Sacramento Monitoring and Assessment Project

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Final Administrative Report

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List of Acronyms

CNPS	California Native Plant Society
CSUC	California State University Chico
EMZ	Ecological Management Zone
ERP	Ecosystem Restoration Program
GIC	CSU Chico Geographical Information Center
GIS	Geographical Information Systems
GPS	Global Positioning System
RA	Rapid Assessment
SHP	Shapefile
SRCAF	Sacramento River Conservation Area Forum
SRMAP	Sacramento River Monitoring and Assessment Project
TNC	The Nature Conservancy
UCD	University of California, Davis
USFWS	United States Fish and Wildlife Service
VELB	Valley elderberry longhorn beetle

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I. INTRODUCTION

The Sacramento River is one of the most diverse and extensive river ecosystems in California, composed of a rich mosaic of aquatic habitats, oxbow lakes, sloughs, seasonal wetlands, riparian forests, valley oak woodlands, and grasslands. In an effort to restore habitat as well as viable wildlife populations, government and non-government organizations have implemented a number of restoration programs along the river. The CA State Legislature, in 1986, passed Senate Bill 1086, which mandated the development of a management plan to protect, restore and enhance riparian habitat along the Sacramento River and its tributaries.

CALFED has provided direct support by funding projects focused on planning, acquisition, restoration, research and monitoring. CALFED has funded over 5,600 acres of habitat protection between Red Bluff and Colusa in the SRCAF Inner River Zone (D. Burmester pers. comm) with 15,000 total acres of protected habitat called for under the Ecosystem Restoration Program Milestone 60 (USFWS et al., 2004). While restoration has been a regional and state goal for almost two decades, there has been little systematic evaluation to the extent to which these projects have influenced the overall ecological status of the Sacramento River system.

The **Sacramento River Monitoring and Assessment Project** ("SRMAP" or "Project") examines the Red Bluff to Colusa Ecological Management Unit of the Sacramento River ecosystem as a whole, including both restored and non-restored areas and the major ecological processes that influence restoration success, such as channel and floodplain processes, to create a framework for comprehensive assessment of the River. The Project combined state-of-the-art Geographical Information Systems (GIS) analyses and the expertise of leading north state researchers to assess current conditions and change in riparian vegetation and river dynamics on the Sacramento River. SRMAP culminated in the establishment of a methodology to track ecosystem responses into the future, through the development of a Monitoring Plan. SRMAP developed a Scorecard 'report card' that scores ecosystem health to be used to inform adaptive management of the Sacramento River's riparian systems. The SRMAP builds on an existing knowledge base as well as data and analysis derived by original research under the Project.

The SRMAP has developed and applied environmental research methods in an effort to;

- *quantify the existing condition of riparian and channel habitats,*
- *evaluate the effectiveness of restoration and conservation actions to date,*
- *develop a Sacramento River "Scorecard" that provides a scientific basis for drawing conclusions about conditions and a means to track changes over time, and*
- *provide a description for how to best monitor conditions in the future.*

The Project seeks to develop and implement an integrated ecosystem monitoring and assessment program to evaluate the effectiveness of Sacramento River riparian restoration projects and the overall condition of the Sacramento River ecosystem.

The SRMAP is a unique effort, integrating the research of knowledgeable scientists into a multi-taxon, multi-scale, analysis framework. It builds on past productive collaborations and is both interdisciplinary and multi-institutional. The Project combined advanced mapping techniques, field investigations, and dynamic modeling to provide scientists, managers and stakeholders with the information needed to understand the status of the Sacramento River ecosystem. At the broadest level, the Ecosystem Scorecard evaluates restoration success and ecosystem integrity, and the complementary long-term Monitoring Plan identifies future data needs and the methods to produce them. At the finest scale, our studies resolve critical uncertainties to advance understanding of the life history needs of a set of organisms that are central targets of CALFED's ERP. By evaluating past restoration actions, the SRMAP supports adaptive management of a primary CALFED ERP Stage 1 Action (*Action 1: Protect, enhance and restore the meander belt between Red Bluff and Chico Landing, CALFED 2000b*), and provides the agencies another resource in prioritizing future conservation and restoration investments in the region.

Project Timeline

The Project was initiated in April 2007. By December 2008 a stop work order was issued, as the State of California withheld bond project payments due to a cash flow shortage with the State. At that time, several components of the Project had been preliminarily completed: field and GIS work for the 2007 riparian vegetation map and validation process, field work for the riparian vegetation understory and dynamics, and field work and initial analysis for the river geomorphology study. The project resumed in July 2009.

II. Project Research Components

The Project focused on the structural condition of two primary foci—1) channel and floodplain geomorphology and 2) riparian vegetation structure and composition. The Project assesses structural condition with data derived from a series of coordinated and complementary field investigations and remote sensing studies. In addition, ancillary data on two biological components that are central to CALFED restoration planning (the VELB, and neo-tropical songbirds) were incorporated into original SRMAP vegetation and geomorphology data collection and analysis as indicators of ecosystem condition.

The SRMAP is comprised of five key research components: the Sacramento River 2007 riparian map, riparian vegetation analysis, channel morphology and dynamics analysis, Sacramento River Ecosystem Scorecard, and Monitoring Plan. SRMAP was a synthesis of three separate 2005 CALFED proposals combined into one project which coordinates research and analyses of a number of investigators to culminate in a comprehensive approach to monitoring and assessing ecosystem health along the Sacramento River.

The SRMAP investigators represent a diverse project team from researchers from UC Davis (UCD), CSU Chico (CSUC), UC Santa Cruz (UCSC), and The Nature Conservancy (TNC). The CSU, Chico-Geographic Information Center (GIC) created an updated set of orthorectified aerial photographs and a vegetation community map of the Project area for 2007. Dr. Joshua Viers, UCD, performed a statistical validation on the 2007 riparian map, and created a crosswalk and calibration to the previous 1999 riparian map also prepared by CSU, Chico-GIC. Dr. Dave Wood, CSU, Chico, and Dr. Karen Holl, UCSC have evaluated restored, remnant and naturally recruiting riparian lands within the Project area, and analyze vegetation trends and factors relating to restoration success. Dr. Eric Larsen, UCD, has analyzed a time-history of channel meander migration dynamics and floodplain geomorphology to link channel process and vegetation at large spatial and temporal scales.

Dr. Golet and colleagues applied an ecological scorecard framework developed by TNC to evaluate the status of terrestrial riparian resources and habitats on the Sacramento River, and to assess progress toward attaining the Vision for the Sacramento River Ecological Management Zone expressed in the CALFED Restoration Program Plan (CALFED 2000). The Scorecard emphasizes indicators and monitoring methods used in the Project, i.e. large-scale pattern analysis through mapping, and field-based research, but also includes information from partner agencies and organizations. The approach taken in the scorecard project was to take full advantage of all available information, and to be as comprehensive as possible in drawing from existing quantitative data on Sacramento River terrestrial resources and floodplain dynamics.

Dr. Shilling and colleagues drew information from the Sacramento River Ecosystem Scorecard and other sources to develop a Monitoring Plan for the Sacramento River. The plan calls for the collection of data beyond that which was presented in the Scorecard. In addition to providing detailed scorecard information for development of the Monitoring Plan, TNC contributed component monitoring plans for a suite of important parameters including landbirds (Howell 2010), VELB (Holyoak 2010) and flow regime (Kondolf and Minear 2011).

Detailed descriptions of the methods and results of Project research are compiled below.

A. 2007 Riparian Map (including crosswalk and change detection)

i. Introduction

A first step in the SRMAP process was to acquire new 2007 aerial photography of the river and create a map of riparian vegetation, building on existing riparian vegetation maps of the Sacramento River. The new geo-rectified aerial imagery served as the basis for the delineation of riparian vegetation for the 2007 riparian map, and was used by several SRMAP researchers to complete their landscape-level analyses.

The 2007 riparian map provides an updated vegetation community map along the Sacramento River. The GIC mapping effort provided a basis for other SRMAP activities by:

- assessing change in coverage of important indicator species (such as *Arundo*, Himalayan blackberry, *Ludwigia* and black walnut hybrids) for the Scorecard;
- contributing riparian mapping protocols for the SRMAP Scorecard and Monitoring Plan development; and,
- providing landscape-level vegetation information for landscape and riverscape research.

Cross-walk & Calibration to the 1999 Riparian Map

The 2007 riparian map was cross-walked to the 1999 riparian map in an effort to create a method of comparison of total vegetation change throughout the Project reach since 1999 using nominal comparative statistics (see Appendix C for in-depth accounting of Dr. Viers, UCD, methodology and findings). In the 2007 effort, however, the GIC utilized new vegetation types, including classifications from DFG's Manual of California Vegetation, other vegetation aggregations or singular species as requested by SRMAP researchers. As such, vegetation coding differed significantly between the two years, with only six vegetation classes had the same description in both 1999 and 2007. The majority of vegetation classes created in 2007 were created by the division of vegetation types used in the 2007 map. Three types were not used in the 2007 map.

UCD found there were some class comparisons that support successional trends in vegetation over the 8 year period, such as open water to introduced perennials (62%) and gravel bar (41%), and gravel bar to mixed willow (32%) and Gooding's willow (27%). However, owing to the difference in coding between years, statistical association did not show a robust relationship between classes in the 1999 and 2007 riparian maps. UCD's findings that forested types could be lumped to evaluate forest cover change with high confidence, and that the aforementioned successional trends were plausible and well supported by statistical association. Caution is recommended, however, when making direct comparisons between certain vegetation types, such as scrub/willow types, valley oak, mixed riparian and cottonwood riparian.

The analysis provides useful methodology and important considerations for future map comparisons efforts. The Crosswalk Report is included as Appendix C.

ii. METHODS

The CSU Chico Geographical Information Center's (GIC) 2007 mapping approach employed an iterative process of aerial photo interpretation and field verification. The mapping methodology include the acquisition of aerial photo imagery, the development of a vegetation classification list, rapid assessment surveys, photo interpretation and vegetation alliance delineations as polygons in ArcGIS, final field verification and edits. This resulted in the draft 2007 riparian map coverage. An independent validation and accuracy assessment was performed by UCD researchers, Dr. Joshua Viers, which resulted in a 2007 validated riparian map (summarized Section II.B). Subsequently, the GIC updated the draft coverage to include a number of corrections identified in the validation process to create a final, revised 2007 riparian map coverage; an additional product not required as deliverable by the SRMAP grant.

AERIAL PHOTOGRAPHY

In 2007, the GIC contracted with American Aerial Services of Northern California (AAS) to fly and photograph the riparian corridor along the Sacramento River. While the SRMAP effort focuses on the Colusa to Red Bluff Ecological Management Zone, color aerial photography was flown for the entire 222 miles of the river between Verona and Redding, California, which constitute the Sacramento River Conservation Area as defined in SB 1086.

The GIC coordinated the aerial photo flight for optimum calendar dates in an effort to get the best signatures for riparian vegetation interpretation. The June 2007 flight corresponded to peak vegetative growth. Each aerial photograph included approximately a one-mile corridor on each side of the Sacramento River. In some areas, however, riparian vegetation does not extend much beyond the river's edge. In addition, ten aerial photographs were flown in June 17, 2008 to amend coverage.

Aerial photographs were taken using true color 9" x 9" aerial film at a scale of 1:15,840. This scale has a resulting resolution of 4 inches equaling 1 mile. Using PCI's *Geomatica 10 Ortho Engine* software with airplane calibration measurements, United States Geological Survey (USGS) digital elevation models (DEM's), and real world control from the 1999 flight, the GIC ortho-rectified and clipped the aerial images. Digital ortho-photographs were rendered according to USGS Map Accuracy Standards and projected to UTM-meters (Universal Transverse Mercator) and NAD 83 (Datum).

The GIC adjusted the photos for tonal differences, and using GeoExpress software, converted images to geo-referenced .SID tiles. Using the *Mr SID* online server, images from the 2007 mosaic can be clipped and downloaded as 8 megabyte .TIF images from the SRMAP project server (http://www.sacramentoriver.org/sacmon).

RAPID ASSESSMENT MAPPING

The GIC's mapping approach utilized the California Native Plant Society's Rapid Assessment Protocol. Rapid Assessment (RA) is a reconnaissance-level method of vegetation and habitat sampling. RA data can be described with standard classifications and descriptions and can be illustrated in maps across any landscape. RA can be considered a California standard, as agencies including California State Parks, the California Department of Fish and Game, the U.S. Forest Service and others have adopted this method for documenting vegetation patterns. In this project, vegetation is delineated at the alliance floristic level as defined by the Sawyer and Keeler-Wolf's *Manual of California Vegetation* (1995). Naming conventions for the vegetation alliance were established by the dominant/characteristic canopy species.

Aerial Photograph Interpretation

The June, 2007 orthophoto images served as the basis for "heads-up" digitizing of vegetation cover and habitat types. "Heads-up" digitizing refers to the manual creation of vegetation and habitat polygons and associated data to an *ArcGIS* SHP file. A total of 14 vegetation types and 2 habitat types were delineated (see Appendix A for descriptions of each). The habitat types delineated include gravel bars and open water.

Vegetation cover types were differentiated from adjacent types by changes in compositional and structural integrity of the vegetation as perceived by the interpreter. Representative stands were selected for rapid assessment surveys from an initial visual assessment of the aerial imagery. The rapid assessment data aided the characterization of aerial imagery signatures and subsequent polygonning, i.e., vegetation alliance type.

Polygons were assigned vegetation alliances using ocular judgment of the vegetation signatures to determine which species occupies the greatest canopy cover. The interpreter took into consideration the species in the upper layer of vegetation and if it is characteristic of the alliance. A vegetation type was considered dominated by tree species if the tree canopy cover was 10% or greater throughout the polygon. A vegetation polygon with less than 10% tree cover and over 10% shrub cover was considered a shrub type. An herbaceous alliance was assigned to a polygon if the tree and shrub crown cover were both less than 10%.

Polygons were only delineated if alliance boundaries were distinct and perceptible to the interpreter. There were areas where it was difficult to distinguish contiguous 0.5-acre polygons where one alliance was dominant. Since there was not a mixed riparian classification in the 2007 effort, mixed areas were ultimately divided into individual or adjacent alliances. When interpreting very mixed areas, polygons were classified by which alliance signatures were the most predominant. The Report (attached in Appendix A) includes a description of characteristics of vegetation signatures that were used in photo interpretation.

Field Verification

Rapid assessment protocol was utilized during fall 2007 field verification to determine which vegetation types existed in the project area and to introduce aerial photo signatures to corresponding vegetative communities. Representative stands were selected for rapid assessments and more difficult areas were "red flagged" for field checks. The "red flagged" areas included polygons where signatures were unusual or areas that posed any questions, e.g., restoration sites.

