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What Does it Take for a Regulated Central Valley River to Have Ecological Functionality?

Efforts to rehabilitate regulated rivers in the Central Valley of California have generally focused on empirical channel design, ad hoc gravel augmentation, or re-regulated flow releases. Though mindful of some scientific concepts, each of these paradigms has failed to include process based predictive tools to guide design and insure that conceived of ecological benefits will actually come to pass. Instead of pre-supposing which of these approaches should be used or in what combination, it is possible to identify the key environmental processes required for a regulated Central Valley river to be ecologically functional. Based on a decade of research on several streams, it is now evident that many of those are related to persistent channel non-uniformity at multiple spatial scales. Most Central Valley streams now lack such channel non-uniformity, and empirical channel design, gravel augmentation, or flow re-regulation as previously envisioned will not solve the problem. Recent studies of common 1D, 2D, and 3D numerical hydrodynamic models have revealed the capabilities and limitations of each type of model in representing key hydrogeomorphic processes linked to ecological functions and channel non-uniformity. Full-scale manipulative river-rehabilitation experiments on the Mokelumne and Trinity Rivers as well as natural floods on the highly dynamic Yuba River have confirmed the findings of modeling studies and the importance of channel non-uniformity. As a result, it is now possible to use models to predict the hydrogeomorphic and ecological outcomes of design alternatives for proposed projects. The most recent advances now enable such prediction over tens of kilometers of channel simultaneously and at the fish-relevant sub-meter resolution. Consequently, the technical barriers to instream river rehabilitation for the Central Valley are down. Those interested in implementing this peer-reviewed, process-based, comprehensive framework for river rehabilitation in the Central Valley are encouraged to contact the presenter.

CALFED Statement of Relevance
The author presents a summary of a decade of peer-reviewed research that demonstrates how Central Valley rivers can and should be restored. Does CALFED and the audience have the audacity to consider this?

SESSION: River Restoration, 10/23/2008, 8:20 AM, Room 307

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Gravel Augmentation in Bedrock Channels: Can it Work?

Dams throughout California and the Pacific Northwest suppress anadromous salmonid populations by blocking access to historic spawning areas and severing the hydrologic, ecologic, and geomorphic continuity that river ecosystems require. To mitigate for these effects, gravel augmentation has been invoked on highly regulated, low gradient, gravel-bed rivers to provide substrate and increase spawning habitat quality and quantity. However this rehabilitation tool has yet to be evaluated in bedrock channels like the Yuba River below Englebright Dam. This study set out to determine the efficacy of gravel augmentation as a habitat rehabilitation tool in this novel environment by comparing historical imagery, 2-D depth and velocity approximations, sediment transport predictions, and habitat quantifications of a bedrock and alluvial site. While flow convergence routing maintained riffle-pool morphology at the alluvial reference reach it was not observed as a dominant mechanism for alluvial deposition at the bedrock controlled Englebright Dam Reach (EDR). The absence of flow convergence routing and overall channel constrictions at the EDR will promote entrainment and transport of augmented gravels. Shields' stress predictions suggest that gravel retention will be maximized along channel margins and near depositional features that reduce local bed shear stress. Overall, gravel augmentation at the bedrock dominated EDR will not create large scale habitat features susceptible to scour but will instead provide highly localized zones of habitat in concert with depositional features.

CALFED Statement of Relevance
CALFED has stated that gravel augmentation will be used on numerous California rivers to increase the quantity and quality of anadromous spawning habitat. Although it's an established mitigation method in gravel-bed streams, it has not been investigated in bedrock channels where the underlying geomorphic processes are quite different. This research provides insights to the overall efficacy of gravel augmentation along the Yuba River below Englebright dam and a methodology for examining its applicability in other bedrock rivers. The results of the study suggest a limitation on the amount of habitat that can be created in bedrock channels and that they cannot provide the same large-scale spawning habitat features that have been created on gravel-bed channels.

