

The Cosumnes River Experience and Recommendations for Restoration Monitoring

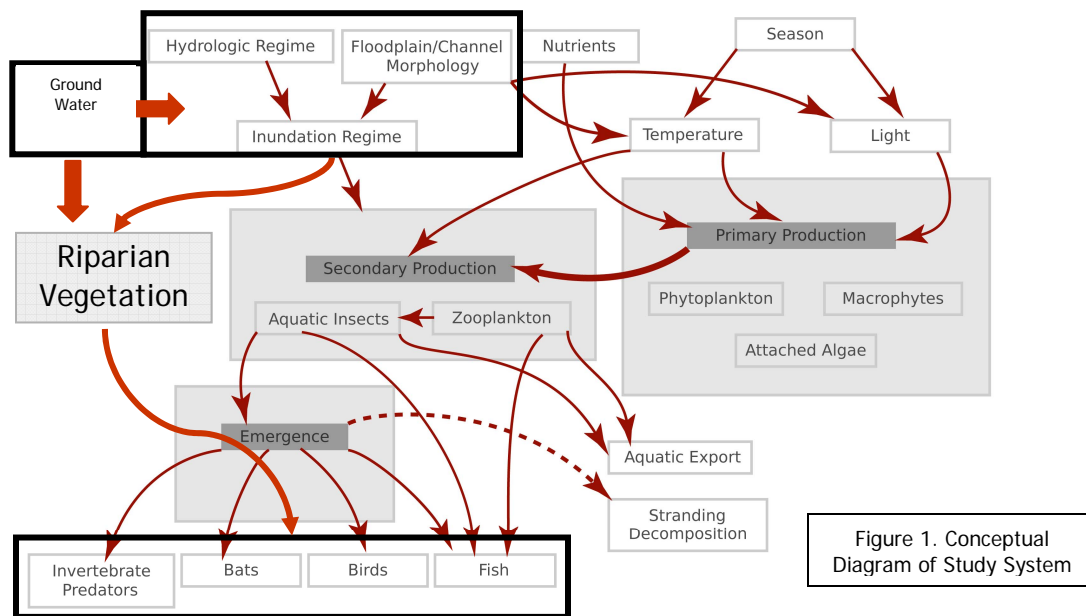
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Floodplains are among the most productive and diverse ecosystems on Earth and are now being recognized globally for the ecosystem services they provide; however, they are also one of the more impacted ecosystems globally and are at risk of further degradation by a fusillade of anthropogenic stressors and consumptive demands. Natural floodplain ecosystems are a product of, and adapted to, highly variable hydrologic regimes – typified by droughts, catastrophic floods, and frequent periods of inundation – expressed across seasonal, yearly, and decadal dimensions. This hydrologic variability acts to reset various biotic populations within aquatic, riparian, and wetland ecosystems through disturbance, acting as an essential ecological process in maintaining complex ecosystem pathways. Multipath ecological relationships, expressed as trophic food webs or transition states, promote high biodiversity and biological integrity. In floodplain ecosystems, these ecological relationships are underpinned by the fundamental linkage between floodplains and river systems, forming a critical linkage that creates and maintains a mosaic of habitats for groundwater recharge, primary productivity and biogeochemistry, the reproductive cycle of fishes, nesting and foraging of birds, and regeneration of riparian vegetation.

It is estimated that less than 5% of the Central Valley's original riparian forest remain intact. This fact, coupled with the simultaneous loss of floodplain wetlands to channel modification, agriculture and urbanization, has resulted in the desire for ecosystem scale restoration. For Central Valley lowland river floodplains, the only cost-effective method for large scale restoration is semi-passive; in essence, through structural modification – such as levee breaches or levee setbacks, followed by natural succession of flood dependent ecological communities – where nature does most of the work. However, past semi-passive restoration efforts have not been uniformly successful either in generating high quality, productive native-dominated vegetation or in re-establishing functioning food webs supporting floodplain sentinel species (e.g., birds, fishes, etc.). The lower Cosumnes River floodplain provides an unprecedented opportunity to examine semi-passive restoration techniques in relation to successional trajectory and opportunities for improved management and also the development of monitoring methodologies, as there is a 20-year history of wetland and riparian habitat restoration – both active and semi-passive in technique – that allows for temporal and comparative analyses.

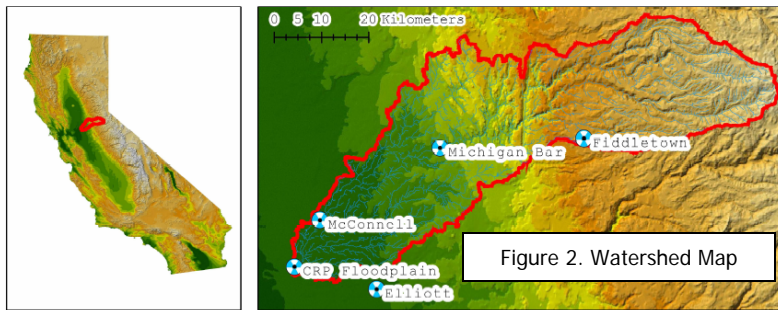
To help elucidate important patterns and processes in semi-passive restoration, we examine the interaction and feedback pathways between the physical regime and the ecological communities in the Cosumnes River floodplain, which is created and maintained by a natural hydrologic discharge regime that promotes habitat heterogeneity, nutrient transformation and exchange, and

spatiotemporal fluxes in productivity. Other important pathways include the interactions between the hydrologic discharge regime and groundwater, subsequent effects of groundwater on establishment of riparian forests, and possible changes in groundwater regime caused by forest evapotranspiration. In turn, forest productivity and structure provide both a trophic and a structural basis for both aquatic and terrestrial productivity, wherein biological indicators such as birds respond to the mosaic of qualitative and quantitative differences created by the differential effects of ecosystem disturbance and restoration (Figure 1).



