Restoration of Multiple-Rut Trails in the Tuolumne Meadows of Yosemite National Park

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Abstract—This study presents the techniques used in a restoration project in Tuolumne Meadows on the old Glen Aulin trail in Yosemite National Park from 1990 to 1994 and the results of follow-up monitoring in the summer of 1998. The project restored the natural hydrology and soils to a 4,200-foot section of abandoned trail which had two to six one-foot deep ruts. The project utilized hundreds of volunteer work hours and showed that restoration of subalpine meadows is possible.

Yosemite National Park has more than 800 miles of trails that guide people through its 1,200 square miles of Sierra Nevada wilderness. The park receives four million visitors per year and is mandated to preserve its natural and cultural resources while providing for public enjoyment. The division of Resources Management is charged with evaluating past management decisions and mitigating actions that adversely affect the resource.

Problem Statement

Yosemite's trails have protected much of the wilderness, while still allowing visitor access, because most visitors stay on designated trails (Chapman 1993). Unfortunately, some trails have caused significant local damage especially in meadows. This problem is most acute on the trails between Tuolumne Meadows and the five High Sierra Camps (HSC). These trails are used by at least 5,000 people and 600 head of stock, which take supplies to the High Sierra Camps each summer. The combination of stock and human use has created many long sections of deeply rutted, multiple-tread trails.

When impacts to wilderness are considered, trail damage is often overlooked. Problems such as soil erosion, trail widening and multiple treads result in significant amounts of vegetation and soil loss in wilderness areas (Scott 1998). Yosemite's resource managers have made mitigating trail impacts in subalpine meadows a high priority.

The original trail to the Glen Aulin HSC was located west of Delaney Creek in Tuolumne Meadows at an elevation of 8,600 feet. The trail cut directly across Tuolumne Meadows from Soda Springs to where the Tuolumne River starts dropping down toward the Tuolumne River Canyon. This 4,200-foot segment of trail developed between two and six ruts, some of which were a foot deep. This cumulatively denuded nearly a half acre (0.2 hectares) of subalpine meadow plant community. By unnaturally channeling water and therefore drying out areas, it negatively impacted an additional one acre (0.4 hectares) adjacent to the trail.

In 1960, this trail was rerouted into the trees to prevent further damage to the meadow. For the next 30 years, the deeply rutted, multiple-tread trail still received sporadic use and channeled water. In 1990, the multiple ruts through the meadow were still clearly visible. This paper describes the restoration process, which began in the summer of 1991, and included the efforts of NPS employees and hundreds of volunteers. The paper then explores the results of a 1998 study evaluating restoration success and species composition.

Restoration Techniques

In the summer of 1991, realizing that the trail was not naturally restoring itself, the Yosemite Ecological Restoration staff started investigating ways to fund the restoration of the old Glen Aulin Trail. The Yosemite Fund had already supported restoration projects in Yosemite through annual grants since 1987. The restoration of multiple-rut trails fit nicely into three general criteria for projects that the restoration staff tried to tackle in the early 1990s: 1) It was negatively impacting the natural resource; 2) It was an eye sore; and 3) It was ideal work for youth and voluntary labor.

This trail was chosen, from among several other rutted trails, because the 30 year-old reroute was firmly established and removed use from the area in need of restoration.

Objective: to improve the microenvironment of the old trail area by restoring the natural hydrology and soils to the impacted areas to the extent that the original meadow species would reestablish themselves.

Restoration staff measured the linear feet of trail ruts and used this measurement to estimate the cubic feet of fill needed to bring the ruts back up to grade. It was determined that fill could be obtained from nearby ephemeral drainages.

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Propagated plants were needed, so staff collected seed from reed grass *(Calamagrostis brewerii* [CABR]) and oat grass (*Danthonia intermedia* [DAIN]) from adjacent areas. Sedges (*Carex fillifolia* [CAFI] var. *erostrata*) and rushes (*Juncus parryi* [JUPA]) were collected and divided into plugs for replanting the following year. An estimate was made on the number of person hours it would take to restore the entire 4,200-foot section of trail. It was clear that it would take more than one summer to complete the project.

