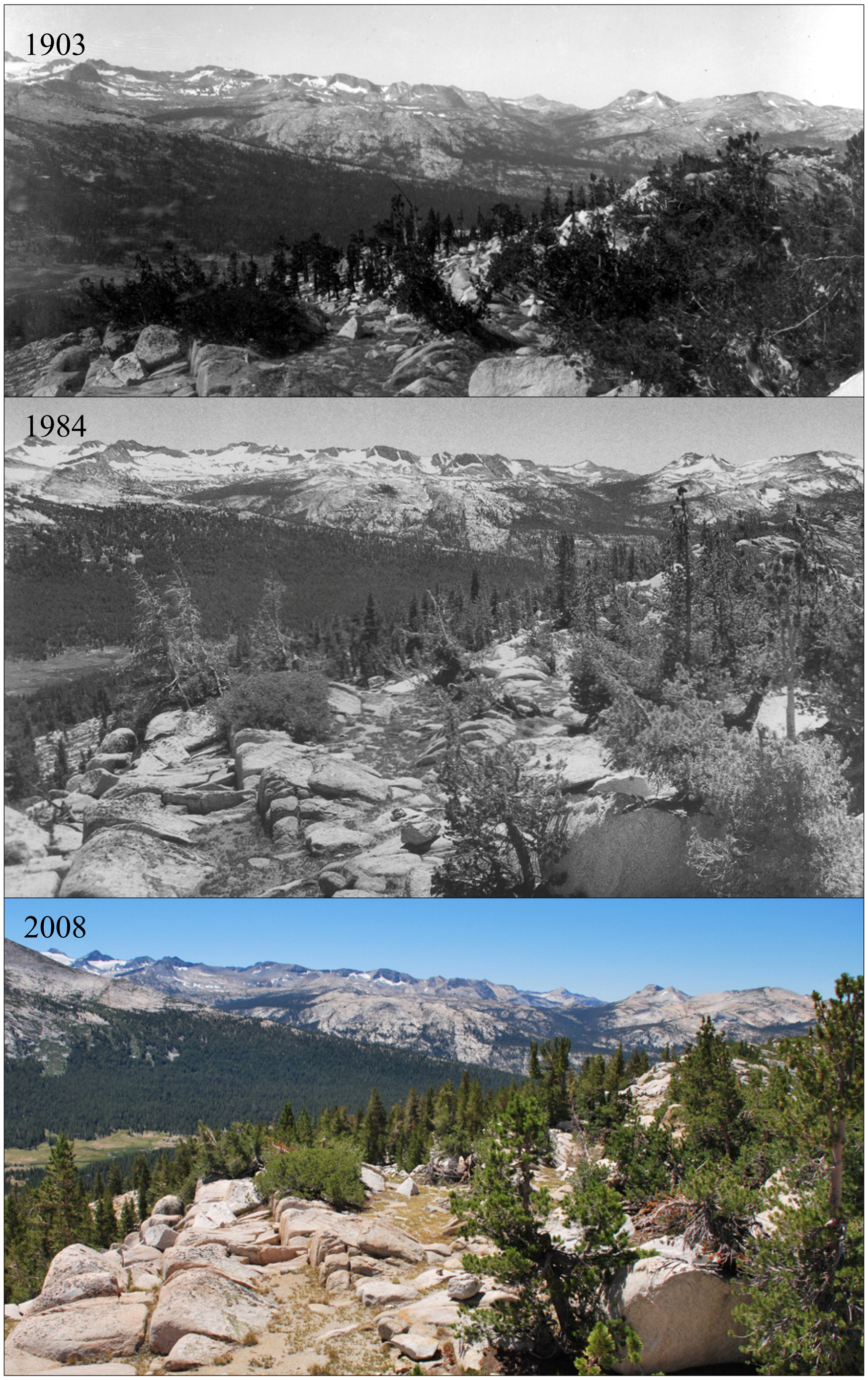


Figure 4. Results - No apparent change in Krummholz
Photo #14, looking southwest from the ridge above Galyor Lakes, at 3,257m. While some individual trees have grown, some have fallen, and many remain stunted. No major growth change is clear between 1984-2008 photos.



Increased average minimum temperatures, a lengthened growing season, and increased availability of moisture have been identified as drivers of growth seen at and above the tree line (Vale 1987; Stevens and Fox 1991; Klasner and Fagre 2002; Millar *et al.* 2004). Though the results of this study do not identify one or more of these drivers specifically, the overall growth trend visible in the photo triplets mirror similar findings found in other regions of the Sierra Nevada. If upper elevation temperatures continue to warm as predicted (see Kiparsky and Gleick 2003; Millar *et al.* 2004), growth of existing trees, emergence of new saplings, and overall growth Krummholz formations will provide important indicators of change within alpine vegetation communities.

The twisted branches of *Pinus albicaulis* and other alpine tree species remain in these wind-swept areas for decades, even centuries in some cases (Weisberg and Baker 1995). To further our understanding of upper-elevation vegetation dynamics it is important that the lifespan of live individuals be tracked and documented over an expanding time-line. While clear findings of increased height and density of Krummholz stands are concluded, further study is necessary to better understand weather and climate conditions and their impact on upper elevation tree stands. Future study of these specific stands could include metrics of growth of individuals and branches. For example, in Figure 3 the height of foreground rocks could be measured to estimate historic growth and establish benchmarks for future growth rates or decline of specific individuals. The photo sample set used in this study was relatively small as compared to others and thus would warrant further monitoring and expanded research of Krummholz formations in the region.

Change in forest stands at the upper tree line

Ninety percent (18 of 20) of photos where the tree line was clearly visible showed evidence of increased density of the forest stand (Table 4 & Figure 5). In most cases, individual branch and foliage assessment was not possible because this level of detail was not visible at the distances photographed (Figure 7). There are numerous theories concerning increased forest stand density at the tree line. For example, evidence of direct anthropogenic drivers such as the cessation of logging is seen in Figure 5, while the less specific affects of environmental/climatic cycling and possible fire regime policy could be potentially explanations of the changes visible in Figure 6. In general, increased stand density at the tree line seen across this data set would confirm increased density trends discussed by Vale (1987). Vale (1987) concluded that increased density of forest stands at the treeline was apparent c1900-c1985.

While Vale had reported little evidence of upslope movement, when you compare c1900-2008 there is evidence of upslope movement of the treeline. Only 30 percent of the photo sites visited in 2008 (6 of 20) demonstrated upslope movement of the treeline since c1985 whereas seventy-five percent of photo sites showed evidence of upslope treeline movement over the past century (Figure 7). This high percentage across the entire study area confirm conclusions of recent vegetation studies of tree line dynamics

(Grace *et al.* 2002; Klasner & Fagre 2002; Roush *et al.* 2007*)* and suggest further research is needed to establish quantitative methods to track and measure tree line movement over time. As mentioned, Vale (1987) did not conclude upslope movement of the treeline was visible, while this study concludes that upslope movement of the treeline is indeed evident across the timeline of photograph review (1897-2008). Consistency of photo analysis is important (same technician used for all review, etc) though this is not always possible. As a qualitative research method, these discrepancies can be expected to a certain extent. It is hoped that the meta-data from each photo triplet and repeat-photography site will be re-examined and reassessed into the future.

Additional measurements taken in the field could provide important metrics (i.e. stand size and measurement of tree line movement over time) to establish consistency of trend analysis. Pairing terrestrial GPS positions of landmarks and visual tree line with aerial or remote sensing images, along with oblique repeat-photography could advance our understanding of tree line dynamics. Study plots or tree core samples within viewsheds of these repeat-photography sites would also help to establish a localized historic story of vegetation change. Specifically, the high level of accuracy demonstrated with improved digital methods for this project would support the application of quantitative methods such as those utilized in Rouch *et al.* (2007). Quantitative measurement of tree line location as well as changes in forest canopy cover could be possible. While alternative methods have been suggested (see Hall 2002 and Roush *et al.* 2007), interdisciplinary cooperation between remote sensing, biogeography, and vegetation management would lead researchers to a greater understanding of change in alpine systems over time.

Table 4. Treeline Photo Analysis

Repeat-photography analysis of photo sets where the tree line was present. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Visible Treeline	Noticeable movement v. c1900 (+, -, /)	Noticeable movement v. c1985 (+, -, /)	Stand density at treeline (+, -, /)	Indiv health/cover (+, -, /)
2	Tioga Pass	2953		y	+	/	+	nv
3	Tioga Pass	3009		y	+	+	+	+
5	Tioga Pass	2976		y	/	nv	+	+
8	Tioga Pass	2992		y	+	+	+	nv
10	Gaylor Lake	3257		y	+	/	+	+
11	Gaylor Lake	3257		y	+	+	+	nv
12	Gaylor Lake	3257		y	+	+	+	nv
13	Gaylor Lake	3257		y	/	/	+	nv
14	Gaylor Lake	3257		y	+	/	+	nv
15	Gaylor Lake	3257		y	+	+	+	nv
17	Gaylor Lake	3257		y	+	+	+	nv
18	Gaylor Lake	3257		y	/	/	+	nv
22	Lyell Canyon	2687		y	+	/	+	nv
24	Tuolumne Meadows	2854		y	nv	/	/	nv
28	Pothole Dome	2622		y	/	/	+	nv
32	Tioga Road	2776	x	y	+	nv	+	nv
66	May Lake	2746		y	+	/	+	nv
78	Tuolumne Meadows	2614		y	+	/	+	nv
89	Mono Pass	2982		y	+	/	+	nv
94	Sunrise	2860		y	+	/	/	-

Figure 5. Results - Increased forest stand density
Photo # 89, view south from silver mining ghost-town of Bennettville at 2,982m. Increased density of individual trees at the tree line is evident in this area, most likely a result of the reduction/ending of logging in the area. The buildings visible in 2008 are maintained for tourism purposes by the Forest Service.

