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Assessment of Practices and Tool Development to Improve Compensatory Mitigation in Southern California

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by

Lisa Susan Fong

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ABSTRACT OF THE DISSERTATION

Assessment of Practices and Tool Development to Support Compensatory Mitigation in Southern California

by

Lisa Susan Fong
Doctor of Environmental Science and Engineering
University of California, Los Angeles, 2015
Professor Richard F. Ambrose, Chair

Wetland loss due to human impacts is a global concern. For certain regulated activities in the United States, the Clean Water Act §404 requires replacement of aquatic functions through compensatory mitigation. In spite of the existing mitigation framework and a 2008 Compensatory Mitigation Final Rule updating regulatory guidance, concerns exist regarding the effectiveness of the compensatory mitigation program. This dissertation contributes to mitigation improvement through three studies. First, we evaluated numbers, sizes, and compensation types of §404 projects permitted before (2002-05) and after (2009-13) the Mitigation Rule to determine how its compensation hierarchy was implemented in southern California. Contrary to expectations, the proportion of third party mitigation projects, and of corresponding acres, decreased after the Rule. Within permittee-responsible mitigation, the proportion of off-site projects increased, as predicted. While is it possible the compensation hierarchy influenced these trends, external factors, particularly the national economic downturn, may also have contributed to the patterns observed. Secondly, we developed chronosequence stream restoration performance curves from projects of different ages to illustrate likely developmental trajectories of high-performing restored streams. The curves, developed using California Rapid Assessment Method (CRAM) data, predicted the time required for projects to achieve reference-level scores for the CRAM index and Hydrology and Biotic Structure attributes, but underestimated the time for projects to achieve the Physical Structure attribute reference level. CRAM-based performance curves could be used to guide standard development, and to predict future project performance. Finally, we developed an aerial imagery assessment method (AIAM) that combines landscape, hydrology, and vegetation observations into one index describing overall ecological condition of non-confined streams. Verification of AIAM demonstrated sites in good condition (as assessed on-site by CRAM) received high AIAM scores, and select components of AIAM and CRAM were highly correlated. AIAM-based time-series trajectories of three projects revealed they improved in condition after restoration, with the most dynamic change over time in vegetation characteristics. AIAM has high potential as an ecological assessment tool to determine restoration status and trajectories, and can be used for restoration management. The findings and tools produced here can improve mechanisms and methods of wetland replacement through compensatory mitigation, and thus help combat wetland loss.

The dissertation of Lisa Susan Fong is approved.

Peggy Fong

Thomas Gillespie

Philip Rundel

Richard F. Ambrose, Committee Chair

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2015

DEDICATION

To my parents, Bryan and Gail, and my grandmother, Kay

And in memory of my grandparents Harvey, Helen, and Walter

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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CHAPTER ONE: INTRODUCTION

Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the land surface or the land is covered by shallow water (Cowardin *et al.* 1979). Examples of wetlands are marshes, swamps, bogs, rivers, lakes, estuaries, and intertidal flats. Wetlands are precious, providing many ecological functions and services including nutrient cycling, carbon sequestration, water quality improvement, groundwater recharge, flood abatement, biodiversity support, and recreational benefits. Because they are valuable for social, health, economic and ecological reasons, their disappearance and degradation is concerning.

The Problem of Wetland Loss

Human-mediated wetland loss is a problem globally, nationally, and locally. An estimated half of wetlands globally have been lost, with a large part of the remaining portion degraded (Zedler & Kercher 2005). Wetland monitoring efforts in the United States revealed vast amounts of wetland loss over the past half century—an estimated 785,350 acres in the conterminous U.S. since the 1950's (Dahl 2011). In the recent Status and Trends of Wetlands in the Conterminous United States 2004-2009 report produced by the U.S. Fish & Wildlife Service for the U.S. Congress, loss of freshwater forested wetlands between 2004-2009 was primarily attributed to silviculture (38%) and development (26%) (Dahl 2011).

Studies indicating wetland loss in southern California indicate the region is no exception to the national trend. Human-mediated wetland loss has been occurring there for over a century. Stein *et al.* (2010) estimated greater than 87% of wetlands in the San Gabriel River watershed, located in Los Angeles and Orange Counties, was lost between circa 1870 and 2006. Dewatering due to groundwater extraction, river channelization, and land conversion to urban and industrial use were cited as factors contributing to the wetland loss. Kent & Mast (2005) found that wetland cover in San Dieguito Lagoon in San Diego County decreased from being at approximately 50% (366 hectares, ha) in 1928 to 15% (109 ha) in 1994. In this area, the construction of a race track, establishment of agriculture fields, highway and road construction, and commercial and industrial development contributed to wetland loss.

Compensating for Wetland Loss in the United States

Policy has been established to combat wetland degradation and loss in the United States. In 1972, §404 of the Clean Water Act established a program to regulate the discharge of dredged and fill materials into navigable waters. Through this program, the practice of compensatory replacement mitigation grew (Hough & Robertson 2008). Compensatory mitigation is meant to offset environmental losses due to unavoidable impacts authorized by §404 permits to Waters of the United States (US Army Corps of Engineers & Environmental Protection Agency 2008). It is carried out through the methods of restoration, establishment (creation), enhancement, and preservation. Restoration is the re-establishment or rehabilitation of a wetland or other aquatic resource with the goal of returning natural or historic functions and characteristics to a former or degraded wetland. It involves the manipulation of the ecological (i.e., physical, chemical, or biological) characteristics of a site, and may result in a gain in wetland function, wetland acres, or both. Creation is the manipulation of ecological characteristics to develop an aquatic resource that previously did not exist at an upland site, and results in a gain in aquatic resource area and functions. Enhancement is the manipulation of ecological characteristics to heighten, intensify, or improve one or more specific aquatic resource functions. It results in a gain of selected aquatic resource functions, but may also lead to a decline in other aquatic resource functions. Neither enhancement nor preservation results in a gain of aquatic resource area (US Army Corps of Engineers & Environmental Protection Agency 2008). Following avoidance and minimization of impacts, compensatory mitigation is the third measure of the three-step mitigation sequence introduced by the 1990 Memorandum of Agreement (MOA) between the Environmental Protection Agency (EPA) and US Army Corps of Engineers (the Corps). The sequence was designed to guide mitigation decisions to determine appropriate levels of mitigation (Department of the Army & Environmental Protection Agency 1990).

Three mechanisms are used to satisfy compensatory mitigation requirements for impacts authorized under §404 permits: mitigation banks, in-lieu fee (ILF) mitigation, and permittee-responsible mitigation (PRM) (US Army Corps of Engineers & Environmental Protection Agency 2008). A mitigation bank is a site, or suite of sites, where resources are restored, created, enhanced, and/or preserved. ILF mitigation involves the restoration, creation, enhancement, and/or preservation through funds paid to a governmental or non-profit management entity (ILF program) that has or will plan and execute mitigation. ILF programs function more through the instrument (i.e., legal documentation) for the establishment, operation, and use of the program than mitigation banks because permittees pay funds to support future mitigation activity, not completed work as with mitigation banks. Mitigation banks and ILF programs sell credits to permittees whose obligation to provide compensatory mitigation is then transferred to mitigation bank or ILF sponsors. Compensatory mitigation carried out through both mechanisms often occurs on large, ecologically valuable parcels of land. This is intended to benefit watersheds by involving more rigorous scientific and technical analysis, planning, and implementation than PRM. Under PRM, mitigation activities are undertaken by the permittee or an authorized agent or contractor hired by the permittee to provide compensatory mitigation. In this mechanism, the permittee retains full responsibility for the mitigation. PRM may occur either within or outside of the same area as the impact site (on- or off-site), and to a resource of similar (in-kind) or different (out-of-kind) structural or functional type as the impacted resource. Compensatory mitigation is always off-site in the cases of mitigation banks and ILF programs.

The Corps, which was formally authorized to issue permits for impacts to waters in the 1977 Amendments to the Clean Water Act, oversees mitigation requirements. They authorize four types of permits: Standard permits, Letters of Permission, Nationwide permits, and Regional permits. Standard permits and Letters of Permission are types of Individual permits, which involve evaluation of individual, project-specific permit applications. Nationwide and Regional permits are types of General permits, which are designed on a state, regional, or national basis for impact for categories of activities that are similar in nature (Hough & Robertson 2008; US Army Corps of Engineers 2012).

Loss of wetland acreage through gaps in the permit requirement and compliance processes with compensatory mitigation is a concern. In a review of 75 compensatory mitigation projects permitted in Orange, Riverside, Los Angeles, San Bernardino Counties in California from 1987-1989, Allen & Feddema (1996) found a cumulative 77.33 ha of successful mitigation for 80.47 ha wetlands lost due to impacts. This translated into a net loss of 3.14 ha of wetland (a replacement ratio of 1: 0.96). Sudol & Ambrose (2002) reviewed §404 permits in Orange County, CA from 1979-1993, and observed that mitigation activities over that time period covered 139 ha, which was greater than the 128 ha required by the permits. However, they also found that 1.6 ha was lost where permittees were in absolute non-compliance (i.e., no required compensatory mitigation attempted), and that acreage loss from small impact activities for which mitigation was not required collectively totaled 21 ha. So despite the apparent success of the permit program in replacing intended acreage, there was still a net loss of 11.6 ha in the region over the study time period. Studies of compensatory mitigation in North Carolina, Tennessee, and Massachusetts have also observed fewer acres gained through compensatory mitigation than lost to impacts (Pfeifer & Kaiser 1995; Robb 2000; Brown & Veneman 2001).

Although many studies document lost acreage, other studies report the contrary. Holland & Kentula (1992) investigated impacted and compensated wetland acreage in §404 files from 1971-1987. They found an overall net gain of 79.6 ha of wetland documented during that period. However, many files they reviewed contained incomplete information (38% were missing acreage data for impacted wetlands and 42% were missing acreage data for compensatory wetlands), so the conclusion of net wetland gain was based on estimated values. Ambrose, Callaway & Lee (2007) reviewed compensatory mitigation in 143 Clean Water Act §401 certification files (§404 permits are subject to this certification) from California, and verified that impacted wetlands were compensated for at an overall 1.9:1 ratio in the study sample. In a more detailed breakdown of the results, they observed that wetland gain did not characterize all permit files. Seventy-two percent of permitted projects met or exceeded their acreage requirements, 28% had wetland loss, 39% had net loss of overall acreage, and 47% had net loss of navigable waters acreage. In light of the mixed results in acreage accounting analyses, loss of acreage with the compensatory mitigation program remains an important concern.

In addition to the issue of acreage loss, there is a concern of net functional loss in wetlands with the compensatory mitigation program. Many compensatory wetlands do not sustain the functions they were created to replace. For example, a salt marsh creation in San Diego Bay, CA was intended to create eight ha of tall cordgrass stands to serve as nesting habitat for the endangered light-footed clapper rail. The project did not install a substrate that sustained cordgrass at a height required by the clapper rails, and thus failed to achieve its intended function (Zedler & Callaway 1999). Sudol & Ambrose (2002) observed a 55% project success based on permit compliance of 55 projects, but found only a 16% project success based on an in-field vegetation-based qualitative assessment of the same projects. In study of 79 compensatory mitigation sites in California, Ambrose & Lee (2004) deemed 30% of them to be "extreme failures" when ecological services gained through their condition was compared to services lost through corresponding impacts. The services evaluated in the study were flood storage, flood energy dissipation, biogeochemistry, sediment accumulation, wildlife habitat, and aquatic habitat. Ambrose, Callaway & Lee (2007) used the California Rapid Assessment Method (CRAM) to evaluate the wetland ecological condition of 129 compensatory mitigation sites in California. They observed that 24 % of the sites exhibited marginal to poor condition, 57% exhibited sub-optimal condition, and only 19% of the sites exhibited optimal condition. Associated with concern regarding loss of functions and services is a concern that compensatory mitigation permit conditions do not give adequate, if any, attention to functional restoration (Wilson & Mitsch 1996; Reiss, Hernandez & Brown 2009). In light of concerns of wetland acreage loss and failure of compensatory mitigation to replace aquatic functions, it is highly appropriate to continue to improve its design and practice.

This dissertation includes three studies designed to improve the success of compensatory mitigation:

- The first study investigates whether newer regulatory guidance intended to improve compensatory mitigation has affected changes in compensation in southern California. In 2008 the Corps and EPA issued a compensatory mitigation Final Rule that included a new compensation hierarchy prioritizing credit purchase from mitigation banks and ILF programs and permittee-responsible mitigation with the watershed approach. We evaluated numbers, sizes, and compensation types of §404 projects permitted before (2002-05) and after (2009-13) the Final Rule to see if regional practices shifted in later years to favor these recommended forms of compensation.
- The second study focuses on development of stream restoration performance curves to help determine the success of stream restoration projects, including those conducted as compensatory mitigation. The curves help to address the disconnection between required monitoring periods and the actual time necessary to achieve ecological success. They are based on a chronosequence of California Rapid Assessment Method (CRAM) data, and demonstrate the hypothetical development of high performing projects over time. They can be used to form expectations for restoration project performance.
- The third study presents the development and testing of an aerial imagery-based remote multi-metric assessment that can capture the condition of small riparian restoration projects, and demonstrates how it can be used to monitor the development of individual projects. This remote assessment is potentially a fast and inexpensive supplement for monitoring compensatory mitigation and other stream restoration projects.