Thus, restored floodplains and their biota depend on the ecological coupling of aquatic and terrestrial communities to promote successional trajectories and ecosystem functioning. At the most fundamental level, successful restoration of Central Valley riparian forests and floodplains requires that both foodwebs and structural habitats are transformed by and respond to changes in physical processes. We examine the exchange of energy and matter, as promoted by a natural flood regime, from floodwaters to invertebrates, fishes, forests, and birds. By examining incipient ecological processes in floodplain restoration, including invasion by an alien plant species, we document these transformations as promoted by hydrologic connectivity. Flooding has profound consequences for ecosystems and ecosystem managers alike; as such, in the following pages we share our insights and experiences from the Cosumnes River Experimental Floodplain to help inform future restoration and watershed monitoring strategies.

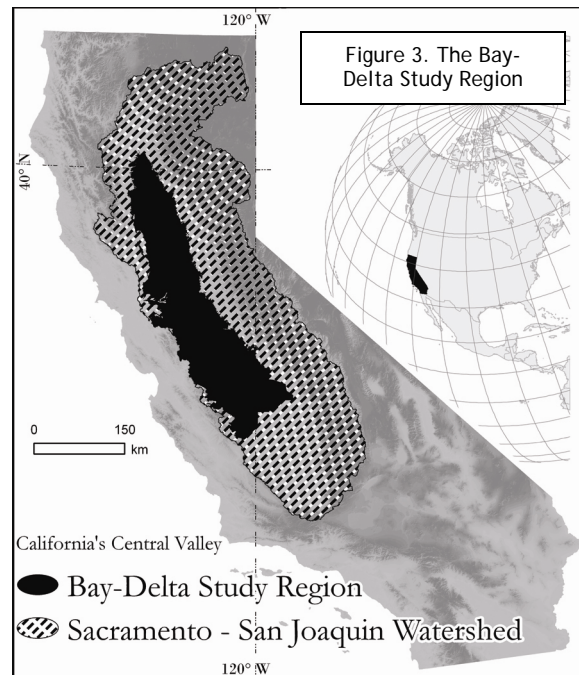
Background



The Cosumnes River watershed (Figure 2), located in southeast Sacramento County, drains ~2000 km² of land starting with its headwaters (2300 m) located in the Sierra Nevada mountain

range and ultimately draining into the Mokelumne River (2 m) and then the San Francisco Bay - Delta (Figure 3). The Cosumnes River is recognized as one of the few unimpounded rivers on the west slope of Sierra Nevada and - with the exception of base flow loss in the summer and fall months (see Groundwater Vegetation Interactions section below) - maintains a relatively natural hydrograph.

The lower Cosumnes River is considered historically as a dynamic, low-gradient, multi-channel anastomosing river system dominated by frequent avulsions and regular inundation of the floodplain during winter and spring. For the last 200 years, however, the Cosumnes River has been impacted by a range of land use activities. Once elevated sediment loads, created in part by hydraulic mining and grazing, diminished in the early 1900's, the river was further impacted by subsequent levee construction and channel incision. Compounded with widespread conversion of the floodplain forests and wetlands of the lower Cosumnes River to agricultural fields, few remnant stands of riparian forest remain. Today, the river is confined to a single-channel and remains almost entirely disconnected from its floodplain except during high flows when levees are overtopped through engineered levee breaches or levee failure.



Our study site (Figure 4) is a restored experimental floodplain located on the Cosumnes River Preserve (CRP), comprising over 18,000 hectares of land managed by a consortium of state, federal and non-profit organizations. Our study has been conducted in coordination with The Nature Conservancy California, with whom we partnered during previous California Bay-Delta Authority funded research. In particular, this partnership was instrumental in

documenting the restoration of agricultural fields adjacent to the river achieved by engineered breaching of levees in 1996.