Realizing that thousands of hours of physical labor in this beautiful area would be needed, the Restoration Staff teamed up with several groups that often provide volunteers to the National Park Service. The Student Conservation Association (SCA) sends six-person high school crews to national parks for four weeks each summer. One SCA crew worked on the Glen Aulin trail in 1992, 1993, and 1994. Because the same leader returned every year, the quality of their work was very high, and they needed minimal guidance. Youth Conservation Corp (YCC) places groups of 12 high school age individuals who are paid minimum wage in the national parks for eight weeks each summer. The Sierra Club (SC) offers work trips where adults pay to come and work in parks for about one week. Finally, Yosemite Association (YA) places groups of 15 adults in the park for one week. Through a partnership between the National Park Service, Yosemite Association, Yosemite Institute and Yosemite Concession Services, the volunteers are provided campsites and meals for a week in exchange for labor. These groups accomplish a varied amount of work based on the proximity of the worksite to their campsite and their degree of acclimatization to the subalpine environment.

1992 Restoration (Segment One)

Work began in a dry meadow section where the old trail departed from the present trail. A YCC crew began by removing old rock check dams that were built with the intention of reducing erosion. Next, the YCC crew salvaged the topsoil and the few scattered plants that had established themselves in the rutted trail tread. An SCA crew scarified the bottom of the ruts to loosen up the soil. Finally, fill material was added to the ruts to bring them up to the level of the surrounding meadow.

The fill material was collected from a nearby ephemeral drainage. These borrow pits were trenches dug wide enough for a string of mules to walk into. Two workers standing on either side of the trench shoveled fill material into dirt boxes carried by the mules. The NPS packers used these mules to move 64 cubic yards (376 mule loads) of fill in 1992. As a result, a 1,350-foot section of trail was brought back up to grade, and a one to two-inch layer of the salvaged meadow topsoil was spread on top.

In late September, a restoration staff member and two wilderness rangers began replanting 2,200 propagules, 150 meadow pieces and 25 lodgepole pine seedlings. A gas-powered water pump and 1,000 feet of fire hose were used to water the propagules during transplanting. Water helped to get the plants firmly into the ground since damp soil tamps down much tighter. Plants that workers forgot to tamp were frost-heaved out of the ground by 1993. Planting was done in late September to avoid having to re-water (plants experience less water stress when daytime temperatures are cooler and they are nearing winter dormancy) (Rochefort, 1990). Propagules are particularly susceptible to water stress. This method has been found to be successful in other areas (Olympic National Park, Scott 1998).

Labor for the 1992 section (table 1):

a) Six-person Student Conservation Association high school work group worked for three weeks bringing 850 feet of trail back up to grade (715 hours).

b) Twelve-person Youth Conservation Crew work group worked for one week bringing 400 feet of trail back up to grade (400 hours).

c) Three NPS employees replanted 2,200 nursery propagules (150 hours).

d) One packer and five mules for one week (40 hours).

1993 Restoration (Segment Two)

In 1993, a total of 1,050 feet of trail through wet meadow was restored. Of this total, 330 feet was brought to grade in 1992. Work progressed slowly because this section of old trail had five distinct ruts, each over a foot deep. Although some vegetation was growing in the ruts, it was primarily pioneer species not found in the undisturbed meadow.

In an area one foot wider than the distance across all the ruts, all living plant material was dug up in pieces averaging 12 inches on a side and 10 inches deep. This left a trench averaging 12 feet wide with purposely undulating sides to reduce unnatural straight lines. Where topsoil existed, it was removed and stockpiled next to the trail. The trench was

Table 1—Finances for the Glen Aulin Trail restoration project.