CHAPTER TWO: COMPENSATORY MITIGATION IMPLEMENTATION IN SOUTHERN CALIFORNIA BEFORE AND AFTER THE 2008 RULE FOR COMPENSATORY MITIGATION FOR LOSSES OF AQUATIC RESOURCES

Abstract

Section 404 of the Clean Water Act requires compensatory mitigation for replacement of aquatic functions lost to adverse impacts. In 2008 the US Army Corps of Engineers and Environmental Protection Agency issued a compensatory mitigation Final Rule (the Rule) that included a new hierarchy for prioritizing compensation: (1) mitigation bank credits, (2) in-lieu fee (ILF) program credits, (3) permittee-responsible mitigation (PRM) under the watershed approach, (4) on-site and/or in-kind PRM, (5) off-site and/or out-of-kind PRM. To determine how this compensation hierarchy was implemented in southern California, we evaluated numbers, sizes, and compensation types of §404 projects permitted before (2002-05) and after (2009-13) the Rule. We hypothesized that after the Rule there would be no change in project numbers and sizes; no change in net impact and mitigation acres; the proportion of third party mitigation (i.e., bank and ILF mitigation) would increase and PRM would decrease; and the proportion of off-site PRM would increase and on-site PRM would decrease. Contrary to the predicted pattern, the proportion of third party mitigation projects decreased (35% before, 34% after), as did the proportion of corresponding acres (34% before, 25% after). As predicted, the proportion of off-site PRM increased and that of on-site PRM decreased. Off-site PRM acres were greater than either third party or on-site PRM acres. While is it possible the Rule's

compensation hierarchy influenced the trends of compensation types, external factors may also have contributed to the patterns observed.

Introduction

It is estimated that over half of all global wetlands present in 1900 have been lost (Davidson 2014), with much of the remaining areas degraded. In the conterminous United States, an estimated 785,350 acres of wetland have been lost since the 1950's (Dahl 2011b). In 1987 a National Wetlands Policy Forum convened to address wetland loss recommended a "no net loss" policy, which was brought to the forefront when embraced by the 1988 campaign of then-presidential candidate George H. W. Bush (Hough & Robertson 2008). "No net loss" is largely aided by §404 of the Clean Water Act (CWA), which requires replacement of lost aquatic resources through compensatory mitigation.

Compensatory mitigation is the restoration, establishment (creation), enhancement, and/or preservation of aquatic resources to offset unavoidable adverse impacts (impacts) to said resources (US Army Corps of Engineers & US Environmental Protection Agency 2008). It is the third and final option in a mitigation sequence established by the U.S. Army Corps of Engineers (the Corps) and the Environmental Protection Agency (EPA), following the (1) avoidance and (2) minimization of impacts (US Department of the Army & US Environmental Protection Agency 1990). Day-to-day management of compensatory mitigation through the §404 permit program is administered by the Corps.

Compensatory mitigation is achieved through three mechanisms: permittee-responsible mitigation (PRM), mitigation banks, and in-lieu fee (ILF) programs. Under PRM, sites are restored, enhanced, established, and/or preserved by the impacting party (the permittee) either on-site or off-site of impact locations. The permittee remains responsible for the performance of the compensatory mitigation project. A mitigation bank is a site, or suite of sites, where resources have been restored, established, enhanced, and/or preserved. Banks are set aside for future compensation of impacts through the sale of credits to permittees. Because banks sell credits for approved instruments, they supposedly present lower risk, uncertainty, and temporal loss of resource functions and services than PRM or ILF. (An instrument is the legal documentation for the establishment, operation, and use of a bank or ILF program.) ILF mitigation involves restoration, establishment, enhancement, and/or preservation through funds paid to a governmental or non-profit management entity (ILF program) that already has, or will, plan and execute mitigation (US Army Corps of Engineers & US Environmental Protection Agency 2008). When permittees purchase credits from banks or ILF programs, the obligation to provide compensatory mitigation is transferred to the bank or program. These transactions constitute "third party" compensation, with compensatory mitigation projects located off-site of impact locations.

There are several concerns and criticisms about the effectiveness of compensatory mitigation. Studies of compensation projects observed loss of wetland acres (Allen & Feddema 1996; Kettlewell *et al.* 2008) and function (Turner, Redmond & Zedler 2001; Brown & Veneman 2001; Stefanik & Mitsch 2012), sometimes due to a temporal lag in restored wetlands' abilities to provide services (BenDor 2009; Gutrich, Taylor & Fennessy 2009). Administratively, there has been poor documentation, reporting, and monitoring of compensatory mitigation projects (Holland & Kentula 1992), and non-compliance with permit requirements (Sudol & Ambrose 2002; Ambrose *et al.* 2007). A report on compensatory mitigation prepared by the National

Research Council (NRC) in 2001 concluded that §404 permits were often unclear, without compliance being assured or attained (National Research Council 2001). In 2005, the U.S. Government Accountability Office (GAO) concluded that the Corps' guidance of compensatory mitigation was inconsistent, and its oversight was uneven among mitigation types (US Government Accountability Office 2005). That is, PRM, mitigation banks, and ILF were being held to varied ecological and administrative standards. The GAO recommended that more specific guidance with clarified expectations be established for compensatory mitigation oversight.

In 2008, the Corps and the U.S. Environmental Protection Agency (EPA) issued a Final Rule for Compensatory Mitigation for Losses of Aquatic Resources (the Rule) that consolidated compensatory mitigation regulations and guidance to one set of regulations for its improved quality and success. The Rule established equivalent performance standards and criteria by requiring that a mitigation plan for each project be approved by district Corps engineers regardless of the compensatory mitigation mechanism (US Army Corps of Engineers & US Environmental Protection Agency 2008). It also prefers mitigation be within the same watershed as the associated impact and where it is most likely to replace lost functions and services, and promotes a watershed approach, an analytical process for making compensatory mitigation decisions to support the sustainability or improvement of aquatic resources in a watershed through watershed management planning. The Rule also presents a new compensation hierarchy for mitigation: (1) mitigation bank credits, (2) ILF program credits, (3) PRM mitigation under the watershed approach, (4) on-site and/or in-kind PRM, (5) off-site and/or out-of-kind PRM (Table 2.1). An in-kind resource is of similar structural and functional type to the impacted resource; an out-of-kind resource is different (US Army Corps of Engineers & US

Environmental Protection Agency 2008). Prior to the Rule, a 1990 Memorandum of Agreement (MOA) between the Corps and the EPA designated on-site, in-kind PRM as the first choice for compensatory mitigation (US Department of the Army & US Environmental Protection Agency 1990). Now, due to the supposed lower risk of mitigation banks and ILF systems, they are thought to be more reliable compensation methods than PRM (Hough & Sudol 2008).

Whether the Rule will improve compensatory mitigation remains undetermined. Skeptics raise questions about several items, including the preference for mitigation banking, the reliance on the watershed approach, and the general flexibility in the language used to communicate the new guidelines—e.g., that several approaches are to be taken to an undefined "extent practicable" (Murphy, Goldman-Carter & Sibbing 2009; Bronner *et al.* 2013). Due to the limited amount of time since the Rule's establishment, few studies have confirmed or refuted these concerns, or its effectiveness in improving compensatory mitigation. BenDor & Riggsbee (2011) found that exactly one year after the Rule was published, mitigation bankers still felt that equivalent standards for mitigation mechanism were not being implemented. Beyond the results of their study, there are myriad knowledge gaps about whether the Rule has changed compensatory mitigation.

This study explores whether the Rule has changed how compensatory mitigation is practiced in southern California. Focusing on freshwater aquatic resources, we evaluated whether mitigation types followed the new compensation hierarchy after the Rule was issued. Was there more mitigation bank and ILF credit purchase in the region, and less PRM, in years following the Rule than prior to it? We hypothesized that after the Rule:

- Project numbers and sizes would be similar to before;
- Net impact and mitigation acres would be similar to before;
- The proportion of third party mitigation would increase and that of PRM would decrease;
- The proportion of off-site PRM would increase and that of on-site PRM would decrease.

To test these hypotheses, we evaluated the compensation methods (i.e., third party credit purchase, PRM, on-site, off-site), and associated impact and mitigation acres of §404 projects from ten southern California watersheds before (2002-05) and after (2009-13) the Rule.

Methods

Overview

We compared impacts and required compensatory mitigation acres in southern California between time periods before (2002-05) and after (2009-13) the issuance of the Rule, and among metropolitan statistical areas. Focusing on implementation characteristics, we also evaluated the project numbers, acres, and relative proportions of mitigation conducted as PRM on-site, PRM off-site, third party (credit) off-site, and combinations of those approaches.

Study area

We obtained the bulk of compensatory mitigation permit data for 2002-05 and 2009-13 through the Los Angeles and Santa Ana Regions of the Water Board. The Los Angeles Region includes the Ventura River, Calluegas Creek, Santa Clara River, Santa Monica Bay, Los Angeles River, and San Gabriel River watersheds in Ventura and Los Angeles Counties (Figure 2.1), and the San Pedro Channel Islands. The Santa Ana Region includes the Anaheim Bay-Huntington Harbor, Newport Bay, San Jacinto River, and Santa Ana River watersheds generally located in

Orange, Riverside, and San Bernardino Counties. We excluded mitigation activities on the San Pedro Channel Islands to focus our study on mainland watersheds.

To maintain grouping by regional characteristics, we separated the permits along US Census Bureau metropolitan statistical area (metro areas) boundaries. A metro area includes a core urban area with a minimum population of 50,000 and one or more counties surrounding the urban area that have a high degree of social and economic integration with the core (US Census Bureau 2015a). The watersheds in our study extended into three metro areas containing Ventura, Los Angeles, Orange, San Bernardino, and Riverside Counties. Los Angeles and Orange Counties form a metro area, as do San Bernardino and Riverside Counties. Ventura County is a separate metro area.

Southern California is densely populated, with some of the fastest-growing cities in the United States (Cohen, Hatchard & Wilson 2015). The collective population of Ventura, Los Angeles, Orange, San Bernardino, and Riverside counties grew by over 1.5 million residents from 2000 to 2010 to reach near 17.9 million in 2010, according to the US Census Bureau. Of those counties, Riverside experienced the highest net population growth between 2000 and 2010 (644,264 resident increase; 41.69 % growth rate), and San Bernardino saw the second-highest (325,776 resident increase; 19.06 % growth rate).

The increasing population was complemented by large investments in new building development (Figure 2.2). From 2001 to 2013, the collective valuation of new privately owned housing building units authorized by building permits in the five counties was over $114.9 billion (US Census Bureau 2015b). However, this era also spanned a national housing bubble around 2001-06, followed by a housing market collapse around 2007, and a national financial crisis in 2007-09 (National Bureau of Economic Research 2015). Of the billions of dollars represented by building permits in the counties, 67.2 % was authorized during 2001-06, and 32.8 % was authorized during 2007-13. Percent change of new housing permit net valuations between the two study periods was -79% in the Ventura and San Bernardino-Riverside metro areas, and -22% in the Los Angeles-Orange area (rounded to the nearest one percent) (US Census Bureau 2015b). New building construction is a source of impacts to aquatic resources.

Data collection

The Corps maintains centralized §404 permit information in the OMBIL Regulatory Module (ORM), an automated information system, and in paper files. Unfortunately, ORM data for permits issued before 2007 are not reliable, and the paper files were logistically challenging to locate and review in large quantities due to their physical distribution throughout several Corps offices. We found CWA §401 certifications issued by the California State Water Resources Control Board (Water Board) to be the optimal centralized source of the information needed to test our hypotheses. Under §401, applicants for §404 permits must provide the Corps a certification from the state where an impact occurs. For every §404 permit issued by the Corp in California, a complementary §401 certification containing impact and mitigation details is approved by the Water Board.

Section 401 mitigation is occasionally greater than what is required under a §404 permit because water quality and Waters of the State (WoS) are included in the purview of the Water Board. We included impacts to WoS and corresponding required compensatory mitigation acres in our analyses, rationalizing that their inclusion provided additional resolution to the picture of impacts and compensatory mitigation that occurred in the area. The Water Board indicated it closely follows the trends in mitigation requirements of the Corps (LB Nye, Los Angeles Regional Water Quality Control Board, pers. comm.). Therefore, we assumed the compensation hierarchy was also applied in California WoS mitigation.

Our study included only projects with both the §404 permit and §401 certifications dated between 2002-05 or 2009–13. The Rule was fully adopted in April 2008, but Corps project managers gradually began to prioritize methods of compensation in a new way as early 2006 (Dan Swenson, U.S. Army Corps of Engineers Los Angeles District, pers. comm.), when a proposed rule was released. Therefore we excluded projects permitted during 2006-08 due to uncertainties about how different forms of compensation were prioritized during the transition period.

To obtain project information, we reviewed over 1,300 §401 certifications. We targeted certifications with impacts to freshwater resources (i.e., streambed, wetland, lake, or riparian areas). To simplify data collection and processing, we excluded certifications for impacts to marine resources (i.e., ocean, bays, and estuaries), as most of these impacts were not permitted under §404 (they were permitted under the Rivers and Harbors Act §10, which the Corps and Water Board also regulate). We collected the following information for each project as available: impact location, §404 permit type, acres of proposed temporary and permanent impact, impacted wetland type, required compensatory mitigation acres, on-site or off-site mitigation, and whether compensation was through PRM or a third-party. We did not verify that proposed impacts, required compensatory mitigation acres, or proposed compensation methods were actually implemented; all analyses were based on proposed impacts and required compensation. For projects where data in §401 certifications were insufficient, we referenced permit files kept by the Water Boards and the Corps, and ORM (for projects after 2007). Permit files may contain relevant documents, such as habitat mitigation and monitoring plans and compensatory mitigation project monitoring reports. We did not examine the permit file of every project due to the logistical difficulty of obtaining and reviewing such a large number of files.

