Analysis of Meadow Condition in Tuolumne Meadows

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Introduction

Tuolumne Meadows, located in Yosemite National Park near the headwaters of the Tuolumne Watershed, can be classified as a montane meadow using the description outlined by Purdy and Moyle (2009). Montane meadows exist at high elevations, and are created by the erosion of steep mountain sides into relatively flat alluvial plains (Purdy, Moyle 2009). These meadows encompass less than 0.01 percent of the area of the Sierra Nevada Mountain Range, but bolster more species of wildlife than any other habitat type within the range (Purdy, Moyle 2009). Meadows and other riparian communities have not only been titled the most important habitat to avifauna in the western United States, but also, a large percentage of Sierran terrestrial vertebrates use meadows in one of their life stages, and many threatened and endangered amphibian species are dependent on montane meadow habitat to survive (Purdy, Moyle 2009).

Anthropogenic land use in Tuolumne Meadows, over millennia, has shaped the landscape, flora, and fauna that presently occur in the meadow. From Native American irrigation, weeding, and burning practices, to European market hunting and livestock grazing, the species composition in the meadow has endured a dramatic shift (Warren, 2003/National Parks Service, 2006). For example, in Tuolumne Meadows, we would expect a dense cover of

rhizomatous monocotyledonous species, but the vegetation is dominated by a tap-rooted plant that doesn't generate sods (National Parks Service, 2006). Low density of this below ground rhizomatic network allows pocket gophers and voles to maintain a new equilibrium (drier) plant community, different than pre-grazed Tuolumne Meadows (National Parks Service, 2006).

Purpose

This study is based on the hypothesis that meadow condition, as outlined by Purdy and Moyle (2009), in Tuolumne Meadows has not recovered from historic grazing impacts. Our purpose is to determine if current ecological equilibriums and anthropogenic activities are hindering the meadow's recovery.

Methods

We selected two study reaches in Tuolumne Meadows to account for possible heterogeneity in downstream and upstream locations. Each study reach contained at least one set of geomorphic units (riffle, pool, run), to obtain the most diversity in habitat composition. Our study methods were designed to parallel those of Purdy and Moyle (2009) on meadow condition, but with some limitations due to studying within the boundaries of a national park. In their report, they created a new metric to better assess ecological condition in meadows, using five indices of biological integrity (IBIs): fish, amphibians, aquatic macroinvertebrates, physical habitat, and vegetation condition. Each IBI is a score out of 100 – the scores can be averaged to give an overall IBI. Table 1 interprets IBI scores.

Fish Sampling

Fish sampling deviated from the methods of Purdy and Moyle (2009). We were unable to complete any block netting or electrofishing because of park regulations. Instead, snorkel surveys were completed by three snorkelers at each reach. Snorkelers started at the upstream

boundary of the reach, and worked their way downstream by floating, or gently pulling themselves through the water. The snorkeling team spread out (one at each bank and one in mid channel) to minimize double counts. To tally fish, they would lift their heads from the water and call out to the most experienced snorkeler, who recorded counts on an underwater writing slate.

Aquatic Invertebrate Sampling

Benthic macroinvertebrates (BMI) were sampled using protocols similar to those from Purdy and Moyle (2009). At each reach, we surveyed a single transect (preferentially selecting riffles) and randomized locations along the transect. Four samples were taken at each reach for a total of 8 samples within Tuolumne Meadows. At each location, a D-net was held against the bottom of the stream bed with the opening facing upstream. A team member vigorously agitated the substrate in an approximately 1 foot^2 area in front of the net, 30 seconds by hand and 30 seconds by feet. Afterwards, team members elutriated the samples, and placed them in a white enamel pan. For a 10 minute period, team members picked out invertebrates using forceps, and sorted them into an ice tray filled with stream water. After this 10 minute period, at least 3 team members worked to identify all to order by eye. Samples were released back into the stream after identification.

Habitat Sampling

We used modified Purdy and Moyle (2009) habitat surveys, Protocol II. *In situ* we measured: sediment characteristics using a gravelometer, and took no less than 100 samples; velocity, depth, and discharge, using a Marsh-McBirney flow meter; and channel morphology using an auto-level and a stadia rod. We completed the Rapid Habitat Assessment Data Sheet (Purdy and Moyle, 2009) via *ex situ* using estimations from photographs and reach sketches taken on site.

Vegetation Sampling

Vegetation sampling deviated from Purdy and Moyle (2009) methods, in that we only roughly estimated one of the three metrics, percent bare ground, using the *ex situ* procedures described above.