Finances	1991	1992	1993	1994	Total
Restoration staff	1,000	3,107	3,518	856	8,481
Student Conservation Association		8,000	10,760	12,395	31,155
Youth Conservation Corps		4,500			4,500
Supervision of Student Conservation Association and YA			2,400	1,800	4,200
Packing (mules)		Free	Free	248	248
Tool/vehicles		2,230	500	2,373	5,103
Nursery plants		4,000			4,000
Totals	$1,000	$21,837	$17,178	$17,672	$57,687

then filled with imported fill soil collected from ephemeral drainages in the same method as 1992. It was then capped with the stockpiled topsoil. The meadow sod pieces were then planted randomly to imitate the natural mosaic in the adjacent plant community. The large pieces of salvaged sod were replanted in late August but did not suffer as much water stress due to their size and the higher natural soil moisture of this area.

Labor for the 1993 section (table 1):

a) A six-person Student Conservation association group worked for four weeks restoring 750 feet of trail. A 330-foot section of this trail was revegetated in an area already brought up to grade by the YCC crew in 1992 (1,134 hours).

b) Twelve Sierra Club volunteers restored 100 feet of trail in six days (480 hours).

c) Sixteen Yosemite Association volunteers restored 80 feet of trail in four days (480 hours).

d) Six NPS Restoration staff members restored 120 feet in three days (180 hours).

1994 Restoration (Segment Three)

The final 2,000 feet of trail led out of the dry meadow and into the meadow-forest ecotone. The techniques used in 1993 were repeated. When transplanting sod, buckets of water were hand-carried from Delaney Creek. On one sloped section, old down trees were partially buried in the old trail to hold the soil in place. Since the entire old trail was brought to exact grade, the buried tree trunks were to slow surface runoff until the vegetation grew back. Some sections of trail needed very little work, while other areas needed large amounts of fill material.

The 1992 and 1993 borrow pits had filled in as a result of ephemeral drainages that drop their sediment load during spring runoff. The 1994 borrow pits were caved in and contoured by work leaders at the end of the summer so that they appeared to be natural low spots. These areas have been naturally filled in since the 1994 season.

Labor for the 1994 section (table 1):

a) Six-person Student Conservation Association crew restored 1,380 feet in four weeks (1,134 hours).

b) Twelve Yosemite Association volunteers restored 250 feet in four days (408 hours).

c) Seventeen Yosemite Association volunteers spent one day finishing 370 feet of trail (544 hours).

1996, 1997 Touch Up

Many of the YA volunteers return to Tuolumne and volunteer almost every summer, and they often spend one day each year working on the Old Glen Aulin Trail. In 1997, crews restored a section of old trail adjacent to Delaney Creek because the January 1997 100-year flood washed away some of the fill soil. Seeing the long-term success of projects they worked on keeps volunteers coming back.

The 5,180 hours of volunteer time were essential to the completion of the project. NPS staff worked with many of these volunteers and were able to instill stronger wilderness ethics and graphically show how much work is required to restore subalpine meadow areas.

1998 5-Year Evaluation

In the summer of 1998, Ecological Restoration staff evaluated the restoration success on the Old Glen Aulin Trail. This study was exploratory and descriptive in nature. Its objectives were to evaluate percent cover and species richness within the restored multiple trail ruts and in the adjacent undisturbed meadow. The study highlights factors leading to the success and failure of plant reestablishment in the restored trail area.

Methods

This study compared 40 pairs of adjacent quadrats on the Old Glen Aulin Trail. Within each pair, one quadrat was in the restored area and one was adjacent to the restored area. The quadrats outside the restored area may not represent "pristine meadow" but do represent areas that have been relatively free of compaction and wear by stock and hikers. Of the 40 pairs of quadrats sampled, 15 were in wet meadow, 13 were in dry meadow, and 12 were in meadow-forest ecotone. Meadow-forest ecotone has an understory of predominantly dry meadow species and a sparse canopy created by lodgepole pines (*Pinus contorta* ssp. *murrayana*). The study utilized quadrats that were one meter by 1/10 meter in order to maximize width and sample across the multiple-rut trail. Each quadrat was divided into 10 even sections in order to estimate percent cover of each species most accurately. Two Ecological Restoration staff visually estimated the percent cover of every species. The quadrats were somewhat randomly placed but always between 30 and 50 meters apart. After each quadrat in the old trail (restored area) was assessed, the quadrat was flipped twice, end on end, to sample the adjacent undisturbed meadow, two meters away from the old trail. The direction of placement was alternated, beginning with the right of the old trail and alternating to the left of old trail with every count.