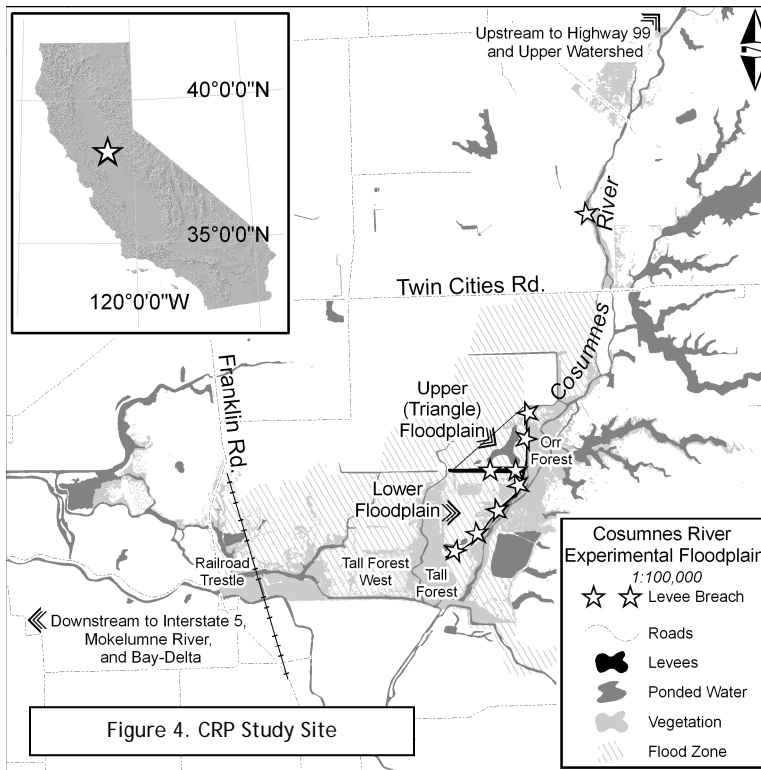


Figure 4. CRP Study Site

Project History

The multi-faceted research project described in this final report contains some stand-alone subprojects that were begun and completed between 2001 and 2006 and entirely supported by the current agreement, but much of it represents a continuation of a longer-term cooperative land management, monitoring, adaptive management, and research program carried on by an

evolving coalition led by The Nature Conservancy, BLM, CDFG, and to a lesser extent many of their partners in the Cosumnes River Preserve, and has involved multiple research partners beyond those (UC Davis, UC Berkeley, and PRBO Conservation Science) represented in this report. Some of the findings are derived from theses begun before the agreement became active, but that received some assistance from the investigators in their later stages. Some (e.g., PRBO's work) have had multiple sponsors. In addition, there was a considerable time-gap (from institutional causes) between approval of the project and its actual formal launching, and some investigators, to maintain continuity of the field record, commenced the proposed research under other funding.

To do justice to the entirety of the program and make the context of particular subprojects clear, we have reported on the results of all of the activities described in the original proposal, even though some of those were actually partially done before the official beginning of the project and/or with outside sponsorship. The delays and staggered start did, however, permit us to extend the environmental and research record for an extra year at no net cost to CALFED/CDBA.

While not timed exactly as originally proposed, the project evolved in phases, briefly described below.

Phase 1

The Cosumnes Research Group's collaborative study of the watersheds began in July of 1998. The initial multi-year segment of the project was funded primarily by the California Bay-Delta Authority (CALFED), and was completed in December of 2002. Research and monitoring efforts were directed to five broad areas: hydrology, geomorphology, water quality, aquatic resources and data management.

Phase 2

Beginning in January of 2001, a second, overlapping phase of study was begun, funded entirely by the California Bay-Delta Authority Ecosystem Restoration Program. For this now completed phase, our focus was extended to include: flood regimes, riparian restoration success, groundwater and vegetation interaction, linking aquatic and terrestrial ecosystems, bird populations as ecosystem indicators, data management, and floodplain monitoring.

Project Overview, Results, & Recommendations

Cosumnes River Flood Regime

Our studies rely on understanding the inherent hydrological dynamics of the Cosumnes River, as it is the natural variability of this undammed river that makes its restoration and study unique. To help elucidate and parameterize the frequency and variability of flooding on the Cosumnes River floodplain – in essence describing the flood regime – Booth and colleagues categorize a 98-year hydrograph and found that the Cosumnes River floodplain experiences two distinct periods of flooding.

The first period is comprised of floods that tend to be flashier and have larger peak flows but sustained flooding is not as common during this period as in the second period. The second period, later in the season, contains smaller peak flows compared to the first period, but days of flooding are more abundant. These two distinct periods of the flood season are most likely due to later-season snowmelt contributions and larger shallow groundwater inputs in the second period from sources earlier in the season. Flood types that transport sand onto the floodplain occur at least once in approximately two out of every three years and twice in half of the years. Very large magnitude floods occur at least once in one out of every five years on average. The long duration flood types occur at least once in roughly six out of every ten years.

The flood type classification along with the flood statistics determined for each flood event on record can also be used to test the potential long-term frequency of certain biological phenomena observed on the Cosumnes River floodplain. Booth and his colleagues calculated that “productivity pumping” as

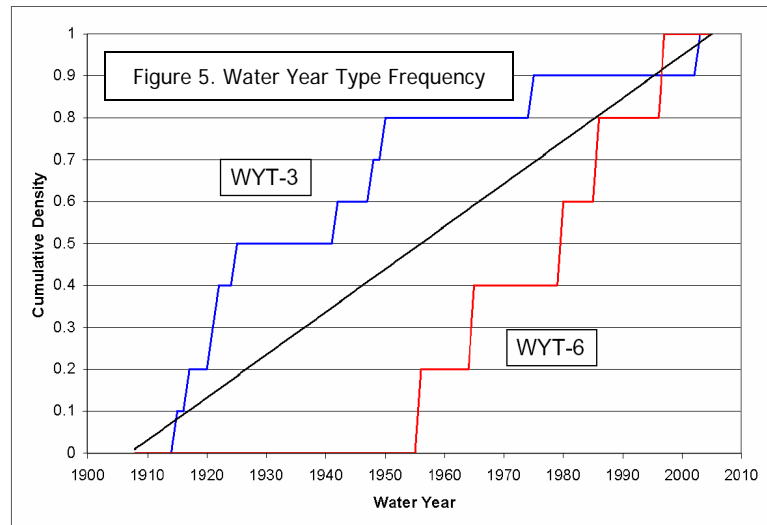
described by Ahearn (see below) occur in two out of every three years, and at least two effective floods occurred in roughly half of the years.

