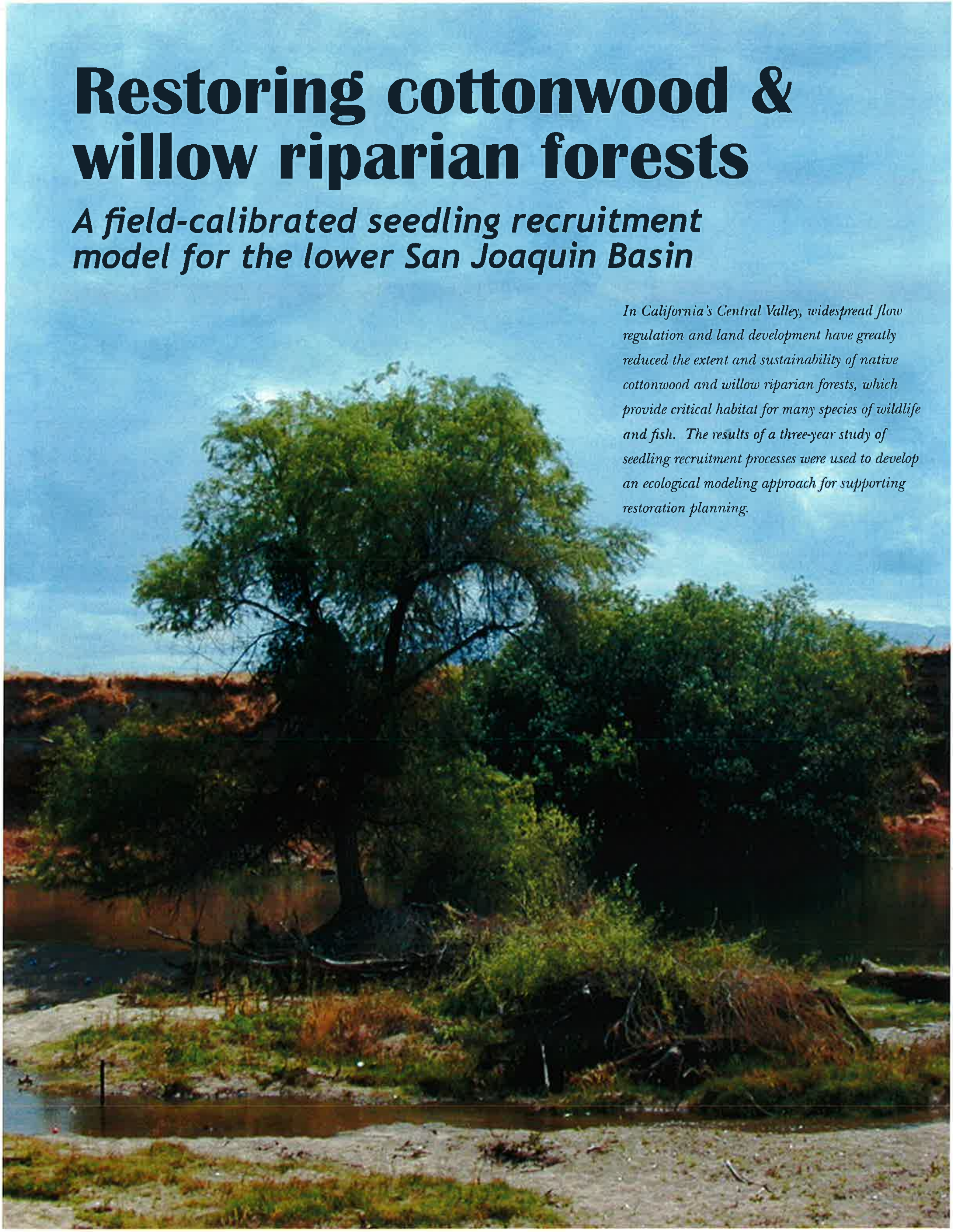
Restoring cottonwood & willow riparian forests

A field-calibrated seedling recruitment model for the lower San Joaquin Basin

In California's Central Valley, widespread flow regulation and land development have greatly reduced the extent and sustainability of native cottonwood and willow riparian forests, which provide critical habitat for many species of wildlife and fish. The results of a three-year study of seedling recruitment processes were used to develop an ecological modeling approach for supporting restoration planning.