Results

After data collection and analysis, IBI scores were calculated using Purdy and Moyle's (2009) indices, excluding amphibian data, as well as several of the metrics for each index.

Fish IBI

We encountered a total of 223 fish among our two study reaches in Tuolumne Meadows. The most abundant taxa was the Brook Trout (*Salvelinus fontinalis*) which was 44% of all identifications, followed by an unknown trout species encompassing 37% of identifications, and then Rainbow Trout (*Oncorhynchus mykiss*) at 14%, and Brown Trout (Salmo trutta) at 4%. Historically, Preston Falls (located downstream of O'Shaughnessy Dam) acted as a natural fish barrier, therefore all fish in Tuolumne Meadows are not technically native to the region. We took this into account when analyzing the overall IBI, including a calculation that rejects fish data comparatively.

We based our fish IBI on 2 of the 4 metrics: total abundance, and total number of species. The metrics we discarded were (1) trout biomass, because we were unable to sample in hand, and (2) number of age classes of natives, because Tuolumne Meadows was historically a fishless stream. In reaches 1 and 2, we found that fish IBI scores were 80, and 80, respectively. A calculation of fish IBI including data from both of the sites, also found the IBI to be 80 (Table 2).

Invertebrate IBI

The total number of macroinvertebrates identified at all sites was 99. The overall EPT index was 62%. Plecoptera was the dominant species at 39% of the total, while Ephemeroptera composed 22%, and Trichoptera was absent from both reaches. Two other orders, Coleoptera and Diptera, composed 2% and 36%, respectively. The invertebrate IBI scores were found to be 60 in the first reach and 50 in the second, while the overall invertebrate IBI (both reaches combined, not averaged) was 75 (Table 2).

Habitat Index

Habitat index scores were calculated out of 200 and then normalized to 100 to be averaged into the overall IBI. In reach 1 the score was 148 (74 on a scale of 100), and in reach 2 it was 110 (55 on a scale of 100). The average of these scores was 129 (65.5 on a scale of 100). Few quantitative measurements were used in calculating this index. These measurements include cross section data, as well as discharge and sediment data.

Vegetation Index

Vegetation indexes were scored using only 1 of the 3 metrics provided by Purdy and Moyle (2009) – percent bare ground. Reach 1 scored 100, while reach 2 scored 20. The average value of the two reaches was 60.

Discussion

The results indicate that Tuolumne Meadows still suffers from lasting effects of anthropogenic uses, but shows promise of recovery. The fish index scored the two reaches significantly higher than the rest of the indices, which is contradictory, considering Tuolumne Meadows was historically fishless. For this reason, we also included a calculation for the overall IBI which ignored fish data, and yielded slightly different results. A wider variety of indices, or

the use of more index metrics in our study may have resulted in data that would be more inclusive of the different spatial and temporal scales that each index operates on.

Fish IBI

Trout were planted in Tuolumne Meadows because of their popularity in sport and recreational fishing. It is difficult, then, to determine how their presence denotes meadow condition (Purdy and Moyle, 2009). While they can be an indicator of good water chemistry, cold water, complexity of habitat structure, and diverse aquatic macroinvertebrates, they are themselves a disturbance to systems in which they are not native (Purdy and Moyle, 2009). In the Purdy and Moyle (2009) assessment of meadows, a combined "Fish and Amphibians" is an alternate index used in place of the "Fish only" index, to more accurately measure the relationship between these taxa. We were unable to complete a study on amphibians in Tuolumne Meadows, therefore we cannot quantify any negative interactions caused by trout populations. In our study, meadow health was likely higher as a result of (1) including the non-native fish in our analysis, and (2) excluding amphibian data from the analysis.

In Table 2, we can see that the overall scores in both reaches decline after removing fish from the calculations. Reach 1 has only a very slight reduction in overall IBI, which can be attributed to a huge discrepancy in the vegetation index between reaches, essentially buffering the IBI score. Because the vegetation data was taken *ex situ* and by rough estimates, an intensive study could easily skew the overall IBI, and obtain more accurate (and likely less positive) results.

Invertebrate IBI

Invertebrate samples, studied independently, scored in the marginal to fair range (Table 1), but when considered as a single sample, scored in the higher boundary of the fair range. The

invertebrate index is based on the EPT index (an overall of 62% in this study), the amount of orders, percent dominant species, and percent stoneflies. Our study was able to obtain data on each of these metrics, making our results more representative of in-stream conditions than other IBIs.