Rapid assessment surveys were performed in representative stands of each alliance and information recorded includes site location, geology and soil, slope, site history, tree diameter, height classes, age classes for shrubs and percent coverage of vegetation. Rapid assessment forms include space for up to 20 vegetation species encountered along with their respective cover. Sites are linked to individual aerial photographs that include GPS points in UTM coordinates and representative ground directional photographs. A sample field form is included in the Report.

Vegetation rapid assessment field forms were collected in 59 locations in an attempt to acquire representative sampling of all the alliances mapped. As a part of the iterative field verification process, a number of additional “area checks” were made where assessment surveys were not completed but vegetation alliances were verified. Again, areas that were more difficult to interpret using aerial photographs were targeted. These areas included young and mature restoration sites in addition to particular alliances, such as mature black walnut and California sycamore. We note that it was difficult to distinguish the signature for California sycamore from that of valley oak.

Field verification sites were accessed on foot and by vehicle on public lands, but also via boat on the Sacramento River. As many as possible of the adjacent polygons were checked during field verification as well.

Map Production

The minimum mapping unit in the 2007 riparian map is 0.5 acres. Invasive species are the exception to this rule. For ecosystem monitoring purposes it was desired to capture any clearly visible stands of exotics. Invasive species such as *Arundo donax*, *Ludwigia peploides*, *Juglans hindsii x* and *Rubus discolor*, were mapped down to 0.1 acre.

In addition to the polygon topology developed, the GIS database also includes information for tree types mapped that include alliance; height class (1-6) and density cover class (sparse, open, moderate and dense). Additional fields were completed in the database if the polygon was a restoration area, i.e., unit name, year restored, forest type planted (if known), and any interpreter comments. The following attributes are possible for each polygon, although a number of polygons will not have all attributes assigned.

- FID: unique number assigned by *ArcGIS* program to each polygon.
- SHAPE: attribute assigned by *ArcGIS* program to describe topology of SHP file.
- CLASS: the vegetation alliance as determined through aerial photo interpretation and field sampling. Vegetation alliances are listed in Appendix A.
- COMMENTS: includes interpreter observations which may be useful to others using this data.
- RESTORATION: Y indicates riparian restoration occurred within the polygon.
- UNIT: refers to the agency ascribed name for the tract of land.
- HEIGHT: the estimated height of the dominant species. Six height classes (1-6) were used and correspond to the following: 1-seedling (0-6.6’), 2-sapling (<20’), 3-pole (20-33’), 4-small tree (34-65’), 5-medium to large (>66’), 6-multi-layered tree (>66’ with 6.6’ to 32.8’ below).
- COVER: the estimated total cover of the upper vegetation layer in the polygon. Four cover classes were used and correspond to the following: Sparse (10-24%), Open (25-39%), Moderate (40-59%) and Dense (60-100%). Used in tree classifications only.

iii. RESULTS

A total of 14 alliances and 2 habitat types were mapped, equaling 8,868 polygons over 32,811 total acres. A distribution of polygons and acreage by alliance is detailed in the table below.

TABLE 1. Total Acreage by Alliance Type

ALLIANCE	TOTAL ACREAGE	TOTAL # POLYGONS
Bulrush-Cattail (*Scripus-Hypha*)	27.9	29
Box elder (*Acer negundo*)	863.6	421
Blackberry scrub (*Rubus discolor*)	310.3	250
Black walnut (*Juglans hindsii x*)	2,538.1	645
California Annual Grasslands/Herblands	3,910.6	555
California sycamore (*Platanus racemosa*)	1,76.9	110
Fremont cottonwood (*Populus fremontii*)	7,892.5	968
Floating-leaved plants	65.1	80
Gravel Bar	1,717.4	409
Giant reed (*Arundo donax*)	135.6	1,830
Goodding's willow (*Salix gooddingii*)	92.2	31
Water Primrose (*Ludwigia peploides*)	386.6	234
Mixed Willow (*Salix* spp.)	1,849.5	677
Open Water	6,277.5	419
Perennial Grassland	470.4	313
Riparian Scrub	2,477.3	839
Valley oak (*Quercus lobata*)	4,212.9	1,058
TOTALS	**33,404**	**8,868**

The GIC determined accuracy constraints of the 2007 riparian map to be based on the resolution of imagery obtained, the differentiation of vegetation signatures during the June 2007 flight, and time and access constraints for ground-truthing.

The 1999 riparian map has a classification for mixed riparian forest (MF). To bring the vegetation classification up to the Manual of California Vegetation standards the classification MF has been separated out into the different riparian tree alliances. Field surveys suggest that it may be appropriate to have a mixed riparian forest category, as both aerial photo signatures and field verification indicate there are areas of high tree species diversity where it is difficult to distinguish contiguous 0.5-acre polygons where one alliance is dominant. The use of stereoscopic photo pairs could potentially aid future interpretation of vegetation alliance boundaries.

The Change Detection Effort

A goal of the SRMAP was to evaluate change within and between riparian vegetation types over time. As such, UCD researcher, Dr. Joshua Viers, analyzed the detectability of change between the 1999 and 2007 GIC riparian maps. Due to severely altered hydrology, much of the Sacramento River riparian vegetation changes are expected to be gradual outside of successional communities like willow or box elder. For example, it can take more than 20 years for certain upland forest communities (like black walnut and Fremont's cottonwood) to reach detectible change through aerial photo interpretation.

Dr. Viers' report detailing methodology and analysis for the change detection subtask can be found in Appendix D. With the time scale being relatively short, from 1999 and 2007, the analysis was not expected to yield significant change, although the analysis provided useful information on the trajectory of specific vegetation types. The analysis examined which vegetation types were prone to cartographic inaccuracy such that their inclusion in change detection and analysis would create and propagate error. The analysis also established a useful methodology for map comparison in future efforts.

Using the negative buffering technique, observations found were indicative of cartographic imprecision and semi-rapid compositional turnover. While there were certain types of changes that were plausible and predicted in riparian successional change, the approach found that comparisons between other vegetation types were problematic that suggested cartographic imprecision and semi-rapid compositional turnover.

Viers' suggested recommended interpreting certain vegetation classes with caution. To maximize comparisons between map versions, aggregating 2007 vegetation types was recommended.

B. 2007 Riparian Map- Validation

i. Introduction

Repeat vegetative mapping along the Sacramento River allows for assessment of changes in composition and extent of riparian habitat. Validation and accuracy assessment of the mapping effort, and data derived, is a critical component of future trend analysis as it assures the level of validity of subsequent analyses at local and landscape scales. Riparian vegetation maps are considered one of the most challenging assemblages of vegetation communities to map, as the riparian zone contains many diverse vegetation types within a limited area, and are often an ignored component of map creation (Congalton et al., 2002). UCD researcher Dr. Joshua Viers performed a rigorous accuracy assessment on the Colusa to Red Bluff stretch of the GIC 2007 riparian map under subtask 2.1.1 (see complete report attached as Appendix B).

ii. Methods

Dr. Viers' validation methodology consisted of a dual approach: The validation approach included a robust field survey component, using multiple vegetation survey methods, as well as replicated digitization method to test for interpreter consistency for this complex mapping area and statistical analyses.

Field Surveys

From June to September 2008, field validation was conducted on over 30 properties within the Project area which were either publically owned, or owned by The Nature Conservancy. Multiple field survey methods were employed. Polygon accuracy was checked visually in the field, coupled with CNPS rapid assessments (RA) and intensive, plot-based sampling techniques. Polygons were individually identified using a Trimble® global positioning system receiver (GPS); corrections and notations were made by editing polygon attributes in ArcPad 7.1 (ESRI, Redlands, CA).

Field check goal was to achieve a 10% polygon visitation rate for each vegetation category; forested categories were prioritized and visitation was limited by property access and time. Field observations were augmented by revisiting and referencing Vaghti relevé (Vaghti, 2003) and McClain species frequency data (McClain, 2008).

Additional analyses included a GIS-based investigation into interpreter consistency, which consisted of randomly selecting 500 x 500m blocks of mapped areas to re-digitize and attribute; comparison were made for relative representation and inter-rater reliability.

All field data were collected electronically; data were downloaded and backed up on a regular basis, checked for consistency, and controlled for quality. Differential correction was conducted using Trimble Pathfinder (Trimble, Sunnyvale, CA). All GIS analyses were conducted in ArcGIS v9.2 (ESRI, Redlands, CA). We conducted comparative and contingency analyses, with accompanying Kappa statistic of agreement, in JMP IN 7 (SAS Institute, Cary, NC).

Visual Inspection

Polygon accuracy was checked visually in the field by determining overstory species dominance (>10% canopy cover) within polygons loaded into ArcPad 7.1 on Trimble® GeoXM™ and Juno™ units. Vegetation polygons were edited in the field by updating polygon attributes in ArcPad 7.1 loaded into Trimble® GeoXM™ units. The original GIC map (vegetation polygon shapefiles) was edited to contain additional attributes (data table fields) that indicate corrected information and observational comments; this data transformation was saved as a feature class in a formatted personal geodatabase.

The following fields were added to original GIC vegetation polygon to provide accuracy information collected by UC Davis:

- CLASS_UP: Updated vegetation classification from infield accuracy assessment
- FieldChk: Indicates if the polygon was checked for accuracy (Yes/No)
- VegChk: Is the vegetation classification correct? (Yes/No)
- VegUpdate: If VegChk=No, suggested alliance name of the standing vegetation
- PolygonChk: Does this polygon need to be broken up into more than one polygon? (Yes/No)
- OtherType: If PolygonChk= Yes, what other vegetation types are present?
- RA: Was there a UCD rapid assessment completed for this polygon? (Yes/No)
- UCDcomment: Any additional comments, including whether or not Vaghti or McClain plots were referenced.
- VisualAA: If yes, this polygon was checked visually in the field
- PlotAA: If yes, a plot (UCD or Vaghti) was used to validate this polygon
- HtClass: Tallest tree height class taken from in-field tree measurements. Height Classes: 1: <2m, 2: 2-6m, 3: 6-10m, 4: 10-20m, 5: >20m.

Rapid Assessment

Rapid assessments (RA’s) were collected using California Native Plant Society (CNPS) protocol as outlined in the Vegetation Rapid Assessment Protocol created by the CNPS Vegetation Committee (http://cnps.org/cnps/vegetation/). RAs were then used to validate the GIC map by assigning the observed dominant vegetation type to the Class_Up update field. These RA data are contained in the appendix of the Validation Report (Appendix B) and will ultimately be transferred the Department of Fish and Game vegetation program and other interested parties upon project completion.

Collaboration

While collected at a different temporal and spatial scale and for a different purpose, data from both McClain and Vaghti (2003) were used to confirm vegetation categories based on GPS position. To reduce the potential error associated with introducing these data, they were not used as an indicator of incorrect vegetation classification but only as confirmation of current species dominance. Additionally, these classification updates are used as a reference in the UCDcomment field.

Tree Heights

Tree heights were collected using a Laser Technology Impulse 200LR rangefinder along transects created for data collection associated with Subtask 2.3.4 for a proportion of validated polygons throughout the study area. Tree heights (meters) were converted to the height classes referenced in the GIC mapping process: 1: <2m, 2: 2-6m, 3: 6-10m, 4: 10-20m, 5: >20m. The maximum value of UCD field collected tree heights was compared with GIC attributed tree heights as a measure of height accuracy via contingency analysis in JMP IN 7 (SAS Institute). These values are contained in the HtClass column of the UCD shapefile.

Digitizing

In ArcGIS 9.2, 500 x 500m blocks were created which extended over the entire study area. Blocks overlapping > 33.3% of the 2007 riparian vegetation map were selected at random for redigitization. UCD validation GIS technicians, after a period of training and cross-calibration, digitized vegetative cover within each selected block using the 2007 aerial photos as reference for interpretation (i.e., identical to GIC map creation methods). In all, 132 blocks were re-digitized for statistical analysis. Statistical analyses consisted of paired comparisons, first for inter-rater reliability, and second for vegetation class representation in JMP IN 7 (SAS Institute).

iii. Results

Sample Size and Longitudinal Distribution

Field accuracy assessment totaled just over 15% of the total number of polygons digitized. While not more than 10% of each vegetation category was field visited, a representative sample was obtained of the most dominant vegetation categories, including all of the forest types and both of the herbaceous types. Moreover, the types with <10% visitation were either purposefully ignored (e.g., open water) due to temporal mapping issues, or were perpetually infrequent in the field (e.g., bulrush cattail). Sampling was stratified across the entire study area – in effect along a longitudinal profile, which varied with geographic latitude – but statistically more field validation was completed in the northern portion of the study area than in the southern.

Map Accuracy

Validated GIC map polygons were examined in several ways. Some positional bias was found based on vertical (UTM Y coordinate) location for correct or incorrect polygon classification; however, bias existed in both the north to south and south to north direction depending on the vegetation class (Appendix 8.2) – in effect canceling out any potential error caused by interpreter learning bias.

By creating a contingency or confusion matrix, overall map accuracy for validated classes was calculated at 85.3%. This value is above the threshold at which map categories would need to be revisited and updated by the GIC. Additionally, the Kappa statistic, calculated to show the statistical correlation between the original dataset and the field validated dataset while accounting for random association, was 0.83 and indicates strong agreement between the validated and un-validated maps). This Kappa statistic will allow for reliable comparisons between this map and future validated maps of similar accuracy.

Vegetation Category Accuracy

Specific vegetation category accuracy was calculated on a users and producers accuracy basis within the confusion matrix by measures of polygon count and polygon area. Producers error, or the error rate associated the GIC map, is calculated in the Col% rows for each vegetation class. User's error, the error rate of the user while using the map, is calculated in the Row% for each vegetation category. While accuracy values are variable between each map class, they rarely vary structurally.

This analysis resulted in two types of confusion matrices (polygon count and area in hectares) some of the categories exhibited dissimilar user and producer accuracy rates. These differences are indicative of the positive or negative relationship between the error associated with number of polygons within a category and the polygon area associated with those same polygons.

Recommended map changes commonly included more than one update to a single polygon and are noted in the "OtherType" field in the UCD shapefile (Table 1; Appendix 8.3). Polygons that needed to be split into multiple polygons accounted for ~17% of the total validated polygons visited during the 2008 field season. These polygon updates were not included in the overall accuracy assessment due to their 'fuzzy' nature (i.e., partially correct). Partially correct polygons should be revisited by map interpreters to determine if field validation recommendations are practical within the scope of the 2007 mapping methods.

The calculated difference in user and producers error between the area confusion matrix and polygon count confusion matrix was greater than ten percentage points for a number of classes. Box elder was most commonly misclassified as riparian scrub, and black walnut was most commonly misclassified as box elder or valley oak. California sycamore and Fremont cottonwood were commonly misclassified as valley oak forest. Annual grassland vegetation types were commonly misclassified as introduced perennials.