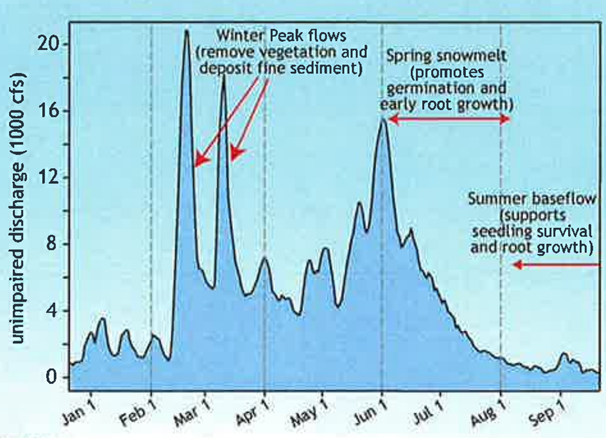
Riparian zones are critical areas in the landscape that connect and sustain river and terrestrial ecosystems. Riparian trees stabilize streambanks, filter nutrients and pollutants, cool nearby air and waters, contribute nutritious leaf litter and large woody debris to the aquatic ecosystem, and provide migration corridors and vertical habitat for birds and wildlife.

Over the last 150 years, 90% of riparian habitat in the Central Valley has been lost to land conversion, channelization, and flow manipulation. In the lower San Joaquin Basin, alteration of natural flow regimes for flood control, irrigation, and hydropower has reduced seedling establishment for the dominant cottonwood and willow species. Because these are the first trees to colonize young floodplain surfaces ('pioneer species') and the fastest growing, they are among the most important in the ecosystem. With decreased seedling establishment, near-river forest patches have become older, more fragmented, and more likely to be replaced by other, less beneficial habitat types.

To combat the decline of riparian areas, rehabilitation of channels and floodplains in degraded river reaches has become an increasingly frequent restoration activity in the lower San Joaquin Basin. Numerous large projects have been implemented on the Tuolumne and Merced rivers, with more planned on these and other Basin rivers. However, these efforts are limited by a lack of knowledge of ecological requirements for native plant species and practical ways to predict the effects of restoration actions.