Results

Five years after restoration, the entire restored area has maintained the grade of the natural meadow. The overall mean percent cover in the disturbed area was 43.2 %, while the mean percent cover in the undisturbed area was 55.9% (fig. 1). Seventy species were observed in the undisturbed meadow quadrats, while 64 species were counted inside the restored trail. This is excellent recovery for a high-elevation site but it is more informative to look at what happened in the three different plant communities.

Wet Meadow—The wet meadow areas had numerous deep ruts because people and stock tried to walk on higher, drier areas next to the trail, thus creating a new rut. Unlike many subalpine areas in Yosemite, this wet meadow actually has a true topsoil, meadow loam, which is easily compacted and highly erodible. The wet meadow species tend to have low resistance to trampling, but a high degree of resilience. Some pioneer species like *Juncus balticus* (JUBA) did become established in the ruts, but the natural meadow species could not establish due to a lack of topsoil.

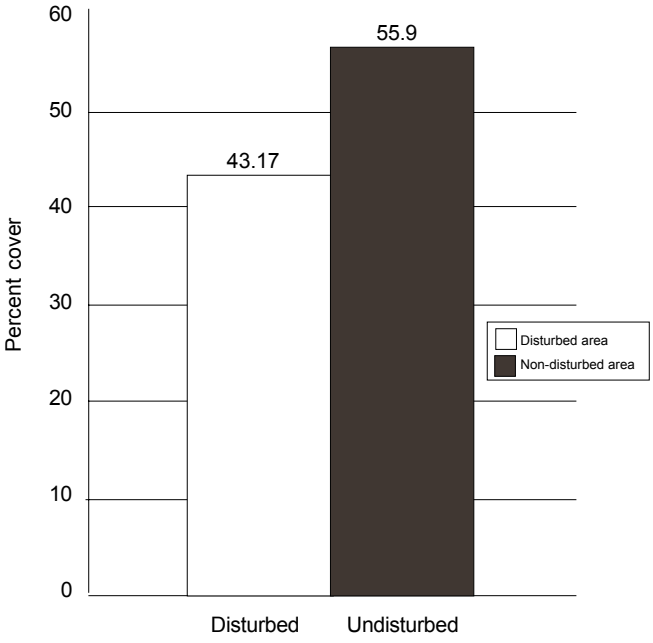

Figure 1—Comparison of overall percent cover in adjacent quadrats in the old restored trail and in the adjacent meadow.

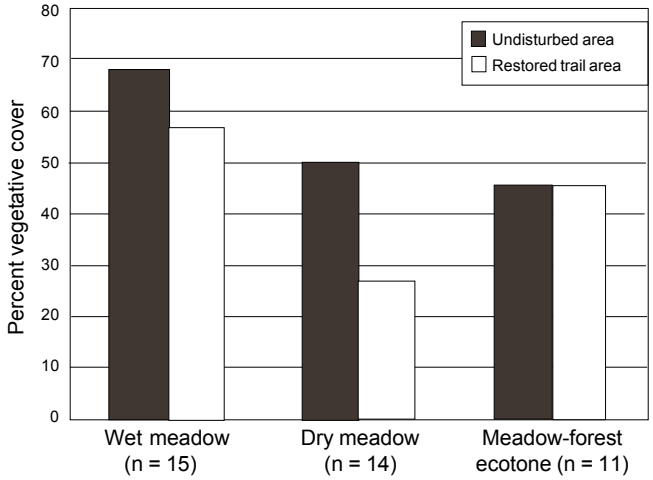

Figure 2—Comparison of percent cover by plant community.