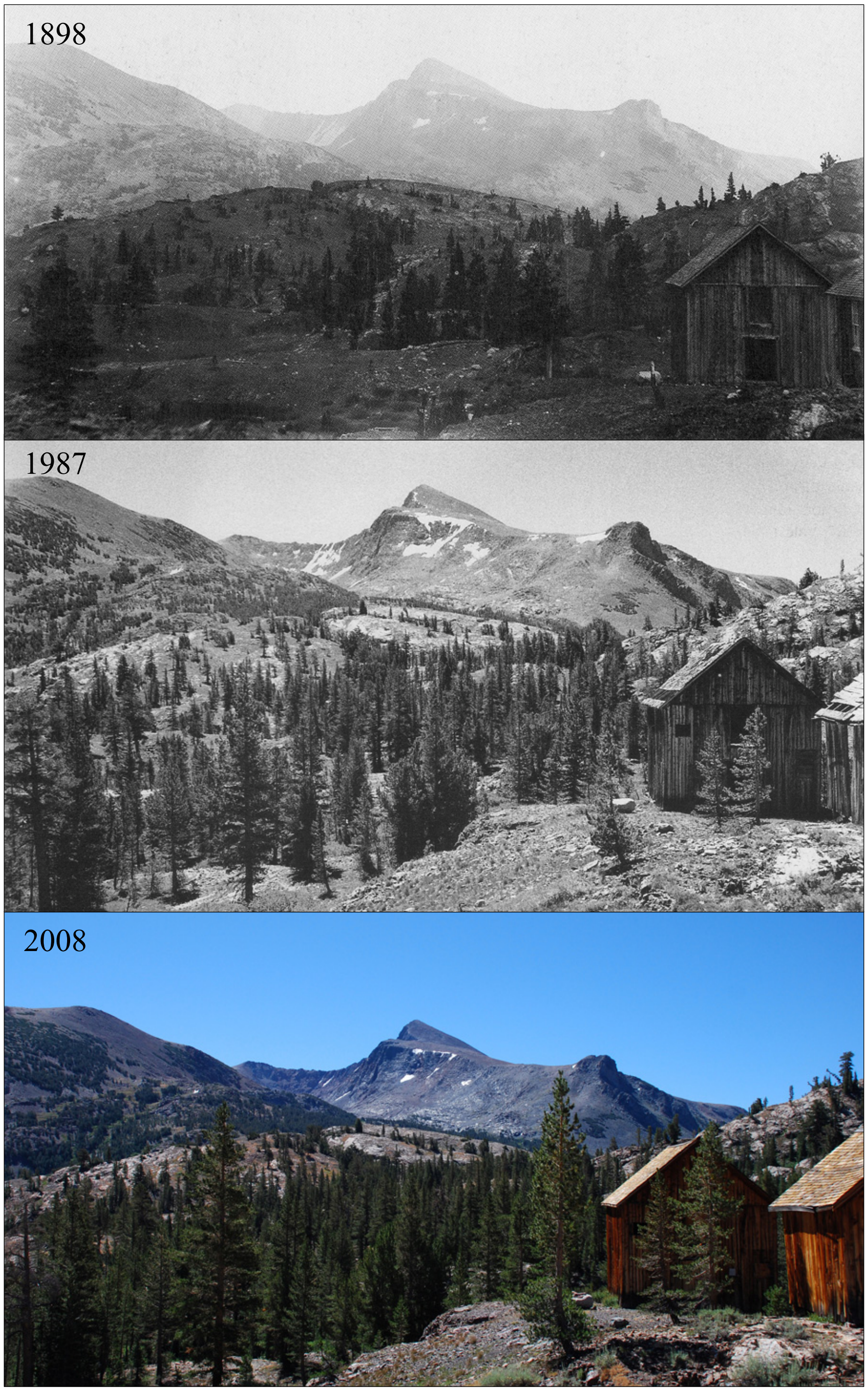


Figure 6. Results - Increased individual health
Photo #10, increased branch and foliage growth is visible in foreground stand in this view looking east along the Gaylor Lake ridge at 3,257m. Across the valley on the flanks of Mt. Dana, tree line stands are visible.

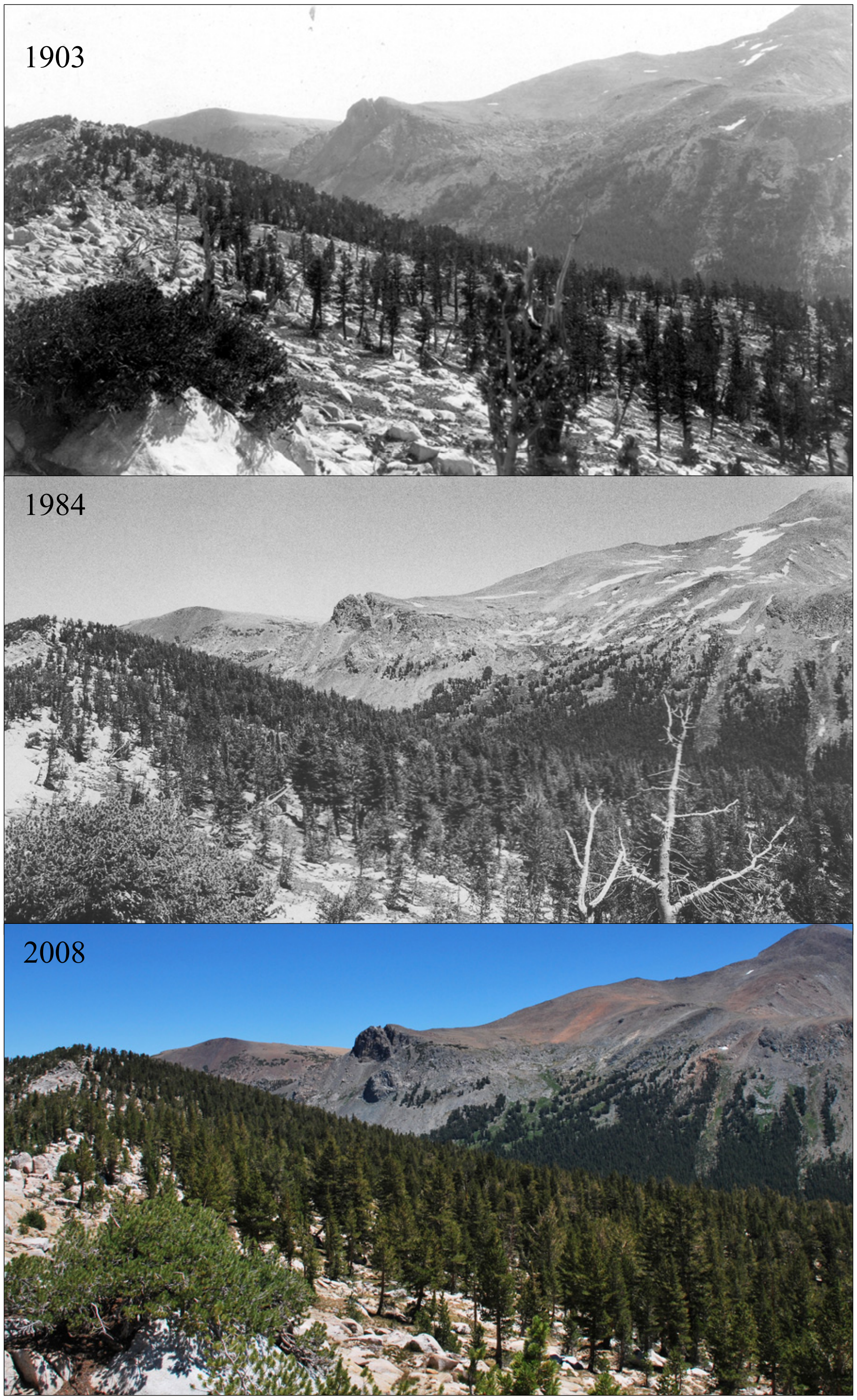
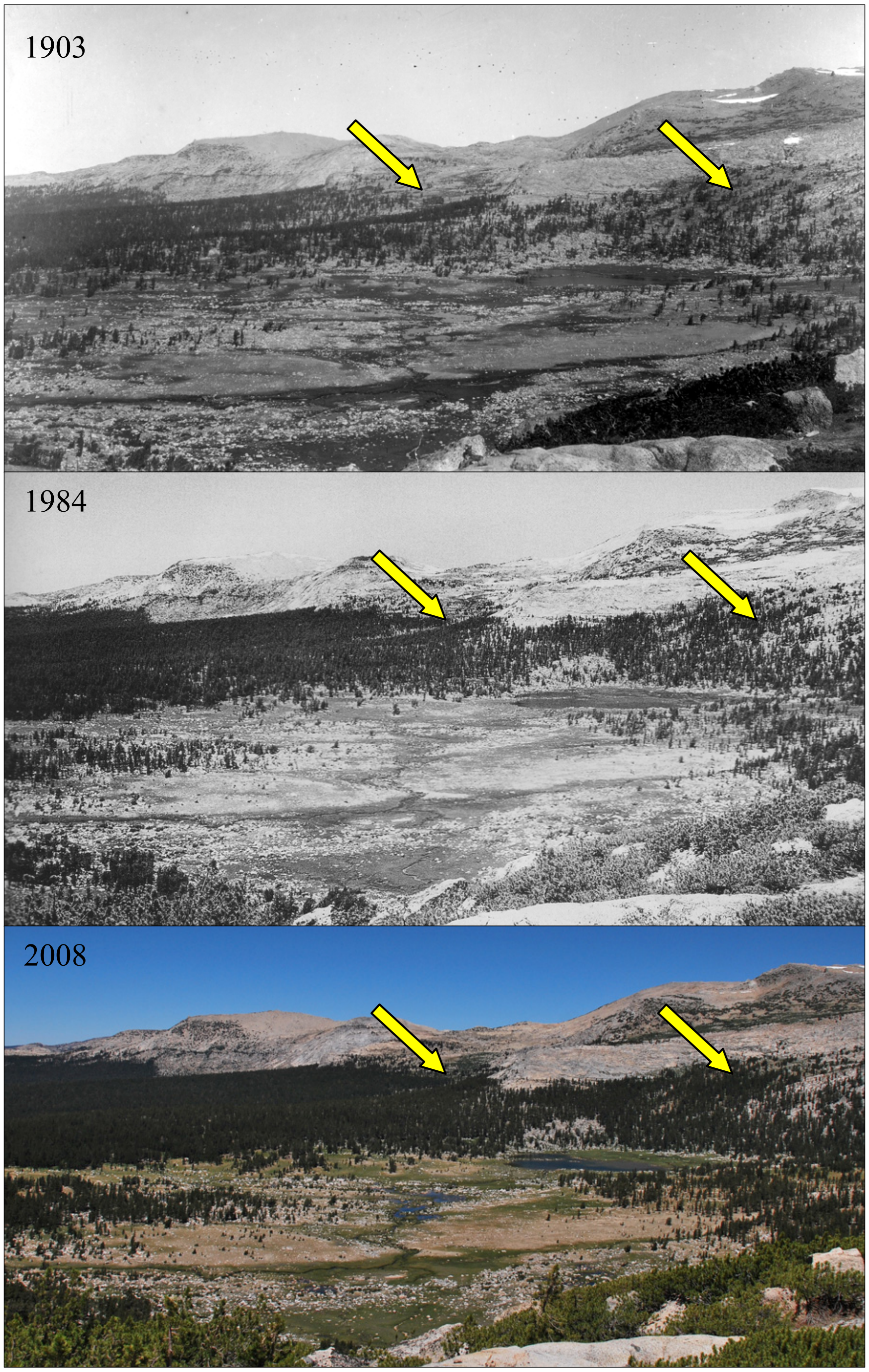


Figure 7. Results - Upslope movement of the tree line
Photo #17, a view northwest across the Gaylor Lakes Basin.Vale (1987) concluded no upslope movement of the tree line was evident, but when compared across 105 years of growth, evidence of upslope tree growth (although slight) can be seen. Arrows indicate areas of increased stand density and highlight upslope movement of tree line.