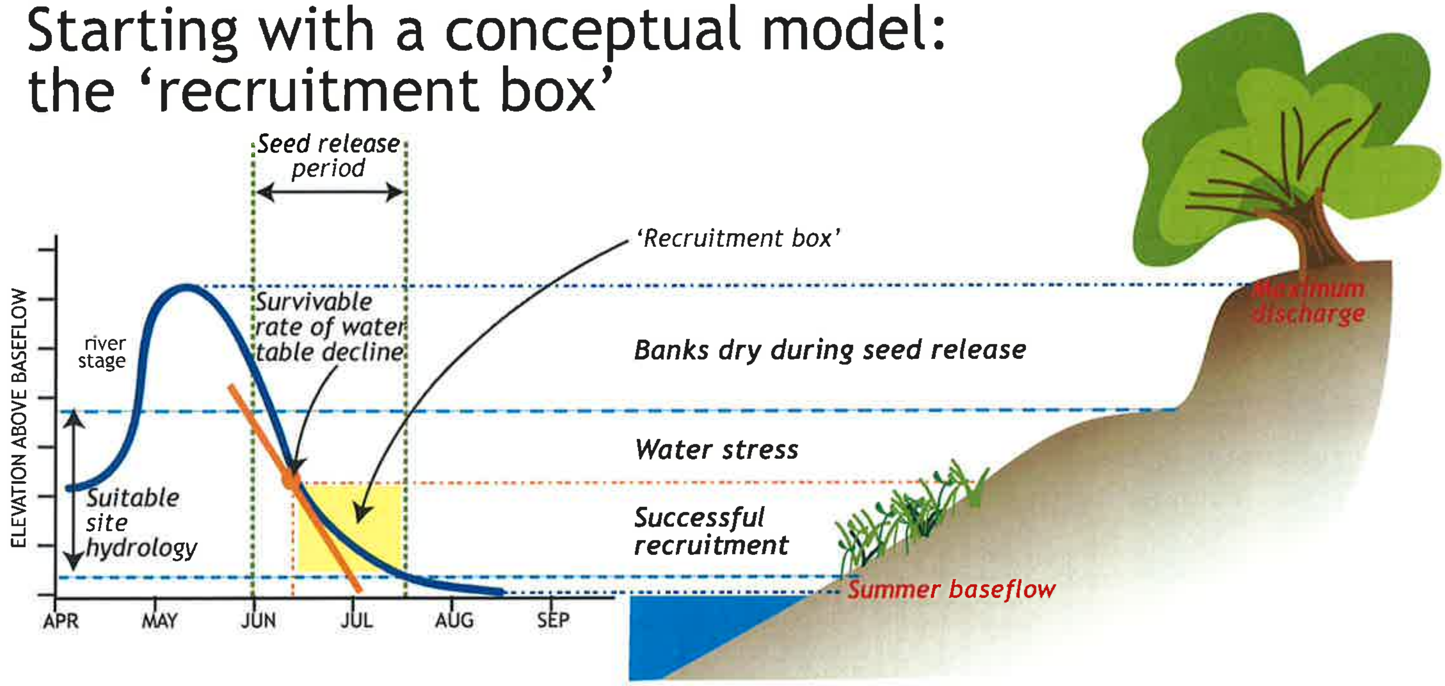
From 2002 to 2005, we studied the key physical and ecological processes needed to restore riparian cottonwood and willow ecosystems in the San Joaquin Basin. Using a simple conceptual model as a guide, we conducted innovative field studies and experiments to quantify factors controlling seedling recruitment for the three species dominant throughout the Basin: Fremont cottonwood (*Populus fremontii* ssp. *fremontii*), Goodding's black willow (*Salix gooddingii*), and narrow-leaved willow (*Salix exigua*). We used the data from these studies to develop a predictive recruitment model that can make restoration strategies more effective and less costly, such as modifying the timing and magnitude of flow releases to ensure the greatest possible benefit for tree populations and their dependent riparian ecosystem.

Our study area was the lower San Joaquin Basin in the Central Valley of California, with field sites on the Tuolumne and San Joaquin rivers.



Riparian tree recruitment in this region is controlled by river flow timing and magnitude, soil conditions, and climate. Characteristics of the annual river flow regime critical for successful recruitment are noted in the figure to the left.

Starting with a conceptual model: the 'recruitment box'



The key ecological drivers of seedling recruitment in near-channel riparian zones include three components: site hydrology, seed release timing, and seedling tolerance to desiccation (Mahoney and Rood 1998). Site hydrology determines the availability and condition of potential seedbeds and water table dynamics throughout the growing season. Because these species have short-lived seeds, dispersal timing controls when and where on the riverbanks seeds germinate. Recruitment typically occurs as spring floodwaters recede, and avoiding or tolerating water stress is critical for long-term survival. The area in yellow illustrates the **'recruitment box'**, where these three factors determine a temporal and spatial zone of opportunity for successful seedling recruitment. Along riverbanks, we see this process in action as a band of dense seedlings whose upper margin is limited by the magnitude of flooding during the seed release period as well as rapid rates of water table decline. The lower margin is limited by scour and deposition from subsequent high flows.

In a nutshell...