The 15 quadrats in undisturbed areas had 68% cover (SE= 4.7) and an average species diversity of 11.1 (SE=1.1) species per quadrat in 1998. CAFI was present in 75% of the quadrats and accounted for 12% vegetative cover. CABR, *Antennaria corymbosa* (ANCO), DAIN, *Muhlenbergia filiformis* (MUFI) were also present in between 50% and 75% of the quadrats. These five codominant species accounted for 47% of the vegetation. The total species diversity across all 15 quadrats was 52 species.

The 15 disturbed quadrats had an average of 57% cover (SE=6.0) and an average species diversity of 10.9 (SE=1.3) species per quadrat in 1998. CAFI, DAIN, ANCO were present in 75% of the quadrats. MUFI and CABR were present in between 50 and 75% of the quadrats. These five species accounted for 52% of the vegetation. Total species diversity across all 15 quadrats was 43 species.

Plant reestablishment on these sites was extremely successful because the vegetative cover in the disturbed areas reached 83% of the cover levels in the undisturbed area and species diversity per quadrat was almost identical (fig. 2). The dominant species were the same in both disturbed and undisturbed quadrats. *Juncus covielli* (JUCO), *Elymus elymoides* (ELEL), *Poa cusickii* (POCU), *Ivesia lycopodioides* (IVLY) and *Gentiana newberri* (GENE) were present in the undisturbed but absent in the disturbed areas. *Juncus nevadensis* (JUNE), *Gayophytum diffusum* (GADI), *Gentianella amarella* (GEAM), *Lupinus lepidus* (LULE), and *Madia minima* (MAMI) were present in the disturbed areas but absent in the undisturbed.

The authors hypothesize that high moisture levels and high species diversity gives this plant community a high level of resilience. Since the wet meadow started with five codominant species, and 20 other species with significant cover, any type of weather year would facilitate reestablishment of at least a few of these species. The meadow loam soil is rich in nutrients and allows new plants to quickly establish a strong root system and therefore survive the dry end of summer.

Dry Meadow—Dry meadows have coarse, sandy, granitic soils. Because of the large particle size, the soil has a low moisture-holding capacity and a low cation exchange capacity (CEC) causing it to be a poor growing medium (Brady and Weil, 1996). The plants in dry meadows generally have an initial resistance to trampling but once destroyed are slow to reestablish. In the dry meadow segments of the restoration project there were two to four ruts, each one-foot deep. Tread compaction was not a large problem, due to the angular, sandy soil's resistance to compaction. Most soil loss occurred where the trail slope exceeded four percent. In these sections, water was channeled in the slightly lower (2-5 cm) trail tread caused by hooves and feet, and once into the tread it gained momentum and scoured the area down 10 to 20 cm more.

The 13 undisturbed dry meadow quadrats averaged 47% cover (SE=6.2) and had an average species richness of 5.3 (SE=1.1) per quadrat. CAFI was present in every quadrat and accounted for 50% of the total vegetation. ANCO, *Lewisia nevadensis* (LENE) and MUFI were each present on 33% of the 13 quadrats and accounted for 9 % of the vegetation. Total species diversity on all 13 quadrats was 23.

The 13 disturbed dry meadow quadrats averaged only 22.7% (SE=5.6) plant cover and had an average species richness of 4.3 (SE=1) per quadrat. CAFI was present in 70% of the quadrats and accounted for only 37% of the vegetation. MUFI was present on approximately 50% of the quadrats. No other species were present on more than 25% of the sites. JUPA was strongly established on two quadrats. Total species diversity was 25.

Plant reestablishment is happening slowly on these dry sites. CAFI was the single dominant species on the undisturbed quadrats and is slow to reestablish. JUPA, MUFI and ANCO are reestablishing on two or three quadrats. Species diversity was actually greater (25) in the disturbed area than in the undisturbed (22).