Changes in tree growth into meadows

Within the study area, there was significant evidence of tree invasion into meadows (Table 5). Vale (1987) found that of the 32 photos he analyzed showing meadows, 94 percent (30 photo sites) showed evidence of tree invasion. Tree growth in and around meadows since c1985 reveals 57 percent (20 of 35) of photo sites exhibiting growth beyond the meadow edge[†] (Figure 8) and the remaining 43 percent (15 of 35) of photo scenes exhibiting little or no clear evidence of changed growth into meadows (Figure 9).

While increased tree invasion into meadows was evident between c1900 to c1985 and c1985 to 2008, the most substantial meadow invasions were seen by comparing c1900 to 2008 (Figure 10). In instances of substantial growth, the encroachment of individuals from meadow edges completely obscured previously unencumbered views across meadows and/or of distance ridges and peaks (Figure 11). This had the potential to hinder site location, in particular Vale (1987) site #53 which was not located in 2008 due to tree growth into the meadow and obscured view of surrounding ridges and peaks.

[†] Encroachment along meadow edge relative to tree growth further into or across meadow(s) is noted as a precursor to more extensive meadow invasion.

Figure 8. Results - Increased tree invasion into meadows
Photo #22, along the Lyell Fork of the Tuolumne River, looking south east at Potter Point (right). Growth of established trees and new saplings is visible between 1984 and 2008.

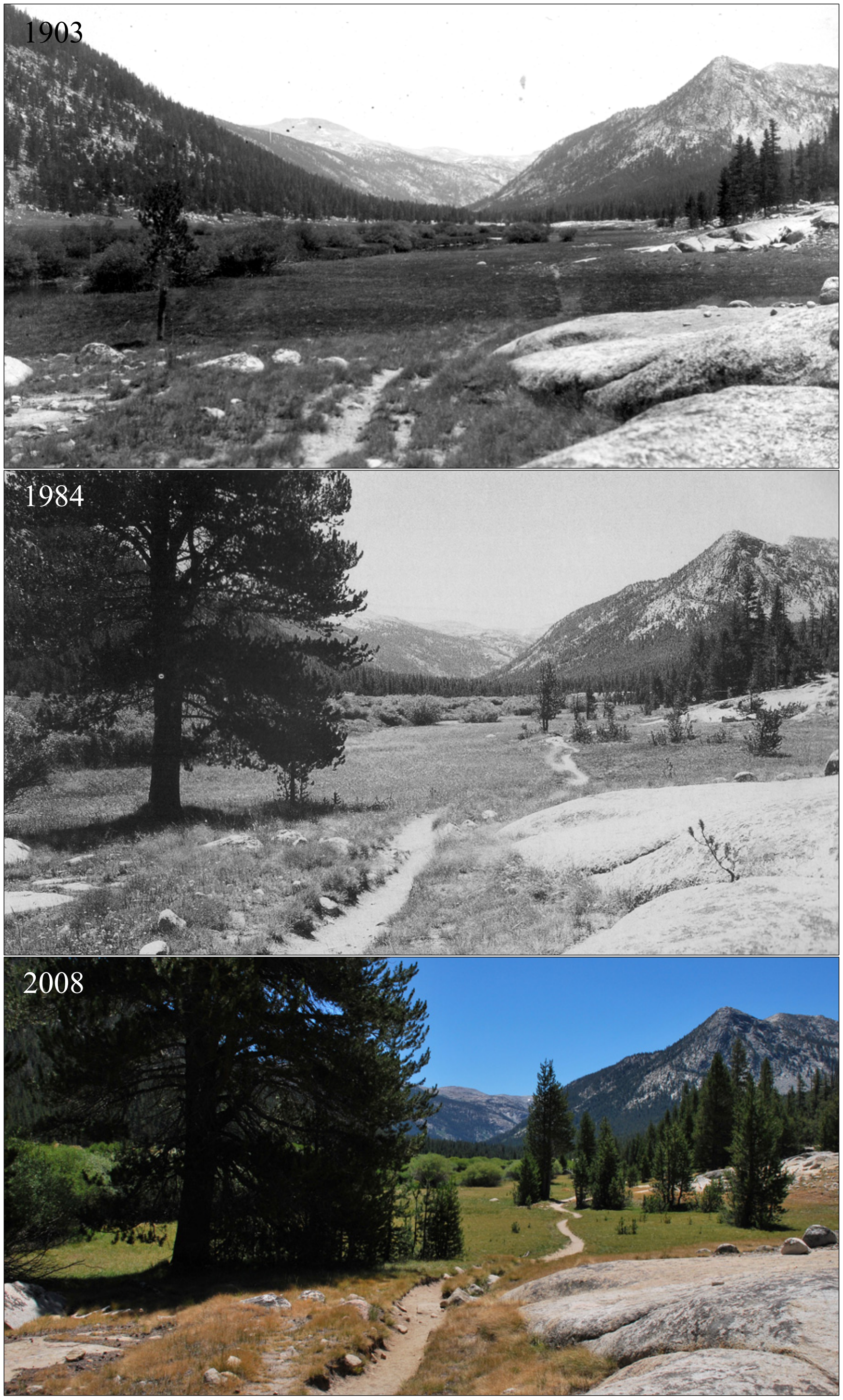


Table 5. Meadow Photo Analysis

Repeat-photography analysis of photo sets containing meadows. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Meadows Visible	Invasion (+, -, /)	Meadow edge visible (+, -, /)	Non-arboreal vegetation (+, -, /)
3	Tioga Pass	3009		y	+	+	+
4	Tioga Pass	3024		y	+	+	/
5	Tioga Pass	2976		y	+	+	+
8	Tioga Pass	2992		y	+	+	+
11	Gaylor Lake	3257		y	+	+	nv
12	Gaylor Lake	3257		y	+	+	nv
13	Gaylor Lake	3257		y	+	+	/
14	Gaylor Lake	3257		y	+	+	nv
16	Gaylor Lake	3257		y	+	+	+
17	Gaylor Lake	3257		y	+	+	nv
18	Gaylor Lake	3257		y	+	+	nv
19	Parker Pass	3393	x	y	/	/	+
20	Parker Pass	3462		y	/	/	/
22	Lyell Canyon	2687		y	+	+	+
24	Tuolumne Meadows	2854		y	+	+	nv
26	Tuolumne Meadows	2627		y	+	nv	-
27	Tuolumne Meadows	2636		y	/	/	+
28	Pothole Dome	2622		y	+	+	nv
29	Pothole Dome	2616		y	/	/	nv
30	Pothole Dome	2621		y	/	/	nv
32	Tioga Road	2776	x	y	+	+	nv
33	Tioga Road	2776		y	+	+	nv
34	Tioga Road	2778	x	y	+	+	nv
36	Tuolumne Meadows	2619	x	y	+	+	nv
45	Tenaya Lake	2533	x	y	+	+	nv
50	May Lake	3308		y	/	+	nv
51	Cathedral Lake	2918		y	+	+	nv
52	Cathedral Lake	2933		y	+	+	/
54	Elizabeth Lake	2898		y	/	/	nv
56	Vogelsang	3152	x	y	/	/	nv
57	Vogelsang	3152	x	y	/	/	nv
58	Vogelsang	3158	x	y	+	+	+
59	Vogelsang	3097		y	/	/	+
60	Vogelsang	3361	x	y	+	+	+
61	Vogelsang	2856		y	+	+	/
62	Tuolumne Meadows	2609		y	+	+	/
63	Pothole Dome	2621		y	/	/	/
67	Tuolumne Meadows	2625		y	/	/	-
68	Parker Pass	3023		y	/	/	nv
71	Parker Pass	3324		y	/	/	nv
76	Tenaya Lake	2618		y	/	/	+
78	Tuolumne Meadows	2614		y	/	/	/
92	Tuolumne Meadows	2621		y	+	/	/
94	Sunrise	2860		y	+	+	nv

Figure 9. Results - Meadow edges unchanged
Photo #78, the west end of Tuolumne Meadows looking south with Cathedral Peaks in the background. Areas of meadow edge (right) show no change since 1988, whereas other areas (left, further down meadow) show evidence of meadow invasion away from the edge.

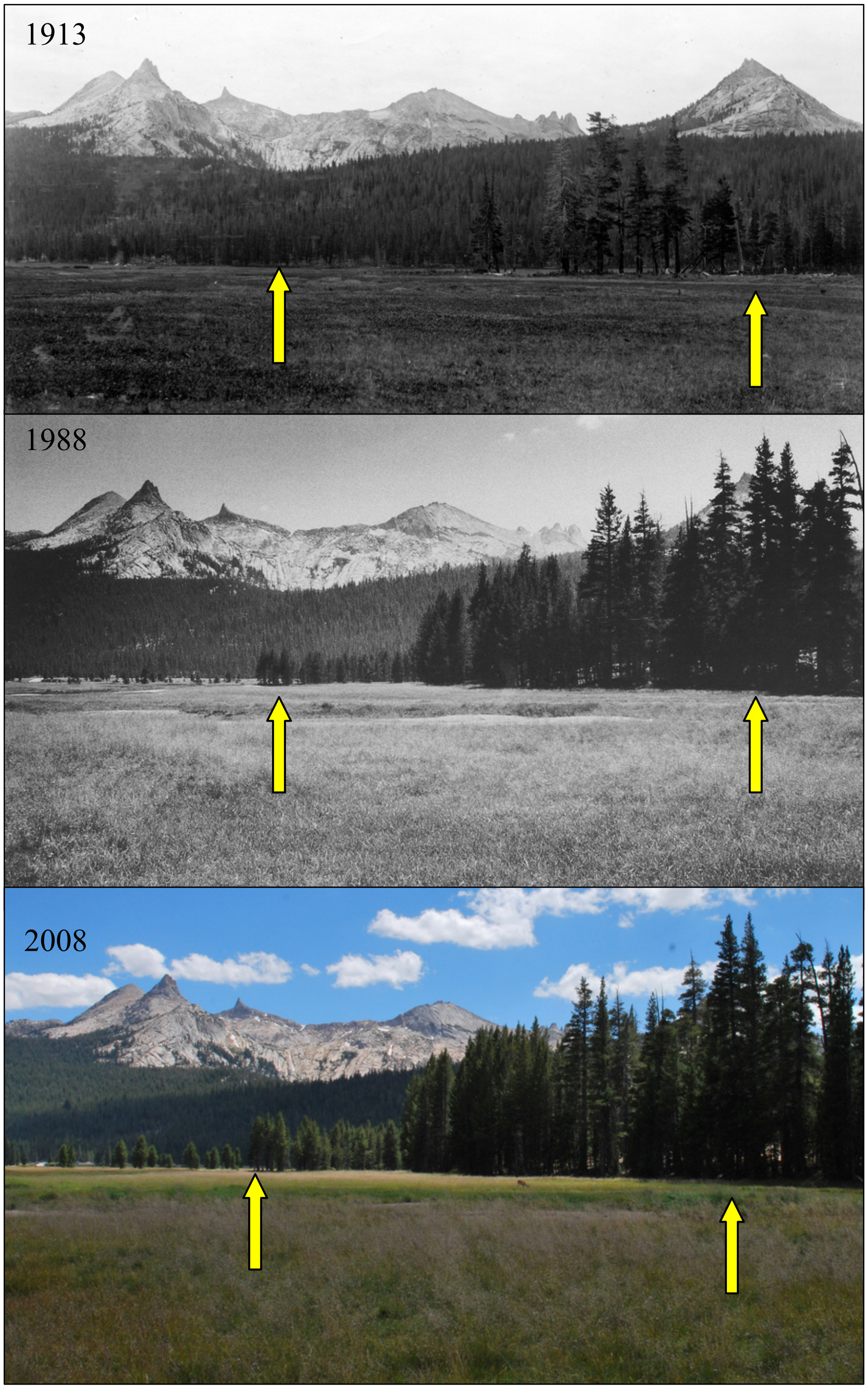


Figure 10. Results - Meadow Invasion
Photo #62, view of Fairview dome across the western end of Tuolumne Meadows demonstrating tree invasion into the meadow from the forest stand to the left (east).