Seedling recruitment is critical for sustaining near-channel riparian forests along lower San Joaquin Basin rivers, but extensive changes to the natural flow regime reduce the successful establishment of young trees.

We adapted an existing conceptual model of seedling recruitment to quantify the 3 key factors limiting cottonwood and willow establishment in the ecosystem:

- the influence of site hydrology versus biological processes;
- seed release patterns;
- seedling water stress thresholds.

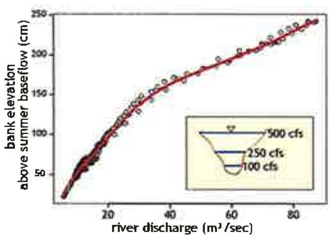
Using empirical data from these studies, we developed a model that simulates recruitment patterns, and tested predictions for the lower Tuolumne River in 2002–04 against independently-observed field data.

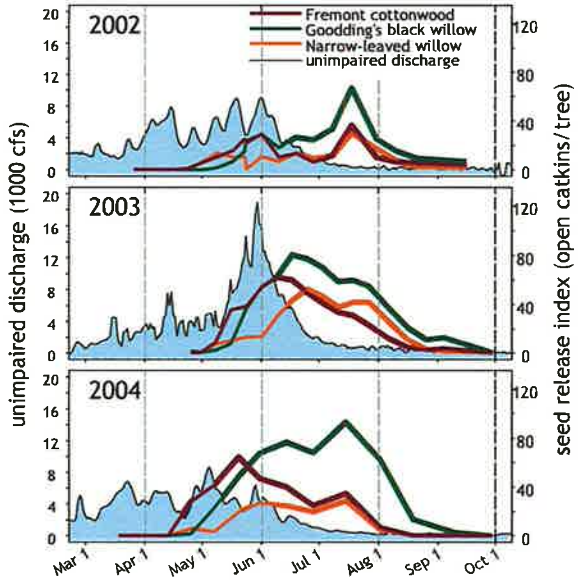
What we measured: site hydrology, seed release timing, & seedling water stress

We developed stage-discharge relationships at 3 sites in order to convert annual flow records to relative bank elevation (photo above & figure to right).

Site hydrology sets the stage

Because cottonwoods and willows need moist seedbeds to germinate and grow, site hydrology—the amount and pattern of soil moisture available during the growing season—is a crucial limiting factor for successful recruitment. We tested the influence of site hydrology and other factors on recruitment at three sandbar sites along the lower Tuolumne River. Seedling occurrence and survival were correlated positively with soil moisture, negatively with bank elevation, and not at all with the density of competing plants.





Temperature influences seed release timing

Cottonwood and willow species have short-lived seeds and no long-term soil seed bank. For seedling recruitment to be successful, trees must release seeds when sandbars are saturated and clear of competing vegetation. Historically, this happened in late spring as snowmelt floodwaters began to subside. Peak seed release needed to coincide with elevated river levels for seedlings to establish high enough on river banks to escape scouring flows later in the year.

We tracked the seed density and dispersal timing at six floodplain sites along the lower Tuolumne and San Joaquin rivers from 2002–04. Cottonwood trees consistently released seeds before the willows, and dispersal was earliest in 2004, the year when spring air temperatures were warmest. We adapted a simple but robust method—a 'degree-day' model commonly used in crop science—to predict the annual timing of peak seed release (measured as a seed release index; see caption below). We can use this approach and the field data to predict the best dates to release river flows for maximizing seedling recruitment throughout a river corridor.

For three years, we observed seasonal seed release patterns (right) and calculated a seed release index, measured as the number of open catkins per tree during each survey (figure to left).