SESSION: River Restoration, 10/23/2008, 8:40 AM, Room 307

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Stream Restoration Tools to Address Stream Channel Degradation: The Lower Clear Creek Floodplain Restoration Project

Historic land use and flow regulation resulted in highly degraded conditions in lower Clear Creek. Many stream segments were scoured to claypan, reducing the structural complexity required for numerous aquatic organisms. Abandoned mining pits favored exotic species and trapped juvenile salmonids. Riffles matrices, winnowed but not replenished by post-dam floods, became fossilized. Reduced sediment supply prevented formation of new alluvial features and simplified the channel pattern. Floodplains were abandoned and riparian regenerative processes were reduced as groundwater retreated following channel incision. The strategy adopted on three miles of lower Clear Creek was to restore the physical processes that would create and maintain key physical attributes of a functional alluvial ecosystem: a frequently mobilized streambed, floodplains accessed by annual floodflows, and a dynamic channel. Tools employed to achieve these conditions included: stream channel and floodplain engineering to accommodate the post-dam flow regime; supplying the new channel with ample spawning-quality gravel; filling off-channel mining pits; floodplain planting to provide hydraulic roughness to enhance fine sediment deposition; reclamation of mining spoils for gravel augmentation; channel alignment determined by depth of alluvium; and bio-engineered structures strategically placed to prevent channel re-capture. The effectiveness of these tools toward achieving management objectives has been continuously monitored since 2002 using a variety of experiments designed to quantitatively evaluate project success. Results of monitoring indicate that designed streambeds mobilize near the design bankfull discharge (3,000 cfs), that floodplains are inundated by the average annual flood, the channel is seeking longer, more sinuous paths through its floodplains and that spawning riffles do not typically scour to a lethal depth for incubating salmon. The successes and lessons learned from the Lower Clear Creek Floodway Restoration Project facilitated a basin-wide vision, in which key reaches are targeted with restoration proposals intended to enhance habitat conditions and facilitate dam-to-mouth sediment transport continuity.

CALFED Statement of Relevance
The restoration of degraded upstream ecosystems is integral to the recovery/integrity of the Bay-Delta system. Restoration tools employed on Clear Creek have a unique history of evaluation and may prove applicable to other central valley systems.

SESSION: River Restoration, 10/23/2008, 9:00 AM, Room 307

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Are Juvenile Chinook Salmon using the Restored Habitat in Clear Creek?

The Lower Clear Creek Floodway Rehabilitation Project is a multi-phase project, designed to restore 2.5 miles of stream channel and floodplain habitat. One of the primary goals of the Project was to maintain or increase the quantity and quality of juvenile salmonid rearing habitat. Our study focuses on Phase 3 of the Project, which constructed new channels and functioning floodplains. Phase 3A, completed in 2002, moved 1,400 feet of creek from a bedrock streambed to a gravel-filled channel, and Phase 3B, completed in 2007 realigned 3,600 feet of the channel. Both Phases incorporated juvenile salmonid rearing habitat features including; revetment and habitat rootwads, boulder clusters, alcoves, retention of old creek channel as backwaters, and preservation of some existing riparian vegetation. We conducted habitat use surveys in the spring of 2003, 2005, and 2008 to evaluate the affect of the Project on juvenile Chinook densities. We estimated both Chinook and Steelhead numbers from underwater snorkel observations. The survey area consists of two control reaches, which are above and below the restoration, and the two restoration phases. We originally predicted that restoration would result in lower juvenile densities due to reductions in channel complexity and cover. The Project exceeded this prediction by incorporating rearing habitat features. In both phases, Chinook densities were high in the revetment rootwads and saved vegetation. Fish density was also high in the old creek channel retained as a backwater in Phase 3A. In Phase 3B, boulders and habitat rootwads had lower densities than expected. Higher densities in Phase 3A during 2005 suggested that the restoration improved the quality of habitat used by juvenile Chinook. We will compare Chinook densities during 2008 between reaches, years, and meso-habitat types. We recommend inclusion of the highly effective juvenile habitat features when designing large-scale geomorpologically-based channel restoration projects.

CALFED Statement of Relevance
Clear Creek is a high priority watershed for CALFED, which funded construction of the Floodway Rehabilitation Project. Our monitoring evaluated one of the goals of the restoration project. CALFED also funds similar projects and this monitoring will be useful in improving future projects.

