How to Make Meadow Restoration Work for California's Mountain Frogs?

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Introduction

Intensive land uses have transformed many of the Sierra Nevada's low gradient streams and meadows from multi-thread channels with annually inundated floodplains into single-thread, incised channels that store less water and have reduced habitat quality for a diverse suite of meadow-associated wildlife (Kattlemann 1996, Loheide et al. 2009). Recovery of the beneficial functions of these systems has become a priority in California's water infrastructure plans. The increased commitment to upper watershed stream and meadow restoration has facilitated a dramatic increase in the pace and scale of mountain meadow restoration projects (Drew et al. 2016). However, many of the techniques being implemented by the restoration industry are failing to accomplish restoration objectives, or are not meeting natural reference standards (Pope et al. 2015). An overarching goal of stream and meadow restoration projects is to recover self-sustaining ecological systems and the dynamic processes that support them. In spite of this, common design approaches often include channel form and stability criteria that prevent the dynamic physical processes that support biodiversity (Arscott et al. 2002, Ward et al. 2002, Florsheim et al. 2008). In order to achieve long-term sustainability, a process-based design approach that allows for natural changes in channel condition through time and thus sustains critical ecological functions may be warranted.

Understanding the relationship between hydrologic processes in meadows and the focal taxa that use meadows can provide insight into not just ways to create habitat features in restoration projects, but also insight to which physical processes maintain those habitat features. Among the organisms that inhabit montane meadows, amphibians are particularly sensitive. Meadows may serve as refugia for amphibians, including the declining Sierra Nevada yellow-legged frog (*Rana sierrae*) and Cascades frog (*R. cascadae*), due to their complex and varied habitat conditions. Therefore, the processes that create habitat heterogeneity in meadows may be directly linked to habitat conditions that support these sensitive amphibians. We evaluated the relationship between meadow hydrological conditions and habitat use by these frogs to understand the conditions that promote population persistence. Our specific objectives were to (1) describe important hydrologic, geomorphic, and thermal processes pertinent to meadow restoration that create and maintain habitat for focal amphibian species; (2) evaluate the effectiveness of common meadow restoration approaches in improving native amphibian habitat; and (3) provide recommendations for prioritizing likely restoration sites and incorporating specific design elements to enhance conditions for focal amphibians.

Methods

We monitored surface and ground water patterns and habitat use by Cascades frogs at three reference meadows in the northern Sierra Nevada/southern Cascades between 2014 and 2017. We also assessed two meadows that had been restored using a pond-and-plug technique and

one that used beaver dam analogs (BDAs). When Cascades frogs were found, data were collected on numbers, life stage, and size. The location of each observed frog, group of larvae, or egg mass was recorded using GPS, and habitat measurements including water temperature, water depth, flow, substrate, percent emergent vegetation, and canopy cover were taken at the site. Within the meadows occupied by Cascades frogs, we used this local habitat data associated with individual frogs and egg masses to describe the characteristics of habitats used by frogs.

To relate surface and ground water conditions with important frog habitats, we collected detailed topographic and hydrologic data. We collected overlapping aerial imagery from a set altitude with a 3D Robotics Solo quadcoptor with a Canon S100 camera. Ground control points were surveyed during flights with a Topcon GPS-RTK system (Hiper Lite and Hiper V models) with centimeter accuracy. Agisoft Photoscan Professional software was used to stitch and rectify the imagery and create digital surface elevation models with 2-5 cm resolution of the three meadows. We mapped surface water pathways on the ground using a Trimble Pathfinder Pro GPS that allows accurate measurements to below 30 cm horizontally. In 2015, we established transects of ground water monitoring wells at each meadow, and we installed staff gauges in the primary stream channel at the top and bottom of each meadow and in channels bisected by well transects. After summarizing the hydrologic data collected for each meadow, we related core frog habitats with the underlying hydrology of the meadow in a GIS framework. We compared the surface elevation models created from the drone imagery with groundwater elevation raster layers developed from the measured well data to assess ground water flow patterns and elevation change relative to topography both spatially and temporally.