The validation effort also provides recommendations for future vegetation categories on the Sacramento River and recommendations for collapsing categories when conducting comparative analyses.

C. Channel Morphology & Dynamics

i. Introduction

Large alluvial rivers like the Sacramento River have a tendency to migrate laterally over time. Meander migration, consisting of bank erosion on the outside bank of curved channels and point bar and flood plain building on the inside bank, is a key process for many important ecosystem functions (e.g. Malanson, 1993). These functions include examples like 1) vegetative establishment for the riparian forest, 2) floodplain creation through progressive meander migration, 3) habitat creation (i.e., bank erosion for swallow habitat), and 4) the creation of off-channel habitats (e.g., oxbow lakes, side channels, and sloughs) by progressive migration and cutoff processes.

The meander migration process is a function of flow, channel form, and bank characteristics. All have been altered on the Sacramento River, through the construction of Shasta Dam, channel restraints like revetment and levees, and the land-use changes like the transition from riparian forest to agricultural lands. To develop effective strategies for the conservation and restoration of key ecosystem features, it is important to relate the role that meander migration plays.

Measuring and planning for channel change are some of the most important challenges for managing a meandering river corridor (Golet, Roberts et al., 2004). The dynamic processes related to meander migration benefit ecosystem health (Ward and Stanford, 1995; Stanford, Ward et al., 1996). At the same time, conflict between natural river meander dynamics and infrastructure protection has led to the placement of channel riprap and groins to limit channel dynamics. Whether the goal is to promote channel dynamics for ecosystem health or to enhance channel stability, methods to quantify natural dynamics of river channel migration is critical.

In this study, Dr. Eric Larsen analyzed river changes using roughly 100 years of maps detailing river channel locations of the Middle Sacramento River, to document historical patterns and processes to ascertain a better understanding of the forces driving river channel migration and promoting ecosystem health.

Because river channel dynamism is important to many ecosystem processes, such as vegetation establishment, quantitative indicator metrics that reflect the characteristic dynamism of the channel are useful. A suite of metrics was measured on the channel centerlines from the Middle Sacramento River study section. Seven of the measured metrics were chosen to represent river ecological process health. Based on the observed trends for the indicator metrics in those time periods, preliminary "Scorecard" ratings and desired goals were estimated.

Dr. Larsen's study documents the general methods used to analyze the channel geometry and dynamics on the Sacramento River, and presents the results of change over time. Then the chosen indicator metrics are presented one-by-one, describing in detail how each one was determined, and assigning very good-through-poor ratings to the numeric values.

ii. Methods

Channel centerlines were mapped on a 160 km meandering alluvial reach of the Middle Sacramento River, California (from Red Bluff to Colusa) from historic topographic maps (1904) and aerial photographs (in 7 time periods between 1937 and 2007). Centerlines were broken into individual segments (between successive inflection points) and analyzed in a GIS for eight different metrics for all segments, and six different metrics for segments that had a sinuosity greater than or equal to 1.1.

iii. Analysis

The whole river length was divided into individual segments based on the methods described above. Between 1904 and 2007, the total number of segments was relatively constant ranging from a minimum of 119 to a maximum of 129 and the total river length varied from a minimum in both 1997 and 2207 to a maximum in 1904. Whole river sinuosity varied exactly as channel length, because whole river sinuosity is divided by a constant reference valley length.

After the initial analysis of geomorphic change, each indicator metric was considered, with a description of specifically how it was defined, a rationale for being a meaningful metric, and a description of how the rating thresholds were established. A desired rating is a value judgment that might best be decided by an expert panel. For this research, however, a reasonable target was proposed. For total river length, for example, the following led into the target value. A longer channel allows more potential area for all riparian forest dynamics, and by definition is a large scale metric that assesses the overall health of the river. In order to establish the rating threshold from the existing data, four evenly spaced categories suggested themselves and were chosen by eye. A target was chosen to be 156,000 m which is the mid-range of the lengths over the last century.

For each indicator, ratings were established in four steps ranging from very good to poor. Because all the metrics are related to the channel morphology, some of them are interrelated.

iv. Results

Temporal changes in channel centerlines and bend geometry were tracked over the 103-year time interval. The river channel length, beginning and ending in the same valley location, tended to decrease from 1904 to 2007. This suggests that river length lost due to cut-off and other processes has not been replaced by channel length gained by migration over the study period. In addition, the formation of high sinuosity bends susceptible to future cut-off has declined. The river sinuosity, the average entrance and exit angle magnitudes, the average migration rate (and floodplain reworked), and the number of high-sinuosity bends – all tended to decrease with time. This suggests that the complexity of the river has decreased over the last century, which has implications for the health of the riparian ecosystem.

The whole river had an average sinuosity of 1.26 (calculated as the length-weighted average of the bend sinuosities), and the following average values for sinuous bends (i.e. greater than or equal to 1.1 sinuosity): half wavelength 1039 m, radius of curvature 676 m, and bend entrance angle and exit angles of 65 and 64 degrees respectively.

Table 2 Measured channel geometric values for all segments

All Segments										
Year	Number of segments	Channel length (m)	Half wave length (m)	Whole river sinuosity	Entrance Angle (Degrees)	Exit Angle (Degrees)	Floodplain reworked (sq m/yr)	Migration rate (m/yr)	Number of bends M/L > 2.0	Number of bends M/L > 2.4
1904	119	160529	1057	1.31	46	47			8	5
1938	129	160474	996	1.26	47	46	969556	6.04	6	2
1952	119	156070	1045	1.26	42	42	1116432	7.15	6	3
1966	119	156423	1052	1.25	44	42	554168	3.54	7	3
1976	124	157303	1019	1.25	43	44	1036478	6.59	7	1
1987	122	155528	1023	1.25	45	41	1112001	7.15	5	2
1997	120	154221	1046	1.23	40	40	635516	4.12	3	0
2007	119	154229	1050	1.24	40	41	636451	4.13	4	2
Mean	121	156847	1036	1.26	43	43	865800	5.52	5.75	2.25

From 1904 to 2007, the geometric complexity and meander migration dynamics of the Middle Sacramento River have decreased, which has implications for the health of the riparian ecosystem. The river channel length tended to decrease, suggesting that the river length lost to cut-off and other processes has not been replaced by an increase in length due to channel migration over that time period. In addition, the formation of high sinuosity bends susceptible to future cut-off has declined. The river sinuosity, the average entrance and exit angle magnitudes, and the average migration rate (and floodplain reworked) – all tended to decrease with time.

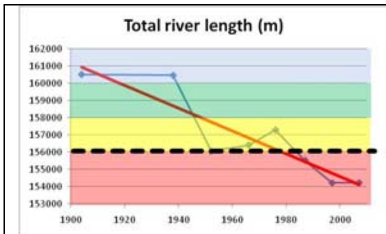
In order to provide quantitative metrics that can indicate the health of the river system, especially over time, seven of the measured metrics were chosen specifically as ecosystem health “indicators”. Establishing ratings for the river health indicator metrics provides a first estimate in defining metrics of ecosystem health that can be used to evaluate, enhance and restore ecosystem functioning related to the riparian ecosystem of the Middle Sacramento River. The ratings established were qualitative estimates based on expert knowledge of the river system. For the 2007 data, each indicator resulted in a “poor” rating. The “desired” or “target” rating was also a qualitative estimate based on expert knowledge. Both the “very good-through-poor” rating and the desired target rating are subject to more analyses. The metrics and ratings are shown in the following table.

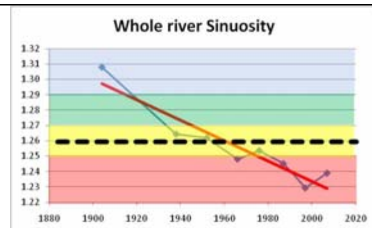
TABLE 3 INDICATOR METRICS RATING THRESHOLDS

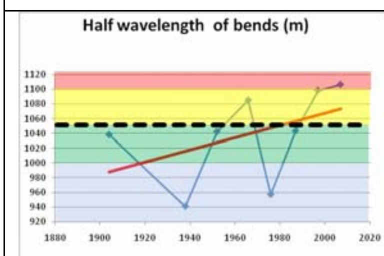
	Indicator	Target	Rating threshold			
			Very Good	Good	Fair	Poor
1	Total river length (m)	156,000	> 160000	> 158000	> 156000	< 156000
2	Whole river sinuosity	1.26	> 1.29	> 1.27	> 1.25	< 1.25
3	Average half-wavelength of bends (m)	1050	< 1000	< 1050	< 1100	> 1100
4	Number of single bends with sinuosity greater than 2.0	6	> 7	> 6	> 5	< 5
5	Average entrance angle of all segments (Degrees)	42	> 46	> 44	> 41	< 41
6	Average area of floodplain reworked per year (m2/year)	800,000	> 1,000,000	> 900,000	> 700,000	< 700,000
7	Average meander migration rate (m/year)	5	> 6.5	> 5.75	> 4.5	< 4.5

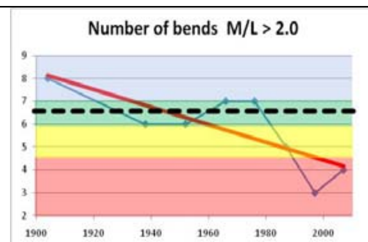
Channel dynamics and River health indicator metrics on the Sacramento River

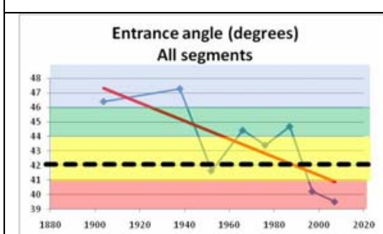
Each indicator metric was considered, with a description of specifically how it was defined, a rationale for being a meaningful metric, and a description of how the rating thresholds were established. For each indicator, ratings were established in four steps ranging from very good to poor. These rating ranges are shown below in different colors. The blue is very good, green is good, yellow is fair, and red is poor. The target value, which is the value that is targeted for a restoration goal, is show by the heavy dotted line. The data that were analyzed to produce the graphs of indicators over time are the data developed in the channel metrics analysis over time. The ecological implications of each metric are described in the final report in Appendix F.

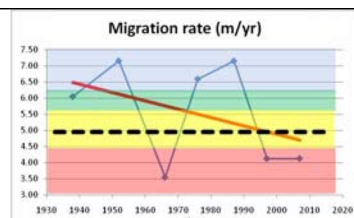


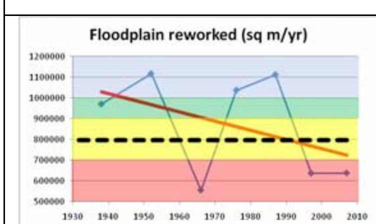












More details on this research component can be found in Appendix F.

Shifts in Species Composition as Interpreted Through Floodplain Age on the Sacramento River

Riparian areas generally follow a successional model of vegetation dynamics with a progression of species assemblages from new to old floodplains. However, the assemblage of species on newly created surfaces can be highly variable. Assembly rules posit that the initial physical and biotic conditions on newly created surfaces should have a strong impact on determining the species composition through time.

As a component of the Channel Morphology and Dynamics research of the SRMAP project, the variability in vegetation composition using both assembly rules and a successional model of vegetation dynamics is examined. A detailed analysis was performed to analyze vegetation development on the Sacramento River Floodplain in relation to two landscape variables- floodplain age and relative elevation. Specifically, the research considers two questions:

1) what are the patterns of species composition over these gradients?
2) with the loss of cottonwood, what is the character of the replacement community?

The encroachment and potential stand replacement of Fremont's cottonwood by Northern California walnut (*Juglans hindsii*) and California box elder (*Acer negundo var. californicum*) on the Sacramento River were investigated, as they are hypothesized to have expanded as a result of hydrological modifications and agricultural practices throughout the 20th century (Fremier 2003).

While research has described the relationship between species occurrence and floodplain age on the Sacramento River, a description of the full complement of species in relation to floodplain age and relative elevation remains understudied with respect to channel abandonment and the replacement of cottonwood. This research utilizes the newly developed floodplain age composite map, and regroups the floodplain age gradient into five distinct time periods, each spanning roughly 20 year intervals: 2007 to 1984, 1983 to 1969, 1970 to 1954, 1953 to 1921, and 1920 to 1903. Vegetation surveys were performed on 43 distinct floodplain age surfaces to calculate species composition, relative cover, and frequency to investigate the distribution of species across the floodplain age surface. Vegetation community values were based on overstory dominance and understory, making the analysis more applicable to the 2007 riparian map.

Species richness was not found to be higher in any of the floodplain age groups, and Jaccard dissimilarity results indicated that the lowest floodplain areas (gravel bar, grassland, and willow communities) were most dissimilar to all other floodplain age groups. Areas most similar to each other were on higher floodplain ages, indicating increased heterogeneity on low to mid floodplain surfaces where disturbance is more frequent.

This research finds that the relationship between riparian species composition and the construction of floodplain age generally conforms well to a successional sequence in forest types. However, in analysis of the entire floodplain, the successional model lacks the structure to explain non-forested community types and invasive species. In the case of abandoned channels and the loss of pioneer species, the assembly rules model can be a useful framework to understand changes in riparian vegetation. Researchers observed repeatable transitions in forest stand development of species dominance between each floodplain age groups. The transition of species composition that occurs between about year 38 and 70 provides a detailed description of what species play a role in the advancement of valley oak forest and the disappearance of Fremont's cottonwood. California box elder and Northern California walnut communities are presumed to become more prevalent on the floodplain with the continued poor recruitment of cottonwood. These communities have already become dominant on the landscape and appear to follow cottonwood in the forest successional sequence.

More details on this research component can be found in Appendix F.

D. Vegetation Analysis- Native Riparian Understory Recovery

i. Introduction

To better understand how ecological succession has transpired in restoration sites along the Sacramento River, and how this succession compares to the vegetation assemblages of remnant riparian habitat, Dr. Karen Holl, UCSC, compared two successional models as guides for restoring native riparian understory species. Dr. Holl's research provides insight as to whether native understory species have colonized naturally (passive relay floristics model), and whether restoration planting of understory species has accelerated community recovery (initial floristics model) by detecting change within restoration sites over a time scale of 2001 to 2007.

Restorationists are recognizing the importance of understory plant layer and have begun including understory species into restoration designs. Understory species are responsible for more than 80% of overall species richness in some forests and are critical in nutrient cycling (Gilliam, 2007). They provide forage and habitat for wildlife (Golet et al., 2008), and help control the flow of water during flooding events that threaten developed areas further down-regulated rivers (Tabacchi et al. 2000). Dr. Holl's research aimed to answer the following questions: (1) Has cover and species richness of naturally establishing native understory plant species increased over time in restored riparian forest? (2) What local (e.g. overstory cover, competition with exotic understory species) and landscape factors (e.g. proximity to remnant forest or river) most strongly affect establishment of native understory species? (3) Have recent efforts to actively restore native understory plants been successful?