This typology also has the ability to determine the frequency of certain phenomena but on an annual time-scale. This study documented that the ratio of flood types is changing through time. In particular, water years with a relatively dry winter but a relatively wet spring, decreased in frequency in the second half of the streamflow record (post-1956) (Figure 5).

In contrast, water years with a very wet winter but a relatively dry spring, increased in frequency in the second half of the record. These two opposite trends are consistent with the notion of a rising snow-rainfall transition line at critical elevations due to increased winter and spring air

temperatures since the mid-20th century, known as global warming, which is leading to larger winter floods and diminishing the later snowmelt-dominated part of the hydrograph. This finding presents a profound challenge to managers of floodplain ecosystems as the dynamical balance of flood flows, as we know it, is changing.

To characterize the biogeochemical nature of the Cosumnes River flood regime, we quantified the flux of nutrients and food resources across the channel-floodplain boundary while delineating the chemical and hydrological signature of different stages of the flood pulse. We also studied the influence of the flood pulse on the spatial distribution of suspended algal biomass across the surface of a restored floodplain. The findings of Ahearn and others contained in this report indicate that periodic connection and disconnection of the floodplain with the channel is vital to the functioning of the floodplain as a source of concentrated suspended algal biomass for downstream aquatic ecosystems. This conclusion is based on the observation that peak chlorophyll levels on the floodplain occurred during flood disconnection and distribution across the floodplain was controlled by water age and local conditions, such as water depth. Storm-induced floodwaters entering the floodplain not only displaced antecedent floodplain waters, but also redistributed floodplain resources, creating complex mixing dynamics between parcels of water with distinct chemistries (Figure 6).



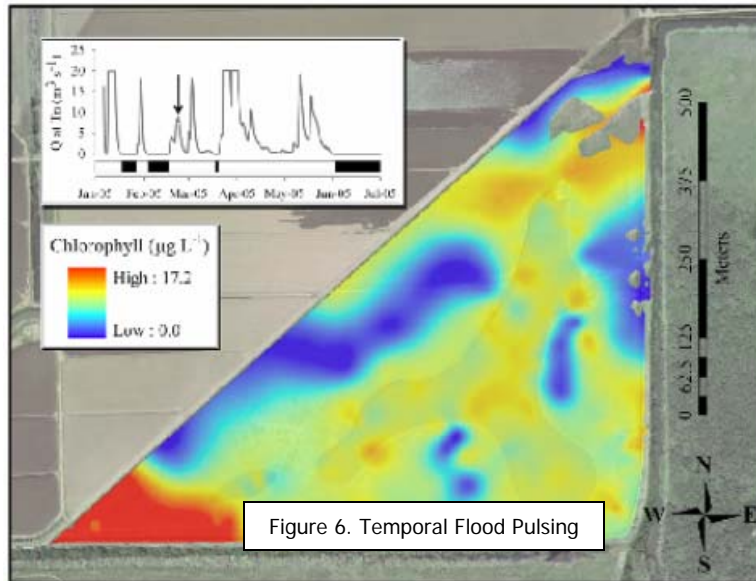


Figure 6. Temporal Flood Pulsing

Partitioning of the phases of the flood pulse revealed three physically and chemically distinct stages: the flushing phase, the transport phase, and the draining phase. The flushing phase was a brief period of export on the rising limb of the flood, this phase only occurred after an extended period with no upstream connection. The

transport phase dominated the flux balance of the system and was marked by retention of all the measured constituents on the floodplain. The fact that small floods were not dominated by the retentive transport phase helps explain why these floods tended to cause net export, rather than retention, of materials on the floodplain.

Ahearn and his colleagues propose the notion of “floodplain proportional flooding” for restored floodplain systems, whereby flood size should not overwhelm floodplain volume. In this way, residence time is increased as is the potential for the floodplain to be a source for valuable food resources for downstream aquatic ecosystems. They continue by observing that the degree of complexity revealed in their analysis makes clear the need for high-resolution spatial and temporal studies to begin to understand the functioning of dynamic and heterogeneous floodplain ecosystems.

Floodplain Restoration

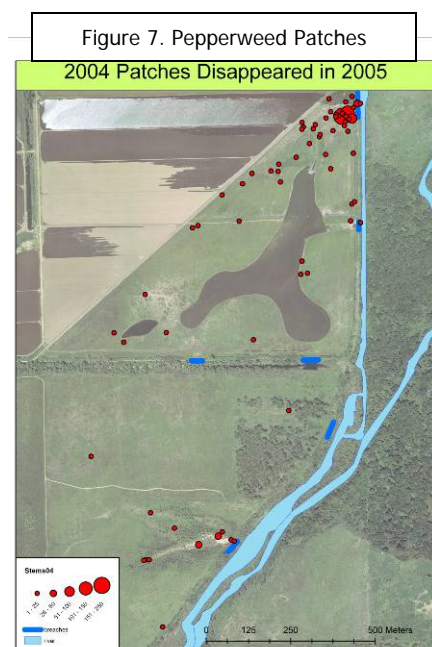
Our studies were designed to help answer outstanding questions concerning landscape-scale physical factors that either promote or diminish restoration success, and how these factors can be modeled to identify potential restoration sites for future investments. Further, the differences between semi-passive restoration (i.e., breaching levees, restoring floodplain connectivity) and active restoration (planting trees, intensive management) are largely untested over large areas. As a result, an important goal was to document the underlying differences among sites treated with semi-passive versus active restoration implementations. As non-native invasive plants often disrupt and become the limiting factor in long-term success of restoration efforts, we began an ongoing process of assessing how non-native plant invasions are affected by physical and environmental site characteristics found in semi-passive restoration areas.