Some certifications reviewed did not separate acres of compensation through actual replacement of aquatic resources from other forms of compensation. Other compensation included cases where large tracts of land were preserved, or mitigation for impacts to California Department of Fish and Game (CDFG) jurisdictional habitat was indicated. Preserved acres were sometimes a mix of upland and wetland, and CDFG habitat includes upland. To focus on the acres of aquatic resources gained through compensation, we removed projects where mitigation acres included upland habitat. In cases of compensatory mitigation through preservation, the preservation acres were removed from analyses, but restoration, enhancement, and creation acres were included. We separately conducted analyses that included preservation and upland mitigation acres, and the results were not qualitatively different from those we present. Results of those analyses are in Appendix 2A.

Analyses

To understand general project characteristics, we examined projects' permanent impact and mitigation acres. To evaluate changes in project sizes from before to after the Rule, we conducted Welch unequal variances t-tests for impacts and mitigation acres of individual projects between 2002-05 and 2009-13. We evaluated cumulative acres of impact and mitigation to determine the pattern of general impact and mitigation acreage between census areas and over time.

We classified mitigation associated with each project as “permittee on-site”, “permittee off-site”, “credit off-site”, “permittee on-site & permittee off-site”, “permittee on-site & credit off-site”, “permittee off-site & credit off-site”, or “unknown” mitigation types based on data obtained from their associated permits and files. “Permittee” refers to PRM, and “credit” refers third party mitigation, with no distinction between mitigation bank and ILF mitigation. To assess shifts in frequencies of these compensation methods, we evaluated cumulative numbers of projects using each method, and associated acreage. These were examined before and after the Rule, and in proportion to all projects during each period. Analyses and graphics were developed with R version 2.15.3 with ggplot2 version 0.9.3.1

Results

Overview of projects

We obtained details for 612 projects with impacted streambed, wetland, lake, or riparian areas and corresponding compensatory mitigation. Fewer of these projects were located in Ventura (93) versus in the Los Angeles-Orange and San Bernardino-Riverside metro areas (278 and 241, respectively) (Table 2.2, Figure 2.3). There were fewer projects in the second time period, both overall and in each metro area. The balance of the 1,300 certifications initially reviewed either did not contain compensatory mitigation, were ocean/bay/estuary projects, or did not clearly occur during 2002-05 or 2009-13.

The majority of individual projects’ permanent impacts and mitigation acreages were less than one acre (Figure 2.4). Projects’ permanent impact acres between 2002-05 and 2009-13 did not differ (Welch’s $p = 0.177$), but there was a significant difference indicating more acres of mitigation per project prior to the Rule (Welch's p = 0.007). Average mitigation acres per project were 1.919 prior to the Rule, and 1.083 after. The projects' permanent impact areas for the entire sample ranged from 0.0001 to 16.3 acres; median impact size was 0.14 acres. Projects' mitigation areas ranged between 0 and 74.5 acres; median mitigation size was 0.55 acres.

Cumulative required mitigation acres were greater than permanent impact acres during both 2002-05 (786.718 acres mitigation; 231.875 impact) and 2009-13 (218.844 acres mitigation; 76.528 impact). Cumulative mitigation acres were also greater than impact acres in each metro area during both time periods (Figure 2.5). Both impact and mitigation acres were constantly lower in the Ventura metro area than in the Los Angeles-Orange and San Bernardino-Riverside areas.

Compensatory mitigation evaluation

On-site PRM, off-site PRM, and off-site credit purchase were the most-represented mitigation types (Table 2.3, Figure 2.6a, b). The relative proportion of on-site PRM decreased over time from 40% of permits during 2002-05 to 27% during 2009-13. Off-site PRM increased over time, comprising 11% of projects in 2002-05 and 20% in 2009-13. The relative proportion of projects with off-site credit purchase remained relatively constant, experiencing only a 1% shift between the two periods (35% in 2002-05 and 34% in 2009-13). A small proportion of projects involved some combination of PRM and credit purchase and/or on-site and off-site mitigation (8% in 2002-05, 6% in 2009-13). Projects for which mitigation types could not be determined comprised 7% in 2002-05 and 14% in 2009-13.

On-site PRM, off-site PRM, and credit purchase also comprised the greatest proportions of mitigation acres (Figure 2.6c, d). On-site PRM accounted for 38% of all acres in 2002-05 and dropped to 20% in 2009-13. Off-site PRM comprised 11% of acres in 2002-05 and rose to 36% in 2009-13. Mitigation through credit purchase comprised 34% of acres in 2002-05 and 25% in 2009-13. Combinations of PRM and credit and/or on-site and off-site mitigation comprised 14% of acres during 2002-05 and 12% in 2009-13. Acres with unknown mitigation types comprised 4% and 9% in 2002-05 and 2009-13, respectively.

Discussion

Did the Final Rule affect mitigation patterns?

The observed mitigation patterns revealed a shift in compensation methods from before to after the Rule. These changes may be due to the Rule, but also might have been influenced by external factors including credit availability and economic influences on permit activity. Although third party mitigation did not increase, it is possible the Rule encouraged off-site, watershed-based mitigation. The shift toward off-site PRM observed after the Rule may suggest more willingness on both the part of the Corps and permittees to consider off-site options. The fact that patterns did not trend toward third party mitigation might reflect a shortage of bank or ILF credits available to support credit-based compensation, keeping compensation as PRM off-site. Mitigation bank sales are limited by the amount of credit release, which can be tied to different steps in the mitigation banking process such as land acquisition, hydrology establishment, vegetation planning, and performance measure completion (Robertson 2006). ILF credit sales may have slowed while programs implemented internal reforms required by the Rule. These new requirements included having in place formal mitigation instruments with advanced planning frameworks, providing compensatory mitigation to offset temporal losses, detailed financial accounting requirements, and undergoing interagency and public review (Hough & Sudol 2008; Wilkinson 2009). A 2006 Environmental Law Institute review of 38 ILF programs nationwide revealed that some programs would need to substantially adjust their practices to meet new requirements by the designated 2010 deadline (Wilkinson 2009).

Future research could investigate whether third party mitigation providers faced sales constraints after the Rule by analyzing project details and credit purchase records. The Corps has established a public, on-line Regulatory In-Lieu Fee Bank Information Tracking System (RIBITS; ribits.usace.army.mil). This working database includes credit ledger transactions, and was designed to be kept current by giving some bank managers updating permissions (Martin & Brumbaugh 2011). If updated as intended, this tool may be an excellent resource for studying trends in compensatory mitigation through credit purchase.

It is also possible economic factors concurrent with the Rule influenced the results of the analysis. The drop in permit numbers was likely connected to economic recession. The results contradicted our predictions of steady project numbers, sizes, and acres; each of those decreased in the second time period. These decreases occurred not only in concert with the issuance of the Rule, but also with the 2007-09 financial crisis. As mentioned earlier, our greater study period (2002-13) included a big decline in housing permit valuation in southern California. Between 2007-10, the national construction industry decreased by 19.8%: residential construction jobs decreased by 27% and nonresidential, by 14.8% (Goodman & Mance 2011; Hadi 2011). Decreases in construction almost certainly led to fewer impacts, fewer permits, and less compensatory mitigation. This chain of logic is supported by the large negative percent changes in both new home permitting and §404 project numbers in the study area.

Economic recovery efforts following the financial crisis were also potentially related to the relative increase in off-site PRM. The predominant permittees right after the Rule (and recession) might have favored off-site PRM over third party mitigation. This would produce results (as were observed) that deviated from the predicted proportional increase in compensation through credit and corresponding decrease in PRM. The American Recovery and Reinvestment Act of 2009 (ARRA) was signed into law to stabilize and stimulate the economy after the recession. This stimulus provided a surge in public construction funding: $105.3 billion was promised to infrastructure investment, including $48.1 billion for transportation (Honek, Azar & Menassa 2011; Kim *et al.* 2014). Public agencies competed for funds, and the public construction sector surged with roadway and other projects. It is likely that public agencies were better-represented among §404 permittees in years following 2009 than prior to it.

Furthermore, public agencies, such as state transportation agencies, often conduct compensatory mitigation through single-client banks (US Army Corps of Engineers 1995; Martin & Brumbaugh 2011). In these banks, the sponsor initiates the bank, produces its mitigation credits, and is also the principal client. Because the permittee supplies their own credits, our study design did not categorize these scenarios as third party mitigation, but as off-site PRM. The observed increase in off-site PRM may be explained in part by the public funding increase in combination with a propensity of the funded agencies toward single-client mitigation banks; this could also be tied to the relative decrease in on-site PRM. This explanation of observed mitigation type patterns could be tested through further analysis of permittee characteristics and additional review of specific mitigation mechanisms. Time constraints precluded this analysis at this time.

Multiple factors potentially affected compensation methods following the Rule. Some of the predicted patterns were not supported by the results, and those that were supported could also be explained by alternative influences. In the longer term, more evidence of change in compensation types that can be attributed to the compensation hierarchy may emerge, possibly in a geographic region (as we tested) or within a subset of permits (e.g., permits granted to private applicants).

Other facets of the Rule

Although our analyses focused on the new hierarchy of prioritization, we thought it relevant to comment briefly on other facets of the Rule. Ultimately, the Rule was intended to improve compensatory mitigation. We think the Rule's requirement that mitigation plans be developed for all projects has great potential to improve oversight of compensatory mitigation. Well-detailed mitigation plans are incredible information sources, especially when complemented by annual monitoring reports. Our information collection process was arduous. We searched for specific, basic data in §401 certifications, ORM, and §404 permit files, and still could not confirm the impact acres, mitigation acres, or mitigation types of several permits. When available, we found mitigation plans that included site, project, and mitigation descriptions to be the most useful single sources of information about compensatory mitigation associated with a permit. Helpful monitoring reports confirmed or denied whether compensatory mitigation was attempted in the size, type, and location initially proposed. Records confirming execution of proposed plans are valuable for project management. Past studies have uncovered cases of mitigation non-compliance (e.g., Sudol & Ambrose 2002; Ambrose *et al.* 2007), but organized and detailed mitigation planning and monitoring can help regulatory program officials follow mitigation progress, leading to better oversight and higher mitigation success.

The ultimate goal of the watershed approach is to maintain and improve the quality and quantity of aquatic resources within a watershed through strategic selection of sites (US Army Corps of Engineers & US Environmental Protection Agency 2008). The rationale of the watershed approach has not been questioned (National Research Council 2001). However, the Rule's emphasis of the watershed approach received criticism from those troubled that watershed management plans, the expected vehicles for accomplishing the approach, had not been developed (Mann & Goldman-Carter 2008; Murphy *et al.* 2009). Planning efforts in the southern California watersheds included in our study suggest that this concern has been lessened. We found watershed management plans or programs for all ten watersheds included in our study. Undoubtedly, organizations and agencies in other U.S. regions have likewise developed watershed management plans in the years since the Rule was issued.

Concerns about mitigation

This study examined the logistical influence of the Rule; however, the ultimate question is whether it will help the nation achieve the goal of "no net loss." There are multiple concerns about the mitigation process for which the Rule does not make provisions.

The Rule does not provide incentives or guidance for avoiding and minimizing impacts before involving compensation (Bronner *et al.* 2013). It does state that compensatory mitigation is to take place to offset impacts that remain after "appropriate and practicable avoidance and minimization has been achieved" (US Army Corps of Engineers & US Environmental Protection

Agency 2008). However, critics suggest that the first two steps of the ‘avoid, minimize, compensate’ sequence are not given proper weight (Murphy *et al.* 2009). Avoidance and minimization are especially crucial for difficult-to-replace resources (e.g., bogs, fens, springs, streams, Atlantic white cedar swamps) (Mann & Goldman-Carter 2008). The Rule acknowledges that they are hard to replace (although some, if not all, are actually impossible to replace (e.g., Bernhardt *et al.* 2005)), yet merely specifies that required compensation should be provided “if practicable” through in-kind methods. Bronner *et al.* (2013) suggested incentivizing avoidance and minimization through measures such as higher compensation ratios, an ecosystems service tax on compensation, or more protective zoning laws. We observed fewer impacts before versus after the Rule, with no significant change in project sizes. As mentioned, we attributed the decrease in numbers to the economic climate. Project impacts could be reduced if effective guidance and incentives to avoid and minimize impacts were present to complement the required §404 mitigation process.

The Rule does not appease the criticism that preservation is not compensation. The 1990 MOA allowed preservation in “exceptional circumstances” and the Rule states its application “in certain circumstances,” a change in wording considered by some to aggravate an overreliance on preservation (Murphy *et al.* 2009). Regardless of the emphasis placed on the method, nothing changes the fact that (as the Rule states) “preservation does not result in a gain of aquatic resource area or functions.” There is value in preventing the decline of resources, but it is illogical that an activity (i.e., preservation) that does not increase wetland acres, function, or services compensates for losses of wetland acres or attributes (Ambrose *et al.* 2007).