For her analysis, Dr. Holl conducted repeat surveys of 15 restoration study sites (surveyed previously in 2001) which were planted with overstory species to test the passive relay floristics model (RF). Surveys were also conducted on 20 additional sites, 14 of which were planted with understory species to test the initial floristics model (IF). 10 remnant forest sites were surveyed as reference for successional trajectory. Detailed presentation of her research locations, data collections, analysis and findings is in her Summary Report, attached as Appendix U.

ii. Methods

This research employed the vegetation sampling methodology of Holl and Crone (2004), in order to achieve accurate comparisons between data collected in 2001 at the same location previously. Surveys consisted of 20-80 vegetation measurements per site in 1 x 1-m quadrats on a grid of points separated by 40-80 m. Distances between sampling points within a restoration site were determined by their sizes: 40 m (4–8 ha); 50 m (8–16 ha); 60 m (16–24 ha); 70 m (24–36 ha); 80 m (≥36 ha). In order to avoid sampling at the same location relative to rows of planted trees and shrubs, the quadrats were located a random distance ranging from 0 to 5 m to the left or right of the perpendicular to the transect line. Quadrat values were averaged to obtain a site mean for all analysis, except for comparisons of change within individual sites between 2001 and 2007.

For each quadrat, total live cover, total litter cover, and bare ground was estimated to the nearest 5%, as was cover of individual species using a modified Braun Banquet ranking scale: 0–1%, 1–5%, 5–25%, 25–50%, 50–75%, 75–100% (Mueller-Dombois and H. Ellenberg, 1974).

The midpoints of these ranges were used for the statistical analyses. Understory plants were defined as any species not included in the 1989–1996 restoration design and any vegetation less than or equal to 1.5 m tall. As the focus was on naturally colonizing understory species, woody seedlings of planted species as understory (primarily *A. negundo* and *Q. lobata* which comprised <2% of the native cover) were not considered.

To answer questions related to the RF model, one-way analysis of variance (ANOVA) was used with native and exotic vegetation cover, frequency, and richness as the dependent variable and site type (data from 2001 and 2007 in 15 sites that had not been planted with understory species and data from reference forests) as a fixed independent variable. Changes over time were tested in relative native cover within each of the 15 restored sites using used unpaired *t* tests. One widespread native species (*Galium aparine*) comprised approximately 50% of relative native cover on average and thus dominated the results; therefore, tests were run with and without it.

Non-metric multidimensional scaling (NMS) in PC-ORD version 5.0 (McCune & Mefford 1999) was used to determine whether the understory composition of restored sites followed a successional trajectory towards that of reference forests. Ordination procedures, such as NMS, aim to extract overall trends in community composition; because native species in restoration sites comprised a low percentage of overall cover and were dominated by one species, running the analysis with both natives and exotics together provided more insight into overall successional trajectories.

To answer questions about the IFC model, restoration sites where native understory species were planted was compared to sites where understory species were not planted, and to reference forest sites. Native understory species planting densities and composition were derived from restoration plans and reports; Dr. Holl and staff consulted with restoration agencies when reports were incomplete. Based on the available data, understory restoration sites were grouped either as “low intensity”, having 1–3 understory species planted at a total density of ≤88 seedlings/ha and no species seeded, or “high intensity”, having 5–11 understory species planted. All high intensity sites except two were seeded with native species, primarily grasses, at 9.2–14.9 kg/ha and were planted at densities ranging from 20 to 1005 seedlings/ha.

Understory planting has become increasingly common over time, so although they only compared the more recently restored (≤10 years old) unplanted sites to minimize confounding site age with understory planting, the unplanted sites (8.5 ± 0.4 years since restoration) were slightly older than low (6.5 ± 0.5 years) or high (5.4 ± 0.5 years) intensity sites. They used one-way ANOVA with overstory cover, native cover and frequency (with and without *G. aparine*), and native species richness as the dependent variables and site type (restored no understory planted n = 6, restored low intensity understory planting) as the independent variable.

Finally, Dr. Holl compared cover and frequency of the three native understory species that were planted in a sufficient number of sites and native grass cover in sites where they were not planted to sites where they were planted and to reference sites using a similar one-way ANOVA to those described previously. All analyses except NMS were done using SAS version 9.13 (SAS Institute 2007). Cover and AQ4 frequency data were arcsine square-root transformed when necessary to meet assumptions of normality. Ranked data was used when transforming did not meet normality. Standard error of the mean is reported throughout.

iii. Results

The research found that mean cover and frequency of native understory species changed little over time in sites in sites where they were not planted initially; increases in native cover in a few sites were primarily due to a single common species (*Galium aparine*). From the 2001 dataset, species composition shifted from light demanding to shade adapted species, both exotic and native, in response to a doubling of overstory cover. Sites with high intensity understory plantings had greater cover and frequency of native understory species than unplanted sites, but were still low relative to reference forests. Light-demanding natives established in sites where they were planted; however shade-adapted species (*Carex barbarae*) did not survive well. The research indicated that passive relay floristics and initial floristic composition approaches serve to restore a few common native understory species, but that planting species as site conditions become appropriate (active relay floristics model) will be needed to restore entire native understory communities.

Analysis of Understory Vegetation Composition as a Function of Local and Landscape Variables

As a part of the SRMAP project, Dr. Holl analyzed the effects of local and landscape variables on understory plant communities (see Appendix G for complete report), drawing on her repeat large-scale understory vegetation sampling effort described above in Section D of the report. Following the same analysis methods by Holl & Crone (2004), Dr. Holl utilized GIS coverages of agricultural and urban land use, the 2007 GIC riparian map, and California Department of Water Resources (2003 and 2004) data to expand beyond analysis of temporal vegetation changes to factors affecting understory succession.

Specifically, the following hypotheses were tested:
(1) exotic understory cover depends on distance from each quadrat to the river, overstory cover, and elevation above river baseflow; and,
(2) native understory cover and species richness depend on distance from each quadrat to the nearest forest larger than 0.5 ha, percentage of remnant forest or total forest (remnant and restored) within 50, 100, 500 and 1000 m of each quadrat, distance to the river, overstory cover, exotic understory cover, and elevation.

Dr. Holl analyzed land use within different buffer areas surrounding each sampling location. The distance from each quadrat to the main river channel and to forest patches of at least 0.5 ha were calculated. A spatial model of surface topography relative to dry-season base flow was developed by S. Greco (Greco et al. 2009) and used to estimate the elevation of each sampling point above base flow.

Dr. Holl tested effects of general scales of landscape influences and a suite of abiotic and biotic variables on understory plant communities. Two separate analyses (one at the sample/quadrat level and one at the site level_ were conducted as some variables were highly heterogenous (overstory cover, elevation) within sites, and others were completely homogeneous (e.g. patch size, previous land use) within sites. In both analyses, stepwise regression was used to identify variables that best explained exotic species cover, and native species richness and cover, with forward addition of parameters. Relationships between among-quadrat residuals from site means and potential explanatory variables were tested. In addition to analyzing the aggregate native plant community, analysis of cover was repeated separately for species grouped by dispersal mechanism (animal-, wind- or gravity/water) and for two individual species that were relatively abundant, *Galium aparine* and *Artemisia douglasiana*.

The site and sample analyses showed that differences in exotic understory cover were primarily explained by overstory cover; exotic understory cover decreased as overstory cover increased consistent with the earlier 2004 study. In addition, exotic species understory cover was higher at sites that were used as orchards (compared to those in rows crops or fallow) immediately prior to being restored. In the earlier study, exotic cover was greater higher on the floodplain, but that relationship was not significant in the current data. Likewise, as in the earlier study, native species richness was higher at locations within sites where there was lower exotic cover. Across sites native species richness was greater at older sites and sites lower on the floodplain. Site age and relative elevation were not correlated.

Shifts in Species Composition as Interpreted Through Floodplain Age on the Sacramento River

Riparian areas generally follow a successional model of vegetation dynamics with a progression of species assemblages from new to old floodplains. However, the assemblage of species on newly created surfaces can be highly variable. Assembly rules posit that the initial physical and biotic conditions on newly created surfaces should have a strong impact on determining the species composition through time.

As a component of the Channel Morphology and Dynamics research of the SRMAP project, the variability in vegetation composition using both assembly rules and a successional model of vegetation dynamics is examined. A detailed analysis was performed to analyze vegetation development on the Sacramento River Floodplain in relation to two landscape variables- floodplain age and relative elevation. Specifically, the research considers two questions:

1) what are the patterns of species composition over these gradients?
2) with the loss of cottonwood, what is the character of the replacement community?

The encroachment and potential stand replacement of Fremont's cottonwood by Northern California walnut (*Juglans hindsii*) and California box elder (*Acer negundo var. californicum*) on the Sacramento River were investigated, as they are hypothesized to have expanded as a result of hydrological modifications and agricultural practices throughout the 20th century (Fremier 2003).

While research has described the relationship between species occurrence and floodplain age on the Sacramento River, a description of the full complement of species in relation to floodplain age and relative elevation remains understudied with respect to channel abandonment and the replacement of cottonwood. This research utilizes the newly developed floodplain age composite map, and regroups the floodplain age gradient into five distinct time periods, each spanning roughly 20 year intervals: 2007 to 1984, 1983 to 1969, 1970 to 1954, 1953 to 1921, and 1920 to 1903. Vegetation surveys were performed on 43 distinct floodplain age surfaces to calculate species composition, relative cover, and frequency to investigate the distribution of species across the floodplain age surface. Vegetation community values were based on overstory dominance and understory, making the analysis more applicable to the 2007 riparian map.

Species richness was not found to be higher in any of the floodplain age groups, and Jaccard dissimilarity results indicated that the lowest floodplain areas (gravel bar, grassland, and willow communities) were most dissimilar to all other floodplain age groups. Areas most similar to each other were on higher floodplain ages, indicating increased heterogeneity on low to mid floodplain surfaces where disturbance is more frequent.

This research finds that the relationship between riparian species composition and the construction of floodplain age generally conforms well to a successional sequence in forest types. However, in analysis of the entire floodplain, the successional model lacks the structure to explain non-forested community types and invasive species. In the case of abandoned channels and the loss of pioneer species, the assembly rules model can be a useful framework to understand changes in riparian vegetation. Researchers observed repeatable transitions in forest stand development of species dominance between each floodplain age groups. The transition of species composition that occurs between about year 38 and 70 provides a detailed description of what species play a role in the advancement of valley oak forest and the disappearance of Fremont's cottonwood. California box elder and Northern California walnut communities are presumed to become more prevalent on the floodplain with the continued poor recruitment of cottonwood. These communities have already become dominant on the landscape and appear to follow cottonwood in the forest successional sequence.

More details on this research component can be found in Appendix F.

E. Vegetation Analysis- Riparian Vegetation Dynamics

i. Methods

Restoration Recovery

Dr. David Wood and colleagues sampled four restoration sites in summer 2008: River Vista 3 (n=27 plots), River Unit (n=25), Sam Slough (n=29), and Princeton Ferry (n=21). Permanent plots at all sites (restoration and remnant reference) are 20 x 30 m. Within each plot, the diameter of all woody stems >2.5 cm dbh (1.5 m high) was measured in order to obtain stem density, basal area, and size distributions by species. Basal area was determined by converting diameter to area and extrapolating to a hectare basis (m2/ha) for easy comparison with published values for other forests. Importance Values for each woody species were calculated for each plot as the sum of relative density plus relative basal area and then averaged by species and over sites. Shrub cover was estimated to the nearest 0.5 m using the line intercept method along five 10-m transects oriented perpendicular to the long axis of the plot. Herbaceous species cover was visually estimated over the entire plot using the Braun Blanquet scale of + (<1% cover), 1 (1-5% cover), 2 (2-25%), 3 (25-50%), 4 (50-75%), 5 (75-95%), and 6 (95-100%). Midpoints of ranges were used for quantitative analysis.

Data from 2008 were compared to restoration sites sampled in 2006, and to data from 25 remnant forest plots sampled in 2002, 2003, 2006 and updated in 2008. These remnant forest sites are Chico Landing, Pine Creek East, Shaw, Capay, Deadman's Reach, Jacinto, Phelan Island, Sul Norte, River Vista 3, Princeton Ferry, and Flynn.

Point Bar Recruitment

Six point bars sites along the middle Sacramento River between river miles 163-245 were resampled for woody riparian colonists. Sites were chosen in 2002 based on criteria of accessibility, size, and to achieve a wide geographic range. At each bar, belt transects 1m wide and oriented perpendicular to the river channel were established at upstream, midstream, and downstream locations. Transects extended from the water's edge to the beginning of mature riparian forest (defined as complete canopy cover, with stems at least 2.5 m high).

Transects were sampled in summers of 2002, 2003, and 2008. Microtopography was recorded along the transect using a rod and level and the river's height at the time of sampling as a zero point for relative elevation. Along each transect, stem density and heights of all woody species were recorded in contiguous 1-m^2 quadrats. Stems were counted if <10 and recorded in classes if >10 stems m^2 (classes were 21-50, 51-100, and 100-200). Midpoints of classes were used for statistical analysis. No attempt was made to distinguish seed-origin stems (genets) from sprout-origin stems (ramets). Height for each species was visually estimated by averaging over all stems rooted in the quadrat. Surface substrate type was recorded for each quadrat as silt, sand, gravel, cobble, or their combination (not more than two combinations per quadrat. Species nomenclature follows the Jepson Manual.

ii. Results

Restoration Recovery

Basal area: Restored sites had a mean basal area of 12.7 m^2/ha during 2008, a significant 95% increase ($p<.001$; paired t-test) from a mean of 6.5 m^2/ha for the same plots sampled during 2003. By comparison, the mean basal area of all remnant forest plots of 28.3 m^2/ha (range: 8.3 to 67.2). One restoration site (Phelan Island) had exceeded the mean value for remnant forest by the time of the 2006 surveys. The restoration site with the lowest basal area was River Vista 3, due to poor soils which retard tree growth. Individual species were all found to be increasing in basal area, with tree species exhibiting the fastest increases (*Acer negundo*, box elder; *Salix gooddingii*, black willow; *Populus fremontii*, Fremont cottonwood; *Quercus lobata*, valley oak; and *Platanus racemosa*, western sycamore) and shrub species the slowest (arroyo willow, *Salix lasiolepis*; and *Sambucus mexican*a, blue elderberry). Given the wide range of basal areas in remnant forest, most sites are on pace to achieve basal area values comparable to remnant forest in another 10-15 years.