Active restoration of riparian forests and floodplains is time-consuming and expensive, reliable methods are not yet established, and end results are highly variable with limited explanatory power. For these reasons, Viers and colleagues argue that riparian and floodplain restoration efforts should focus on re-establishing diverse river functions, such as ecological succession and hydrologic connectivity between surface and subsurface waters. Not only do semi-passive restoration techniques cover larger areas for far less investment, the incipient ecological processes that accompany the re-establishment of hydrological functions create habitat mosaics beneficial to many upper-trophic level species and promote staged successional trajectories that are the embodiment of structural and functional diversity.

In examining regional of plant species diversity and rates of turnover in relation to localized ones, Viers and others found that herbaceous species are more important than woody species in driving localized diversity measures. These results stem from the observation that riparian woody species, including trees such as valley oak, cottonwood, and willows, are largely cosmopolitan across the California Bay-Delta region. At the end of the day, biodiversity is dependent upon underlying physical complexity, which in the case of California's riverine floodplains, is created by hydrologic variability shaped by a natural flow regime.

Unfortunately, our analysis shows in part that haphazard historical restoration, absent the context of a larger experimental design and structured monitoring effort, makes definitive assessment of restoration success problematical. Despite the incomplete record, however, some patterns seem clear. Levee breaching is not a panacea that will effortlessly restore high quality riparian forests at will. Restoration appears most successful near channels with intermediate to high moisture - likely locations that were originally heavily forested. However, clay soils, site history (particularly irrigated grazing) and invasive species all contribute to alternate outcomes, including weed-dominated grasslands and sparse, stunted trees. Some of the causes are not yet known, but standard statistical methods applied within a GIS give some ability for managers to predict where restoration is likely to be successful, and to allocate their resources accordingly.

Hogle and colleagues studied the invasion of a non-native plant onto the Cosumnes River experimental floodplain to help determine, which, if any, landscape factors promote its invasion. As part of this process, they followed its population dynamics of perennial pepperweed to better understand its habitat



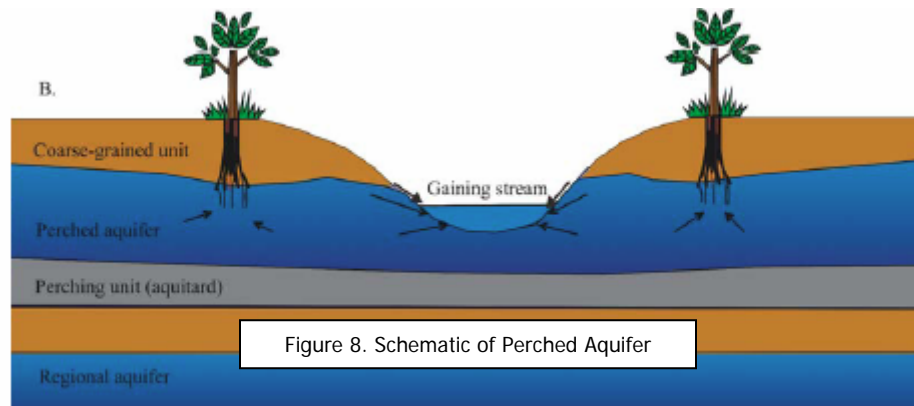
(Figure 7). Understanding the invasion process, especially the phases of introduction, colonization, and naturalization, helps determine appropriate remediation. Weeds typically spread through a two-phase increase with an initial lag followed by exponential increase, or an immediate exponential increase. The type of expansion trend exhibited is important for weed control strategies in that it helps gauge the amount of time available to leverage resources against the invasion. Based on four years of monitoring, areal expansion of established patches of perennial pepperweed at our site appears to be following a pattern of exponential growth, generally irrespective of floodplain position. New patches tend to In addition to further research on the ecology of perennial pepperweed, we recommend early eradication of emerging populations.

Groundwater Vegetation Interactions

Our intent was to explore groundwater and vegetation interactions. As such, we developed a hydrologic model for a combined river-reach and floodplain area of the Cosumnes River to estimate separate water budget components (including channel, vadose zone, and bank storage, riparian evapotranspiration, and aquifer recharge). The hydrologic model developed by Niswonger and colleagues was designed to establish the presence of perched aquifer systems at the Cosumnes River, which may function to buffer near stream ecosystems and riparian forests from drought. This model, and complementary work by Fleckenstein, provides quantitative analyses of the many key characteristics governing perched groundwater hydrology, providing insights about processes as well as the foundation for future studies. These groundwater studies were coupled with site intensive surveys intended to measure riparian evapotranspiration at two separate sites within the Cosumnes watershed. This component of our study estimated the amount of water lost from the hydrologic budget via evapotranspiration and likewise observed the effect of groundwater availability on riparian ecosystem evapotranspiration. Niswonger and colleagues found that perched aquifers form beneath the Cosumnes River and have significant influence on the hydrologic budget surrounding the river. Perched aquifers near the river correspond to patches of riparian vegetation not present in adjacent areas along the river (Figure 8).

These perched aquifers can shift the water budget near the river by maintaining saturated conditions within the riparian root zone, which allows water seeping from the river to be lost as evapotranspiration rather than seeping back to the river or to regional aquifers. Further, they recommend artificial recharge during periods of water surplus. Perched aquifers should be recharged by releasing water down the channel from Folsom South Canal and by breaching levees to cause floodplain inundation. Most importantly, however, is further refinement of groundwater modeling to locate areas favorable for the development of perched aquifers and mounded regional groundwater levels

that can enhance river baseflow and perched aquifer systems can be maximized.



