TASK 1: Floodplain Restoration Success Criteria and Monitoring

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Preface of study task intent

To better understand how restoration of riparian vegetation is influenced by a variety of factors, such as physical processes, especially inundation, and the multiple methods of restoration (both, active and semi-passive) that land managers have used in the Cosumnes floodplain, we developed four complementary approaches to addressing different facets of assessing restoration outcomes. Embedded within this overall objective, we are interested in understanding of the spatial dynamics inherent to riparian vegetation across multiple scales, and how this information can help inform restoration efforts in the California Bay-Delta region.

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.

General background on study system

Riparian vegetation is a key habitat in California's Central Valley, and one that is much diminished from historical distribution. Riparian habitats, including terrestrial vegetation and freshwater aquatic ecosystems, are impacted by a number of anthropogenic activities and have been identified as a restoration priority for the California Bay-Delta Authority and many conservation organization, such as The Nature Conservancy. The Cosumnes River Preserve is using two different approaches to restoration of the riparian zone and floodplain ecosystem. One method is the active planting of tree species. Active restoration provides some control over the composition of incipient forests, but it is also localized, labor-intensive, and bypasses natural successional processes. The other approach is semi-passive in the sense that certain manipulations, such as breaching levees, are intended to promote "natural" fluvial processes to the floodplain and thus provide a vector for the natural re-establishment of riparian forests.

The restorative impact of levee breaches and setbacks can cover large areas and emulate natural floodplain processes, but there is no guarantee that re-vegetation will favor native species or restore a desirable mix of habitat structures. Active planting of native species may help to “jump-start” revegetation towards desired species assemblages, but restoration methods are still being developed, with highly variable results throughout the Preserve. Additionally, the invasion of exotic species such as perennial pepperweed (*Lepidium latifolium*) into both active and passive restoration areas threatens the establishment and maintenance of native species, and presents an ongoing management challenge.

The Cosumnes River Preserve encompasses myriad individual land parcels, which are subdivided into restoration sites subject to unique environmental conditions and management histories, Differences between sites include variable soil characteristics, hydrology and restoration methods employed. Restoration efforts have been erratically documented and monitored over the history of the Preserve, making analysis of the relative success of different restoration techniques a difficult task. Variables in active restoration techniques include species planted, type of planting, frequency and amount of summer irrigation, and soil manipulation (disking, scraping, etc.). Hydrology ranges from uplands to restored floodplains, and soils range from deposited sand splays to shallow claypans to deeply tilled former agricultural fields with good drainage.

Brief methods

The first phase of our study focused on identification of physical factors such as location of water bodies, soil type, flood frequency, and elevation change from nearest waterbody in relation to individual sites in order to inform models of restoration opportunities. Keller and Quinn extend a raster-based GIS to include physical conditions that affect riparian community growth and establishment. The resultant models relate restoration potential to physical parameters including flood frequency, distance from the nearest body of water, change in elevation from the nearest body of water, maximum soil permeability, and a calculated wetness index.

The second phase of our study was dedicated to assembling a robust collection of riparian plant species present at the Cosumnes River Preserve and comparing it to other Central Valley riparian systems at differing scales. By using a nested analysis, Viers et al. were able to document known and expected rates of species diversity as expressed by local and regional measures. This analysis provides a quantitative framework for evaluating the degree to which a restoration site, such as the Cosumnes floodplain, can capture regional biodiversity as opposed to reflecting unique on-site biological values. By calculating regional rates of plant diversity in comparison to local ones, we can identify any potential deficiencies and promote them as targets for future conservation and restoration efforts.

The final two phases of our study used GIS geodatabase technology to assemble and analyze spatial and empirical environmental data at the species, population, and site level. This included conducting a retrospective analysis of riparian restoration monitoring, and monitoring the extent of a non-native invasive species on the experimental floodplain. In order to evaluate environmental conditions present on the Cosumnes River Preserve, we compiled and collected information on site characteristics and vegetative change in all active and passive restoration areas. We used aerial imagery to track changes in areal tree cover extent in restoration areas over time. We incorporated all known restoration records over the 20 years of active and passive restoration at the Preserve (1985 – 2005) into a geodatabase. Lastly, we monitored the invasion of perennial pepperweed, a non-native herb which threatens to create monocultures in riparian systems, on a restored floodplain from 2002 through 2005. We analyzed vegetative change in restoration sites for correlation with this and other site conditions including distance from water bodies, soil type, flood frequency, and elevation change from nearest waterbody.

Key findings

Keller and Quinn found that 72% of all riparian forest is within 100m of the active Cosumnes River channel, and that flood frequency and distance to water features were the strongest predictors of historical riparian forest distribution. Valley oak establishment success and growth rates varied considerably among restoration sites, suggesting that on a coarse scale, passive restoration approaches may be most suitable for re-establishing valley-oak riparian forests adjacent to channels where they presumably were concentrated prior to agricultural land-clearing.