Importance Values: Importance values (sum of relative density plus relative basal area) of major species in restoration plots were statistically unchanged (paired t-test; all $p>0.1$) from 2003 to 2008, indicating that the species composition in restoration sites continues to reflect that of the initial planting design. Importance values increased slightly from 2003 to 2008 for three of the five major tree species (box elder, Goodding's black willow, and valley oak) but decreased slightly for two others (Fremont cottonwood and western sycamore). Valley oak in both 2003 and 2008 had the highest importance in restoration forests, reflecting its high planting density. For shrubs, importance values increased for *Baccharis pilularis*, coyote brush; decreased for blue elderberry; and arroyo willow remained stable. As forests mature, we should expect to see a continued increase in values for the eventual community dominants (valley oak and Fremont cottonwood) followed by stabilization at maturity.

Remnant forests have highest importance values of (in descending order): Fremont cottonwood, box elder, Gooding's black willow, and valley oak. Arroyo willow currently has the second highest importance value in restoration, second only to valley oak, but its remnant forest value is much lower.

The analysis showed that, of the eventual dominants in restoration, cottonwood is increasing more as compared to other major tree species such as box elder and black willow. The low importance value of cottonwood in restoration sites may be due in part to the continued high importance of arroyo willow, as the two species often were planted together and may compete. Cottonwood is also subject to mortality from wind and beaver (personal observation), although the magnitude of this effect is unknown. The increase in coyote brush occurred mainly in plots where tree growth was limited, e.g. at River Vista 3 where tree growth is hindered by poor soils. The decline in blue elderberry may be due to its relative shade intolerance; growth of trees planted concurrently may be suppressing it. California black walnut has a high importance in remnant forests and its importance in restoration is slowly increasing even though it was not planted. Its ability to recruit into young-aged forests is apparent, and thus it has the potential to become a major component of restoration forests

It is important to note that importance values are relative measures, reflecting species composition. Absolute growth, as measured by basal area, shows that all major species continue to increase in size, albeit at different rates. Most restoration forests are still immature and their species composition continues to reflect initial planting composition. Over time, shade-intolerant shrubs such as arroyo willow and elderberry should decline in importance as the canopy closes and taller tree species exert greater dominance.

Stem size distributions: Distributions for the major tree species were compared to remnant forest are shown below. Fremont cottonwood and box elder exhibit the expected pattern for immature restoration forests in that their stem sizes shifted towards the smaller size classes. For example, in remnant forest 12% of cottonwood stems are >70 cm dbh but only 2% are that size in restoration. Goodding's black willow lags remnant forest primarily in the 40-50 cm dbh size class, suggesting that growth of this species is quickly approaching the size distribution of remnant forest. Valley oak most closely approximates that of reference forest, although large diameter trees (>30 cm dbh) are still uncommon in restoration sites. It should be noted that reference forests for valley oak are uncommon within the study area and are poorly represented in this research. A larger sample size of remnant oak forest may change conclusions drawn here for valley oak. Arroyo willow is the one species in restoration whose overall size distribution is greater than in remnant forest. California black walnut, not planted in restoration and considered an undesirable species in this study area, is present in 20% of restoration plots sampled in 2008; individuals of this species remain small as compared to remnant forest.

Point Bar Recruitment

No trend in either stem density or height is apparent during the six years of this study at five of the sites. The sixth site, River Mile 172, was omitted from this report due to technical issues. Mean stem density (all species) increased from 1.21 in 2002 to 1.8 2003, during which time there was little flooding, but then decreased to 1.38 in 2008. Mean height also exhibited a slight increase from 2002 to 2003 at slightly over 1 m but then declined in 2008 back to the 2002 level. It is possible that high flows of the 2005-2006 winter season reduced pioneer biomass.

Individual species generally follow the overall pattern. Only the group of willows denoted 'willow spp.' showed an upward trend. This group is composed of *Salix lucida* (shining willow), *S. laevigata* (red willow), and *S. melanopsis* (dusky willow) and was not adequately sorted out taxonomically in 2002 or 2003, so any trend cannot be attributed to a single species. In the absence of disturbance from flooding or channel movement we would expect to see a directional trend towards forest development (i.e. increasing vegetation height as tree growth occurs and decreasing density of shade intolerant pioneer species such as narrow-leaved willow). At present there is no evidence for such a trend.

F. Ecosystem Scorecard

i. Introduction

A flagship component of the SRMAP is the development of the Ecosystem Scorecard for the Sacramento River. The Ecosystem Scorecard is a method TNC has developed to promote a quantitatively rigorous method of Ecological Integrity Assessment (see Appendix I for the complete Scorecard Report and associated resource documents). Recognizing that significant restoration and conservation efforts has occurred on the Sacramento River, Dr. Greg Golet, TNC, has prepared a framework designed to provide information needed to evaluate the effects of conservation actions in large landscape scale projects. Such an assessment is necessary to determine the extent to which natural resources have been conserved or restored. Ideally, knowledge gained from status assessments will inform subsequent conservation action via the adaptive management process.

Properly applied, the framework generates standardized methodologies and testable hypotheses, and promotes the advancement and transfer of knowledge among scientists and natural resource managers. Moreover, when appropriately implemented, this methodology should translate to more effective and efficient allocation of scarce conservation resources.

Woven through each of these components are two principal objectives: (1) the maintenance or improvement of biodiversity health and (2) the abatement of critical threats to biodiversity. Achieving these objectives requires the integration of the best available ecological knowledge into the measures employed.

In this framework, the concept of key ecological attributes is presented as the currency for identifying and measuring the composition, structure, and function of focal biodiversity. For each of these key attributes ecological indicators are described and ratings thresholds are set which form a consistent, scientific basis for evaluating the status of individual key attributes. To the extent possible these thresholds are based on reference conditions that reflect the acceptable ranges of variation. The result is a categorical measurement system that is detailed in its scientific justification, yet simple, informative and compelling to any type of audience regardless of their scientific or conservation training.

ii. Methods

The framework is developed using a process for setting conservation goals and measures of success, and assessing the viability, or ecological integrity, of focal biodiversity at multiple scales. Specific vision statements of the ERP were used to establish corresponding ecological attributes and indicators which the Scorecard assesses restoration and conservation efforts' success.

The framework consists of the following four components:

1. Identification of ***key ecological attributes*** that determine the composition, structure, and function of focal biodiversity.
2. Identification of ***measurable indicators*** to describe key attribute status.
3. Determination of ***acceptable ranges of variation*** for key attributes based on reference conditions, and establishment of ***minimum integrity threshold criteria*** for conservation.
4. The ***rating of key attribute status*** and assessment and monitoring of overall integrity status based on status of all key attributes.

The framework rests on the premise that for any species, community or system there are a number of identifiable key ecological attributes that sustain the conservation target and maintain its composition, structure and function. Examples of key ecological attributes include natural hydrologic regimes, species composition/dominance, population size, etc. The Ecological Integrity Assessment framework is based on the assumption that significant disruption in the function of any of these key ecological attributes will degrade the integrity of that conservation target.

Field-based indicators are needed to measure the status of each key ecological attribute. An indicator for a key ecological attribute consists of some characteristic of that factor, or some collection of characteristics combined into an overall index, that strongly correlates with the status of that factor. Such indicators are a measurable means for obtaining information that substitutes for or summarizes what you most need to know about the key ecological attribute, when the attribute cannot be measured itself. Ideally, there would be a single indicator inextricably linked to the status of each key ecological attribute that directly informs practitioners of the key ecological attribute's true state. At times, however, more than one indicator is needed to characterize the key ecological attribute's status.

As the composition, structure, and function of all conservation targets are widely considered to be naturally variable, it is necessary when assessing the status of key attributes, to identify a particular range of variation over space and time which is recognized as natural and consistent with the long-term persistence of each conservation target. While what is "natural" is difficult to define, careful scientific reference, reflections on historical data, and comparisons with best preserved reference examples of a conservation target can at least identify an outer range of variation for key ecological attributes which can maintain the composition, structure and function of the conservation target.

The most important threshold to consider for each key ecological attribute is its minimum integrity threshold. The minimum integrity threshold for a key ecological attribute is the outer limit of its acceptable range of variation. Once this threshold has been crossed, the overall integrity of the conservation target cannot be restored.

This system rates the status of focal biodiversity's size, condition, and landscape context as *Very Good*, *Good*, *Fair*, or *Poor*, based on scientific inquiry, in order to convey a snapshot of biodiversity health and conservation progress over time in a clear and compelling manner. The Ecological Integrity Framework seeks to provide increased rigor and consistency to that inquiry by determining the key attributes within the categories of *size*, *condition*, and *landscape context*, and by rating their status based on the minimum integrity thresholds as stated above.

- *Size* is a measure of area of occurrence of an ecosystem or community, or the population size of a species.
- *Condition* measures biotic interactions and physical or age structure of communities and populations.
- *Landscape Context* refers to the important ecological processes that maintain the focal biodiversity and issues of biological and spatial connectivity.

This categorical framework has proven to be helpful in assisting conservation practitioners think broadly and comprehensively about important elements of the focal biodiversity's ecology that must be managed and conserved, and in allowing practitioners to speak a somewhat common language about these elements.

The status indicator ratings compare the status of the ecological process or attribute relative to a target condition, or as change in condition. The status indicator ratings are defined as:

- *Very Good:* The indicator is functioning within an ecologically desirable status, requiring little human intervention for maintenance within the natural range of variation (i.e., is as close to —natural as possible and has little chance of being degraded by some random event).
- *Good:* The indicator is functioning within its range of acceptable variation, although it may require some human intervention for maintenance.
- *Fair:* The indicator lies outside of its range of acceptable variation and requires human intervention for maintenance. If unchecked, the target will be vulnerable to serious degradation.
- *Poor:* Allowing the indicator to remain in this condition for an extended period will make restoration or prevention of extirpation of the target practically impossible (e.g., it will be too complicated, costly, and/or uncertain to reverse the alteration).

The Nature Conservancy developed an automated Excel-based tool to assist in the assessment of ecological integrity and to archive the supporting documentation for development of the Ecological Scorecard and Monitoring Plan. Data for the Ecosystem Scorecard were compiled from a number of scientists, both internal to the SRMAP and external. A Scorecard information worksheet was used to organize quantitative and qualitative information and references from consulting scientists. These data provide the supporting information and rationale for the Scorecard findings, and were also used in the development of the Monitoring Plan. Information captured for each of the indicators in the Scorecard includes:

- How specifically the indicator is defined
- Rationale is for it being a meaningful indicator and references that support its use as an indicator of river health.
- Scale at which the indicator is most useful (e.g., site, reach, parcel, patch, whole river)
- Selected rating cutoffs for poor, fair, good and very good condition, and how they were selected
- Methods for calculating the indicator or citations to published documents
- Current indicator value (and rating status), and the date and location that this corresponds to.
- Desired rating (and rationale) and when it should be achieved by
- History of data collection, and any additional values
- Source of the current indicator data, including contact information.
- Additional comments (considerations for interpreting data, related or alternative indicators, etc.)

iii. RESULTS

Application of the Scorecard to Assess the Status of Biodiversity of the Middle Sacramento River

The overall status of biodiversity, as determined by the application of this framework to the Sacramento Project area is “Fair”. When considering the conservation of targets individually, two of them (terrestrial riparian habitats and birds) ranked as “Fair” and one (aquatic riverine habitats) ranked as “Poor”. Examining the status of the individual indicators that were rolled up to produce these conservation target ratings can help explain why the conservation targets received the overall ratings that they did.

In short, the riparian habitats and the terrestrial species that inhabit them (including birds) are in “Fair” condition due to all of the efforts that have been put towards reestablishing native vegetation throughout the Sacramento River Project area. Many positive outcomes have been observed as a result of these efforts. This report details such outcomes by reporting changes in ecological indicators that have been observed through time at restoration sites, and in comparison to remnant habitats.

Table 4. Overall Status of Sacramento River Project Conservation Targets.

Sacramento River Project Conservation Targets		Landscape Context	Condition	Size	Combined Viability Rank
Target #	Current Rating				
1	terrestrial riparian habitats	Fair	Fair	Fair	**Fair**
2	aquatic riverine habitats	Fair	Poor	Poor	**Poor**
3	birds (resident and migratory)	-	Fair	Poor	**Fair**
Overall Project Biodiversity Health Rank					**Fair**

[Each of the three categories (landscape context, condition, and size) displayed in columns of the table below were evaluated with a suite of ecological indicators. See Appendix I of the Scorecard Report (attached to Appendix I) for the complete list of indicators and their individual ratings values.]

In contrast, the status of the third conservation target, aquatic riverine habitats was determined to be “Poor”. This is the direct result of the hydrologic and geomorphic processes being constrained by anthropogenic alterations to the river. Of particular concern is the steady increase in riprap that has been observed since the 1930s, and the alteration of the natural flow regime since the mid 1900s. As more and more riprap has been installed, and the hydrology has been increasingly altered, the river has lost much of its natural dynamism, and with that, a reduction in its ability to create and maintain the habitats that are essential to native species and communities. Planting of native vegetation has been an important “stop gap” measure, and has kept the status of the two other conservation targets from dropping to “Poor”, however, their continued persistence, even at this level, is uncertain.

Application of the Scorecard to Assess Progress toward Achieving the Goals and Visions of the CALFED Ecosystem Restoration Program

Another related use of the Scorecard indicators is to assess progress toward achieving the goals and visions of the CALFED Ecosystem Restoration Program (ERP) for the Sacramento River Ecological Management Zone (CALFED 2000). The findings related to selected visions are summarized below.

Progress toward achieving ERP Vision for Habitats was assessed for Riparian and Riverine Aquatic Habitats by synthesizing information on 12 indicators. Overall, progress has been "Fair". Mild increases were observed over the past 20 years in the percent of historical riparian zone currently in conservation ownership, and the percent of historical riparian zone currently in natural habitat. Landscape metrics such as the Forest patch proximity, Forest patch core size have shown positive changes with implemented restoration. Indicators that prevented progress toward this vision being rated as "Good" include Total river length and whole river sinuosity. Both have declined since the early 1900s, and have not changed significantly in recent decades.

Progress toward achieving ERP Visions for Species and Communities was assessed for Plant Species and Communities, Neotropical Migratory Birds (including the Yellow-billed cuckoo and bank swallow), and the Valley Elderberry Longhorn Beetle. Overall, progress has been "Good". There have been significant increases in the acreage of native vegetation, largely as a result of all the planting that has been done at restoration sites. At restoration sites there have been positive responses in terms of habitat development. Less encouraging is the status of understory vegetation. At restoration sites native understory species have been slow to colonize, and frequency of occurrence has been low. These findings have led to the implementation of an understory component to the more recent (post-1999) restoration plantings. Survival of understory plantings has generally been good.