The in depth evaluation of evapotranspiration not only helped parameterize the groundwater modeling effort, but also revealed several important findings. For example, Kochendorfer and colleagues found that during the growing season of 2004-2005, the Accidental Forest (predominately *Populus fremontii*) had free access to ground water, although its ability to photosynthesize may have been affected adversely by persistent late season flooding. Further, the vegetation monitored at Deer Creek experienced water stress due to the fact that site located trees use water from perched aquifers during the summer, and these aquifers can dry up seasonally depending upon the timing and the strength of rainy season recharge.

Aquatic and Terrestrial Linkages

The primary intent of this component of our integrated study was to understand how the flood cycle influences the controls of primary and secondary production and how and to what degree this aquatic production supports consumers in riparian habitats.

Grosholz and colleagues investigated algal community development and edibility as a function of abiotic factors, such as flood phase and water residence time, and by biotic factors, such as trophic cascades. This research examined ecological linkages and phase changes, such as whether nutritionally less valuable cyanobacteria dominate during the initial phases of a flood event, but are then replaced by slower growing, more edible algae, which provide food for and are eventually suppressed by rapidly expanding invertebrate populations. Flood events can have other ecological effects, such as the drain period, when sites with lower residence time and better connectivity may be more favorable to fish, suppressing the invertebrate community and allowing algae of greater edibility (e.g., smaller-celled diatoms, cryptophytes, and chrysophytes, as well as many protists such as ciliates) to persist. These observations are in contrast to others, where sites with higher residence time and less connectivity have fewer fish and more invertebrates, giving rise to a phytoplankton community dominated by larger and less edible algae (e.g.,

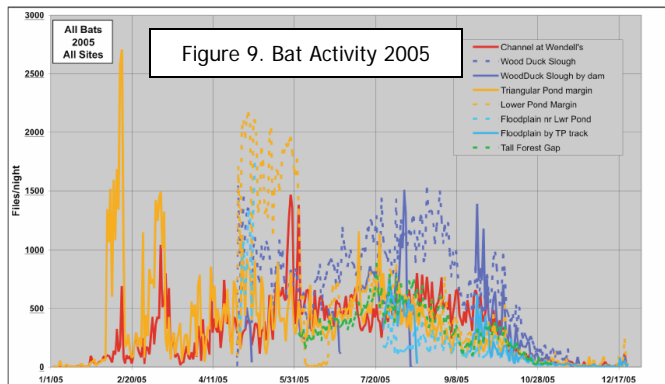
large pennate diatoms). Grosholz and his colleagues recommend that resource managers maintain diverse floodplain habitats, including open floodplain areas without large woody vegetation, forested floodplain, and pond habitats that become seasonally dry. They also argue for water management that ensures multiple, repeated inundation events – frequent hydrologic connectivity – to maintain the variety of ecological linkages that are manifest over spatial and temporal dimensions.

Insect Emergence & Bat Activity

An important question in assessing how restoring floodplain connectivity contributes to biodiversity and ecosystem processes is the degree to which flood-generated aquatic productivity, expressed as a mix of habitat and trophic resources, is capable of supporting rich communities of native species at higher trophic levels. As much of the aquatic productivity of floodplain ecosystems enters terrestrial foodwebs in the form of emergent aquatic insects, this portion of our project investigated feeding and population responses in bats, as a dominant insectivore and indicator of higher trophic viability. In concert with bird monitoring, bats provide an attractive indicator species to assess restoration success at a floodplain scale, as there exist effective and standardized methods for assessing relative populations. The methods used to monitor bats are sufficiently mobile to sample impacts over large areas, and many of the methods can be widely deployed by volunteers and interns as well as specialized biologists. Bats are also generally accepted as conservation targets for their own sake.

The insect emergence and bat study was led by the University of California, Berkeley, with the goal of examining how spatial and temporal factors influenced emergence of aquatic insects (primarily nematocerans, the midge and mosquito suborder) and the activity of insectivorous bats on the Cosumnes River floodplain restoration site. Aquatic insect populations assessed in other subprojects were also assessed at emergence using standard emergence traps and related methods. Bats were detected acoustically with solar-powered recorders set in multiple habitats. Specifically, Rainey and colleagues looked at how patterns of insect emergence and bat activity varied across geomorphically distinct floodplain habitats (and different types of emergent vegetation in these habitats) over three annual cycles that also varied considerably in the timing and duration of local precipitation and flooding (Figure 9). In addition to describing variation in the composition and abundance/activity of the insect and bat assemblages, a goal was to provide suggestions about combinations of factors that could enhance the ability of insectivorous bats to limit populations of night-flying aquatic insects, as well as habitat characteristics that can sustain bats populations long term as important, and increasingly appreciated, components of native biodiversity.

To the extent that manipulation is possible, the flood regime ‘prescription’ is early season, cold water events, emptying the floodplain before it warms



seasonally and favors carp and other alien fishes. Rainey and colleagues found that that early season floods may have a low short-term impact on insect prey available to bats active later in the same season. While longer, pulsed late season floods with repeated input of nutrients to the floodplain maximize insect

emergence available to aerial insectivores (i.e., bats and birds), this flood pattern also supports alien fish and mosquitoes. They go on to suggest that acoustic monitoring of bats offers a low cost, low effort tool for exploring landscape patterns of bat populations change, feeding, and migration. Over shorter intervals, this methodology has application in assessing 'progress' in habitat restoration from the perspective of one relatively diverse group of native mammals.