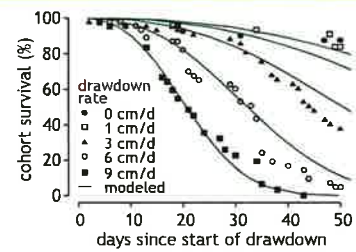
Declining water tables impair seedling growth and survival

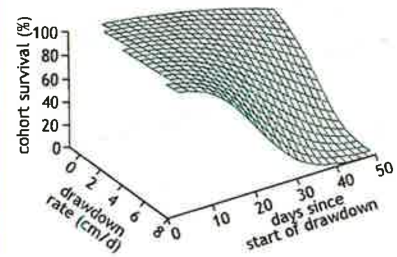
The rate of water table decline following peak runoff is a critical limiting factor for seedlings. Stage declines that are too rapid will desiccate roots. We grew seedlings at five simulated river drawdown rates (range 0–9 cm/day) and measured survival, growth and physiological response to water stress. Results of the drawdown experiment indicate that 50% of Fremont cottonwood seedlings will survive a constant water table decline of 1 centimeter per day for 50 days. That critical threshold (50% survival after 50 days) is met at 1.5 cm/day for narrow-leaved willow, and 3.5 cm/day for Goodding's black willow. Almost no seedlings survived water table decline rates 6 cm/day or greater.

At all treatment levels, Goodding's black willow seedlings had the highest survival and growth, which they achieved by minimizing water vapor loss through their leaves. Control group plants (grown at a stable water table) were the largest for all species, and growth declined with increased rates of water table decline. Survival was greatest for individuals with faster root growth rates and more root biomass (relative to shoot mass), although there was no evidence that seedlings actively adjusted their growth in response to water stress.

Both willow species tolerated water stress better than Fremont cottonwood. This pattern is consistent with differences in the species' environments during seedling establishment. River flows are generally stable and high in the early spring, during cottonwood peak seed release and germination, and decline more steeply during the late spring, when willows establish.

We drew down water levels for 50 days and tracked seedling survival, growth, and physiological response (left). For each species, empirical data (top right) were used to model cohort survival (bottom right).





Quantifying the conceptual model

We used results from the field studies and experiments to make the conceptual recruitment box model (Mahoney and Rood 1998) a quantitative tool for predicting seedling recruitment patterns. The table to the right summarizes the key conceptual model processes, the studies we conducted to measure them, and how we translated the empirical data as input functions to the quantitative recruitment model. The resulting model predicts, for each species, seedling density and rooting elevation along riverbanks at the end of summer.

Conceptual Recruitment Box Model Component	Empirical Data Collected	Recruitment Model Input Function
Site hydrology	-Pressure transducer stage data -Tuolumne River daily flow records	-Stage-discharge relationships -Daily flow records -Daily stage hydrographs
Seed dispersal timing	-Seed release data (open catkins/tree) -Continuous air temperature	-Seed release index -Degree-day model
Seedling water stress thresholds	-Seedling survival, growth and physiology for 5 rates of water table decline (0, 1, 3, 6, and 9 cm/day)	-Seedling cohort survival model for a continuous range of water table decline rates

Testing the model

We tested the model by predicting species-specific recruitment patterns for the lower Tuolumne River in 2002-04 and comparing predictions to seedling distributions observed independently in annual boat surveys conducted along a 20-km reach.

The model predictions capture the basic recruitment patterns among species and between years. In both model predictions and field data, seedling densities and rooting elevation were highest in 2004 and lowest in 2003. Both predicted and observed data showed Goodding's black willow densities to be highest and narrow-leaved willow the lowest in all years.