These sites get 14 hours of direct sunlight during the summer and have soils with low moisture holding capacity.

The existing plants spread vegetatively, but slowly. The area rarely gets sufficient afternoon thundershowers for a first-year seedling to survive the dry August and September months. This community has only one dominant species, CAFI, as opposed to having several codominant species. The authors hypothesize that the combination of high evapotranspiration stress, and having only one dominant species hinder this community's ability to reestablish itself. A codominant community has several species that can proliferate in a wide range of summer moisture conditions. Because the dry meadow community is largely made up of CAFI, percent vegetative cover did not expand during summers with moisture conditions not favorable to CAFI growth.

Meadow-Forest Ecotone—These areas have between 10% and 30% lodgepole pine canopy cover. This is important due to less transpirative loss from herbaceous plants and because pine litter inhibits herbaceous vegetation growth. The trail originally disturbed a five-foot wide swath, which did not develop into distinct ruts, but wore down the entire swath by 10 or more centimeters. Since the old trail had been designed to accommodate stock, it wound between trees but generally stayed outside the canopy.

The 12 undisturbed quadrats averaged 49.6% cover (SE=6) and an average of 5.6 species (SE 0.7) per quadrat. CAFI was growing on 80% of the quadrats and accounted for 30% of the total vegetation. CABR accounted for 23 % of the total vegetation even though it occurred only in 3 of the 12 quadrats. ANCO, MUFI and *Agrostis variabilis* (AGVA) were sporadically present. There were a total of 33 species present on all quadrats.

The 12 disturbed meadow-forest ecotone quadrats averaged 48.3% cover (SE=6.0) and had an average species diversity of 7.5 (SE 0.7) per quadrat. CAFI was found on 66% of those sites but accounted for only 15% of the cover. AGVA and GADI were present on more than 50% of the quadrats and made up less than 10% of the cover. ANCO, LULE, PHAL, ACLE and DAIN were present on 25% to 50% of the quadrat and made up 36% of the vegetation. In summation, there were eight common species, but none of them was dominant.

Neither percent cover nor species diversity was statistically different in the undisturbed versus disturbed quadrats in the meadow-forest ecotone (fig. 2). The authors believe that although this may indicate 100% recovery, there were slight problems with the sampling method. The disturbed quadrats were almost always outside of the canopy, whereas their counterparts often ended up under the canopy. Under the canopy the pine needle layer was thicker which inhibits herbaceous plant establishment. CAFI, the one plant that was often present under the canopy may have been present prior to tree establishment. As a result, the disturbed trail area will probably have higher percent cover and species diversity than the undisturbed sites.

Project Summary

Yosemite's Ecological Restoration Program restored a 4,200-foot section of multiple rutted trail by focusing on returning the topography and soils to natural conditions. This was accomplished by importing 100 cubic meters of fill material from nearby ephemeral drainages. The fill was used to bring the ruts to the level of the surrounding meadow and capped with salvaged topsoil. Although some seeds and propagules were used during the first year, transplants and natural regeneration were relied on in later years. These methods were equally successful but less costly. Over 100 volunteers helped replant over three linear miles of transplants salvaged from the islands between the ruts. Utilizing volunteers educates them about NPS preservation efforts and develops a connection between the volunteer and the resource. This trail restoration project cost about $14 per linear foot of trail restored.

After only three years most visitors could not tell there had been a trail in this area. After five years, the percent cover in the restored area was at 77% of that in the adjacent undisturbed meadow. Both the disturbed and undisturbed quadrats had a wide variety of native species. While all trail segments are recovering, plants are reestablishing faster in the wet meadow areas than in either the dry meadow areas or the meadow-forest ecotone. We were fortunate to have a string of above average moisture years.

In this subalpine meadow environment, a 30-year trail closure failed to facilitate plant reestablishment. This four-year project of restoring topography, surface hydrology and soils both educated volunteers and resulted in significant gains in plant establishment in just five years.

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