In examining regional of plant species diversity and rates of turnover in relation to localized ones, Viers et al. 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 in the California Bay-Delta region.

Retrospective analysis of restoration site monitoring data was a particular challenge due to the dearth of information; however, findings from this study phase indicate that hydrologic regime, disturbance processes, soil composition, and to a limited degree management prescriptions drive active restoration success as measured by germination, seedling survival, and growth rates.

In the course of the study, we assembled a data framework that attempts to integrate plant population data from scientific and management information collected by multiple organizations, projects, and investigators. Unfortunately, we found numerous data gaps in our collection of riparian restoration monitoring data, which spans 20 years and covers much of the Cosumnes River Preserve proper. For example, we found that many datasets were grossly incomplete for most years; species identifications were inconsistent, for example, confusing the identification of several willow species with more than one common name; there was no systematic recording of volunteer species establishment within active or semi-passive restoration sites; and there were no exact locations recorded for many restoration activities. All necessarily coarsened our analytical approach, but the data framework developed may serve as a model for future, more complete, restoration monitoring data management.

Among invasive plant species, we concentrated on analysis of the population dynamics of perennial pepperweed, a non-native invasive species that is becoming established in the Cosumnes River experimental floodplain, and that has become the invader of most concern to the land managers due to its threat to native plant diversity. We have found that the initial establishment and subsequent spread of pepperweed populations are promoted by disturbance and site characteristics similar to those favorable to emerging riparian forest, such as soil moisture and nutrients.

Recommendations for management and monitoring

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 this reason, we feel 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. 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 created by a natural flow regime.

Spatial models are an informative mechanism to both gauge ecosystem processes and to leverage future restoration planning. The advent and utilization of geographical information systems allows for continual model improvement and rapid re-analysis of particular scenarios useful for resource management and decision making. That being said, however, it is still difficult to acquire the requisite validation data for many models. Data from recent meter-scale lidar and hyperspectral acquisitions will improve future modeling efforts. These data are expensive to acquire and process, but provide the most realistic method for monitoring species-level change over large passive restoration efforts (e.g., through levee setbacks or breaches) over the California Bay-Delta region. Such data are limited to the last several years; however, we foresee that these data will serve as baseline information for future analyses as these and other technologies become more common and affordable.

We found many data missing from the 20 year history of restoration on the Cosumnes River Preserve, making retrospective analyses difficult. We advocate standardized data frameworks and meaningful metadata – those descriptive data that detail the type, form, and nature of collected information – be required with all programmatic monitoring efforts, such as those mandated by resource agencies or funded by regional governments. Future analyses will want to capitalize on new statistical methods, including the information-theoretic approach, with its explicit model specification, and longitudinal data analysis, which is specific to repeated measures in irregularly spaced time events.

We 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, we followed its population dynamics to better understand its habit. 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.

Populations of *Lepidium latifolium* are increasing rapidly in the Cosumnes River Preserve's restored floodplain, with only minor variability in rate of spread across the landscape. Introductions appear to be from both roads and breaches, and have the potential to spread quickly and dominate open areas and the understory of the rapidly expanding floodplain forests. Although we found that perennial pepperweed patches were most likely to be eliminated in large flood events, relying on scour and deposition to control pepperweed populations is not advised; pepperweed patches need to be within 16m of an active inflow levee breach to have greater than a 50% chance of being completely destroyed.

Control measures should be implemented and evaluated to slow the expansion of this invasive species so as to allow the natural succession of native species in this restored floodplain. Experimental control methods are currently being tested, and will inform adaptive weed management programs at the Preserve. Concurrently, ground-based inventories of management sites are underway. We recommend continuation of these two efforts, and encourage the use of advanced spatial technologies to identify coarser-scale establishment and subsequent spread over time. The use of such technology for non-native species mapping is now robust, and can be used to generate inventory maps for prioritization of control efforts over large spatial areas. Other recommendations for management and monitoring of *Lepidium* include the development of probability surface models that predict future invasion; such models should be based on statistical relationships between relevant factors, such as elevation, distance to disturbance vector, and proximity to former invasion. These models can be correlated with remotely sensed imagery, and derivative measures of plant vigor, to provide a more synoptic view of *Lepidium* invasions that can be applied to other areas within the California Bay-Delta region.

We recommend the use of high spatial resolution remote sensing for extensive monitoring of riparian forests and invasive plant species. Advances in the use of lidar – light detection and ranging or laser altimetry – and hyperspectral sensors have reduced the resolution of most data products to better than 1m on the ground. Lidar provides detailed structural measurements – often more than seven laser measurements per square meter that are better than 10cm in vertical accuracy – that can be constructed to depict microtopographic relief and plant canopy structure over thousands of hectares. Hyperspectral imagery allows for the identification of many constituents, such as flowering non-native species or dead and dying trees, in addition to geomorphically important substrates such as sands and gravels. These types of remote sensing can be conducted on fixed intervals (e.g., yearly) or during time sensitive events (e.g., floods) as robust form of monitoring.