To measure progress toward achieving the vision for Neotropical Migratory Birds (including the Yellow-billed cuckoo, bank swallow,) information was synthesized on 13 indicators. Overall, progress has been "Fair". Nest survival does not appear to have increased and is low at least for the Lazuli Bunting. In contrast, bird species richness has increased, quite dramatically, at restoration sites as has abundance for certain species (e.g., Black-headed Grosbeak, Common Yellowthroat), although not others (e.g., Yellow Warbler and Yellow-breasted Chat). The Sacramento River corridor is the major population center for both Yellow-billed Cuckoo and Bank Swallow. For both species there is cause for concern. For cuckoos, there is a very low number of occupied territories, and for Bank Swallows, there has been a dramatic decline in the number of burrows at active colonies.

To measure progress toward achieving the vision for Valley Elderberry Longhorn Beetle information was synthesized on 2 indicators. Overall, progress has been "Good". At restoration sites there has been a dramatic increase in the percent of elderberry shrubs that are occupied by the VELB. However the Importance value for the VELB's host plant has declined as the sites have matured, raising the question as to what the long-term habitat suitability will be at these sites. Progress toward restoring healthy populations of other native terrestrial fauna was assessed by synthesizing information on 4 indicators. Overall, progress has been "Good". Similar to what was found with landbirds, species richness of bees, beetles and bats was found to be higher at older restoration sites than at younger sites. And overall, the aerial extent of waterbird colonies was found to be fairly extensive.

To measure progress toward achieving the vision for *Central Valley Streamflows* information was synthesized on 4 indicators. In the case of the streamflows for the Sacramento River, 'progress' can perhaps best to understood in the context of preserving the dynamic range of the existing flow regime, and in the future, restoring some of the lost dynamics.

The first indicator is bed mobility, expressed as days exceeding the flow needed to fully mobilize the bed, for which 55,000 cfs is used, based on empirical studies. The second indicator is floodplain inundation (to reestablish lateral connectivity between channel and floodplain), for which we use 70,000 cfs based on prior work along the middle reach of the river, and based on the flow at which Fremont weir overflows and the Yolo Bypass is watered. The third indicator is periodic connection of secondary channels with the mainstem, which drives hydrodynamics and ecological processes in the secondary channels. The fourth indicator is abruptness of changes in flow in the river, in effect one aspect of flow regime alterations from water management.

For the first three of these indicators, the status is measured by number of days above a threshold value, determined based on empirical observations by various researchers over the past three decades. The type of water year (wet, normal, dry) needs to be accounted for, because the river experienced large natural variability in these variables prior to human alterations. The status of the fourth objective is measured by the artificiality of changes in flow, such as unnatural increased in flow in the summer caused by increases in irrigation releases. The goal with all these indicators is to achieve flow regimes more closely based on the natural flow regime for the river. The vision for these flow patterns can be attained first by avoiding further loss of flow dynamics in the Sacramento River system, and more selectively, by supplemental short-term releases from the major storage reservoirs to provide flows that emulate natural peak flow events. The indicators are not such that ever-increasing values are necessarily good.

Overall, progress for achieving the vision has been "Fair". The current status of these indicators, based on a preliminary assessment, is "Good" for bed mobility, "Fair" for floodplain inundation looking only at the flows (but the extent of floodplain inundation is "Poor" when actual flood extent is considered, due to effect of levees along the channel), "Good" for side-channel reconnection, and "Fair" to "Good" for artificiality of flow changes.

To measure progress toward achieving the vision for Stream Meander information was synthesized on 10 indicators. Overall, progress has been "Poor". Although there has been considerable variability in indicator values among time periods (in part due to variations in flows), and most of the indicators that were studied to assess progress toward this vision are only meaningful over long time frames, the collective weight of evidence presents a clear picture. Channel dynamics and channel complexity have shown reductions over the period of record (1906 to 2007), and there has been no appreciable improvement in recent years. Far from it, some of the most important indicators of stream meander (e.g., meters of bank with riprap) have continued to decline, despite goals being set to achieve the opposite. On a brighter note, the length of river with conservation ownership on both banks has increased, suggesting an increase in opportunities for restoration of natural channel processes.

To measure progress toward achieving the vision for *Natural Floodplain and Flood Processes* information was synthesized on 4 indicators (see Goals and Visions section). Overall, progress has been "Poor". Floodplain inundation and side-channel connection may be adequate to support some physical and ecological processes, but actual floodplain extent has not increased, and riprap has increased steadily. A positive outcome is the fairly rapid increase in soil organic carbon observed at restoration sites.

Progress toward achieving ERP Visions for Reducing or Eliminating Stressors was assessed for Levees, bridges and bank protection, and Invasive riparian and marsh plants. To measure progress toward achieving the vision for Levees, bridges and bank protection information was synthesized on 2 indicators. Overall, progress has been "Poor". Riprap has increased, and although the length of river with conservation ownership on both banks has increased, little on-the-ground work has been done. Infrastructure that currently limits natural river processes has yet to be removed, although there have been a few improvements (e.g., small levee breaches at restoration sites).

To measure progress toward achieving the vision for Invasive riparian and marsh plants information was synthesized on 6 indicators. Overall, progress has been "Poor". Reductions have not been observed in the area of non-native riparian and marsh plants. Quite the contrary, Arundo. black walnut, Himalayan blackberry, and Ludwigia have all increased in aerial extent from 1999 to 2007. Relative native understory cover, an indicator of restoration site success has remained virtually unchanged from one survey period to the next. Thus competition that native flora face from non-native species is likely increasing.

G. Monitoring Plan

i. Introduction

The Sacramento River Monitoring Plan is a critical component of the SRMAP, combining monitoring and analysis methodology from different researchers using the indicator framework in the Sacramento River Ecosystem Scorecard. Written by Dr. Fraser Shilling, UCD, with component sections contributed from a variety of sources (Holyoak 2010, Howell 2010, Kondolf and Minear 2011) the Monitoring Plan addresses major aspects of the riparian and channel condition. It includes substantially more detail for indicators researched as a part of SRMAP; however, it does not cover all ecosystem processes and attributes.

The intent of the Monitoring Plan is set forth methodology to monitor and evaluate the changing conditions of the Sacramento River Riparian as natural and management-induced changes occur. The Plan is based upon the best available science and describes quantitative methodologies that are robust and repeatable. It provides the most up-to-date monitoring approaches, describes appropriate statistical and analytical uses of information, and is presented in such a language as to be easily understood by land managers and restoration practitioners.

The monitoring and evaluation approach described in the Plan addresses the following major questions:

1. What is the status of natural riverine processes compared to the hypothesized potential natural condition and desired future conditions?
2. How are the ecological and hydrological changes that have occurred related to vegetative restoration activities?
3. What is the overall status of riparian vegetation, riparian bird communities, and VELB populations along the Middle Sacramento River?
4. How do restored and remnant riparian sites compare in terms of the parameters listed above?
5. What other elements should be considered for monitoring to complement those parameters described in detail in this report?
6. What monitoring programs are in place to complement the program presented herein?

The Monitoring Plan includes approaches for monitoring major components of the riparian system. The Monitoring Plan focuses on methods to evaluate the following primary actions implemented in riparian restoration along the River: land acquisition, horticultural restoration, and levee removal and setback.

For each component, the Plan includes the following vital information as part of the methodological description of how monitoring should be done:

- The purpose of the monitoring – the questions the monitoring is intended to answer
- Evaluation approach the monitoring will inform
- Where monitoring should take place
- When monitoring should take place and frequency of monitoring for change detection
- Data analysis approaches
- Specific field/computational methods

ii. MONITORING APPROACHES

The Monitoring Plan is based on the indicator framework used in the Sacramento River Ecosystem Scorecard. The Score Card approach was developed by The Nature Conservancy to measure attainment of conservation targets (Parish et al., 2003). It is similar in structure to other indicator-based reporting systems used around the world and is based on categories of ecological condition within each conservation target. The categories contain indicators that correspond to specific ecosystem processes and attributes and provide information that can be used to evaluate attainment of the goals set for the conservation targets.

Within the Monitoring Plan, relevant Scorecard targets and indicators are highlighted within each section. The approaches described in the Monitoring Plan are intended to support reporting of ecological condition and restoration success for independent ecological attributes and evaluates attribute conditions at scales relevant to ecological goals. Frequency of monitoring recommended varies with the process or attribute under investigation.

The process of transforming monitoring data into meaningful information for the Scorecard is described both within the Scorecard Report (Appendix **I)** and the Monitoring Plan (Appendix **J**). In short, site conditions monitored at a certain time or place are compared with both desired target conditions and un-desirable conditions and the distance calculated on a 0-100 scale. This uniform re-scaling of each monitoring variable type allows comparison combination of these variables in a Scorecard environment. Subsequent to developing a raw score on the 0 – 100 scale, users can then lump score ranges into "good", "fair", and "poor" classes dramatically simplifying presentation of information.

The approaches described in the Monitoring Plan are primarily for quantitative monitoring; however noting that qualitative monitoring also has its place in evaluating ecosystem condition and restoration effectiveness. The Monitoring Plan identifies what particular indicators should be investigated, at what spatial scale, and at what temporal interval to meaningfully determine change in the overall system; and change at the site scale in response to restoration actions.

iii. MONITORING METHODS

The Monitoring Plan details methods which include computerized mapping and analysis tools, as well as point-based field surveys. The ecological attributes to be monitored include soil, vegetation, wildlife, and channel morphology. Table 2 identifies the attributes of the conservation target terrestrial riparian vegetation which have monitoring methodologies detailed within the Plan. The terrestrial component of the riparian forest provides habitat for birds, mammals, herpetofauna, arthropods and other invertebrates, and plants. A combination of habitat structure, community composition, and habitat function will determine the value of the terrestrial component to various taxa. The Monitoring Plan outlines a number of monitoring methods for important attributes of terrestrial riparian vegetation, including habitat function for terrestrial and riparian biota.

Table 2. Terrestrial Riparian Vegetation Attributes to Monitor

Conservation Target: Terrestrial Riparian Vegetation		
Aerial Photography	Landscape Structure	Ground Surveys
Conservation Ownership	Structure: Fragmentation/patchiness	Photo point monitoring
Mappable Vegetation Cover	Structural/Functional fragmentation indicators	Native overstory species cover
Vegetation Map	Connectivity indicators	Native and Non-

Validation		native understory species cover

Riparian vegetation is an important attribute to monitor as it is a straightforward measure of the output of restoration and protection useful for accounting purposes, and it can be a measure of habitat quality for a number of plant and animal species. Riparian vegetation also has two-way interactions with the river channel and floodplain; as such, it both responds to and influences channel dynamics, another key indicator of riverine ecosystem health.

Table 3. Monitoring Attributes Related to Channel Morphology

Conservation Target	Monitoring Attribute	
Terrestrial vegetation	Floodplain age	
Aquatic riverine habitat	Channel migration	Sinuosity
		Bend geometry
	Bank structure and dynamics	Revetment
	Fish Habitat and Populations	Population Size
		Distribution
	Floodplain and Channel Habitat Function	
	Floodplain age	
	New land formation	

The Plan also includes measures for monitoring wildlife such as landbird species composition and abundance, through point counts, nest monitoring, mist-netting. Methods for measuring Valley Elderberry Longhorn Beetle population size and dynamics are also included, as well as recommendations for visual or auditory detection, sign detection, camera trapping, radio/GPS-collaring, genetic analysis, and live and pit-trapping for mammals, reptiles, and amphibians.

As the physical interactions between channels and their floodplains and banks determine much of the overall shape of a river and its ability to provide structure for habitat to form, it is important to study. Table 2 lists the methods included in the Plan pertaining to channel dynamics:

The Monitoring Plan also includes other aquatic indicators that may be measures of disturbance and condition that are more easily monitored than fish, such as freshwater benthic macroinvertebrates and algae and macrophytes.

iv. Monitoring Plan Summary

The Monitoring Plan can be summarized as being composed of what is monitored, where, when, how, by who, and why. General guidance is provided here for carrying out the monitoring approaches described in Appendix J. The plan is summarized in two ways. One is as a table (Table 4) showing when particular types of indicators should be investigated and at what spatial scales. The other is a timeline (Figure 1) showing an approximate schedule for monitoring different attributes of the riparian system to determine changes in the overall system and changes at the site scale in response to restoration actions.

Table 4. Summary of indicators for monitoring, and spatial and temporal scale.

Monitoring Component	Monitoring indicator/method	Spatial Extents	Spatial Grains	Season	Temporal Frequency
Vegetation: Landscape	Fragmentation	parcel, riparian	30 m cell, parcel	--	5 years
	Connectivity	riparian	30 m cell, parcel	--	5 years
Vegetation: Composition	Photopoint	site	meter	Spring -- Summer	annual (before/ after
	Native over-story cover	parcel, riparian	site, parcel	Spring -- Summer	5 years
	Native under-story cover	parcel, riparian	$1m^2$ quadrat, parcel	Spring -- Summer	5 years (before/ after restoration)
	Non-native species cover	parcel, riparian	$1m^2$ quadrat, parcel	Spring -- Summer	5 years (before/ after restoration)
Vegetation: Habitat function	Birds (point counts, nest monitoring, mist netting)	(site, riparian, site)	site	Year-round	annual
	Valley-Elderberry Longhorn Beetle	site, riparian	site, parcel, patch	Summer	2 - 3 years
	Mammals, reptiles, amphibians	site, riparian	site	Spring -- Fall	annual
Soil	Structure	parcel, grid cell	$1m^2$ quadrat, soil pit patch	Spring -- Summer	before/ after restoration
	Composition	parcel, grid cell	$1m^2$ quadrat, soil pit patch	Spring -- Summer	before/ after restoration
	Processes (nutrients)	parcel, grid cell	$1m^2$ quadrat, soil pit patch	All year	before/ after restoration
Aquatic: Geomorpholgy	Channel meander rate	reach, river	reach	--	5 years
	Channel sinuousity	reach, river	reach	--	5 years
	Channel angle	reach	1/4 channel width segment	--	5 years
	Channel length	river	river	--	5 years
	Floodplain age	parcel, riparian	site, parcel	Summer	5 years
	Land re-worked	reach, river	1/4 channel width segment, reach	--	5 years
	Bank types	reach, river	1/4 channel width segment, reach	--	5 years (annual update revetment map)
	Side/back-channels	reach, river	reach	Spring -- summer	5 years
Aquatic: Hydrology	Flows	site, reach, river	site	Continuous	hourly-annual
Aquatic: Habitat function	Fish populations	reach, river	reach		annual
	Benthic macroinvertebrates	reach, river	reach	Spring, Fall	annual
	Algae and macrophytes	reach, river	reach	Summer	annual

Definitions

Site	A monitoring location or station at a point in space
Parcel	An area on the landscape with one owner and boundary, often defined by homogeneity (e.g., a "patch of grassland")
Riparian	The whole riparian zone along the river
Reach	A geomorphologically continuous stretch of river
Grid cell	A virtual square on the landscape (e.g., 30 m grid cell)
River	The whole river