Habitat and Vegetation Indices

Habitat and vegetation are good indices because they tie together terrestrial and aquatic systems, illustrating how the biology relates to the geology and hydrology (Purdy and Moyle, 2009). They particularly demonstrate incision, erosion, and soil conditions, which are all integral parts of the meadow community. Our data scored vegetation as 100 and 20 at reach 1 and reach 2, respectively. Although we used rough estimates to score these, the criteria did not necessarily reflect true meadow conditions. For example, we scored reach 1 as 100 because it had 0-4% bare ground, but this very small amount of bare soil could actually reflect negative conditions. In this reach, cut banks were completely vegetated, and lodgepole pines were very close to the water's edge, indicating that a high flow event has not reset the community on the proper timescale.

Overall IBI

The calculated value for overall IBI, based on all metrics cumulatively, is 69.87 (Table 2). This scores the condition of Tuolumne Meadow as solidly, "fair." After removing the fish IBI, the score drops (slightly) to 66.5 – still safely within the "fair" category. Referring to Table 1, meadows in "fair" condition are still impaired by some past and current disruptions, but are viable enough to support a large array of taxa. Fair meadows have lost the most sensitive taxa, but respond well to management and restoration due to resiliency, and therefore have likely not crossed the threshold into a new alternative state. Our results demonstrate, then, that Tuolumne

Meadows has indeed not entered an alternative stable state. It is important to note, however, that another study including amphibian data and more metrics could easily tip the scale.

Conclusion

If we consider our overall IBI, excluding fish-only data, to be our truest score of meadow condition, then 66.5 indicates that conditions in Tuolumne Meadow are a manifestation of lasting anthropogenic effects. It is likely, though, that a century's worth of protection from grazing has caused the meadow to significantly recover from historic degradation. Because this meadow is seated comfortably between "marginal" and "excellent," the National Parks Service has the opportunity to improve our understanding of montane meadows, meadow restoration, and to restore the meadow to "excellent" condition. This procedure would be relatively inexpensive in comparison to the restoration of marginal meadows, and would be greatly catalyzed by simple education of park patrons on the sensitivity of meadow habitat. Complete restoration of Tuolumne Meadows would resound in Yosemite National Park, as generations upon generations get the opportunity to visit a pristine landscape.

Literature Cited

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Table 1. Interpretation of IBI Scores (Purdy & Moyle, 2009)

Score	Condition	% Sierran Meadows	Explanation
20-40	Poor	0%	Likely have past and continuing degradation. Severe impacts to biodiversity and overall ecosystem function. Management and restoration would likely require extensive resources.
41-60	Marginal	28%	Site may have significant past or present degradation, but still supports limited ecological function. Biodiversity and abundance of organisms is likely constrained by environmental conditions.
61-80	Fair	69%	Past or current impacts do impair function and cause the loss of most sensitive taxa, but can support many other taxa. These meadows are good candidates for restoration or management because they respond well. "Fair" meadows have not crossed a threshold to a new stable state, and therefore are observed to be more resilient to impacts upon them.
81-100	Excellent	3%	Little or no degradation or impairment observed. These meadows have high biodiversity and ecosystem function. Focus should be placed on the protection of these meadows, as well as using them as reference sites to compare other meadows against.

Table 2. Individual IBI scores and overall score for Tuolumne Meadows

Sampling Location	Fish IBI	Invertebrate IBI	Habitat Index	Vegetation Index	Overall Score	Overall Score Excluding Fish IBI
Reach 1	80	60	74	100	78.5	78
Reach 2	80	50	55	20	51.25	41.66
Combination of both sites	80	75	N/A	N/A	69.87	**66.5**
Average of both sites	N/A	N/A	64.5	60		