SESSION: River Restoration, 10/23/2008, 9:20 AM, Room 307

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Large Wood Aids Chinook Salmon (Oncorhynchus tshawytscha) Spawning in Marginal Habitat on a Regulated River in Central California

To determine whether large wood (≥1-m length, ≥10-cm diameter) plays a role in chinook salmon redd placements in a regulated, medium-sized (average width 30-m), Mediterranean-climate river, characteristics of 542 large wood pieces, locations of 650 redds, and habitat unit delineations (riffle, run, glide, pool) were collected during a spawning season along a 7.7 km reach directly below Camanche Dam on the Mokelumne River. The amount of large wood in the reach was similar to other highly managed rivers, at 9 tonnes/hectare. Large wood was regularly distributed across the reach an average 70 pieces km-1, whereas at the geomorphic scale of ~100 channel widths, large wood clustered at islands. Chinook salmon built 75% of observed redds where spawning habitat rehabilitation projects—which have occurred predominately in the upper 3 km of the reach—have improved spawning conditions. At a hydraulic scale of ~10-1 channel widths, redds were within a 10-m radius of large wood 36% of the time, suggesting that spawners may have utilized large wood as cover and refugia, thus playing an important secondary role in redd placements. Large wood pieces also appeared to play a more direct hydraulic role, with redds within a 5-m radius of large wood 17% of the time. In the lower 4.7 km where marginal habitat was prevalent, redds were within a 5-m radius of large wood 21% of the time and within a 2.5 m radius 10% of the time. Results from random samplings and t-tests indicate that large wood-redd interactions systematically occurred at a greater rate than by random chance alone in the lower 4.7 km but not in the upper 3 km, which implies that large wood aids spawning in marginal habitats.

CALFED Statement of Relevance
Large wood triggers physical and ecological processes that are important to spawning salmon within regulated rivers. This study validates the importance of large wood to spawning conditions, and encourages large wood additions during habitat rehabilitation projects.

SESSION: River Restoration, 10/23/2008, 9:40 AM, Room 307

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Long Term Vegetation Monitoring in Restoration Sites

Riparian forest habitat restoration along the Sacramento River has been occurring for nearly twenty years. The main goal of this effort is to create habitat for animals of high conservation importance. Metrics of success for restoration can therefore be developed for both the target animal species and for the habitat (vegetation) itself. This study measures vegetation development and habitat complexity in 20 x 30m plots (n=106) at four restoration sites originally planted by The Nature Conservancy in 1993 and 1994 and sampled in 2003 and 2008. Plots in remnant forest were used for reference. At the time of planting a soil auger was used to document soil texture and type of refusal (sand, gravel, groundwater, or none at 20 ft). Within a plot, field measurements at the species level include the diameter at breast height (dbh) of woody stems, canopy height, and shrub and herb cover. Derived values include total basal area and species importance value. Results showed that restoration plots varied widely in structure, from zero woody stems to total basal areas > 1000 cm2 and stem densities > 100 in plots with a well-developed tree canopy. Both total basal area and stem density are strongly related to refusal type. Forest growth is promoted by groundwater refusal and inhibited by sand, gravel, or no refusal (indicating no groundwater at 20 ft). Sites with no or limited forest development in 2003 remained that way in 2008. Valley oak had the highest importance value across the sites, followed by arroyo willow, elderberry, boxelder and sycamore. The herb layer remains predominantly nonnative (no native herbaceous species were planted). Where soil conditions permit, forest growth continues to be good and appears to achieve the desired habitat complexity for wildlife.

CALFED Statement of Relevance
A substantial amount of money and effort has gone into habitat restoration along the Sacramento River. The study helps document the success of this effort.