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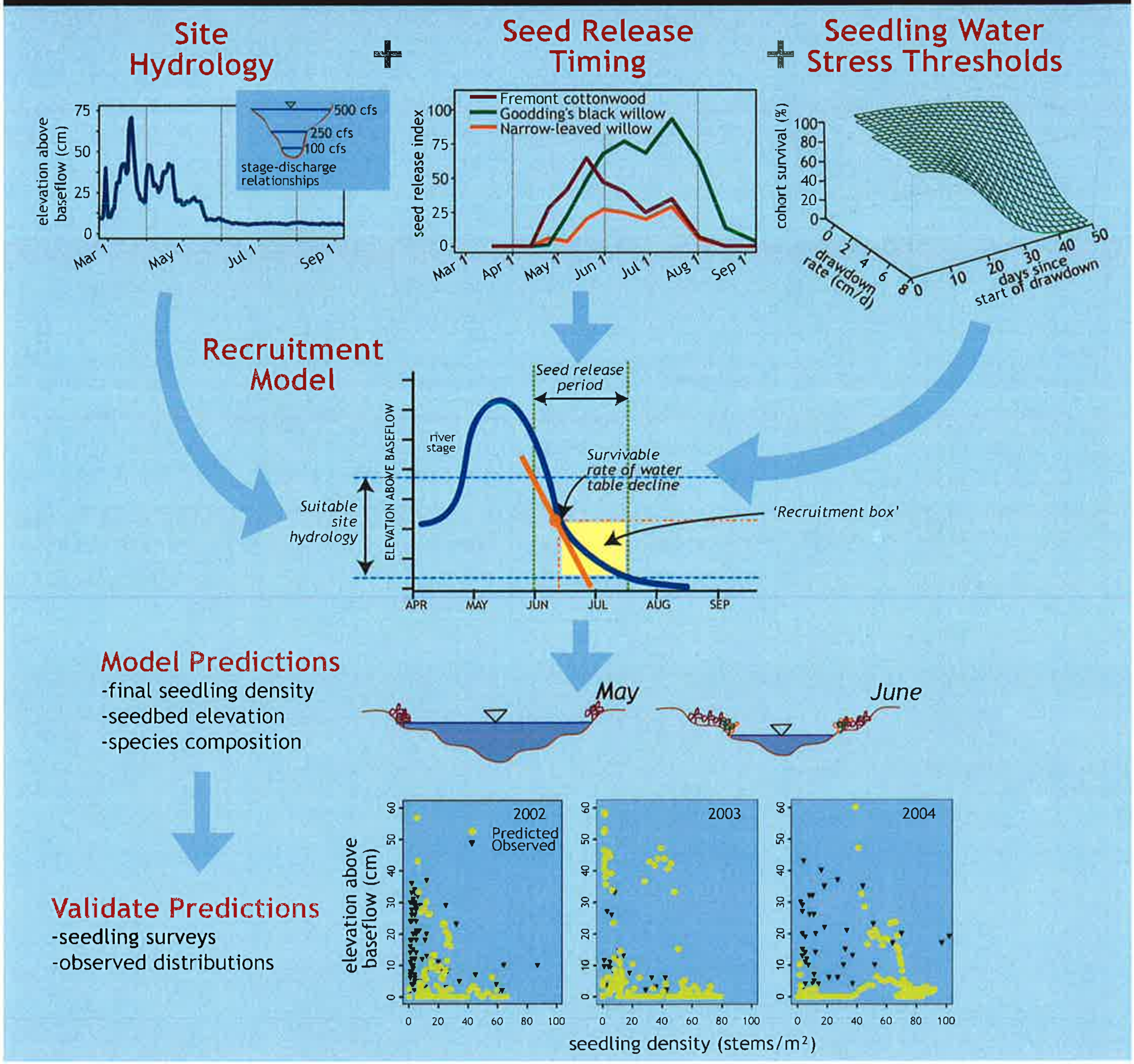
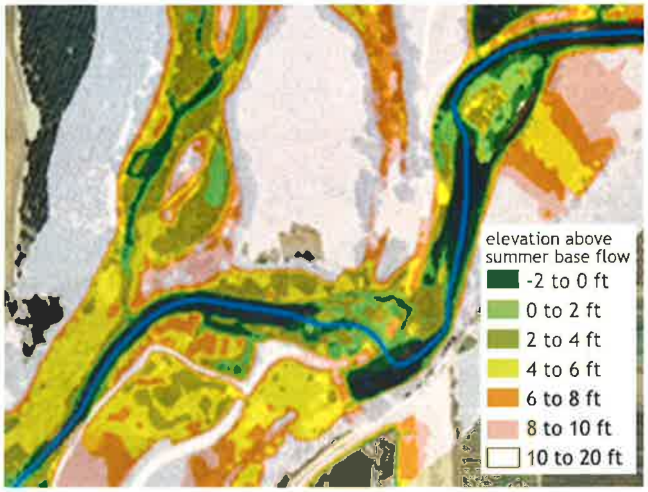
Generating recruitment predictions



Now what?