Figure 1. Tuolumne Meadows Reach 1 Channel Morphology

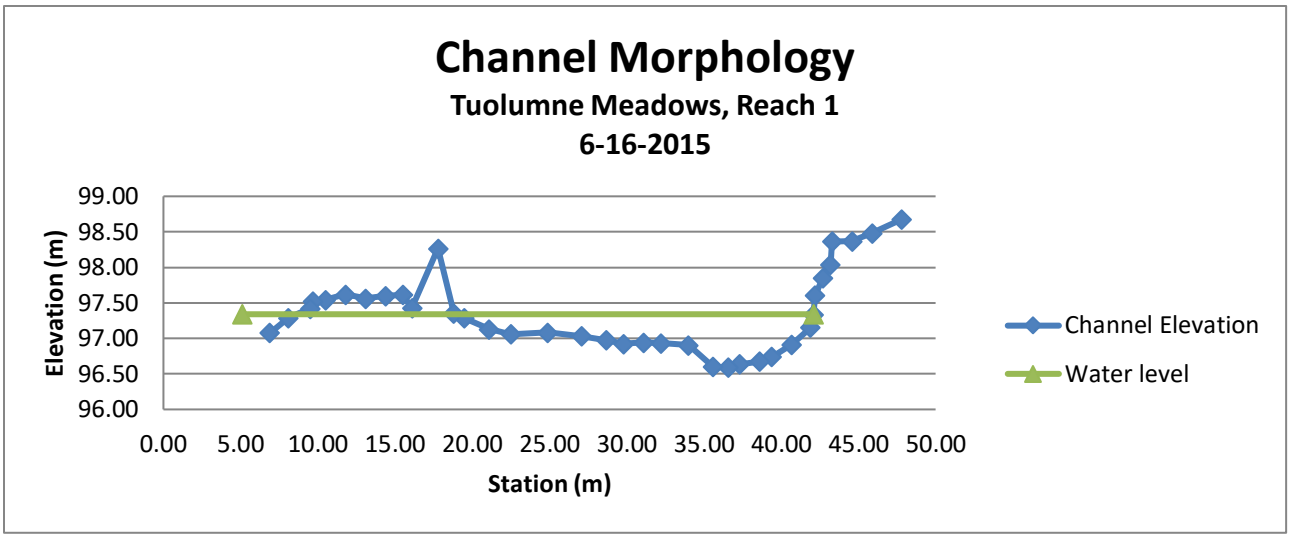

Figure 2. Tuolumne Meadows Reach 2 Channel Morphology

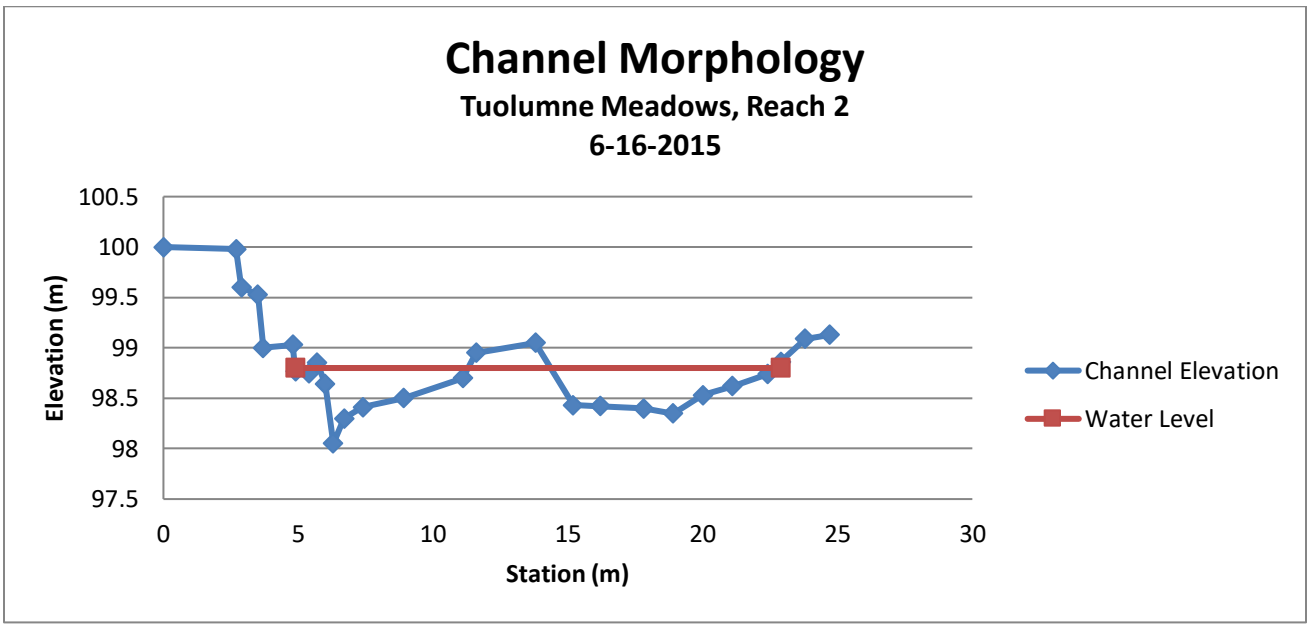

Figure 3. Tuolumne Meadows Reach 2 Channel Morphology, including oxbow channel