A MECHANISTIC MODEL TO EVALUATE AND IMPROVE RIPARIAN RESTORATION SUCCESS

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Riparian forests are crucial zones of biodiversity, dispersal, production and interaction. More resource rich and physically dynamic than the surrounding landscape, they provide important ecosystem functions such as habitat complexity and structure, inputs of nutrients and woody debris, and microclimate amelioration to both the riverine and terrestrial ecosystems.

In the Central Valley of California, Fremont cottonwood (*Populus fremontii* ssp. *fremontii*), Goodding's black willow (*Salix gooddingii*), and narrow-leaved willow (*Salix exigua*) dominate the near-river forests. These are the largest, fastest-growing woody species to colonize young floodplain surfaces. Soon after establishment, they provide ecological structure to the riparian ecosystem by stabilizing the substrate, fixing carbon, generating large woody debris, and creating vertical stratification for wildlife habitat.

In contrast to most tree species, for which adult mortality rates drive population dynamics, riparian trees populations in arid-land ecosystems are more sensitive to rates of seedling establishment. The abiotic processes of river flow timing and magnitude, soil conditions, and climate largely control recruitment of these species. Life history traits such as pulsed seed release in spring, dispersal by hydrochory, and fast root growth are effective at exploiting the transient resource conditions associated with this disturbance-driven river ecosystem. As a result, pioneer riparian tree populations are typically composed of multi-aged cohorts that established in years with large floods.

In the Central Valley of California before the era of large dams, the predictability of seasonal hydrologic cycles allowed disturbance-adapted willows and cottonwoods to thrive and dominate near-channel areas. In this ecoregion—as in much of the developed world—flow regulation of most major streams have created an artificially stable physical regime, which arrests the ecological processes that generate and maintain the natural, non-equilibrium ecosystem. The historically abundant resource pools associated with floods (e.g., increased soil moisture, nutrients and light) are no longer supplied at the appropriate time and rates to sustain pioneer seedlings beyond the first year. As a result, seedlings on regulated rivers establish lower on banks and suffer higher overwinter mortality than under historical conditions, resulting in a lower frequency of viable cohorts. Over the long term, flow regulation can shift the population structure toward older individuals and alter the dominance in the near-channel riparian zone from pioneer communities to ones less dependent on disturbance for establishment. These impacts imposed by regulated flow regimes are exacerbated by the widespread conversion of riparian forests to agriculture and the shifts in seasonal temperature and water availability projected to occur with global climate change.

Restoring the dominant pioneer species in these non-equilibrium riparian communities poses the daunting dual challenge of understanding both the physical and ecological processes that operate on interannual and decadal time scales to structure riparian-floodplain ecosystems. The fundamental scientific question I asked is:

How do we restore disturbance-dependent communities in
disturbance-altered ecosystems?

In order to answer this question for pioneer riparian tree species in California's Central Valley, we need to understand the linked physical and biological processes that limit seedling recruitment and to predict ecosystem responses under both natural and managed disturbance regimes.

Over the last quarter century, numerous researchers have studied these questions for cottonwood and willow species in other western North American riparian ecosystems. Many of the patterns and processes described in these studies were synthesized by Mahoney and Rood[1] into a conceptual model which they named the "recruitment box". This model describes the key ecological drivers of seedling recruitment in near-channel riparian zones: site hydrology, seed release timing, and seedling tolerance to desiccation. Though directly relevant to the restoration needs of pioneer riparian species native to the Central Valley, we lacked sufficient data on these species, despite an early wave of interest and scholarship in the 1980's on California riparian systems.

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[1] Mahoney, J. M., and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment--an integrative model. Wetlands 18:634-645.

My objective in undertaking this research was to apply this conceptual model to the ecology and restoration needs of the three dominant riparian trees in the San Joaquin Basin. My approach, using field and laboratory studies, was to rigorously quantify each of the key driving factors of recruitment—site hydrology, seed dispersal patterns, and seedling ecophysiology—and then integrate these studies into a predictive model.

I conducted this research in four parts, each of which corresponds to a chapter in my dissertation.[2] In Chapter 1, I documented basic patterns of seedling occurrence and tested several key assumptions regarding the influence of biotic factors on recruitment in flow-altered riparian systems. In Chapter 2, I quantified seasonal patterns of seed dispersal and predict them using a temperature-based model.[3] In Chapter 3, I experimentally tested the mortality and physiological response of seedlings to drought stress from simulated river stage decline.[4]

In Chapter 4, I used the empirical studies to develop a process-based, predictive model of seedling recruitment. The recruitment model generates estimates of seedling density and elevation based on projections of site inundation, seed release timing and density, and a survival function that quantifies seedling mortality induced by water table decline. I simulated annual recruitment along the lower Tuolumne River in 2002-2004, and compared these predictions against independent observations of recruitment patterns for the same time period.

Despite the simplifying assumptions and abstraction of topography inherent in the model, its predictions nevertheless capture the basic patterns of interannual and species-level differences in recruitment. In both model predictions and field observations, seedling density was highest in 2004 and lowest in 2003. The model correctly predicted that *Salix exigua* recruitment would be less extensive than for the two tree species. The model predicted the

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[2] Stella, J.C. 2005. A field-calibrated model of pioneer riparian tree recruitment for the San Joaquin Basin, CA. Ph.D. dissertation. Department of Environmental Science, Policy and Management, University of California, Berkeley. 215 pages.

[3] Stella, J.C., J.J. Battles, B.K. Orr, J.R. McBride. (in press) Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. *Ecosystems*.

[4] Stella, J.C., J.J. Battles, J.R. McBride, B.K. Orr. (in review at *Ecological Applications*) Survival, growth, and physiology of riparian tree seedlings in response to simulated river stage decline.

range of bank elevation where the greatest seedling density would occur in a given year, though it over-estimated the limit where seedlings could survive.

As a spatially-implicit simulation for one site, the model clearly underrepresents the high variability in recruitment encountered within a river reach. Nevertheless, the successful pattern replication conducted in this work is a first step toward developing the recruitment model into an analytical tool for prioritizing riparian preservation areas, guiding floodplain rehabilitation designs, optimizing restoration flow strategies, and simulating the impacts of climate-induced changes in physical ecosystem drivers.