The Rule does not help individual projects meet “no net loss” by avoiding project failure and temporal loss of functions. Projects have been deemed failures due to §404 permit non-compliance and lost acres. In a study of 114 constructed mitigation wetland projects in Massachusetts, Brown & Veneman (2001) found that over half were not in compliance. Their shortcomings included poor hydrology, insufficient plant cover, and that some were smaller than required. In their sample of 391 permits, required compensatory mitigation efforts were not initiated in 21.9%. Sudol & Ambrose (2002) observed in a study of 55 mitigation projects in southern California that 55% successfully met non-acreage permit requirements, 35% met some requirements, and 11% completely failed to meet any. Their study also noted that two sites where mitigation should have occurred were unbuilt, resulting in 1.6 ha lost.

Projects have also been deemed failures due to lost ecological function. Of the projects that met all or some permit requirements in the study by Sudol & Ambrose (2002), 20% were considered ecological failures by researchers who visited the sites. Zedler & Callaway (1999) described a wetland compensatory mitigation project in southern California that was intended to provide habitat for an endangered bird species, but inadequate soil quality stunted vegetation growth, and the project failed to meet agency expectations. These problems can occur even under the provisions of the Rule; mitigation plans and a prioritization hierarchy will not prevent incidents where projects are never constructed or ecological restoration efforts fall short of intended function.

Temporal loss, or time lag loss, is where ecological capital is lost in the time required for mitigation projects to develop functional equivalency. Gutrich & Hitzhusen (2004) valuated the cost of time lag loss of constructed wetlands, estimating that lags cost an average $16,640 per acre at Ohio sites, and $27,392 per acre at high elevation Colorado sites. Temporal loss occurs in PRM during the years that projects develop. In third party mitigation, it is a point of controversy because sponsors are allowed to sell credits that are not yet connected to actual physical mitigation activities. The Rule permits banks and ILF programs to release portions of credits upon mitigation plan approval, and when other milestones are achieved. Robertson (2006) described how 70% of mitigation credits in Chicago banks are released for sale before sites achieve performance criteria. When projects eventually achieve performance criteria, functions have been lost in the temporal lag between the time of the impacts for which credits were sold and project completion (Robertson 2006; BenDor 2009).

Final thoughts

The history of the past half-century demonstrates that our national efforts towards “no net loss” of aquatic resources have been effective towards our goal. Average annual national wetland loss was 458,000 acres in the 1950s to 1970s; 290,000 acres in the mid 1970s to the mid 1980s; and 58,500 acres between 1986 and 1997 (Frayer *et al.* 1983; Dahl & Johnson 1991; Dahl 2000). From 1998-2004, wetland area increased by an average 32,000 acres annually (Dahl 2006). The §404 program and compensatory mitigation are credited for these improvements (Dahl 2000, 2006). Over time, institutions undergo review and receive revised guidance based on situational context and available expertise. The Final Rule is the latest product of this process for mitigation. As the U.S. continues to critique, revise, and refine regulatory and scientific processes to manage mitigation, the effectiveness of the methods and mechanisms of this institution should further progress.

Tables

Table 2.1. Compensatory Mitigation Final Rule compensation hierarchy.

1. Mitigation bank credits
2. ILF program credits
3. Permittee-responsible, watershed approach
4. Permittee-responsible, on-site and/or in-kind
5. Permittee-responsible, off-site and or out-of-kind

Table 2.2. Numbers of projects requiring compensatory mitigation before (2005-05) and after (2009-13) the Rule with percent change. Projects are grouped by U.S. Census Bureau metropolitan area.

Metro area	2005-05	2009-13	% Change	N
VC	72	21	- 71.2	93
LAC_OC	173	105	- 41.3	278
SBC_RC	165	76	- 54.7	241
Total	410	202	- 50.7	612

Table 2.3. Numbers and corresponding percentages of projects and cumulative required mitigation acres grouped by mitigation types. Numbers are separated into periods before (2002-05) and after (2005-09) the Rule. Percentages are of the number of projects per period and rounded to the nearest percent.

Mitigation Type	**Number of projects**				**Cumulative mitigation acres**			
	2002-05		*2009-13*		*2002-05*		*2009-13*	
credit off-site	144	(35%)	68	(34%)	264.739	(34%)	53.882	(25%)
permittee on-site	163	(40%)	54	(27%)	300.190	(38%)	39.953	(18%)
permittee off-site	43	(11%)	40	(20%)	85.463	(11%)	79.652	(36%)
permittee on-site & credit off-site	19	(5%)	3	(2%)	72.727	(9%)	7.980	(4%)
permittee off-site & credit off-site	5	(1%)	2	(1%)	7.362	(1%)	1.810	(1%)
permittee on-site & permittee off-site	8	(2%)	6	(3%)	27.320	(4%)	15.870	(7%)
unknown	28	(7%)	29	(14%)	28.917	(4%)	19.698	(9%)
Total	410		202		786.718		218.844	

Figures

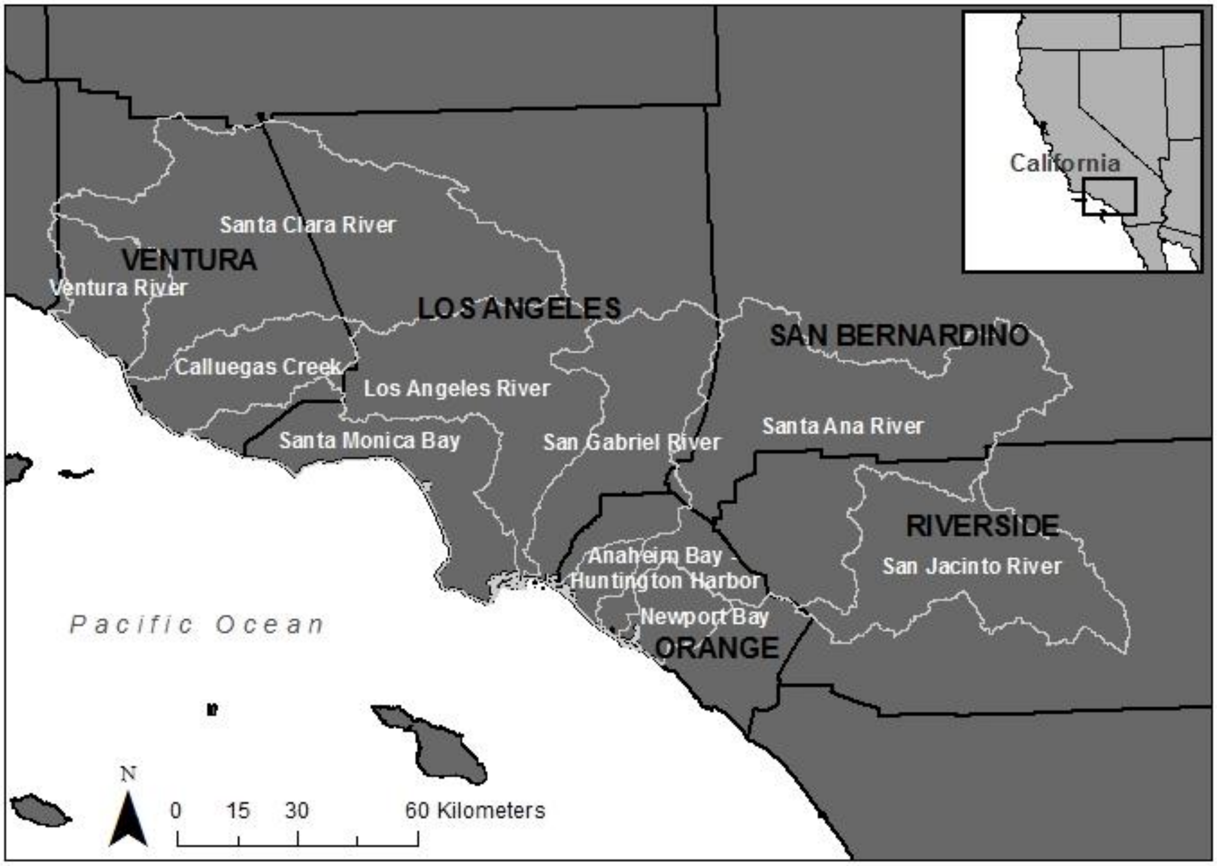


Figure 2.1. The meta-analysis study area in southern California, USA. The area encompassed ten watersheds located in five counties. Watershed boundaries and labels are white; county boundaries and labels are black.

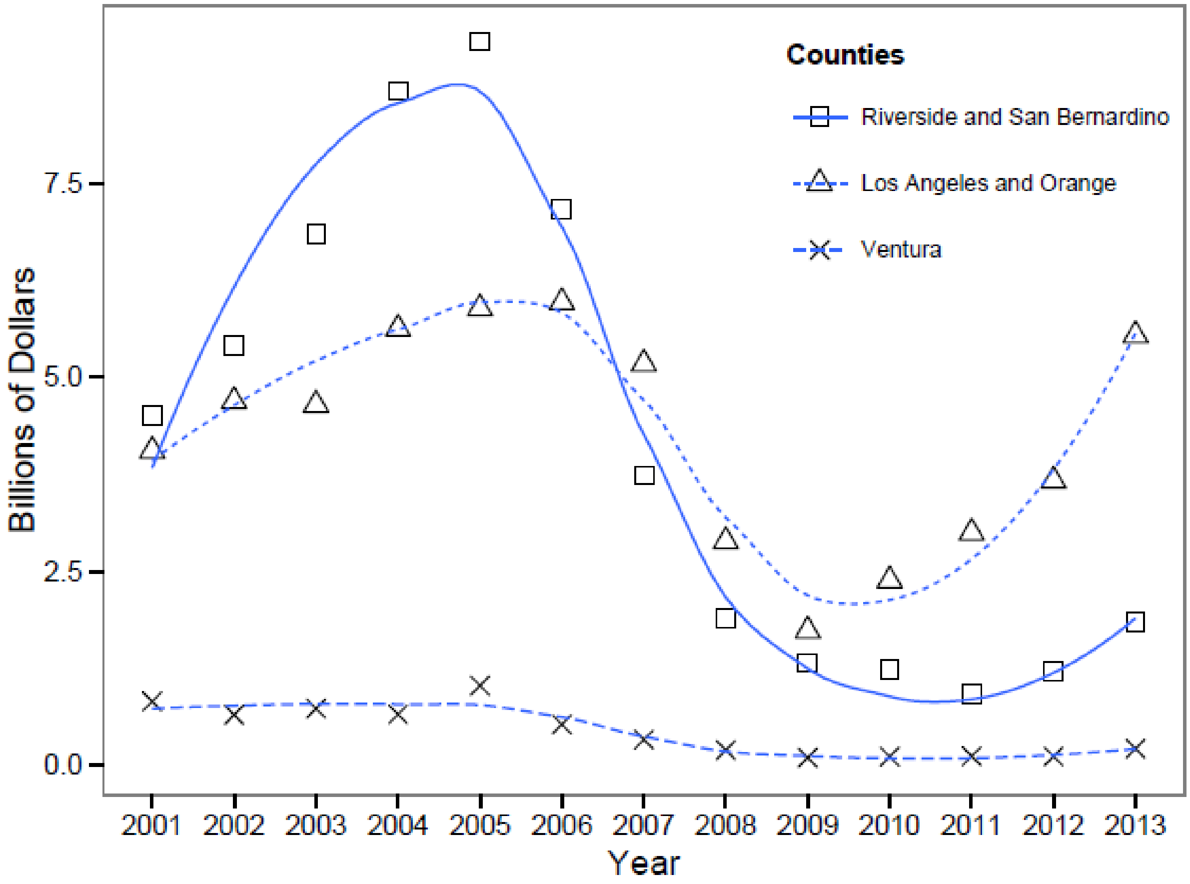


Figure 2.2. Valuation of new privately owned housing units authorized for development in five southern California counties during 2001-2013. The counties are grouped into three metro areas by the United States Census Bureau: Riverside and San Bernardino Counties, Los Angeles and Orange Counties, and Ventura County. Data are from the U.S. Census Bureau (www.census.gov).