Birds Populations as Ecosystem Indicators

The Point Reyes Bird Observatory, now PRBO Conservation Science, began monitoring riparian bird communities within the Cosumnes River Preserve in 1995, in cooperation with The Nature Conservancy and other partners. PRBO continued to study riparian bird populations in 2002-2005, with the aim of evaluating bird populations and conditions in a dynamic floodplain, improving our ability to evaluate restoration success, and elucidating linkages between terrestrial bird species and the aquatic ecosystem. Analyses of the data collected from entire 11 year period (1995-2005) revealed patterns in avian species diversity, abundance, and reproductive success associated with restoration status, floristic composition, flooding regime, and global climate events (e.g., El Niño-Southern Oscillation). These data have important implications for the management and restoration of riparian bird communities.

Avian species diversity and abundance of individual species, as detailed by Nur and colleagues, differed among data collection sites at CRP over the period of years studies. Much of the observed variation was due to variation in age of the riparian habitat, comparing restoration sites of various ages (1 to 22 years since restoration) with mature riparian habitat. Bird species diversity and total number of individuals increased with age of riparian habitat, with about a two-fold difference for both parameters comparing young restoration sites and mature riparian sites.

The analyses of Howell and colleagues assessed the reproductive success and nest survival rates of Song Sparrow (*Melospiza melodia*), which is an open-cup nesting species that is considered a riparian focal species for the Central Valley. PRBO monitored 966 Song Sparrow nests during the spring/early summer

at six nest plots within the CRP. Reproductive success of Song Sparrows differed among plots, with the primary difference reflecting type of restoration: none (i.e., mature riparian habitat), semi-passive (process-based), or active (horticultural). There was also considerable annual variation in reproductive success. El Niño years tended to have lower reproductive success and La Niña years tended to have higher reproductive success. Flooding had an impact on nest survival both during the winter preceding breeding, and while nests were active in the spring/early summer. Flooding during the breeding season had a negative impact on nest survival (and subsequent reproductive success). Winter flooding had a positive impact on nest survival, probably due to changes in the vegetation structure or food supply. Collectively, these results indicate that local and global weather effects are impacting avian nest success at the Cosumnes River floodplain.

Based on the findings of this monitoring based study, PRBO Conservation Science recommends increasing floodplain connectivity to maximize exposure to winter flood events. Several of the Cosumnes River focal species (e.g., Common Yellowthroat, Song Sparrow and Blue Grosbeak) prefer to nest in early successional habitat with dense understory cover. Early successional riparian habitat is dependent on floodplain connectivity and seasonal flooding which includes scouring, soil deposition and point bar formation. Results from this study show a positive correlation between Tree Swallow abundance during the breeding season and the number of winter flood days. In addition, Song Sparrow nest success in restored areas was also positively correlated with the number of winter flood days (Figure 10).



Data Management

In this thematic area of our study, we focused on establishing three primary areas for improved data management: mapping, data integration, and digital repositories for long-term ecosystem monitoring.

CalJep

CalJep is a spatially enabled database that reconciles or cross-walks the two prominent electronic plant distribution lists for California: CalFlora and Jepson. Viers and colleagues intersected the distribution information from the two data sources to create a refined spatial distribution repository that can be used to

examine patterns of plant diversity, distribution ranges of individual plant species or infrataxa, or vegetation associations. The resulting geodatabase allows scientists and resource managers to examine potential range maps for non-native plants, create range maps for plant species of restoration interest, and corroborate lines of evidence for determining appropriate management and conservation activities. In all, CalJep records 7,887 plant species, subspecies, and varieties mapped onto 228 ecological subunits with corresponding distributional information for vascular plant species at varying levels of confidence. CalJep provides a previously unavailable service to vegetation science in California and to resource managers operating within the Bay-Delta ecosystem.

Geodatabases

By combining the advantages of a geographic information system for mapping and data storage with the advantages of a relational database for data management, a geodatabase offers the potential to store environmental monitoring data in a format which is visibly and organizationally accessible. In the Data Management section of the Cosumnes river study, we developed a geodatabase designed specifically to track population dynamics of vegetation patches over time. Standardized data storage methods are fundamentally good scientific practice and provide the basis for incremental experimentation over the long term. Thus, we encourage standardized framework methodologies within a geodatabase structure to provide a measure of certainty to future research initiatives. The fundamental approach to this effort was to provide the opportunity to examine environmental conditions at the scale of hectares to square kilometers, and landscape parameterization at the watershed scale.

Data Management Strategies

The Cosumnes Research Group II digital resources has employed open standards and used open source software as part of an overall data management strategy and in the process has created a data storage framework that can serve as the basis for future data transactions. We feel this has been an important data architecture decision from the inception of CRG. We constructed the CRG website (<http://baydelta.ucdavis.edu/>), which contains published findings, collected data, and a variety of media, using the Drupal Content Management System integrated with the Coppermine Photo Gallery. In addition, the database, webserver, operating system, and programming language running this website have an Open Source software license.

Floodplain Monitoring

In agreement with prior studies conducted on the Cosumnes River experimental floodplain and CRP and funded through a variety of mechanisms, including CALFED/CBDA, we furthered our integrated study through amendment to include continued monitoring of fish populations and communities. Our intent

was to continue the well established baseline monitoring conducted over prior years to assess the impact of flood regimes on fishes and to assess the key differences between native and alien fish species in regards to floodplain use.