Figure 11. Results - Obscured view due to substantial growth
Photo # 68, near the junction of Spillway Lake and Mono Pass trails, the distant ridges and foreground objects are obscured by substantial growth of the forest stand as it moves into the meadow valley. The large dark rock visible in the 1917 image is noted in subsequent photos.

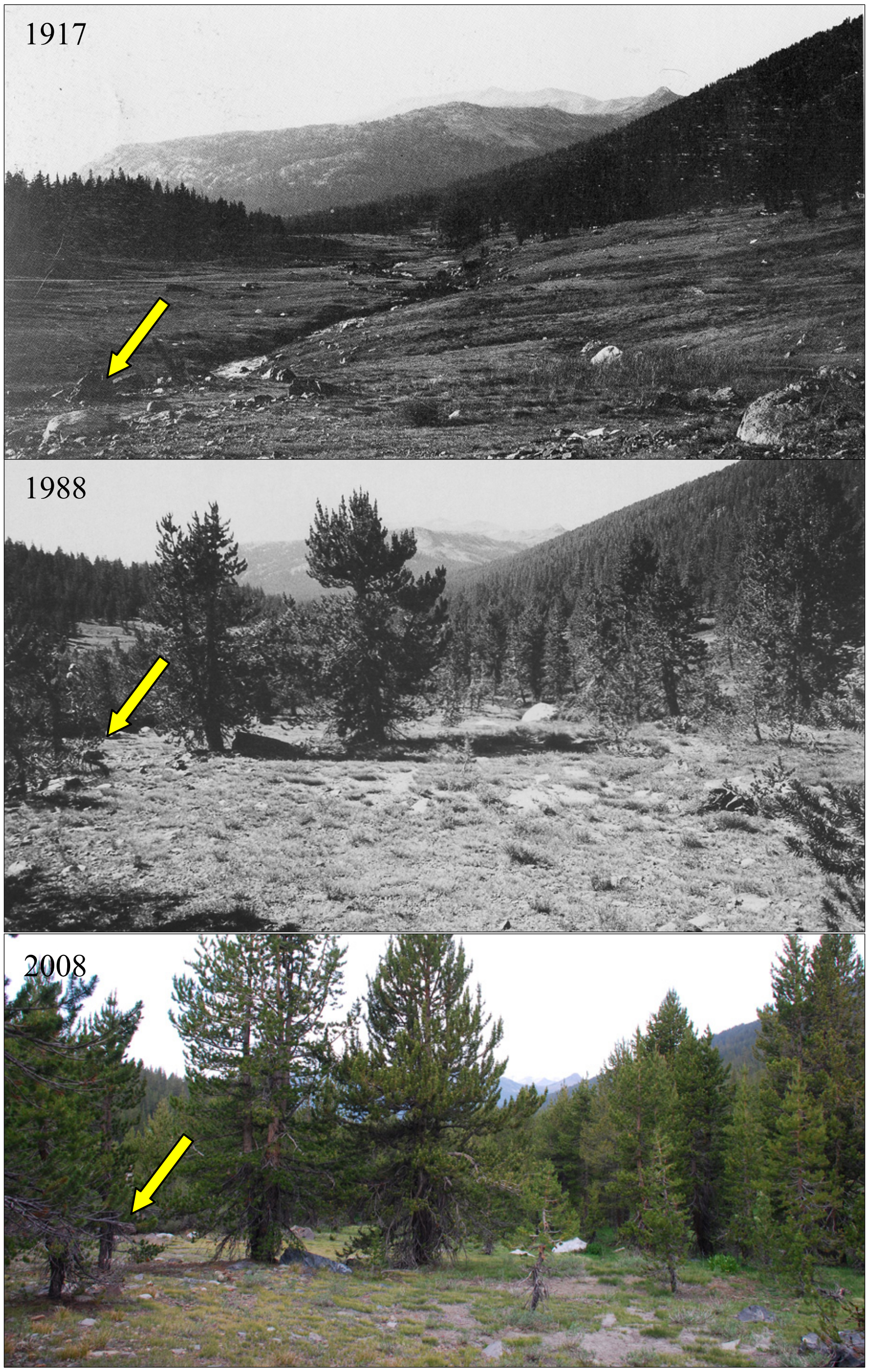
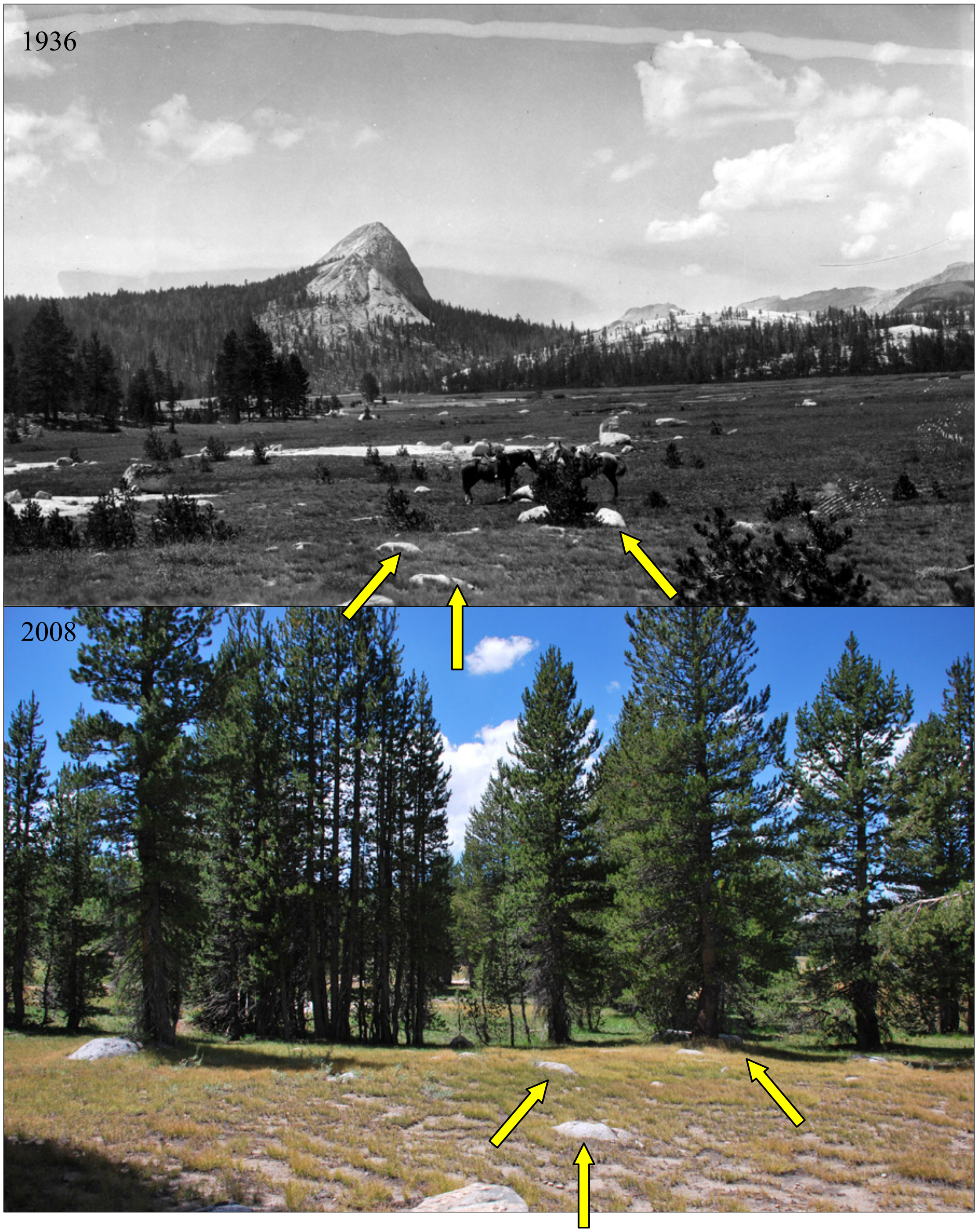


Figure 12. Results - Meadow invasion obscuring scene
Photo #36, looking southwest across Tuolumne Meadows towards Fairview Dome. The three foreground boulders are noted, particularly the set on the right with the tree growing between them. These benchmarks were key in discovering this site. No c1985 photo was available for this scene.



These photo comparisons show invasion of meadows by trees has continued in the Tuolumne Meadows area. In the short term (c1985-2008) there has been notable tree growth along meadow edges and over a century of change, there are numerous examples of substantial tree invasion. Across the Sierra Nevada, the causes of tree encroachment into meadows vary and cannot be neatly defined (Ratliff 1985; Fites-Kaufman *et al.* 2007). Some argue that cyclical climatic patterns, both seasonal shifts in precipitation and water table levels, have the greatest impacts (Fites-Kaufman *et al.* 2007), while others postulate that the removal of grazing (Franklin *et al.* 1971; Dunwiddie 1977; Bahre and Bradbury 1978; Vankat and Major 1978; Vale 1987; Taylor 1990; Miller and Halpern 1998), and/or increased fire suppression have allowed for increased tree encroachment.

Without a clear understanding of what factors or what combination of factors have the most impact, further study into meadow feedback loops is needed. Study plots and survey measurements within the viewshed of these repeat-photography sites could be utilized in future studies to enhance the qualitative data available with specific quantitative measures.