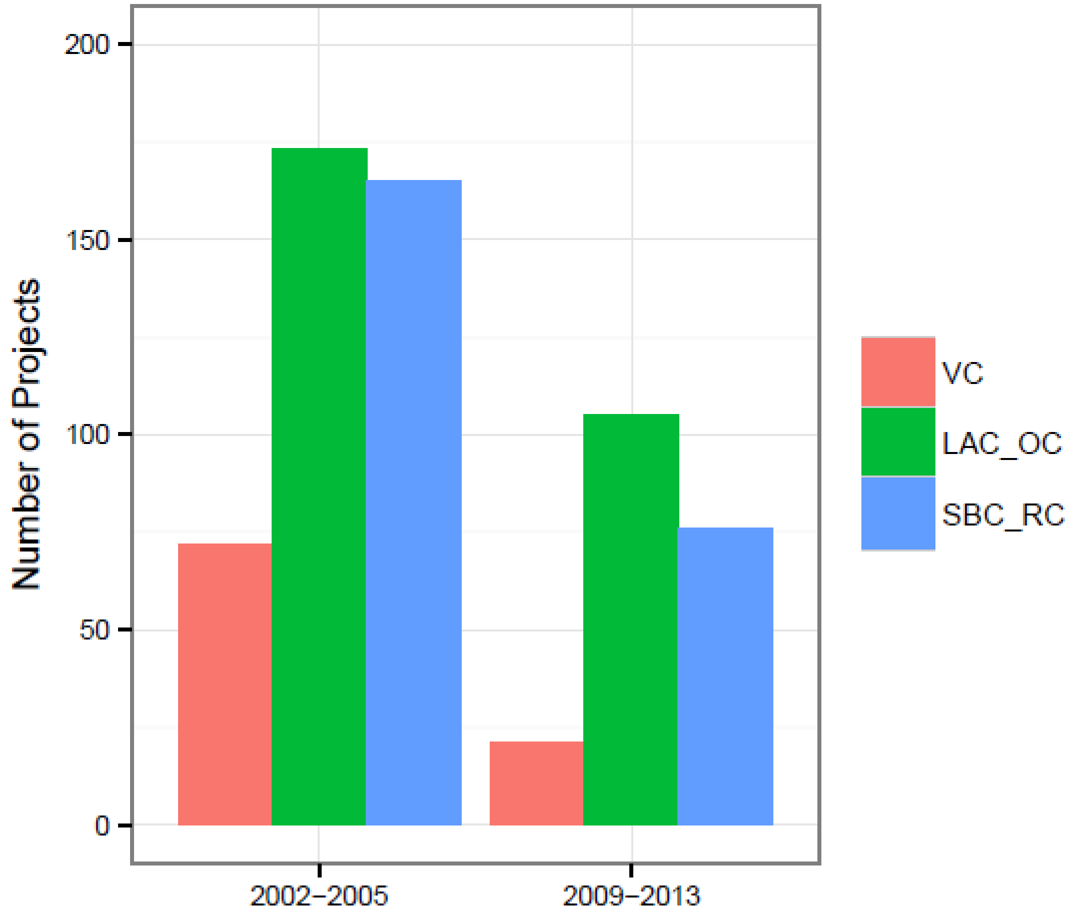


Figure 2.3. Numbers of projects requiring compensatory mitigation before (2002-05) and after (2009-13) the Rule. Projects are grouped by metro area: Ventura (VC), Los Angeles-Orange (LAC_OC), and San Bernardino-Riverside (SBC_RC). Total N = 612.

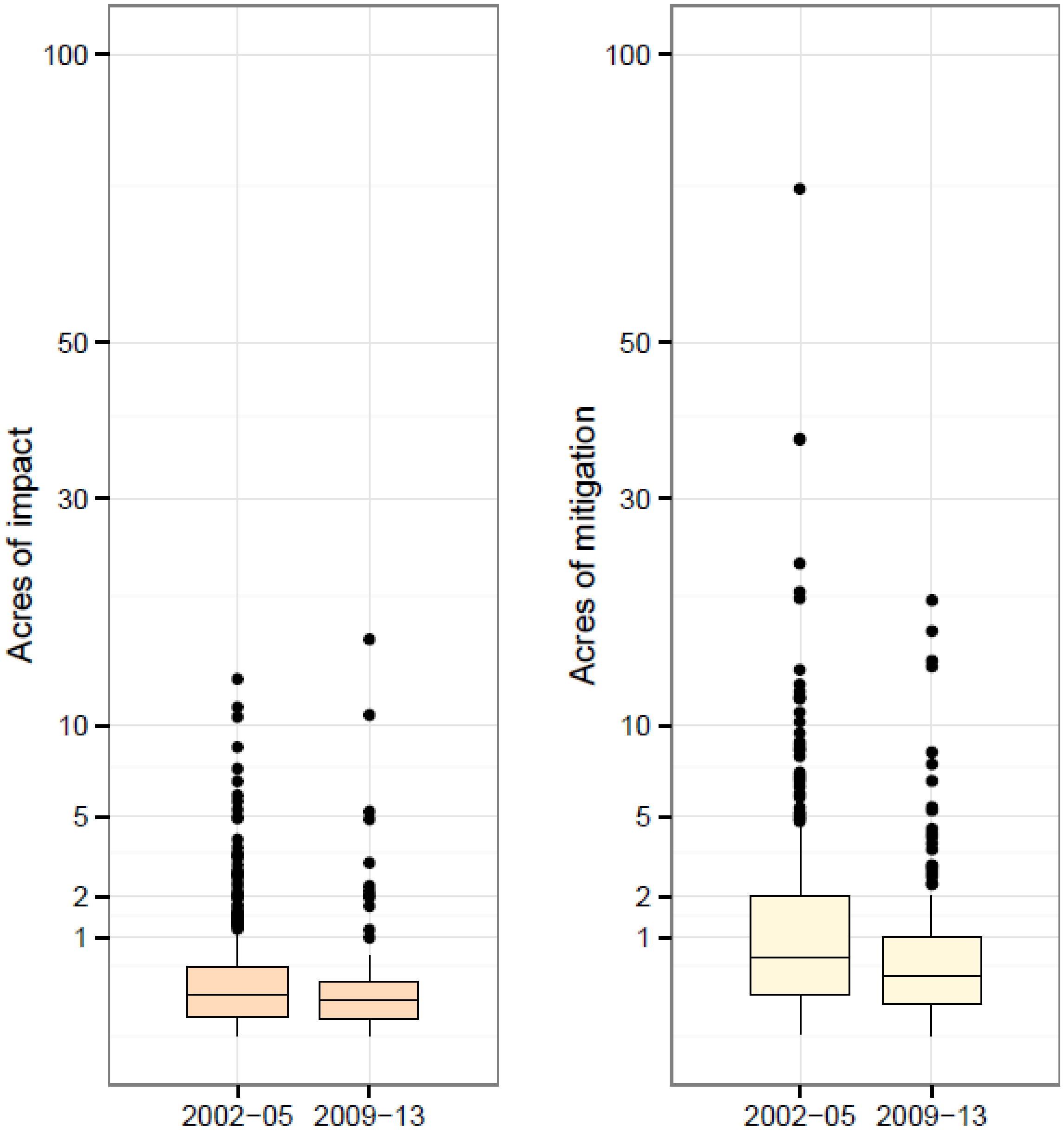


Figure 2.4. Acres of proposed permanent impacts and required compensatory mitigation for individual projects before (2002-05) and after (2009-13) the Rule. Welch t-test p=0.177 for impacts; mitigation p=0.007. Projects were located in Ventura, Los Angeles, Orange, San Bernardino, and Riverside counties. Total N = 612.

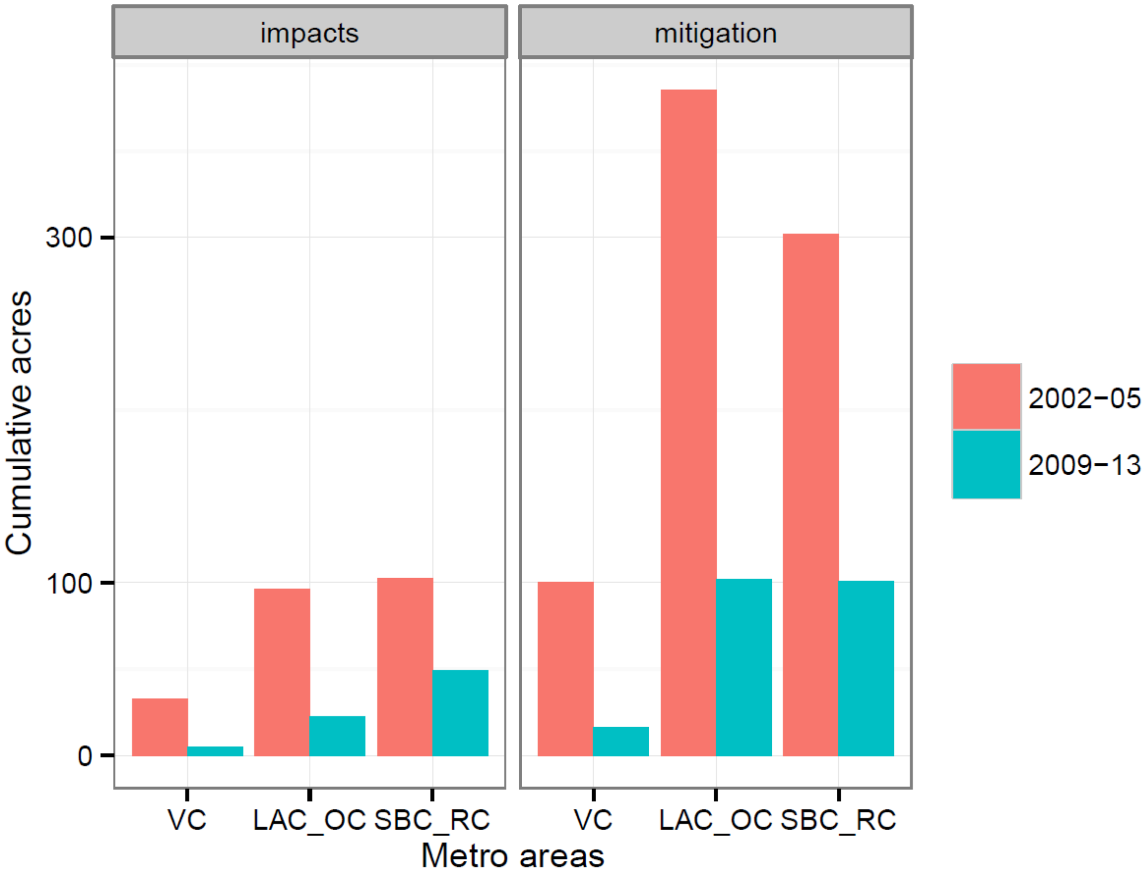


Figure 2.5. Cumulative proposed impact and required mitigation acres. Data are divided by time periods before (2002-05) and after (2009-13) the Rule, and grouped by US Census Bureau metro areas: Ventura County (VC), Los Angeles and Orange counties (LAC_OC), and San Bernardino and Riverside counties (SBC_RC).

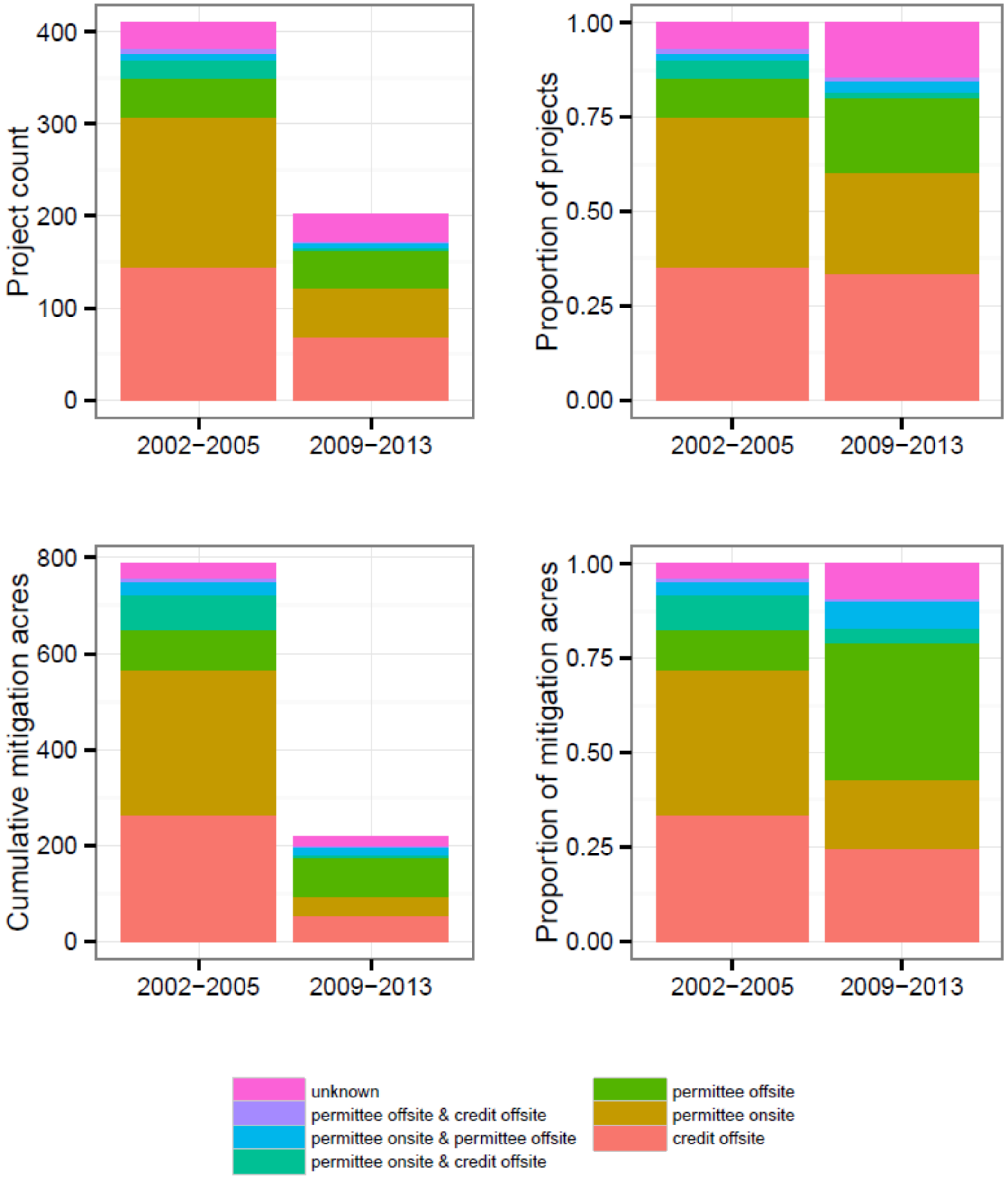
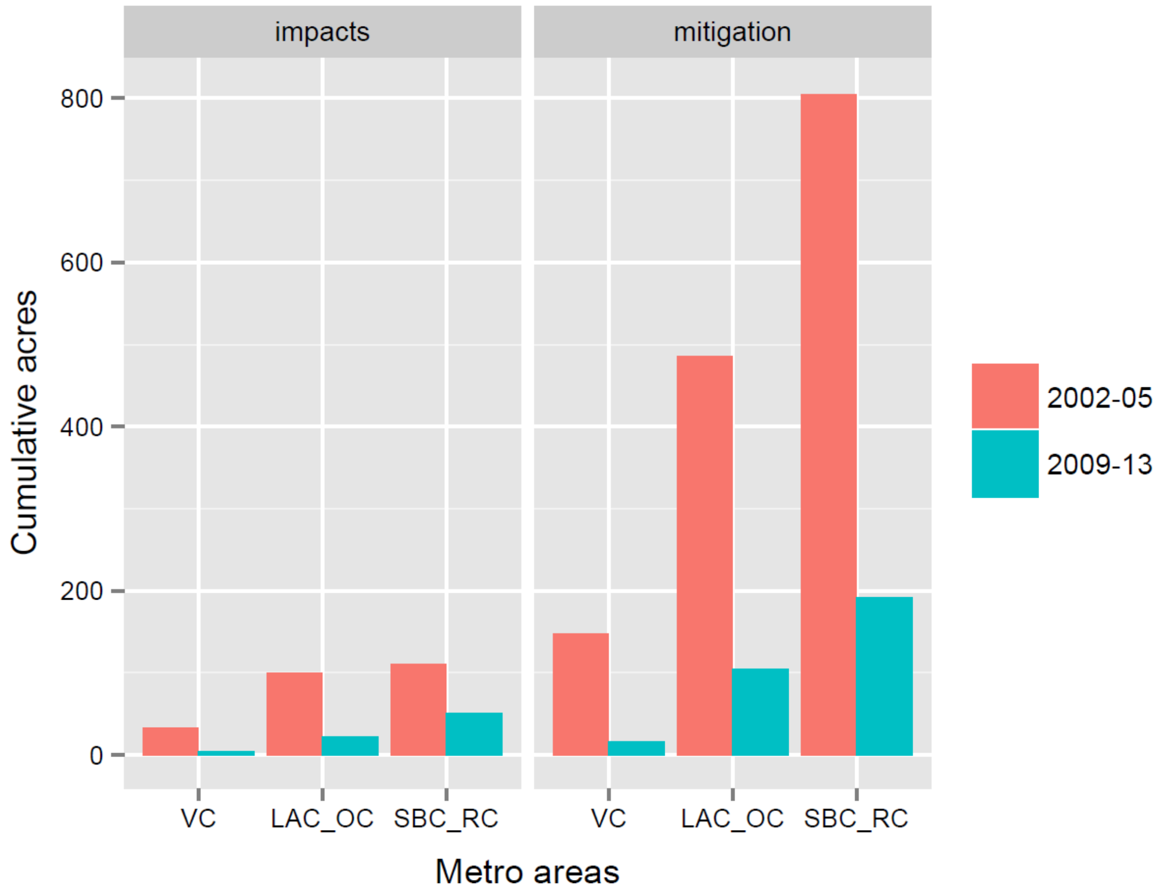