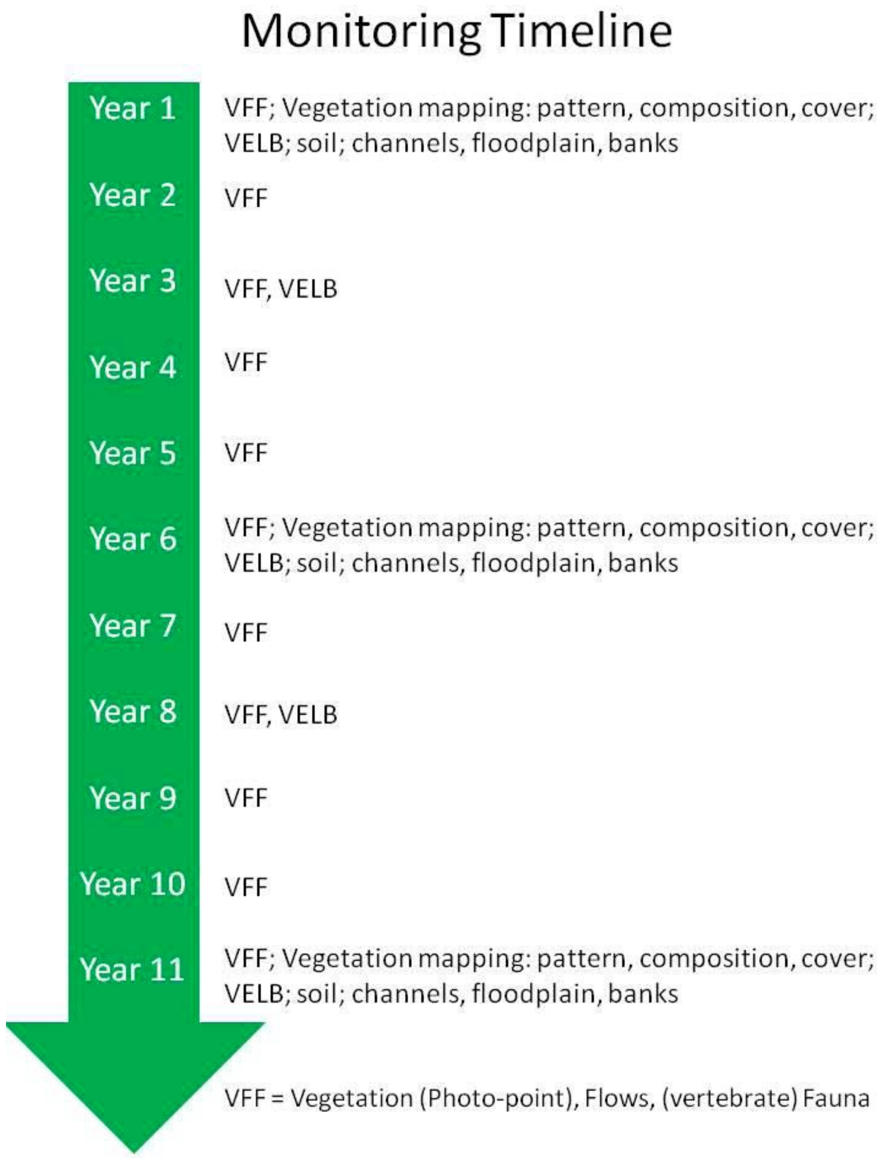


Figure 1. Monitoring Timeline. The timeline shows an approximate schedule that could be followed to monitor riparian conditions, based upon frequencies in published reports for the Sacramento Riparian and other similar systems.

v. MONITORING INTERVALS & PRIORITIZATION

The Plan suggested varying intervals for monitoring attributes using methods described in the Plan. Annual monitoring is recommended for flows, fauna and vegetation (by photo-point). VELB monitoring is recommended every two years, with the rest of the attributes monitored at a recommended frequency of every five years.

Monitoring can be done on a more ad hoc basis, such as before and after restoration activities or particularly large events expected to significantly change the riparian and floodplain zones as necessary, rather than prioritized based on a fixed schedule. Regardless, the prioritization process should be laid out along 3 primary axes: management need, temporal scale, and spatial scale. Management need includes situations like understanding the effectiveness of restoration investments and activities. Temporal scale includes length of monitoring period and frequency of monitoring and spatial scale includes aerial extent of monitoring, and spatial grain of investigation or analysis. Regardless, the temporal scale of monitoring should be sufficiently long to determine whether a given attribute has been restored.

vi. MONITORING DATA TO SCORECARD REPORTING

Individual parameters from monitoring programs and scientific investigations are reported in distinctly different units from each other. To compare or aggregate them into an index, they must first be converted to a common scale. In the Scorecard, data from individual parameters are converted to a common scale of 0 to 100, where 0 corresponds to a very poor condition and 100 corresponds to a very good condition. Poor and good are defined by goals or targets set for the individual conditions. The method used here to re-scale raw parameter values to a common scale is called the distance to target method. This method consists of measuring the distance between an existing condition and a desired/undesired reference or target condition.

Comparing parameter or indicator values against a fixed/reference value is a critical requirement in using parameters to inform condition assessments. This fixed value could be a historical condition, a desired future condition, a legal threshold, or some other reference value. It provides the context for interpreting parameter results – a number against which current or future status trends can be compared. The selection of reference values is as important as the selection of Scorecard indicators themselves because, without this baseline, it is difficult to assess the magnitude of change objectively, whether the magnitude of change is important, or if any efforts at improving conditions are succeeding (National Research Council, 2000).

III. SUMMARY

A. 2007 RIPARIAN MAP (INCLUDING CROSSWALK AND CHANGE DETECTION)

The time scale of the Riparian Map Analysis was relatively short, from 1999 and 2007, and thus the analysis was not expected to yield significant change. However, the analysis does provide useful information on the trajectory of specific vegetation types. The analysis identified those vegetation types prone to cartographic inaccuracy such that their inclusion in change detection and analysis will create and propagate error. The analysis also establishes a useful methodology for map comparison in future efforts.

It was proposed that 2007 vegetation classes be aggregated for any contemporary change detection analysis and map comparisons. A further recommendation was that certain vegetation classes should be interpreted with caution.

It was also found that there were some class comparisons that support successional trends in vegetation over the 8 year period, such as open water to introduced perennials (62%) and gravel bar (41%), and gravel bar to mixed willow (32%) and Gooding's willow (27%). However, owing to the difference in coding between years, statistical association did not show a robust relationship between classes in the 1999 and 2007 riparian maps. The study's findings that forested types could be lumped to evaluate forest cover change with high confidence, and that the aforementioned successional trends were plausible and well supported by statistical association. Caution is recommended, however, when making direct comparisons between certain vegetation types, such as scrub/willow types, valley oak, mixed riparian and cottonwood riparian.

B. MAP VALIDATION

SAMPLE SIZE AND LONGITUDINAL DISTRIBUTION

Field accuracy assessment totaled just over 15% of the total number of polygons digitized. While not more than 10% of each vegetation category was field visited, a representative sample was obtained of the most dominant vegetation categories, including all of the forest types and both of the herbaceous types. Moreover, the types with <10% visitation were either purposefully ignored (e.g., open water) due to temporal mapping issues, or were perpetually infrequent in the field (e.g., bulrush cattail). Sampling was stratified across the entire study area – in effect along a longitudinal profile, which varied with geographic latitude – but statistically more field validation was completed in the northern portion of the study area than in the southern.

MAP ACCURACY

Some positional bias was found based on vertical (UTM Y coordinate) location for correct or incorrect polygon classification; however, bias existed in both the north to south and south to north direction depending on the vegetation class – in effect canceling out any potential error caused by interpreter learning bias. By creating a contingency or confusion matrix, overall map accuracy for validated classes was calculated at 85.3%. This value is above the threshold at which map categories would need to be revisited and updated by the GIC. Additionally, the Kappa statistic, calculated to show the statistical correlation between the original dataset and the field validated dataset while accounting for random association, was 0.83 and indicates strong agreement between the validated and un-validated maps. This Kappa statistic will allow for reliable comparisons between this map and future validated maps of similar accuracy.

VEGETATION CATEGORY ACCURACY

While accuracy values are variable between each map class, they rarely vary structurally. This analysis resulted in two types of confusion matrices (polygon count and area in hectares) and some of the categories exhibited dissimilar user and producer accuracy rates. These differences are indicative of the positive or negative relationship between the error associated with number of polygons within a category and the polygon area associated with those same polygons.

Recommended map changes commonly included more than one update to a single polygon and are noted in the “OtherType” field in the GIS shapefile appended to the report. Polygons that needed to be split into multiple polygons accounted for ~17% of the total validated polygons visited during the 2008 field season. These polygon updates were not included in the overall accuracy assessment due to their ‘fuzzy’ nature (i.e., partially correct). Partially correct polygons should be revisited by map interpreters to determine if field validation recommendations are practical within the scope of the 2007 mapping methods.

The calculated difference in user and producers error between the area confusion matrix and polygon count confusion matrix was greater than ten percentage points for a number of classes. Box elder was most commonly misclassified as riparian scrub, and black walnut was most commonly misclassified as box elder or valley oak. California sycamore and Fremont cottonwood were commonly misclassified as valley oak forest. Annual grassland vegetation types were commonly misclassified as introduced perennials.

C. 2007 RIPARIAN MAP (INCLUDING CROSSWALK AND CHANGE DETECTION)

From 1904 to 2007, the geometric complexity and meander migration dynamics of the Middle Sacramento River have decreased, which has implications for the health of the riparian ecosystem. The river channel length tended to decrease, suggesting that the river length lost to cut-off and other processes has not been replaced by an increase in length due to channel migration over that time period. In addition, the formation of high sinuosity bends susceptible to future cut-off has declined. The river sinuosity, the average entrance and exit angle magnitudes, and the average migration rate (and floodplain reworked) – all tended to decrease with time.

In order to provide quantitative metrics that can indicate the health of the river system, especially over time, seven of the measured metrics were chosen specifically as ecosystem health “indicators”. Establishing ratings for the river health indicator metrics provides a first estimate in defining metrics of ecosystem health that can be used to evaluate, enhance and restore ecosystem functioning related to the riparian ecosystem of the Middle Sacramento River. The ratings established were qualitative estimates based on expert knowledge of the river system. For the 2007 data, each indicator resulted in a “poor” rating.

D. Vegetation Analysis- Native Riparian Understory Recovery

The research found that mean cover and frequency of native understory species changed little over time (2001 to 2007); and that increases in native cover in a few sites were primarily due to a single common species (*Galium aparine*). Over time, species composition shifted from light-demanding to shade adapted species, both exotic and native, in response to a doubling of overstory cover. Sites with high intensity understory plantings had greater cover and frequency of native understory species than unplanted sites, but were still low relative to reference forests. Light-demanding natives established in sites where they were planted; however shade-adapted species (*Carex barbarae*) did not survive well. The research suggests that native understory plant communities are not recovering in sites where they were not initially planted, so it will be necessary to actively plant these species into restoration sites. Light-tolerant species can be planted along side tree seedlings as part of restoration efforts, but shade-adapted species will have higher survival if they are planted after a canopy has established.

E. Vegetation Analysis- Riparian Vegetation Dynamics

Restoration Recovery

The analysis showed that, of the eventual dominants in restoration, cottonwood is increasing more as compared to other major tree species such as box elder and black willow. The low importance value of cottonwood in restoration sites may be due in part to the continued high importance of arroyo willow, as the two species often were planted together and may compete. Cottonwood is also subject to mortality from wind and beaver (personal observation), although the magnitude of this effect is unknown. The increase in coyote brush occurred mainly in plots where tree growth was limited, e.g. at River Vista 3 where tree growth is hindered by poor soils. The decline in blue elderberry may be due to its relative shade intolerance; growth of trees planted concurrently may be suppressing it. California black walnut has a high importance in remnant forests and its importance in restoration is slowly increasing even though it was not planted. Its ability to recruit into young-aged forests is apparent, and thus it has the potential to become a major component of restoration forests

It is important to note that importance values are relative measures, reflecting species composition. Absolute growth, as measured by basal area, shows that all major species continue to increase in size, albeit at different rates. Most restoration forests are still immature and their species composition continues to reflect initial planting composition. Over time, shade-intolerant shrubs such as arroyo willow and elderberry should decline in importance as the canopy closes and taller tree species exert greater dominance.

Point Bar Recruitment

No trend in either stem density or height is apparent during the six years of this study at five of the sites. Individual species generally follow the overall pattern. Only the group of willows denoted ‘willow spp.’ showed an upward trend. This group is composed of *Salix lucida* (shining willow), *S. laevigata* (red willow), and *S. melanopsis* (dusky willow) and was not adequately sorted out taxonomically in 2002 or 2003, so any trend cannot be attributed to a single species. In the absence of disturbance from flooding or channel movement we would expect to see a directional trend towards forest development (i.e. increasing vegetation height as tree growth occurs and decreasing density of shade intolerant pioneer species such as narrow-leaved willow). At present there is no evidence for such a trend.

F. Ecosystem Scorecard

The overall status of biodiversity, as determined by the application of this framework to the Sacramento Project area is “Fair”. When considering the conservation of targets individually, two of them (terrestrial riparian habitats and birds) ranked as “Fair” and one (aquatic riverine habitats) ranked as “Poor”. Examining the status of the individual indicators that were rolled up to produce these conservation target ratings can help explain why the conservation targets received the overall ratings that they did.

In short, the riparian habitats and the terrestrial species that inhabit them (including birds) are in “Fair” condition due to all of the efforts that have been put towards reestablishing native vegetation throughout the Sacramento River Project area. Many positive outcomes have been observed as a result of these efforts. The scorecard report details such outcomes by reporting changes in ecological indicators that have been observed through time at restoration sites, and in comparison to remnant habitats.

In contrast, the status of the third conservation target, aquatic riverine habitats was determined to be “Poor”. This is the direct result of the hydrologic and geomorphic processes being constrained by anthropogenic alterations to the river. Of particular concern is the steady increase in riprap that has been observed since the 1930s, and the alteration of the natural flow regime since the mid 1900s. As more and more riprap has been installed, and the hydrology has been increasingly altered, the river has lost much of its natural dynamism, and with that, a reduction in its ability to create and maintain the habitats that are essential to native species and communities. Planting of native vegetation has been an important “stop gap” measure, and has kept the status of the two other conservation targets from dropping to “Poor”, however, their continued persistence, even at this level, is uncertain.

Another related use of the Scorecard indicators is to assess progress toward achieving the goals and visions of the CALFED Ecosystem Restoration Program (ERP) for the Sacramento River Ecological Management Zone (CALFED 2000). The findings related to selected visions are summarized below.

- Progress toward achieving ERP Vision for Habitats was assessed for Riparian and Riverine Aquatic Habitats by synthesizing information on 12 indicators. Overall, progress has been “Fair”.