Changes in density of local patches of forest and forest clearings

Forest clearings have decreased and forest patches have increased, resulting in denser forest stands (Figure 13). Vale (1987) identified 13 photo pairs that exhibited increased forest density in areas away from the tree line and removed from meadow edges. When comparing c1985 to 2008 photos, 63 percent (26 of 41 photos) exhibited evidence that forest clearings had decreased and overall density had increased (Table 6 and Figure 14). In the case of photo #96, the forest stand is visible but there is not enough detail to determine a change in stand density or reduction in clearings. Similar findings of increased forest density have been suggested within the Sierra Nevada (SNEP 1996; Lloyd and Graumlich 1997; Potter 1998; Millar *et al.* 2004; Fites-Kaufman *et al.* 2007) and across the American West (Hutchinson *et al.* 2000; Murray *et al*. 2000; Butler and DeChano 2001; Klasner and Fagre 2002; Zier and Baker 2006).

As discussed, fire management and precipitation cycles are thought to be the main contributing influences to increased forest stand density (Vale 1987; Peterson *et al.* 1990; Butler and DeChano 2001; Roush *et al.* 2007). Cyclical fire regimes clear the understory, remove woody debris from the forest floor, remove pests and/or diseased trees from stands, and open holes in the canopy which encourages growth of diverse tree species thus forming a heterogeneous forest stand (Millar *et al.* 2004; Fites-Kaufman *et al.* 2007). Together, periods of drought coupled with extended periods between fires can result in higher susceptibility of wide spread and more intense fires (Millar *et al.* 2004).

Figure 13. Results - Reduced forest clearings
Photo #33, view northeast across the Tuolumne River and the northwestern end of Tuolumne Meadows. In this view, denser forest stands and filled in forest clearings are visible.

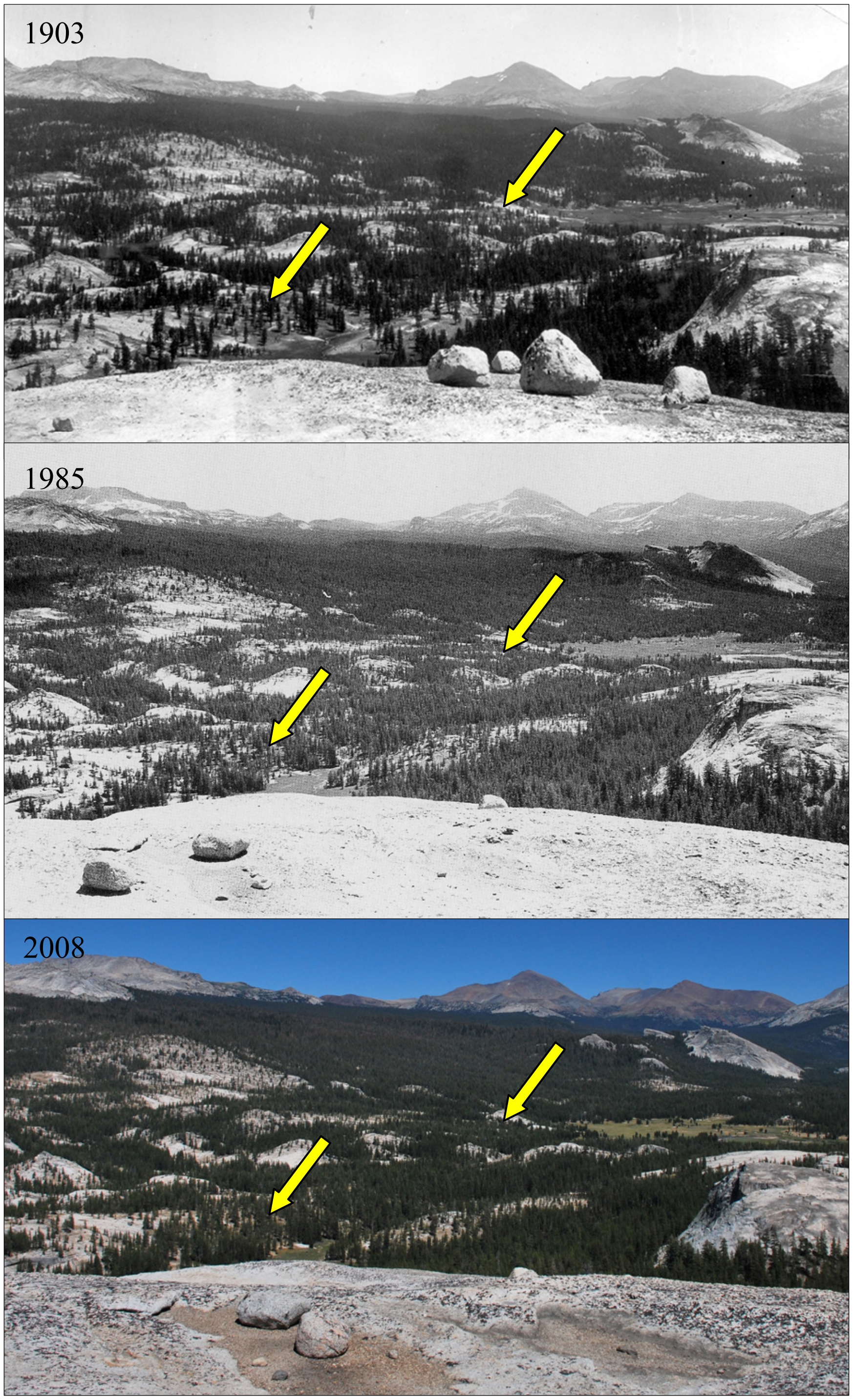
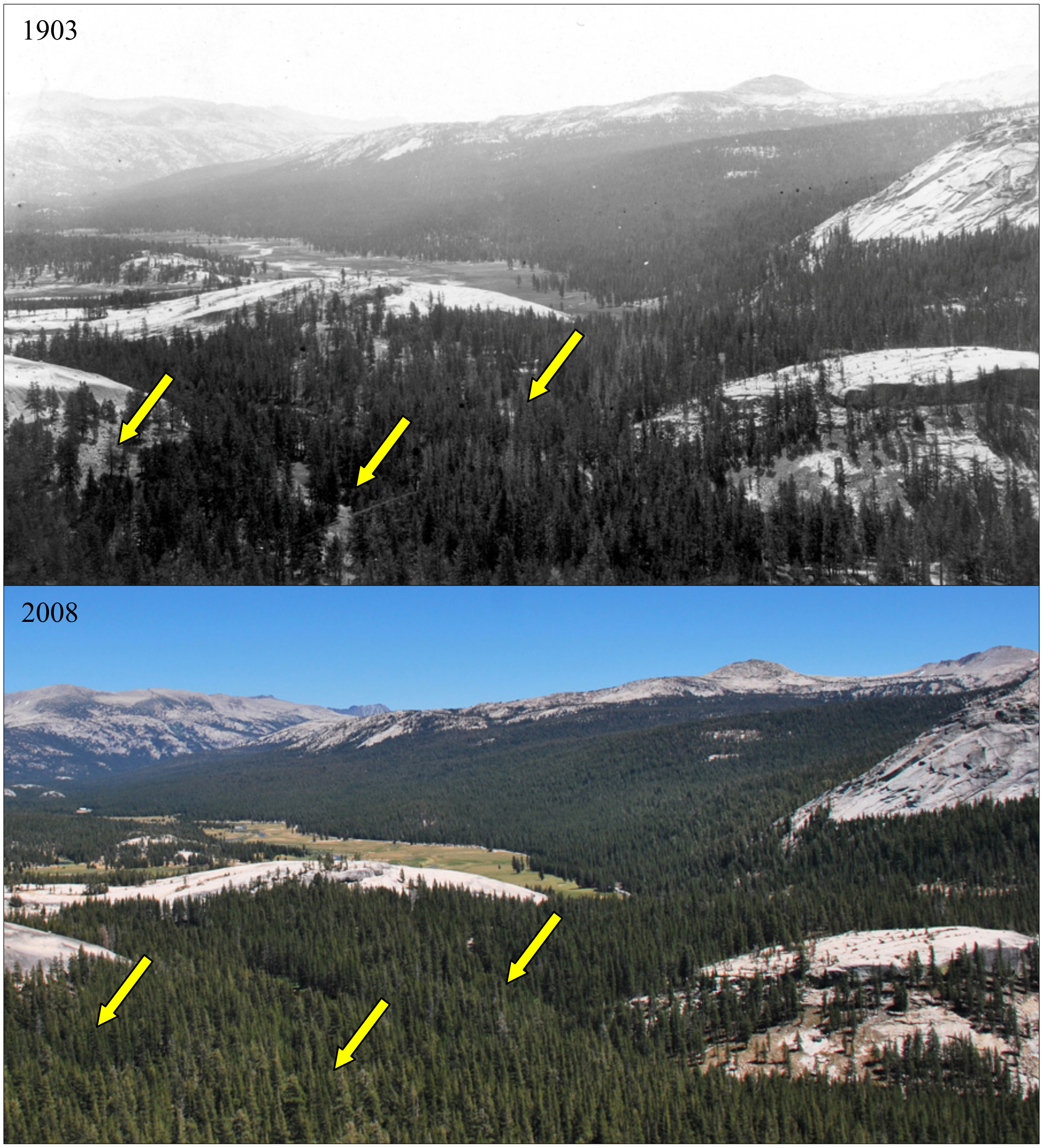


Table 6. Forest Stand Photo Analysis

Repeat-photography analysis of photo sets containing forest stands. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Forest Stand Visible	Density/ Cover (+, -, /)	Visible die off
2	Tioga Pass	2953		y	+	
3	Tioga Pass	3009		y	+	
4	Tioga Pass	3024		y	+	
8	Tioga Pass	2992		y	/	
9	Gaylor Lake	3257		y	+	
10	Gaylor Lake	3257		y	+	
13	Gaylor Lake	3257		y	+	
14	Gaylor Lake	3257		y	+	
15	Gaylor Lake	3257		y	+	
16	Gaylor Lake	3257		y	+	
17	Gaylor Lake	3257		y	+	
18	Gaylor Lake	3257		y	+	
22	Lyell Canyon	2687		y	+	
31	Pothole Dome	2634		y	+	
32	Tioga Road	2776	x	y	+	
33	Tioga Road	2776		y	+	
34	Tioga Road	2778	x	y	+	
35	Tioga Road	2784	x	y	+	
38	Glen Aulin	2663	x	y	+	
40	Glen Aulin	2663	x	y	+	
41	Glen Aulin	2663	x	y	+	
42	Young Lakes	2729		y	/	
44	Cathedral Lake	2990	x	y	+	
45	Tenaya Lake	2533	x	y	+	
46	Tenaya Lake	2535		y	+	
47	Tenaya Lake	2489	x	y	+	
48	Tenaya Lake	2493		y	/	
49	May Lake	2807		y	+	
50	May Lake	3308		y	+	y
51	Cathedral Lake	2918		y	+	
52	Cathedral Lake	2933		y	/	
54	Elizabeth Lake	2898		y	+	
56	Vogelsang	3152	x	y	+	
57	Vogelsang	3152	x	y	+	
58	Vogelsang	3158	x	y	+	
60	Vogelsang	3361	x	y	+	
61	Vogelsang	2856		y	+	y
62	Tuolumne Meadows	2609		y	/	
64	Tioga Road	2655		y	+	
66	May Lake	2746		y	+	
68	Parker Pass	3023		y	+	
74	Tenaya Lake	2588		y	/	
76	Tenaya Lake	2618		y	/	
79	May Lake	2855		y	/	
82	Glen Aulin	2502		y	/	
89	Mono Pass	2982		y	+	
90	Young Lakes	2691		y	+	
91	Tioga Pass	2779		y	-	
94	Sunrise	2860		y	/	y
96	Tenaya Lake	2566		y	nv	
99	Tenaya Lake	2529		y	/	
100	Tenaya Lake	2488		y	/	
101	Tenaya Lake	2495		y	+	y
102	Tenaya Lake	2495		y	-	

Figure 14. Results - Increased forest stand density
Photo #32, a view east across Pothole Dome (center-left) and western Tuolumne Meadows. The forest stand appears denser and lacks small clearings visible in the 1903 photograph (noted with arrows). In this case, no c1985 image was available.