Results

In the three focal meadows that supported Cascades frogs, a common hydrological theme was the presence of a variety of consistent, but shallow, aquatic habitats; including channels, pools, springs, and fens that provide habitat for all life stages from eggs to adult frogs throughout the year, even in drought conditions. Another commonality was off-channel, still water habitat with minimal canopy cover for breeding. These shallow, surface water pools were often augmented by groundwater spring input to extend the hydroperiod well into the summer, allowing tadpoles to successfully metamorphose (Figure 1a). Pool temperatures were warmed by the sun but moderated by the cool spring water input (Figure 1b). Within meadows, all life stages of Cascades frogs occurred most often in locations with minimal (0-25%) canopy cover and avoided areas with high shading. Adult frogs tended to occur in the more fluvially active channels and juvenile frogs resided in secondary channels and oxbows. In general frogs avoided the more stable, densely vegetated meadow flats.

Our assessment of the restored meadows found that one of the pond-and-plug meadows provided appropriate off-channel breeding pools with connection to groundwater, but the pools were often near the larger and deeper borrow pit ponds that also provided habitat for detrimental invasive species including American bullfrogs (*Lithobates catesbeianus*) and brook trout (*Salvelinus fontinalis*). At the second pond-and-plug restoration site, although neither native nor non-native frogs were found, several of the borrow pit ponds supported static habitat conditions (permanent, still water with rooted floating vegetation) known to be more suitable for bullfrogs than native frogs (Figure 2a). We did not find any shallow off-channel pool habitat with extended hydroperiods known to be preferred by Cascades frogs for breeding. The meadow restored with BDAs created appropriate shallow backwater pool habitats behind the dams that could serve as breeding habitat and refuge from brook trout for Cascades frogs (Figure 2b). However, without seasonal maintenance of the dams, the ponds were observed to drain too

quickly in the summer. Once maintenance occurred, juvenile Cascades frogs were observed using the backwater pools.

Discussion

Our study revealed that restoring habitat for native amphibians requires restoring a diversity of aquatic habitat conditions from shallow pools with consistent still water for eggs and larvae to fluvially active stream channels for adults. While raising the water table and thereby increasing the amount of surface water and length of the hydroperiod are part of the solution, restoration of physical processes and associated heterogeneity is also important. Meadows that have some degree of consistent groundwater input should be high priority for restoration and conservation as they may be more likely to provide wet meadow habitat despite varying climatic conditions. Within meadows, locations where low gradient depressions and high water table intersect could be targets for breeding pool enhancement. Meadow alterations that create novel deep, permanent ponds may be colonized by non-native species rather than target native species. In-channel structures such as BDAs seem promising for creating appropriate shallow, backwater pool areas, but they require maintenance. In general, meadow restoration guided by a process-based approach and focused on creating habitat heterogeneity over both time and space will provide greater potential suitability for native frog species with varied life histories and life stages.

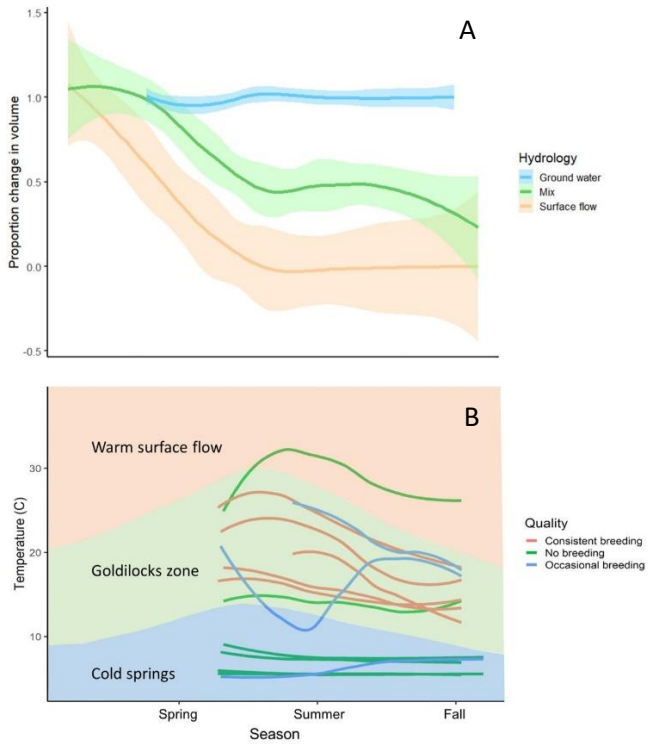

Figure 1. Schematic representation of the change in volume, or dry down rates, over time for three main types of off-channel pools in meadows (A). Spring-fed groundwater pools (blue line) tend to remain stable over the course of the dry season while surface water pools (orange line) quickly dry down. Pools with a mix of surface water and spring water (green line) decrease in volume but tend to stay stable at a base rate driven by the spring flow. (B) Water temperatures at pools where Cascades frogs consistently breed (red lines) tend to be moderate compared to pools where they occasionally (blue lines) or never (green lines) breed. Lines are overlaid on colored polygons representing water temperatures of the pool types shown in A.