SESSION: Riparian Habitat, 10/23/2008, 10:20 AM, Room 307

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Riparian Forest Patterns in Abandoned Channels on the Middle Sacramento River: An Alternative Recruitment Pathway for Pioneer Riparian Vegetation in Gravel-bed Meandering Rivers

Pioneer riparian forests dominated by cottonwood (*Populus*) and willow (*Salix*) are typical of alluvial gravel-bed rivers in semi-arid and temperate climates, and provide a host of ecosystem functions that sustain natural resources and benefit human societies. From our preliminary work along the middle reach of the Sacramento River, California, we have developed a conceptual model that incorporates linkages between vegetation dynamics and the geomorphic evolution of abandoned channels that formed as a result of episodic, punctuated channel cutoff or avulsion events. To date, the contribution of this alternative recruitment pathway to overall riparian vegetation dynamics has received little study, despite the prominence of abandoned channels on the landscape and their potential importance in maintaining functioning riparian forests over the long-term, particularly under regulated river conditions. Based on 1999 vegetation mapping for the entire 100-mile reach, cottonwood-dominated forest associated with abandoned channels comprised 54% of the total mapped cottonwood forest area. In addition, we propose that the rate at which sediment fills the abandoned channel may allow for repeated recruitment events. As the abandoned channel fills, sedimentation rate decreases over time while total sediment accumulation approaches an equilibrium depth. Texture of deposited sediment also becomes finer, and is linked to improved water availability for plants. We propose that a sediment texture threshold occurs where pioneer woody species are excluded by competition with herbaceous vegetation that quickly colonizes finer substrates. Our hypothesis is that abandoned channels experiencing faster initial sedimentation reach this threshold sooner, so there are fewer recruitment opportunities for woody pioneers. We examined the age structure of existing forest stands via dendrochronological techniques on cottonwood, and cored sediments to gauge accumulation on the floodplain. Preliminary results correlate well with estimates of time-since-cutoff based on time-series historical aerial photography, and successive recruitment events were documented at some sites.

CALFED Statement of Relevance
This work seeks to directly inform CALFED's Ecosystem Restoration Program goals by understanding the patterns and drivers of cottonwood establishment and dynamics within abandoned channels. Improving our knowledge of the ecology and population dynamics of Fremont cottonwood is a necessary foundation for conserving, managing, and restoring Central Valley floodplain habitats.

SESSION: Riparian Habitat, 10/23/2008, 10:40 AM, Room 307

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Riparian Seedling Mortality in Semi-arid Ecosystems and Applications to River Restoration

Seasonal water limitation exerts a strong ecological filter on stream communities in semi-arid regions. A major population limitation for riparian willow and poplar trees is desiccation in the first year from declining river flows following germination. We investigated survivorship of first-year riparian seedlings to simulated river stage declines, focusing on the three dominant species in California's San Joaquin Basin: Fremont cottonwood, Goodding's black willow, and narrow-leaved willow. Seedlings grown in mesocosms were subjected to water table decline rates typical in spring on unregulated and regulated rivers. We compared the species differences in survival time and fit the empirical data to accelerated failure time (AFT) models that predicted time until death as a function of drawdown rate, initial seedling size and maternal line. We used AIC to select the most parsimonious model for each species. Water table decline rates 6 cm/day were fully lethal to all species, whereas 1 cm/day had no effect compared to a stable water table (>63% survival). At an intermediate rate (3 cm/day) survival varied most among species (12-38%) and was lowest for cottonwood. For all species the time to peak mortality was negatively correlated with drawdown rate, indicating a cumulative effect of water stress on survival. The best failure time models included drawdown rate as the single parameter for willows, and rate and initial size for cottonwood. Across the range of survivable drawdown rates (¡Ü4 cm/day), Goodding's black willow sustain >20% higher survivorship over the other species after 30-40 days of stage decline. Current river management practices in the San Joaquin Basin have a disproportionately-large impact on spring runoff, and stage declines in most years are greater than can be sustained by seedlings. Using AFT model results we simulated non-lethal flow scenarios for the Tuolumne River in wet years that did not increase the overall discharge volume.

CALFED Statement of Relevance
The technical approach developed herein can guide flow releases along regulated rivers to promote large-scale habitat restoration, influence plant community dynamics, and balance ecosystem needs with growing human demand. This is crucial both in the California Bay-Delta ecosystem and other water-limited regions worldwide.