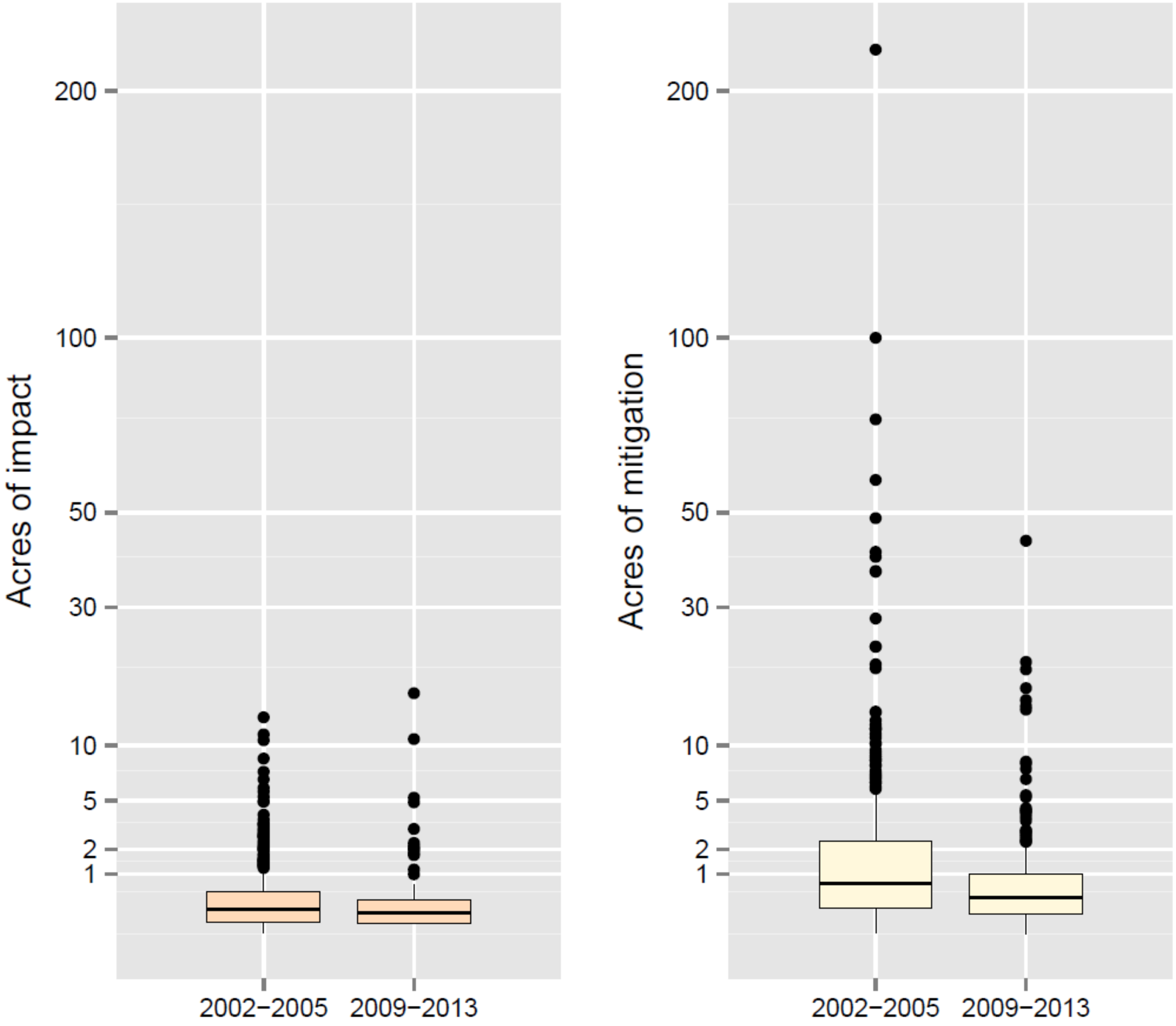
Figure 2.6. Compensatory mitigation types reported by project permits: (a) project numbers, (b) relative proportion of project numbers, (c) cumulative acres, and (d) relative proportion of cumulative acres. Projects are divided by periods before (2002-05) and after (2009-13) the Rule.

Appendix

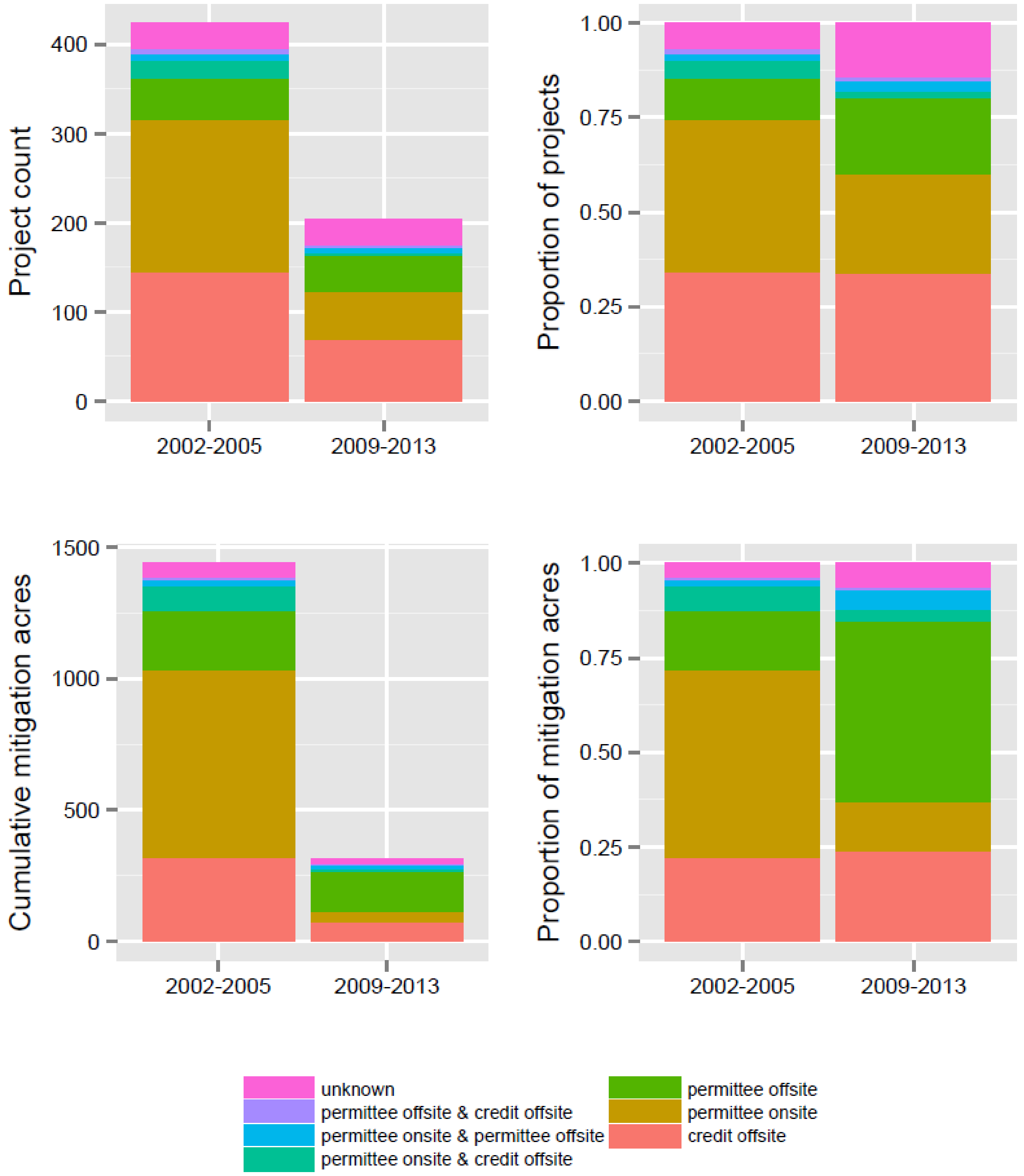
Appendix 2A: Results of Analyses Including Preservation and Upland Mitigation Acres



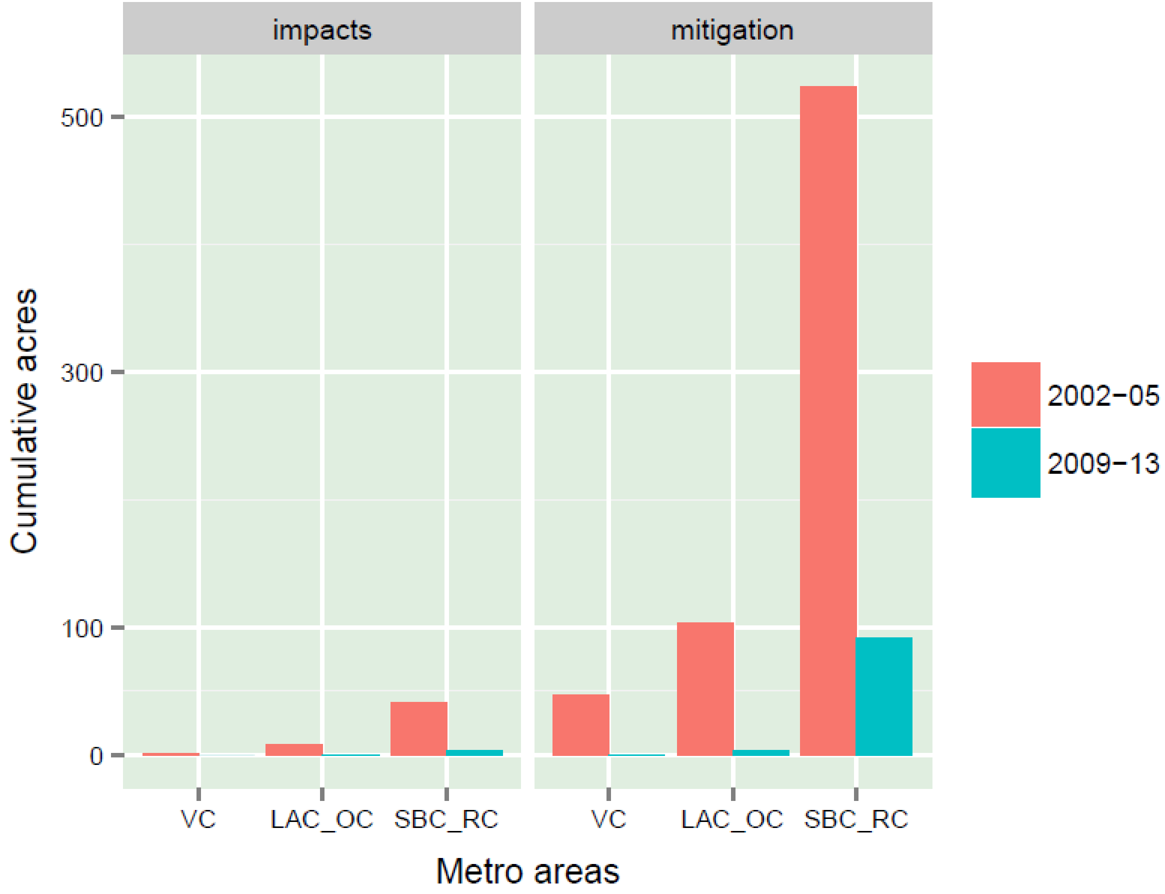
2A.1. Cumulative proposed impact and required mitigation acres of study sample including projects where wetland enhancement, restoration, or creation was combined with preservation and compensation in upland areas. Data are divided by time periods before (2002-05) and after (2009-13) the Rule, and grouped by US Census Bureau metro areas: Ventura County (VC), Los Angeles and Orange counties (LAC_OC), and San Bernardino and Riverside counties (SBC_RC). N = 628. Acres of impact before the Rule: 244.589; mitigation before: 1438.563; impacts after: 78.761; mitigation after: 312.704.