In an innovative study, Jeffres and colleagues reared juvenile Chinook salmon (*Oncorhynchus tshawytscha*) for two consecutive flood seasons within various habitats of the Cosumnes River and its experimental floodplain to compare growth rates of in river and newly created floodplain habitats. This study experimented by placing enclosures in different habitat types (e.g., floodplain, river) and found significant differences in growth rates between salmon rearing in floodplain and river sites. Growth of river-raised juvenile salmon varied with environmental factors (e.g., flow and turbidity) and tidal habitat trials showed very poor growth rates. Overall, however, Jeffres and colleagues found that ephemeral floodplain habitats supported higher growth rates for juvenile Chinook salmon than more permanent habitats in either the floodplain or river (Figure 11). These findings are critical to supporting the continued restoration of hydrologic connectivity to increase the frequency, and spatial extent, of ephemeral riverine habitats to support the recovery and maintenance of this at risk species.



Figure 11. Experimentally Raised Juvenile Chinook Salmon: River Raised Fish (Left) versus Floodplain Raised Fish (Right).

To support our general understanding of aquatic communities and trophic complexity, Moyle and colleagues sampled the Cosumnes River and floodplains during the winter-spring flooding season. In all, they captured 33 species of fish. However, of the 18 abundant species, only eight were natives, while the rest were aliens. This study established that there is a consistent pattern of floodplain use, although it varies annually by the timing and extent of flooding. Moyle and colleagues recommend that to avoid stranding of native fishes on floodplain habitats, a diverse topography must be in place that promotes rapid draining. They observed that most stranding occurs in pits or behind structures that create ponds that do not drain. Maintaining floodplain access to flood pulses with enough power to mobilize sediments is paramount to creating topographic diversity and channel formation. Moyle and colleagues further recommend that permanent or long-residence time water on the floodplains be minimized, whether ponds or sloughs, as they support mainly alien resident fishes, which prey on juvenile native fishes or otherwise alter the system in unfavorable ways.

Conclusion

Freshwater ecosystems, including floodplain and riparian habitats, are among the Earth's most productive and diverse ecological systems providing innumerable services to humans. In addition to these ecosystem services, such as water supply, freshwater ecosystems have productive floodplain and riparian habitats that are essential for sustaining and recovering at-risk resident and migratory populations of native plants and animals. A challenge for floodplain restoration and management in California's Bay-Delta, which is heavily populated by humans and used for agricultural production, is to configure floodplains and their food webs so that populations of beneficial species thrive.

As we restore and manage riparian zones and floodplains, we need to learn how their spatial and temporal characteristics affect ecological function and processes, so we can sustain their ecological services. From our studies, presented here, we understand that natural floodplain ecosystems are a product of, and adapted to, highly variable hydrologic regimes. It is important that the general public, and resource managers, understand and adapt to a hydrologic regime that is typified by droughts, catastrophic floods, and frequent periods of inundation. Our studies document that hydrologic variability is expressed across seasonal, yearly, and decadal units of time, but is also changing its mode. Therefore, restoration and management that uses hydrologic variability to reset various biotic populations through disturbance, must be cognizant of the alternate trajectories that may occur. Understanding the multiple ecological paths, expressed in our studies as physical processes governing trophic food webs, will also allow us to consider long-term consequences to biodiversity and biological integrity.

Using the Cosumnes River floodplain ecosystem as a living laboratory, our studies focused on the ecological relationships that form critical linkages between and maintain a mosaic of habitats for groundwater recharge, primary productivity and biogeochemistry in floodwaters, reproductive cycle of fishes and resulting communities, nesting and foraging of birds, the presence and utilization of bats, as well as the continued regeneration of riparian vegetation. The Cosumnes River Preserve and the river itself has provided us - in part due to its unimpaired flood flow regime maintained by its undammed status - with the unique opportunity to study two approaches to restoration. Passive restoration, defined as letting the ecosystem self-organize following early intervention, clearly affects larger areas with less monetary investment. Active restoration, the continued and direct manipulation of ecosystem members and process, does provide more certainty in short-term effects. Thus, this study and the preceding ones have benefited from the implementation of both restoration methods to study restoration success metrics. There are clear ecological benefits to passive restoration, accomplished through floodplain re-connectivity, through increases in structural complexity and subsequent functional diversity, which in turn gives rise to increased biodiversity through creating additional pathways for species interaction and energy transfer and transformation. From our studies, we emphasize the importance of large floods which can export large woody debris and coarse particulate organic matter from the floodplain to the channel, creating habitat, and creating important avenues for energy transfer across and within the river-floodplain system.

As a result of our studies, we feel that the Cosumnes River restoration experience is a critical step to understanding the process of passive restoration, its relationship to other restoration approaches, and opportunities for creating large-scale returns to other areas within the Sacramento River watershed in particular and the California Bay-Delta more generally. Ultimately, developing an effective science-based landscape-scale restoration process will require a scientific approach that treats each restoration act and experiment within a common assessment design, such as a paired before-after-control-impact study. This approach would require that each restoration site be paired with an appropriate unrestored location, so that differences between the two sites can provide measures of the specific success of the restoration treatment. Effective adaptive management, in complement to this approach, would leverage this information over larger landscapes to improve the predictive science by filling in parts of the overall "experimental" matrix with other meaningful restoration activities.