SESSION: Riparian Habitat, 10/23/2008, 11:00 AM, Room 307

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Factors Affecting and Strategies for Facilitating the Recruitment of Native Understory Plant Species in Restored Riparian Forest on the Upper Sacramento River

Most riparian forest restoration projects have focused on restoring overstory species, whereas few studies have experimentally assessed factors limiting recruitment of understory species. The goal of this research is to determine whether canopy cover or exotic grass competition more strongly affect seedling recruitment, survival, and growth of native understory plants in order to inform restoration efforts. In fall 2005, we broadcast seeded and planted seven species (*Aristolochia californiCA Artemisia douglasiana, Carex barbarae, Clematis ligusticifolia, Euthamia occidentalis, Rubus ursinus*, and *Vitis californica*) at three old restoration sites (restored 1998-99) and three new restoration sites (restored 2004-06) along the Sacramento River. Understory species were introduced to plots with and without grass-specific herbicide and with and without overstory cover (old sites only). As of September 2007, seedlings showed relatively high overall survival given that they were not irrigated (range: *Rubus* - 55% to *Aristolochia* - 14%). Survival of five species was higher in old restoration sites, whereas *Artemisia* and *Euthamia* had higher survival in the new sites. At the old sites *Carex, Clematis, Aristolochia*, and *Vitis*, all had significantly higher survival in plots with overstory cover. The other species showed no difference in survival between the open and overstory plots. Treatments to reduce grass competition had minimal effect on survival and growth, which is likely due to extensive growth of broadleaved weeds in the exotic grass control plots. Establishment from seeds in spring 2006 was low (<5 seedlings/m2) for all species, so plots were reseeded in fall 2006. In spring 2007 seed germination was significantly higher in the canopy treatments for all species except Artemisia and *Euthamia*. Results thus far show some understory species require a closed canopy for germination. Therefore, we recommend introducing these species to restoration sites where the overstory canopy has matured.

CALFED Statement of Relevance
The goal of this research is to determine whether canopy cover or exotic grass competition more strongly affect seedling recruitment, survival, and growth of native riparian understory plants. This information can be used to increase the survival of understory plants in forest restoration projects taking place along the Sacramento River.

SESSION: Riparian Habitat, 10/23/2008, 11:20 AM, Room 307

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Monitoring of Active and Passive Riparian Restoration on Constructed Floodplains, Lower Clear Creek, Shasta County, California

The Lower Clear Creek Floodway Rehabilitation Project, located near Redding, in Shasta County, California, was designed to restore the stream channel and floodplains that were severely altered by aggregate and dredger gold mining and an altered flow regime resulting from the construction of Whiskeytown Dam. During the initial phases of the project, forty-six acres of floodplain were constructed using dredge tailings and floodplain deposits and planted primarily using hardwood cuttings of Fremont cottonwood (*Populus fremontii*), willow (*Salix* spp.) and mulefat (*Baccharis salicifolia*), as well as valley oak (*Quercus lobata*) container stock and acorns. Scour channels were constructed to intercept spring groundwater and encourage natural regeneration of riparian vegetation. A monitoring program was designed to measure the success of the project relative to two broad project objectives along with a number of more specific quantitative objectives. Permanent belt transects were established on the constructed floodplains to measure planting survival, height, and canopy diameter, along with natural recruitment. Line-intercept transects were established within constructed scour channels to measure natural recruitment. Measures of rooted frequency and aerial cover of herbaceous species were added to the monitoring program in 2007. A site assessment was conducted to collect soil and groundwater information in areas with significant differences in survival and productivity. After eight years of monitoring the initial plantings, results indicate that hardwood cuttings are successfully establishing in a patchy distribution, where site conditions are favorable. Structural diversity is somewhat lacking due to the low soil productivity and lack of shallow soil moisture. Woody riparian vegetation is naturally recruiting in reaches of the scour channels where hydrologic conditions are favorable, and is creating high-quality songbird nesting habitat. Valley oak survival and productivity is very low. Recruitment of non-native woody plant species was initially minimal, but is increasing as site conditions become more favorable.

CALFED Statement of Relevance
The use of highly-permeable tailings and floodplain materials to reconstruct floodplains, coupled with an undulating, water-perching claypan layer presents a unique challenge for riparian restoration. Monitoring results are providing adaptive management feedback information for future phase designs of this project and other riparian restoration projects in mined watersheds.

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