- Progress toward achieving ERP Visions for Species and Communities was assessed for Plant Species and Communities, Neotropical Migratory Birds (including the Yellow-billed cuckoo and bank swallow), and the Valley Elderberry Longhorn Beetle. Overall, progress has been “Good”.

- To measure progress toward achieving the vision for Neotropical Migratory Birds (including the Yellow-billed cuckoo, bank swallow,) information was synthesized on 13 indicators. Overall, progress has been “Fair”.

- To measure progress toward achieving the vision for Valley Elderberry Longhorn Beetle information was synthesized on 2 indicators. Overall, progress has been “Good”.

- Progress toward restoring healthy populations of other native terrestrial fauna was assessed by synthesizing information on 4 indicators. Overall, progress has been “Good”.

- To measure progress toward achieving the vision for *Central Valley Streamflows* information was synthesized on 4 indicators. Overall, progress has been “Fair”.

- To measure progress toward achieving the vision for Stream Meander information was synthesized on 10 indicators. Overall, progress has been “Poor”.

- To measure progress toward achieving the vision for *Natural Floodplain and Flood Processes* information was synthesized on 4 indicators. Overall, progress has been “Poor”.

- To measure progress toward achieving the vision for Levees, bridges and bank protection information was synthesized on 2 indicators. Overall, progress has been “Poor”.

- To measure progress toward achieving the vision for Invasive riparian and marsh plants information was synthesized on 6 indicators. Overall, progress has been “Poor”.

G. Monitoring Plan

The Monitoring Plan details methods that include computerized mapping and analysis tools, as well as point-based field surveys. The ecological attributes to be monitored include: soil, vegetation, wildlife, and channel morphology. The terrestrial component of the riparian forest provides habitat for birds, mammals, herpetofauna, arthropods and other invertebrates, and plants. A combination of habitat structure, community composition, and habitat function will determine the value of the terrestrial component to various taxa. The Monitoring Plan outlines a number of monitoring methods for important attributes of terrestrial riparian vegetation, including habitat function for terrestrial and riparian biota.

Riparian vegetation is an important attribute to monitor as it is a straightforward measure of the output of restoration and protection useful for accounting purposes, and it can be a measure of habitat quality for a number of plant and animal species. Riparian vegetation also has two-way interactions with the river channel and floodplain; as such, it both responds to and influences channel dynamics, another key indicator of riverine ecosystem health.

The Plan also includes measures for monitoring wildlife such as landbird species composition and abundance, through point counts, nest monitoring, mist-netting. Methods for measuring Valley Elderberry Longhorn Beetle population size and dynamics are also included, as well as recommendations for visual or auditory detection, sign detection, camera trapping, radio/GPS-collaring, genetic analysis, and live and pit-trapping for mammals, reptiles, and amphibians.

The Monitoring Plan also includes other aquatic indicators that may be measures of disturbance and condition that are more easily monitored than fish, such as freshwater benthic macroinvertebrates and algae and macrophytes. As the physical interactions between channels and their floodplains and banks determine much of the overall shape of a river and its ability to provide structure for habitat to form, it is important to study. The monitoring and evaluation approach developed through this project was designed to monitor major components of the riparian system – riparian vegetation pattern, composition, and structure; channel structure and dynamics; and habitat occupancy by select biota. The Plan includes information, where appropriate, as part of the methodological description of how monitoring should be conducted, such as purpose of monitoring, related Scorecard indicators, appropriate spatial and temporal scale, timing and frequency of monitoring, field and computational methods, and data interpretation approaches. For an additional set of components that are not part of the Plan, a brief and general overview of monitoring approaches is provided, including references to appropriate literature and descriptions of relevant existing Sacramento River Riparian monitoring programs for which information was available at the time of writing. A Monitoring Timeline is also proposed.

III. CONCLUSIONS AND RECOMMENDATIONS

This project has contributed a great deal of data and analysis regarding the Sacramento River. Environmental research methods were applied to quantify the existing condition of riparian and channel habitat, resulting in the 2007 riparian map, validation and crosswalk, and channel morphology and vegetation composition assessment. Through Dr. Holl and Dr. Wood's research, the project has assessed restoration efforts, with respect to remnant forests, by evaluating their change over time and comparing to remnant forests. Dr. Holl and Dr. Larsen's research also addresses local and landscape factors affecting vegetation composition. The Ecosystem Scorecard, compiled by Dr. Golet, compiles and analyzes available data to evaluate the current condition and trajectories of the Sacramento River ecosystem health and analyzes the success of previously implemented restoration projects.

Project research methods and other monitoring methods have been evaluated by Dr. Shilling and compiled into a comprehensive ecosystem Monitoring Plan for the Sacramento River, providing field methodology, timing and frequency of monitoring and analysis methods to acquire data corresponding to the Scorecard indicators.

Project findings provide agencies, land managers, researchers and restorationists with valuable insight. The following recommendations are separated into Sacramento River condition, restoration evaluation, and future monitoring efforts.

CONDITION

The 2007 riparian mapping effort measures a total of 14 alliances and 2 habitat types were mapped, equaling 8,868 polygons over 33,000 total acres. Of the mapped area, the Fremont cottonwood association dominated the vegetation coverage at nearly 8,000 acres. Valley Oak coverage was the next greatest, at just over 4,000 acres.

A detailed analysis of species composition, relative cover, and frequency as a function of floodplain age (FPA) and relative elevation yielded important observations for five floodplain age groups from 1903-2007. California box elder and Northern California walnut communities have increased in abundance when comparing current and historical observations. These communities have already become dominant on the landscape and appear to follow cottonwood in the forest successional sequence. Although newly emerging communities might be following cottonwoods due to lack of recruitment, it is probably not the only community transition. Box elder and walnut are not pioneer species, but can recruit under willow communities. Thus with continued recruitment of willow stands, box elder and walnut may follow in progression, essentially eliminating the cottonwood forest type from a typical successional sequence. It is unclear, however, if there is a riparian woody recruitment problem on the Sacramento River.

On a species basis, overstory cover was historically highly variable and there is evidence of a transition from Fremont's cottonwood/black walnut forest to valley oak forest around 1950 as black walnut and Fremont's cottonwood become less dense and valley oak begins to occur in denser stands. The persistence of box elder forests across the floodplain, a species that was not mentioned as dominant in historical accounts, could be increasing its distribution due to peak flow modifications.

Relationship between riparian species composition and construction of floodplain age generally conforms well to a successional sequence of forest types, however, in analysis of the entire floodplain, the successional model lacks the structure to explain non-forested community types and invasive species. In the case of abandoned channels and the replacement of pioneer species, the assembly rules model can be useful in understanding changes in riparian vegetation. In other words, if different early successional species establish (e.g. invasives) the system may follow a trajectory toward an alternative stable state.

RESTORATION EVALUATION

Restoration areas surveyed were generally on target to achieve basal area values of remnant forest in another 10-15 years. Individual tree species exhibiting the fastest increases are box elder, Goodding's black willow, Fremont cottonwood, valley oak, and western sycamore. Species composition in restoration sites continues to reflect that of the initial planting design.

In restoration sites, importance values (sum of relative density plus relative basal area) increased slightly from 2003 to 2008 for three of the five major tree species (box elder, Goodding's black willow, and valley oak), but decreased slightly for two others (Fremont cottonwood and western sycamore). Remnant forests have highest importance values of (in descending order): Fremont cottonwood, box elder, Gooding's black willow, and valley oak. Arroyo willow currently has the second highest value in restoration, but its remnant forest value is much lower. Cottonwood is increasing much more slowly in restoration sites compared to other major tree species such as box elder, and black willow. This may be due to competition from arroyo willow.

Most restoration forests are still immature and their species composition continues to reflect initial planting composition. As restoration forests mature, a continued increase in values for eventual community dominants (valley oak and Fremont cottonwood) is expected, followed by stabilization at maturity, and shade-intolerant shrubs such as arroyo willow and elderberry should decline in importance as the canopy closes and taller tree species exert greater dominance.

Succession from point bar seedlings to mature cottonwoods and willows on a stable floodplain is considered the primary pathway for natural riparian forest creation on the Sacramento River (Strahan 1984). The pattern and extent over time of woody riparian species establish on point bars along the Sacramento River to determine whether or not pioneer species recruitment on point bars is the beginning of succession to mature riparian forest. In the absence of disturbance from flooding or channel movement we would expect to see a directional trend towards forest development (i.e. increasing vegetation height as tree growth occurs and decreasing density of shade intolerant pioneer species such as narrow-leaved willow). At present there is no evidence for such a trend.

The colonization of restored sites by native understory species into restoration sites is slow. Understory establishment appears to be limited by competition with exotic understory species and to a lesser degree by a lack of connectivity with remnant forest and lack of restoration of riverine processes both of which provide sources of propagules. Cover of most exotic species was lower where there was higher overstory tree cover. This suggests that the best way to ensure successful establishment of native understory species in this system is to first choose sites near remnant forests, and then manage planted overstory species so that the canopy closes quickly and exotic understory species are shaded out. In many cases, particularly when sources of propagules are not available nearby, it will be necessary to plant native understory species to ensure that they establish in restoration sites. Ideally, shade-tolerant species should be introduced after the canopy has closed. Moreover, improving the riverine conditions (e.g. channel meandering, flooding) would likely enhance native understory establishment.

FUTURE MONITORING EFFORTS

Repeated vegetation mapping allows stakeholders and river managers to assess changes in the composition and extent of riparian habitat. Ascertaining and understanding the validity of these mapping efforts, and the data derived from these attempts, is a critical component of future trend analyses. Because of the inherent difficulty in mapping diverse riparian vegetation assemblages the role of accuracy assessment in map creation is an important, and often ignored, component. A systematic accuracy assessment has the benefit of assuring the validity of subsequent analyses at local and landscape scales. Future riparian mapping efforts should allow for greater field sampling and accuracy assessment for both map accuracy as well as aerial photo positional accuracy.

The validation indicated that there was strong agreement between validated and un-validated versions of the 2007 riparian map. The validation process yielded recommendations for certain vegetation classes to be collapsed when conducting comparative analyses, and which vegetation types are problematic to identify using aerial imagery interpretation. Particularly, the crosswalk and calibration effort concludes that there are not were not robust relationships between vegetation classes from the 1999 to the 2007 riparian map. For comparative purposes, all forested types could be lumped to evaluate change in forest cover with high confidence. In addition, the time scale analyzed, from 1999 to 2007, was too short a period of time to indicate any significant changes. Thus, the change detection effort resulted in the determination of 'detectibility', examining which vegetation types are prone to cartographic inaccuracy such that their inclusion in change detection would be prone to create and propagate error. Change detection analysis also suggested that plot-based vegetation classification be conducted for cartographic reference, and that the vegetation mapping process be paired with a significant amount of infield map calibration. The level of detail included in the 2007 map should be refined in future mapping efforts to maximize comparisons between all map versions.

Additionally, stakeholders should consider advances in geospatial technology that would make future mapping efforts both easier to produce, and have higher specificity (i.e., classification accuracy and spatial precision), such as advances in imagery, advances in object recognition software, and advances in classification algorithms. Advances in imagery include pansharpening techniques, wherein ~60 cm panchromatic imagery is meshed with ~2.4 m multispectral imagery, to produce 60 cm multispectral imagery, which importantly includes an infrared channel. A well known, well proven, and physically-based technique in vegetation remote sensing is to difference red and infrared channels, which results in spectral differentiation in photosynthetic materials. As shown in this report, a dominant factor in misclassification was the confusion created by true color aerial imagery, wherein separation of different tree species is exceedingly difficult to overcome. Other advances include object recognition software, such as eCognition, which include contextual and shape information to identify individual objects at a variety of spatial scales, such as trees, meadows, and point bars. This technique is well known, well proven, and mathematically-based.

Lastly, there are a variety of algorithms which are well known, well proven, and statistically-based that readily classifies imagery and ancillary multivariate data into groups that are consistently more alike than different. When these advances in geospatial technology are taken into account with emerging technologies, such as light detection and ranging (LiDAR), there is little reason to support interpretation of aerial photography as the basis for future vegetation mapping in and along the Sacramento River. Most aerial photography is highly error prone due to an inherently unstable platform, specular reflection, and orthographic distortions, among many issues. While some photo interpreters are quite good at identifying and delineating vegetation manually – without consideration to spatial and spectral error – replication across either space or time is challenging for all. Automated detection and delineation results in both a product – the map – and a process, which is easily reapplied to data obtained from a different place, or obtained at a different time, thus allowing for direct comparison of outcomes.

THE IMPORTANCE OF RESTORING NATURAL RIVERINE PROCESSES

The overall status of biodiversity within the Sacramento River project area was determined to be "Fair" based on application of the Ecosystem Scorecard. When considering the conservation targets individually, two of them (terrestrial riparian habitats and birds) ranked as “Fair”, and one (aquatic riverine habitats) ranked as “Poor”. Examining the status of the individual indicators that were rolled up to produce these conservation target ratings can help explain why the conservation targets received the overall ratings.

In short, the riparian habitats and the terrestrial species that inhabit them (including birds) are in “Fair” condition due to all of the efforts that have been put towards reestablishing native vegetation throughout the Sacramento River Project area. Many positive outcomes have been observed as a result of these efforts. This report details such outcomes by reporting changes in ecological indicators that have been observed through time at restoration sites, and in comparison to remnant habitats.

In contrast, the status of the third conservation target, aquatic riverine habitats was determined to be “Poor”. This is the direct result of the hydrologic and geomorphic processes being constrained by anthropogenic alterations to the river. Of particular concern is the steady increase in riprap that has been observed since the 1930s, and the alteration of the natural flow regime since the mid 1900s. As more and more riprap has been installed, and the hydrology has been increasingly altered, the river has lost much of its natural dynamism, and with that, a reduction in its ability to create and maintain the habitats that are essential to native species and communities. Planting of native vegetation has been an important “stop gap” measure, and has kept the status of the two other conservation targets from dropping to “Poor”, however, their continued persistence, even at this level, is uncertain.

Clearly the future of Sacramento River terrestrial resources is dependent upon the degree to which the elemental natural riverine processes of erosion, sediment deposition, and flooding can be restored. Future conservation efforts should focus on restoring these processes where it is possible to do so without adversely impacting important functions that rivers provide to people. Fortunately, opportunities exist to implement projects that provide benefits to both the ecosystem and society at large (Golet et al. 2006).

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V. Appendix

A. 2007 Riparian Map Final Report

B. Map Validation Report

C. Crosswalk Report

D. Change Detection Report

E. Channel Morphology and Dynamics Final Report

F. Floodplain Species Composition Shifts Analysis

G. Riparian Understory Analysis Summary Report

H. Riparian Vegetation Dynamics Summary Report

I. Ecosystem Scorecard Report

J. Monitoring Plan