In four distinct locations (7%), there was visible evidence of large scale tree die-off (Figure 15 & Figure 16). Extended patches of apparently dead and/or dying trees can have numerous causes including disease/pest infestation and areas of recent fires. In the Sierra Nevada, different species of bark beetle have become a widespread threat to alpine and sub-alpine forests due to increased density of forest stands, the lack of cyclical fire regiments, and increased drought intensity (see Ferrell 1996; Fites-Kaufman *et al.* 2007).

This photo set could be used to monitor the spread of disease/pest infestation and/or document post fire succession. From these four identified areas of die off, causality could not be determined (Pest? Fire? Disease?) and thus continued monitoring of die-off extent is suggested. Future study could include continued monitoring and assessment of stand health, pre- and post-disturbance monitoring, and canopy cover estimates.

Figure 15. Results - Forest stand health
Photo #94, Long Meadow adjacent to Sunrise High Sierra Camp, with Columbia Finger in the distance. While tree growth into the meadow is evident in this triplet, there is not enough detail to determine forest stand density (mainly due to obscured view in 2008). Important to note, this view provides an example of large scale die-off (see Figure 16).

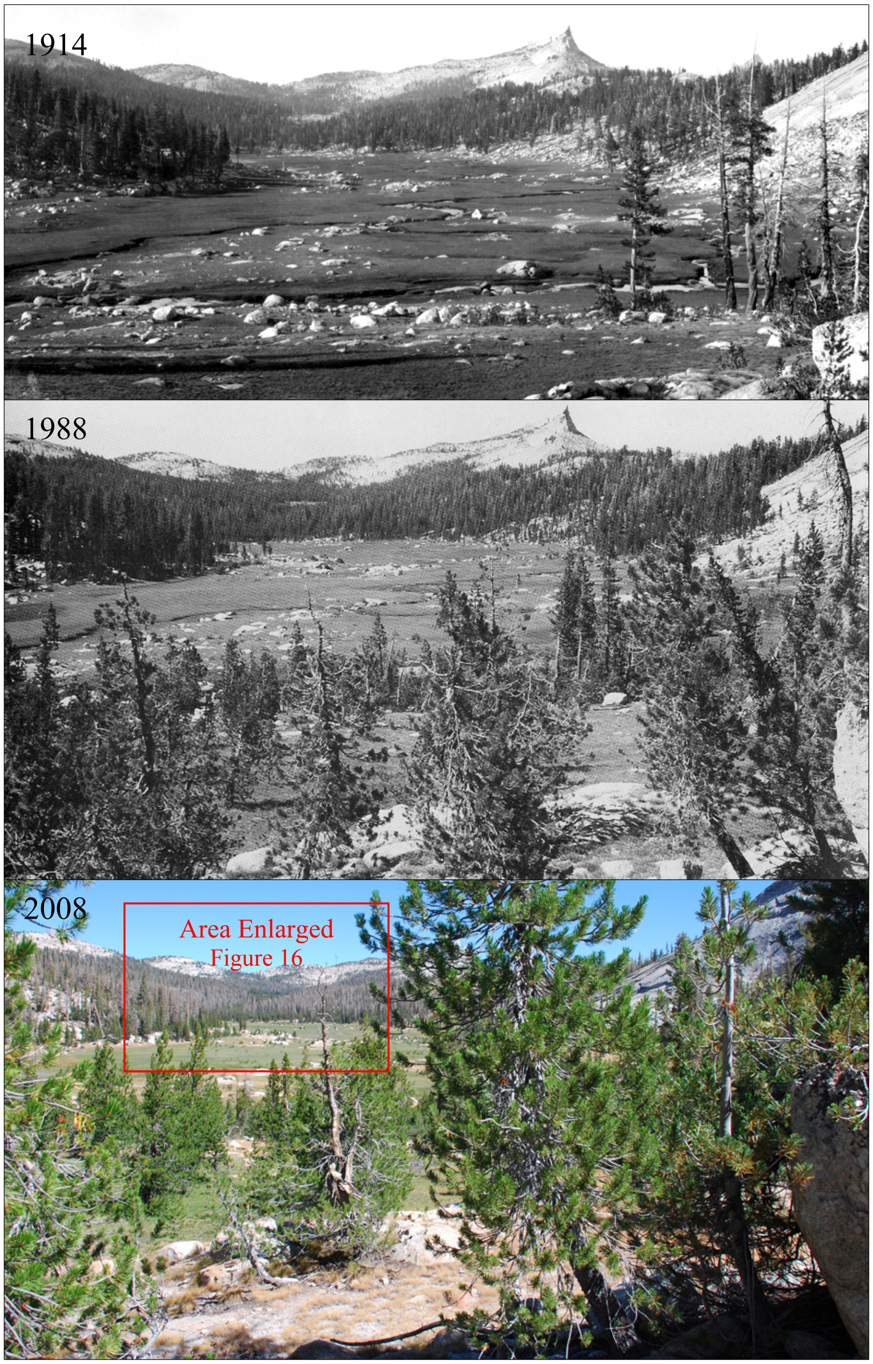


Figure 16. Results - Areas of substantial tree die-off
Enlarged area of Photo #94, Long Meadow near Sunrise High Sierra Camp. Substantial tree die-off is visible across the entire southern exposure of the valley.

Changes in growth patterns of trees on domes and rocky slopes

Tree growth on domes and small patches of forest on rocky slopes has increased, including evidence of tree growth where semi-permanent snow patches once existed (Figure 17). Forty-nine photo sets contained domes and/or small patches of trees on rocky slopes, though only 69 percent (34) could be compared to c1985 photos (Table 7). Of this subset, 76 percent (26 sites) exhibited evidence of increased density and individual tree growth while 24 percent (8 sites) had no detectable change. In some cases, mature individuals were visible in the 2008 photos where sapling had previously been visible in the c1985 photos (Figure 19). In these instances, minimal or no new sapling growth was apparent, only additional growth of already germinated individuals.

As with larger forest stands, tree growth on rocky slopes and on and around domes has increased dramatically over the last century (Figure 20). In historic photographs, widely spaced individual trees and clearings between trees are visible. In the 2008 photo set, there is a visible increase of individual trees on and around domes, a reduction of forest clearings/space between trees, and evidence of new sapling growth (in some cases). Additionally, there are instances of new sapling and tree growth in areas previously containing summer snow patches (Figure 17). Evidence of mixed age stands suggests multiple cycles of germination which confirms Vale’s (1987) conclusions. Decreased forest clearings and increased forest patches result in crowded forest stands, higher instances of disease/pest infestation, reduced forest biodiversity, and greater susceptibility to more intense fires (Peterson 1990; Ferrell 1996; Fites-Kaufman *et al.* 2007).

Domes and rocky hillsides provide interesting examples where individual trees can be identified and monitored remotely (Figure 21). Future study utilizing this repeat-photography data set could include monitoring of growth rates, as well as possible geologic changes surrounding instances of rock fall. Meadow, dome, and forest stand margins along with new growth into snow patches (see Millar *et al.* 2004) could also be studied using the historic reach available with this data set. Domes and rocky slopes, usually sparsely populated by individual trees, provide examples where individual trees could be monitored and tracked with future monitoring.

Table 7. Domes and Rocky Slope Photo Analysis
Repeat-photography analysis of photo sets where domes and rocky slopes were present. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Dome/rock slope visible	Density/ Cover (+, -, /)	Saplings visible
1	Tioga Pass	2985	x	y	+	nv
2	Tioga Pass	2953		y	+	y
3	Tioga Pass	3009		y	+	y
4	Tioga Pass	3024		y	+	y
5	Tioga Pass	2976		y	+	y
24	Tuolumne Meadows	2854		y	+	y
25	Tuolumne Meadows	2858	x	y	+	y
27	Tuolumne Meadows	2636		y	+	y
28	Pothole Dome	2622		y	+	y
29	Pothole Dome	2616		y	+	y
30	Pothole Dome	2621		y	+	y
31	Pothole Dome	2634		y	+	n
32	Tioga Road	2776	x	y	+	y
33	Tioga Road	2776		y	+	n
34	Tioga Road	2778	x	y	+	y
35	Tioga Road	2784	x	y	+	y
38	Glen Aulin	2663	x	y	+	y
40	Glen Aulin	2663	x	y	+	y
41	Glen Aulin	2663	x	y	+	y
44	Cathedral Lake	2990	x	y	/	n
45	Tenaya Lake	2533	x	y	+	y
46	Tenaya Lake	2535		y	+	y
47	Tenaya Lake	2489	x	y	+	y
48	Tenaya Lake	2493		y	/	nv
49	May Lake	2807		y	+	y
50	May Lake	3308		y	+	y
51	Cathedral Lake	2918		y	+	y
52	Cathedral Lake	2933		y	/	nv
54	Elizabeth Lake	2898		y	+	y
57	Vogelsang	3152	x	y	+	y
58	Vogelsang	3158	x	y	+	y
59	Vogelsang	3097		y	+	y
60	Vogelsang	3361	x	y	+	y
61	Vogelsang	2856		y	+	n
62	Tuolumne Meadows	2609		y	/	nv
63	Pothole Dome	2621		y	+	y
64	Tioga Road	2655		y	+	y
65	Tioga Road	2644		y	/	n
72	Glen Aulin	2591		y	+	n
75	Tenaya Lake	2594		y	/	y
76	Tenaya Lake	2618		y	/	n
79	May Lake	2855		y	/	n
81	Tenaya Lake	2503		y	/	n
82	Glen Aulin	2502		y	+	y
83	Cathedral Lake	2906		y	+	y
85	Glen Aulin	2597		y	+	n
90	Young Lakes	2691		y	+	y
96	Tenaya Lake	2566		y	nv	nv
98	Tenaya Lake	2488		y	+	y