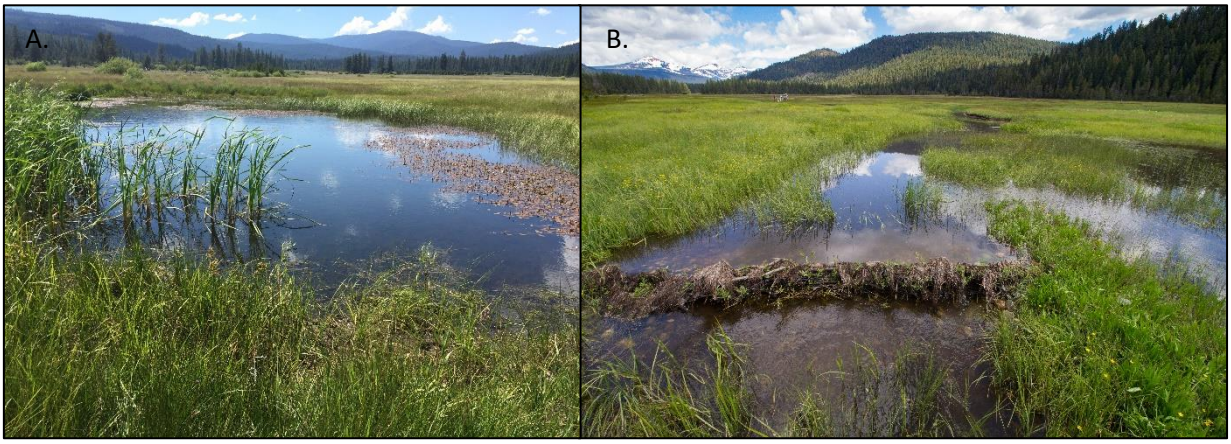

Figure 2. Deep, still water off-channel pond in a meadow restored with the pond-and-plug technique (A) compared to a shallow, backwater pool associated with biogenic instream structures such as beaver dam analogs (B).

References

Arscott, D. B., K. Tockner, D. van der Nat, and J. V. Ward. 2002. Aquatic habitat dynamics along a braided alpine river ecosystem (Tagliamento River, Northeast Italy). Ecosystems 5:802-814.

Drew, W. M., N. Hemphill, L. Keszey, A. Merrill, L. Hunt, J. Fair, S. Yarnell, J. Drexler, R. Henery, J. Wilcox, R. Burnett, K. Podolak, R. Kelley, H. Loffland, R. Westmoreland, and K. Pope. 2016. Sierra Meadows Strategy. The Sierra Meadows Partnership, https://meadows.ucdavis.edu/files/Sierra_Meadow_Strategy_full_report_SHAREABLE_mid.pdf.

Florsheim, J. L., J. F. Mount, and A. Chin. 2008. Bank erosion as a desirable attribute of rivers. Bioscience 58:519-529.

Kattlemann, R. 1996. Hydrology and water resources. Pages 855-920 *in* Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, assessments and scientific basis for management options. University of California, Davis, California.

Loheide, S. P., R. S. Deitchman, D. J. Cooper, E. C. Wolf, C. T. Hammersmark, and J. D. Lundquist. 2009. A framework for understanding the hydroecology of impacted wet meadows in the Sierra Nevada and Cascade Ranges, California, USA. Hydrogeology Journal 17:229-246.

Pope, K. L., D. S. Montoya, J. N. Brownlee, J. Dierks, and T. E. Lisle. 2015. Habitat conditions of montane meadows associated with restored and unrestored stream channels of California. Ecological Restoration 33:61-73.

Ward, J. V., K. Tockner, D. B. Arscott, and C. Claret. 2002. Riverine landscape diversity. Freshwater Biology 47:517-539.