The predictive, field-tested recruitment model we developed is directly relevant to river management and conservation. By combining the recruitment model with geographic information systems and other analytical tools, we can address a number of important needs, such as designing efficient and ecologically-beneficial flow releases, predicting spatial recruitment patterns at restoration sites, and simulating the impacts on tree populations of climate-driven changes in river hydrology and seasonal temperature.

Applying it



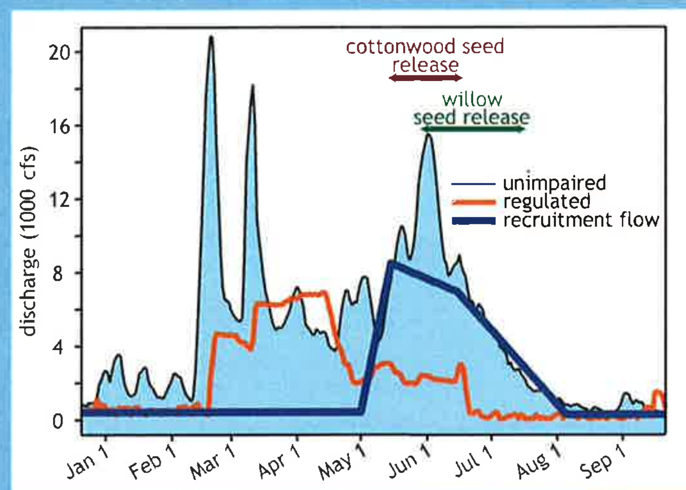
River corridor restoration planning

River corridor planning and large-scale restoration projects are increasingly common in the lower San Joaquin Basin, where channels and riparian areas are degraded by land development, flood control structures, and aggregate mining. The recruitment model can be a useful design tool for revegetating floodplains by predicting where seedlings are likely to establish under a particular flow regime.

For these projects, we would use GIS-based digital topography and stage-discharge data from field sites or hydraulic models to model areas of the floodplain where seedlings would germinate and survive. In the example above, colored floodplain zones are defined by elevation above the summer low-flow stage. Using this coverage with the recruitment model will allow us to evaluate which discharge patterns would maximize the spatial extent of seedling recruitment. This approach has been applied successfully to predict riparian vegetation response to natural and managed flow regimes along other Western rivers.

Managing water for ecosystem benefit

Widespread flow regulation along Central Valley rivers contributes to the decline of pioneer riparian vegetation populations, but also provides a critical opportunity for their recovery. Our research findings on tree reproductive timing and life history traits can be used to make flow releases more effective in promoting seedling recruitment at the lowest water cost. Because seed production is abundant every year, these 'recruitment flows' may be needed only in wet years, when natural water surpluses can meet both human water demand and ecosystem needs.



The figure above illustrates a proposed recruitment flow (yellow line), with unimpaired discharge (blue shaded area) and regulated flow (orange line) for a high-flow year (1986) in a representative river reach in the San Joaquin Basin. The recruitment flow uses the same volume of water as actually released but with the seasonal timing and flow recession modified to address riparian seedling needs. The proposed release peaks at the beginning of Fremont cottonwood's peak seed release period and recedes gradually until the river reaches its summer low-flow stage. The recession rate is less rapid initially to sustain young cottonwood seedlings, which have slower root growth than willows. Recruitment flows will need to be coordinated with water management and other ecosystem needs (e.g., flow releases for native fish).