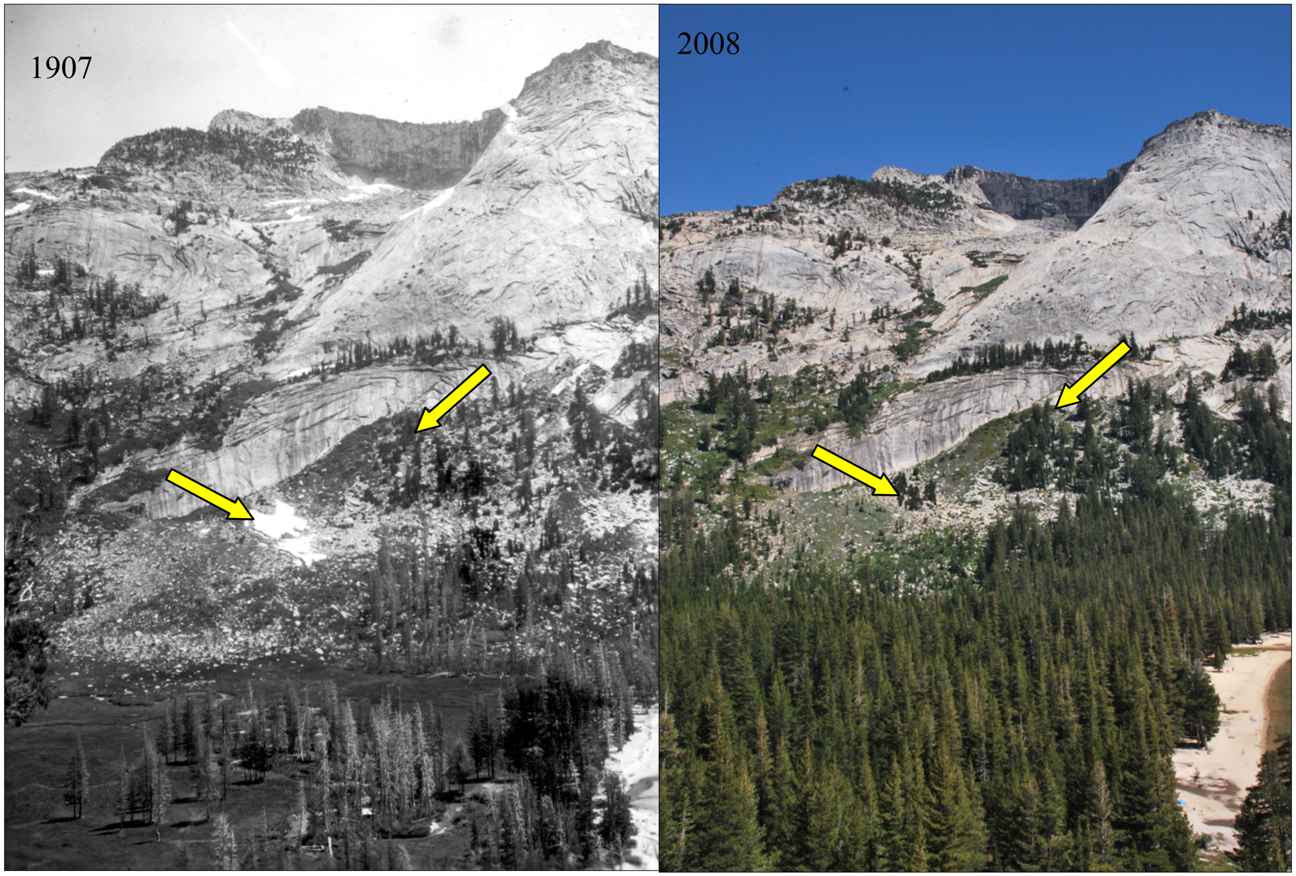


Figure 18. Results - Tree growth in snow patches and on rocky slopes
Photo # 45, the eastern shore of Tenaya Lake. Tree growth has increased on rocky slopes (at photo right) and in areas previously containing snow patches. These snowy areas would provide increased moisture through the summer months (at photo left). This image also includes a good comparison of tree invasion into meadows (at lower left). No photograph from c1985 is available for this site.

Figure 19. Results - No new saplings visible around domes
Photo # 29, at the western end of Tuolumne Meadows looking at Pothole Dome, where no new sapling growth is visible in 2008 along dome apron.

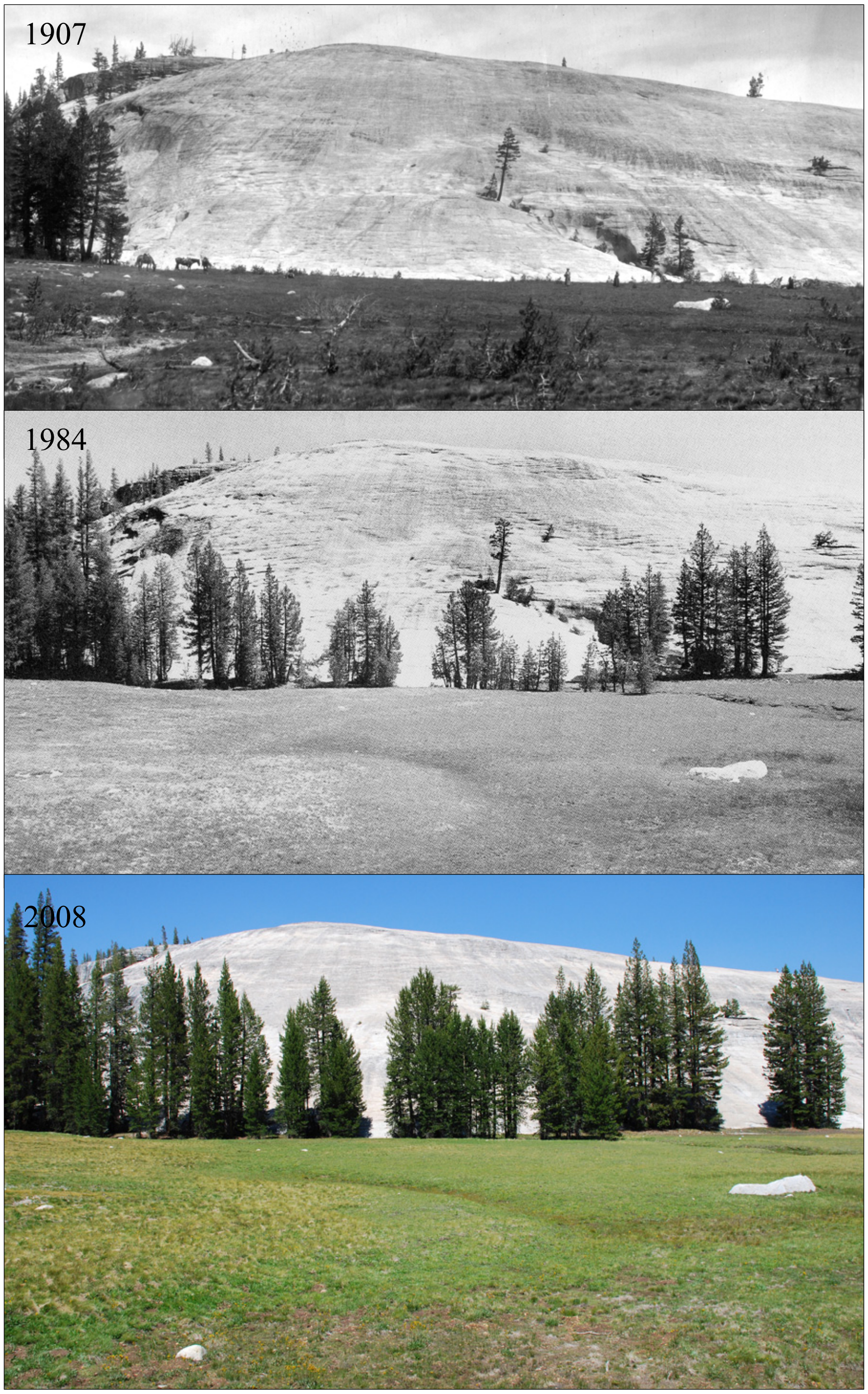


Figure 20. Results - Growth on rocky slopes
Photo #54, rocky hillside growth west of Elizabeth Lake at 2,898m. Note the additional growth and presence of new saplings amongst the protected rocks but not in the avalanche chute.