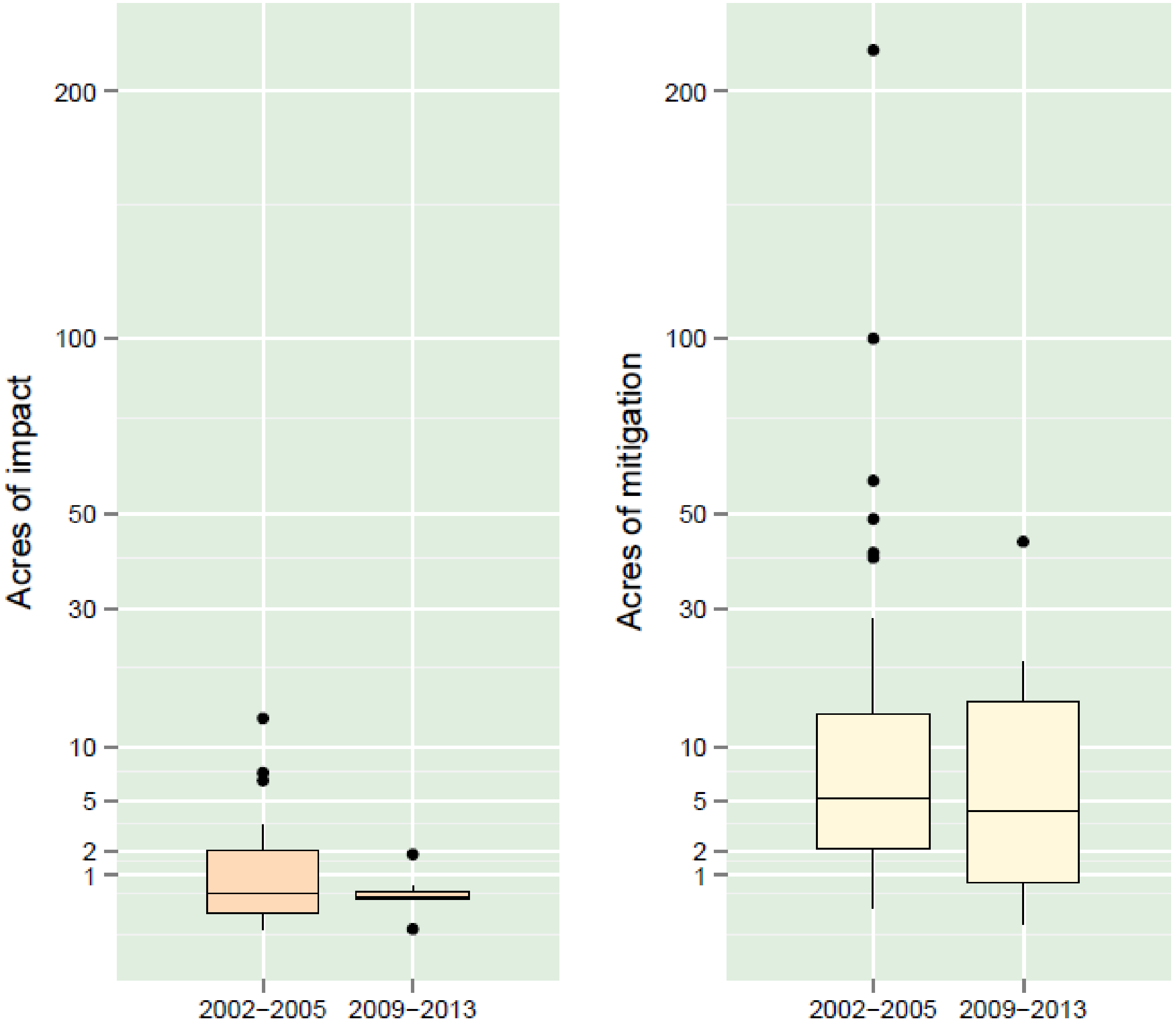
2A.2. Acres of proposed permanent impacts and required compensatory mitigation for individual projects including projects where wetland enhancement, restoration, or creation was combined with preservation and compensation in upland areas before (2002-05) and after (2009-13) the Rule. N = 628.



2A.3. Compensatory mitigation types among projects including projects where wetland enhancement, restoration, or creation was combined with preservation and compensation in upland areas. Projects are divided by periods before (2002-05) and after (2009-13) the Rule.



2A.4. Cumulative proposed impact and required mitigation acres for only the projects where wetland enhancement, restoration, or creation was combined with preservation and compensation to upland areas. Data are divided by time periods before (2002-05) and after (2009-13) the Rule, and grouped by US Census Bureau metro areas: Ventura County (VC), Los Angeles and Orange counties (LAC_OC), and San Bernardino and Riverside counties (SBC_RC). N = 42. Acres of impact before the Rule: 50.885; mitigation before: 674.601; impacts after: 4.077; mitigation after: 95.860.



2A.5. Acres of proposed permanent impacts and required compensatory mitigation for only the projects where wetland enhancement, restoration, or creation was combined with preservation and compensation in upland areas before (2002-05) and after (2009-13) the Rule. Subset n = 42.

CHAPTER THREE: DEVELOPMENT OF RESTORATION PERFORMANCE CURVES FOR STREAMS IN SOUTHERN CALIFORNIA USING AN INTEGRATIVE CONDITION INDEX

Abstract

Determining success of stream restoration projects is challenging, in part due to the disconnection between required monitoring periods and the actual time necessary to achieve ecological success. Performance curves could help address this challenge by illustrating likely developmental trajectories of restored streams. We applied the California Rapid Assessment Method (CRAM), an integrative index of stream condition, in a ten year chronosequence to create performance curves that project the development of highly functioning streams for 30 years following restoration. CRAM scores for high functioning sites between zero and ten years were plotted against time since restoration. Best-fit curves were derived using either power functions or polynomial functions, depending on the CRAM metric. We tested the curves' ability to predict conditions for other projects across a range of ages, flow conditions (ephemeral to perennial), and physiographic settings. The curves are able to predict the time required for projects to achieve reference-level scores for the CRAM index (27 years) and Hydrology and Biotic Structure attributes (1 year), but underestimate the time required for projects to achieve reference-level scores for the Physical Structure attribute (> 30 years). Generally, stream restoration performance curves based on CRAM scores could guide expectations for restoration project performance.

Introduction

Evaluating the success of restoration projects is one of the most important, yet most difficult, elements of stream and wetland monitoring. Time poses a particular challenge when determining success. Systems can take decades to reach functional maturity (Zedler & Callaway 1999; Craft *et al.* 2003; Lennox *et al.* 2011). However, monitoring periods typically end long before projects reach such maturity, making it difficult to determine success before the end of required monitoring. We addressed these challenges by developing performance curves that allow us to forecast how stream restoration projects will perform at future time points.

Kentula *et al.* (1992) proposed the use of the performance curve as a key analytical tool for restoration monitoring because they can be used to visually and mathematically demonstrate developmental trajectories of wetland function or condition in years following restoration efforts (Figure 3.1). Kentula *et al.* suggested that curves may be useful to indicate the best time to begin monitoring, to predict future ecological condition, and to demonstrate whether projects have met their restoration goals.

Chronosequence and time-series methods are two common approaches for assessing the development of ecological function or condition over time. In the time-series approach, curves are developed using ecological data that were repeatedly collected at the same study sites over an extended time period (Craft *et al.* 1999; Craft, Broome & Campbell 2002; Craft *et al.* 2003; Gutrich *et al.* 2009). Collection of time-series data requires foresight and resources to select study sites, and the ability to sample them consistently over long time periods. In the chronosequence approach, data from multiple restoration projects of different ages are applied to develop curves using space-for-time substitution (Stevens & Walker 1970; Knops & Tilman

2000; Morgan & Short 2002). This method is especially useful for creating curves when limited long term data is available at a sufficient number of sites or when there is a desire to generalize curves across a range of stream or wetland types.

Past studies have developed curves based solely on specific ecological attributes. Many such studies have focused on vegetation-based indicators (Matthews, Spyreas & Endress 2009; Matthews & Spyreas 2010). Others have used a wide range of attributes including soil development, microbial processes, algal growth, benthic invertebrate density and diversity, sediment deposition, and organic matter (Craft *et al.* 1999, 2002, 2003). Because ecological attributes change at different rates post-restoration (Craft *et al.* 2003), several single-attribute curves would be needed to comprehensively evaluate the recovery of an entire wetland or stream system.

Integrative indices of biotic, physical, and other environmental conditions have the potential to more clearly capture overall ecological performance than single ecological attributes. However, few studies have attempted to develop performance curves with an integrated index of condition to assess restoration success. In this study, we developed performance curves for streams using the California Rapid Assessment Method (CRAM; Stein *et al.* 2009; California Wetlands Monitoring Workgroup 2013), which integrates information about streams' and wetlands' surrounding landscape context, hydrology, physical structure, and biotic structure to describe their overall ecological condition. Our goals were: (1) to develop stream performance curves based on a chronosequence of different restoration projects; (2) to use the curves to determine whether restored streams reach condition levels comparable to minimally disturbed reference sites and, if so, to find the time to reach those levels; (3) to evaluate how the performance of different attributes of riverine (stream) CRAM vary in timing and trajectory; and (4) to test the validity of the curves by determining how restoration projects not used in curve development performed when measured against the derived performance curves.

Methods

We developed chronosequence performance curves to demonstrate the hypothetical trajectories of high performing stream restoration projects in southern California. We compiled a list of stream restoration projects that involved stream channel construction of varying ages up to 30 years from regulatory and resource agencies. We assessed the projects using CRAM, and used the highest scoring projects aged 0-10 years old to construct the curves. We determined whether curves reached reference-level performance with reference site CRAM data that approximated natural or near-natural conditions (Solek *et al.* 2010). We tested the validity of the curves using projects not used for curve development.

Study sites

For construction of meaningful curves, we selected projects using criteria to ensure sufficient homogeneity in our sample pool. All projects were located in coastal-draining watersheds in the southern California region, USA (Figure 3.2), and consisted of mechanical channel grading and riparian re-vegetation. Enhancement projects, including those focused solely on invasive species control and/or re-vegetation without actual channel re-contouring, were excluded from curve development. We targeted accessible projects where the restored reach length was near or greater than 100 meters, the minimum length required for a riverine CRAM assessment. The projects were in stream channels classified by CRAM standards as non-confined, meaning the width of the valley across which the riverine system could migrate without encountering a hillside, terrace, or other feature that was likely to prevent further migration was at least twice the average bank-full width of the channel (California Wetlands Monitoring Workgroup 2013). This allowed us to calculate the CRAM index score in the same manner for each project.

To locate projects we reviewed publicly available restoration databases and Clean Water Act § 404 permit files, and obtained recommendations from agencies and organizations participating in restoration project funding, monitoring, and research (Table 3.1). We found 55 projects located in 11 watersheds from Santa Barbara to San Diego counties that met our criteria. Project ages ranged from 1-26 years old post-restoration (Appendix 3A). For five projects, the exact restoration dates could not be located, so we estimated their ages based on year of Section 404 permit issuance.