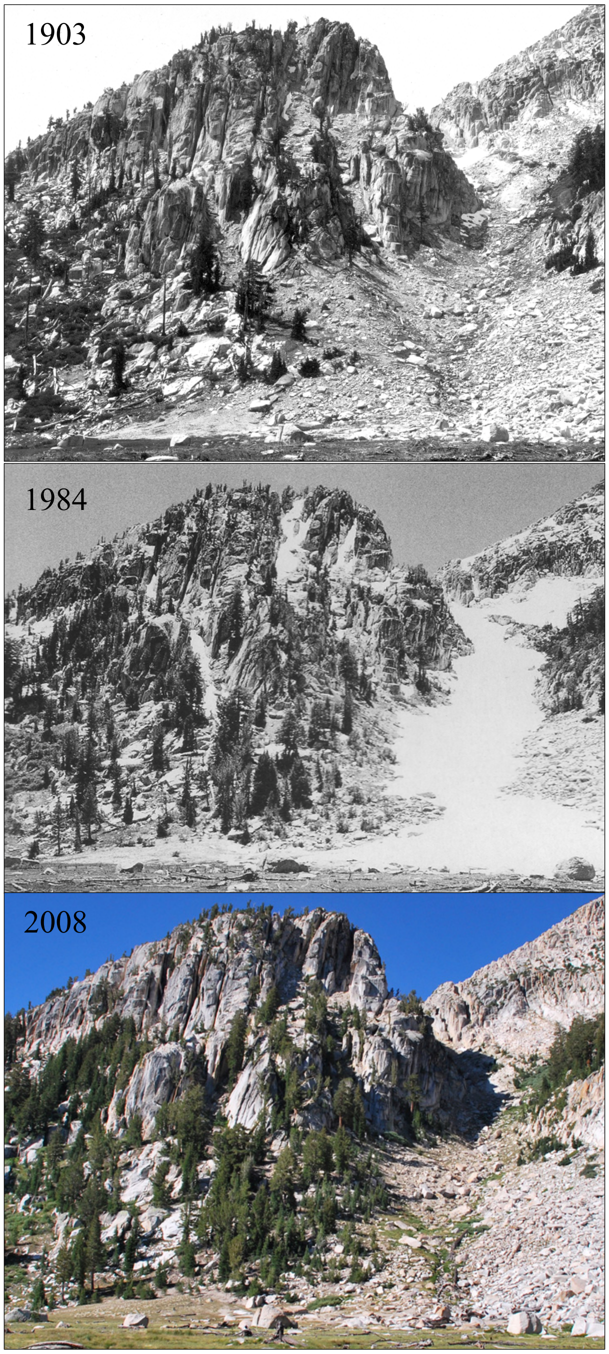
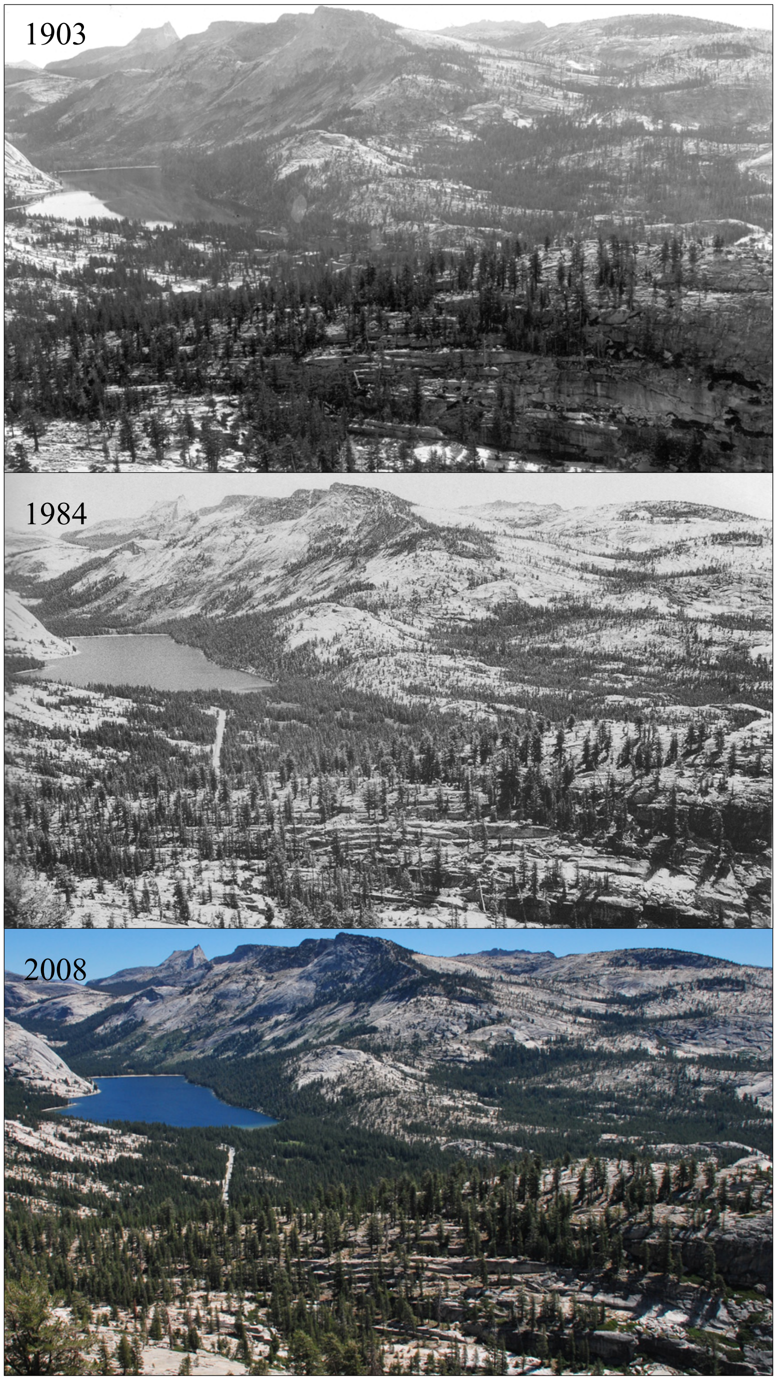


Figure 21. Results - Tree growth on granite domes
Photo #49, looking east from near the base of Mt. Hoffmann, towards Tenaya Lake. The foreground dome section and forest stand extending beyond provide examples of increased tree growth, the establishment of new saplings over time, and increased forest stand density.



Reduction of snow patches

Snow patches at higher elevations, visible during the summer time, were visible at many photo sites (Figure 21). Over 90 percent of photos that contained snow patches showed evidence of reduction (Table 8). In only two photo sets (#71 and 78), no detectable change in the size of patches was evident.

It is important to note that no conclusions are possible from this data set. While we know historic photographs were captured in the summer months, the exact dates of the c1900 and c1985 photographs are unknown. That said, even if we knew these dates it is near impossible to draw concrete conclusions from the visual record. There are few permanent glaciers in this area of the Sierra Nevada, and thus single snapshots of snow patch area are insufficient to glean conclusions. Though most of the snow visible in the summer is left over from the previous winters snowpack, snow and hail fall in the upper Sierra Nevada year round.

Specific time and date meta-data was collected in this study and can and should be used in the future to address snow/precipitation measurements related study(s). Annual snow depths, annual and average temperature analysis, and visible records of snow patches could be combined to address climate change in the Sierra Nevada Mountains. The inclusion of snow related data in this study is meant to prompt further investigation and use of the data set.

Table 8. Snow Patch Photo Analysis
Repeat-photography analysis of photo sets containing snow fields and patches. Photos compared c1985 and 2008 unless only c1900 photo available or otherwise noted. Visual change between photograph pairs identified as increase ("+"), decrease ("-"), no change ("/"), or not visible/not applicable ("nv").

Photo #	Area	Elevation (m)	Only c1900 photo available	Snow patches (+, -, /)
1	Tioga Pass	2985	x	-
2	Tioga Pass	2953		-
3	Tioga Pass	3009		-
4	Tioga Pass	3024		-
5	Tioga Pass	2976		-
8	Tioga Pass	2992		-
9	Gaylor Lake	3257		-
10	Gaylor Lake	3257		-
11	Gaylor Lake	3257		-
12	Gaylor Lake	3257		-
13	Gaylor Lake	3257		-
14	Gaylor Lake	3257		-
17	Gaylor Lake	3257		-
18	Gaylor Lake	3257		-
19	Parker Pass	3393	x	-
20	Parker Pass	3462		-
28	Pothole Dome	2622		-
33	Tioga Road	2776		-
45	Tenaya Lake	2533	x	-
51	Cathedral Lake	2918		-
52	Cathedral Lake	2933		-
54	Elizabeth Lake	2898		-
57	Vogelsang	3152	x	-
58	Vogelsang	3158	x	-
59	Vogelsang	3097		-
60	Vogelsang	3361	x	-
66	May Lake	2746		-
71	Parker Pass	3324		/
78	Tuolumne Meadows	2614		/
90	Young Lakes	2691		-
97	Tioga Pass RS	3030		-

Figure 22. Results - Reduced snow fields
Photo #20, the Parker Pass saddle looking south at Kuna Crest. Note that the exact date of the 1903 and 1984 photos are not available. The 2008 photo was taken July 14th, 2008 at 11:41am.

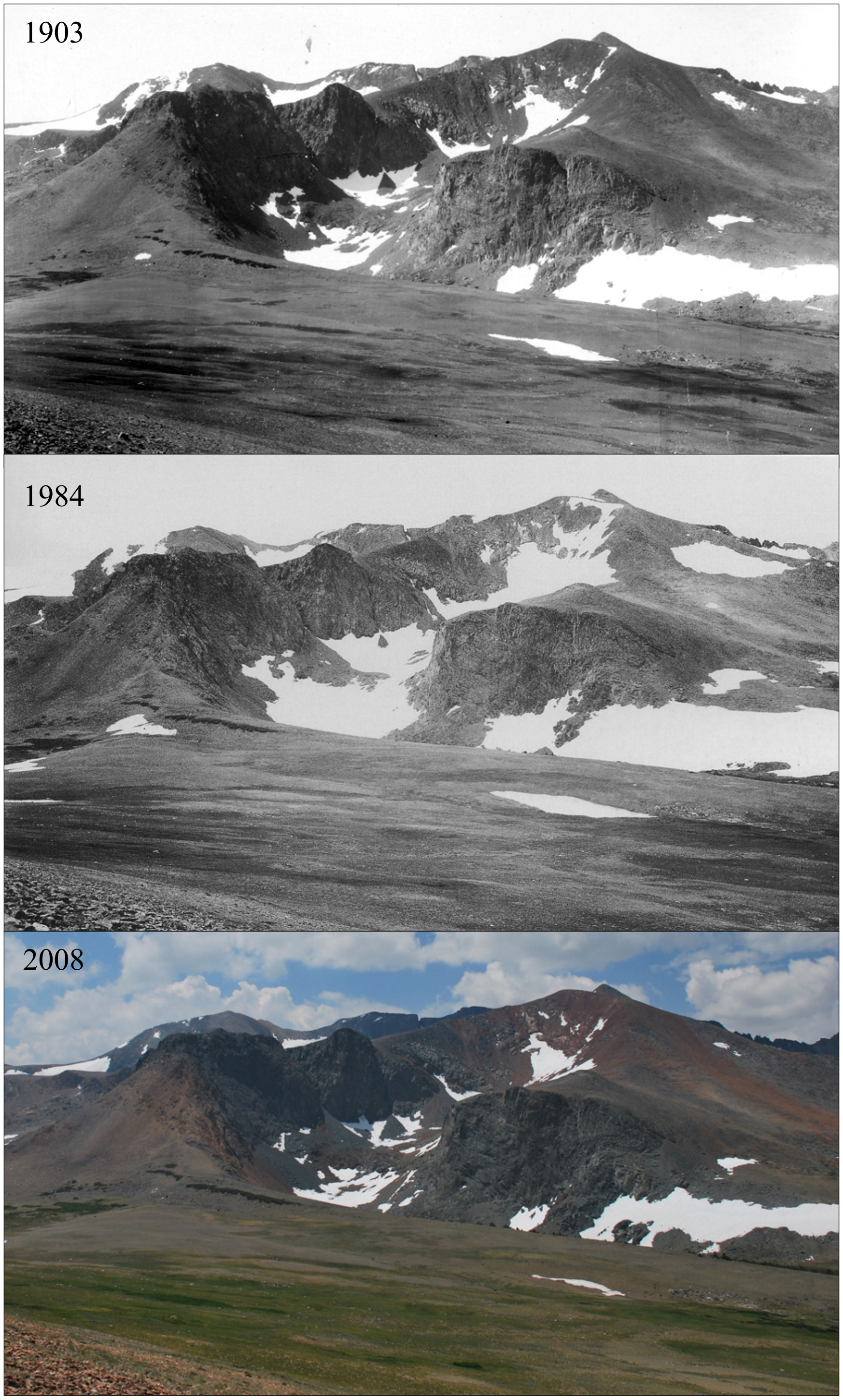


Figure 23. Results - Reduced snow fields II
Photo #13, a view south across lower Dana Meadow and Mammoth Peak captured on August 2nd. Summer snow patches can be seen on northern facing slopes of the surrounding peaks. The exact date for 1903 and 1984 photos was unavailable. The 2008 photo was taken August 2nd, 2008 at 12:10pm.