CRAM data collection

We conducted one CRAM assessment at each of the 55 restoration projects using the riverine module versions 6.0 (in 2012) and 6.1 (in 2013). Version 6.1 includes minor updates and clarifications, and the two versions do not yield different scores. CRAM is a field-based rapid assessment tool used to evaluate the ecological condition of wetlands in California. It is comprised of separate modules for different wetland types, with the field indicators customized for the specific wetland type of interest. The riverine module of CRAM consists of a series of metric and sub-metric observations grouped into four attributes: Buffer and Landscape Context, Hydrology, Physical Structure, and Biotic [Vegetation] Structure (Table 3.2). Observations are conducted over a 100-200 meter long stream reach, identified as the assessment area (AA). Sub-metrics, metrics, and attributes are all described by field indicators that are assigned numerical scores. The scores are applied to an algorithm to produce a numerical CRAM index. The index and attribute scores range from 25 to 100; higher scores imply better ecological condition. We also used CRAM data from the eCRAM database (www.cramwetlands.org) for seven central California region projects and ten southern California reference sites. Reference sites had relatively un-impacted surrounding landscapes and displayed high biotic integrity according to California's stream and river Reference Condition Management Program. The assessments in the statewide CRAM database are performed by trained practitioners and conform to standard methods and quality control measures.

Curve development

With the chronosequence approach, we developed riverine performance curves that display data against project age. We created curves for the CRAM index; Hydrology, Physical Structure, and Biotic Structure attributes; and select metrics and sub-metrics. Although we conducted CRAM in its entirety, we developed performance curves only for CRAM components that are influenced by restoration work inside of the CRAM assessment areas (AA). Therefore, we did not produce curves for the Buffer Landscape Context attribute, its associated metrics, and the Water Source metric of the Hydrology attribute, items unaffected by restoration actions. However, these components were included in CRAM index calculations.

Performance curve formation involved three steps: choosing a set of projects, establishing how to anchor the curves at time-zero (t_0), and finding the best-fit mathematical functions to determine curve shapes. We used projects ten years old or younger that involved perennial or intermittent flow and with stream channels entirely graded prior to restoration. Twenty-two projects fit these criteria; none were under two years old. We withheld southern California projects over ten years old, those with ephemeral flow, and those partially graded at the time of restoration from curve development for testing the validity and transferability of the performance curves.

We set t_0 between initial grading and restoration (e.g., planting). Because the channels were fully graded, we used the lowest Physical and Biotic Structure scores (25) to represent t_0 conditions. We estimated Buffer and Landscape Context and Hydrology scores using planning documents and historical aerial imagery from Google Earth™. We combined the estimated t_0 CRAM scores with field data to develop the performance curves.

We used the highest CRAM index scores of each year to generate curves that represented high performing streams. We also applied the highest yearly scores of each attribute to create attribute curves. Therefore, the lists of projects used to generate each attribute curve varied. Metric and sub-metric curves were generated with data from the same projects used to create their parent attribute curves. For example, data forming the Channel Stability and Hydrologic Connectivity curves were from the same projects used to develop the Hydrology attribute curve. No data were available to represent years one, three, and nine. We regressed exponential, logarithmic, linear, polynomial, and power functions to the data and identified the function with the highest R^2 for regression value for each data subset using Microsoft Excel™. With the best-fitting functions, we inferred curve trajectories to 30 years, and drew error bands around the curves: ± 10 for the CRAM index, ± 5 for attributes, and ± 3 for metrics and sub-metrics (Figure 3.3). These values are based on the reported inter-user variability for CRAM (California Wetlands Monitoring Workgroup 2009) and the consideration that metrics and sub-metrics could potentially be scored one grade higher or lower during assessment.

We formed reference envelopes using an approach similar to that of Craft *et al.* (2003). For each curve, we calculated corresponding mean data values from the ten reference sites and established 95% confidence intervals around those values. We considered a curve to have reached reference performance when it crossed the reference mean, and also noted when the upper boundary of the performance curve error bands crossed into the reference envelope.

Performance curve validation and testing

We tested the CRAM index performance curve by comparing it to CRAM scores from sites not used for curve development. Test groups were: restoration projects older than ten years old, projects located in central California (outside the region used for curve development), projects with ephemeral flow, and partially graded projects. We predicted: (1) CRAM scores from the older (over ten years) projects would meet the curve, demonstrating its forecasting ability. (2) Central California projects would perform in the same range as southern California projects, with the best sites falling on the curve, thereby indicated transferability of the curves to adjacent regions. (3) Ephemerally flowing projects would score below the curves. The flashy hydrology and limited hydration for riparian vegetation in ephemeral streams may suppress their rate of development relative to intermittent and perennially flowing streams, resulting in lower scores. (4) Partially graded projects would exceed the curves. Because these projects began with better time-zero conditions and experienced less disturbance than those used to form the curves, we predicted they would reach reference conditions faster with better overall condition.

Results

Curve development

We produced 18 CRAM-based performance curves that illustrate the expected trajectories of high-performing southern California stream restoration projects for 30 years post-restoration (Appendix 3B). The CRAM index and Hydrology, Physical, and Biotic Structure attribute curves were described by power functions, with rapid rises in condition followed by flattened rates of change (Figure 3.4). Metrics and sub-metric curves were described by a mixture of power and polynomial functions (Table 3.3, Appendix 3B).

The Hydrology ($R^2 = 0.531$) and Biotic Structure ($R^2 = 0.934$) curves achieved reference means at fourteen and seven years following restoration, respectively (Figure 3.4b, 4d). Both curves crossed the error bands around 1 year. While the CRAM index curve ($R^2 = 0.848$) did not cross the reference mean within 30 years, its error band crossed the reference envelope at year 27 (Figure 3.4a). Neither the Physical Structure main curve ($R^2 = 0.320$) nor its error band reached any reference standard within 30 years (Figure 3.4c).

Curve testing

Of the projects over ten years old (n = 6), one score was near the main CRAM index curve, and another within the lower bound of the error band (Figure 3.5a). No projects scored above the curve, and four scores were below the band. The older projects did not generally adhere to the curve, indicating they were in poorer condition than expected. However, the sample pool was likely not representative of the range of projects, so our results were inconclusive as to whether the curves accurately predict older projects' performance.

Scores of four central California projects (n = 7) were near the main curve, one was above the upper error band boundary, and two were below the lower band boundary (Figure 3.5b). The close proximity of four projects to the curve and one that exceeded curve predictions suggest that these curves are suitable for central California projects; greater support for this conclusion should be developed through collecting CRAM data from additional restoration projects outside the southern California region.

Two of seven scores from ephemeral flow projects were near the main curve, and the remaining five were below the error band (n = 7; Figure 3.5c). Two scores were farther below the curve than projects from any other test categories. Ephemeral projects may encompass a wide variety of characteristics resulting in both high and very low scores, which is important to note when assessing their performance. In rare cases they may achieve scores close to those expected for intermittent or perennial sites, but their group’s collective performance suggests they generally yield lower CRAM scores.

Most of the partially graded projects performed near the curve and within the error band, but not all projects exceeded the curves as predicted. Half the scores (10 of n = 20) were above the curve; three of those were above the error band. Ten scores were below the curve; one of those was below the band. The concentration of the scores around the main curve suggest the curve predicts the performance of these types of projects. However, because many partially graded projects exceeded the curve, which demonstrates optimal performance, we think the development of separate curves for this category would provide more appropriate targets for partially restored projects.

Discussion

Performance curve development

This study is one of the first efforts to operationalize the performance curve concepts promoted by Kentula *et al.* (1992). They proposed using performance curves to identify the time needed for projects to reach stable states, and to compare curves to reference conditions to measure the replacement of wetland function in human-manipulated (e.g., created or restored) wetlands. However, in the 20 years since Kentula *et al.* introduced the concept of performance curves, we are not aware of any example of curve development and application for streams. Kentula *et al.* suggested that curves can be used to represent condition or function over time; our results validated their hypothesized concepts. Previous studies used ecological indicators (e.g., plants) as surrogates for function (Craft *et al.* 1999, 2003; Matthews *et al.* 2009; Matthews & Spyreas 2010; Stefanik & Mitsch 2012). Results of this study suggest that curves based on CRAM reflect development of overall stream condition. The CRAM attributes performance curves based on ecologically comprehensive attributes or condition indices can be used to reliably depict systemic development over time. Kentula *et al.* (1992) also suggested a recovering system approaches a natural reference standard and reaches a steady state, a concept supported by our CRAM index curve. Our index and attribute data consistently fit best with power functions, implying that recovering stream trajectories generally assume that function shape.

This study also shows that overall condition indices, such as CRAM, can provide an efficient way to measure ecological condition in the context of a chronosequence. CRAM is an appropriate assessment tool for generating performance curves because it is grounded in ecological theory and has been validated and calibrated against quantitative data including riparian bird diversity, an index of biotic integrity based on benthic macro invertebrate diversity, and indices of landscape context or condition (Sutula *et al.* 2006). These intensive measures of wetland condition verified that CRAM attributes accurately represent ecological condition, so curves based on CRAM provide robust predictions of expected ecological condition.

The power function shape of the hypothetical performance curves is a valid post-disturbance recovery pattern. Studies have demonstrated this pathway with wetland invertebrate (Craft *et al.* 2003), soil (Zedler & Callaway 1999), and vegetation metrics (Morgan & Short 2002; Matthews *et al.* 2009). McMichael *et al.* (2004) created a chronosequence of post-fire chaparral vegetation recovery in central California based on leaf area index (LAI) values found using satellite data. LAI describes the total transpiring leaf surface, and therefore general vegetation development, above a given ground area. Their LAI-based curve followed a power curve shape over a 0 to 81 year post-disturbance timespan. Hope, Tague & Clark (2007) demonstrated the same developmental shape through a time-series examination of a single, fire-disturbed site in the same region using the normalized difference vegetation index as their measure of ecological function. The development and stabilization of ecological function depicted in these studies indicated that post-disturbance maturation of the system can be characterized by this shape.

Variability among environmental trajectories should be considered when evaluating system responses to restoration. The different development rates among CRAM attributes reflect the fact that ecological components advance along distinct pathways. We found in restored streams that biological attributes developed more quickly than physical. Morgan & Short (2002) also developed chronosequence curves to track the increase in constructed salt marsh function over time by measuring primary production, plant diversity, soil organic matter accumulation, and sediment filtration and trapping. Their curves indicated that aboveground biomass and plant species richness reached reference standards before 10 years, sediment deposition at 10 years, and soil organic matter at 15 years. Their curves also varied in shape and direction because they illustrated trajectories of biological and physical ecological components with different developmental patterns. Craft *et al.* (2003) evaluated biological, soil, and microbial metrics along a chronosequence of constructed salt marsh development. Based on their observations, they proposed that upon construction processes related to hydrology (e.g., sedimentation, soil C and N) are the first to achieve or exceed reference equivalence, followed by biological processes, then soil development after a much longer time.

In contrast to our Hydrology and Biotic Structure curves, Physical Structure did not meet the reference envelope. This could be due to the relationship between riparian vegetation and physical habitat structure development in streams. Riparian vegetation may interact with stream flow to affect fluvial geomorphic processes (Corenblit *et al.* 2007) such as channel widening (McBride, Hession & Rizzo 2010), in-stream habitat formation (Lennox *et al.* 2011), and the rates of erosion and deposition (Hupp & Osterkamp 1996). Therefore, we might expect physical structure metrics to mature after riparian vegetation is well-established to facilitate in-stream physical complexity.

The delayed Physical Structure curve could also be due to project-specific restoration design. Stream channels at several projects we visited were engineered for stability with willow or straw wattles, and geotechnical fabric, preventing the undercut bank physical patch type. We had little evidence that physical habitat features were included in project design. Several physical structure CRAM metrics need time to develop. For example, standing snags contribute to Physical Structure scores, but time is needed for trees to grow and die to create this feature. If we included older projects in curve development, then the Physical Structure curve might approach the reference envelope because those projects have more time for physical features to develop naturally.

Distinct from physical habitat's slow development, vegetation growth rates and active planting to support rapid establishment of native riparian species boosted the Biotic Structure scores and curve. Because plants can establish and grow quickly, floral indicators of functional replacement in restored or created wetlands are able to match reference conditions in under five years after project installation (Craft *et al.* 1999, 2003; Gutrich *et al.* 2009).

Flow patterns also influence ecological condition in restoration projects. Hill & Platts (1998) observed substantial development of riparian vegetation and in-channel habitat features within the first five years of stream restoration in a passively restored project with sufficient water flowing in an appropriate regime. In contrast, Physical and Biotic Structure development may be stunted without flow. Low scores we observed in projects with ephemeral flow were a function of low performance, particularly of those two attributes.

Application of curves for stream restoration management

Results of our analysis suggest that many sites will not reach functional maturity until at least 7-10 years post restoration (or longer in some cases). Extending the required monitoring period would improve the ability to directly evaluate restoration success. This conclusion is also supported by other studies, such as Osland *et al.* (2012), who observed various soil properties in created mangrove wetlands reaching equivalency between 18-28 years. Similarly, Craft *et al.* (2003) observed soil C and N levels at constructed marshes to be lower than those found in corresponding natural marshes after 28 years. However, longer monitoring periods may involve more resources than are feasible for either project proponents or regulatory agencies. If longer monitoring is not feasible, performance curves provide a valuable tool to help achieve long term ecological success. Curves can be used to establish performance targets and restoration goals, and to predict whether a project is on track and likely to reach ecological targets in the future. If project sites miss the correct trajectory, additional remedial measures can be implemented.

Although the curves were based on southern California projects, our results indicate that they will have broader applicability. CRAM was designed to be consistent across regions in the state (Sutula *et al.* 2006) and therefore the developmental patterns for the same wetland type and function should be similar among different regions (Kentula *et al.* 1992). Preliminary evaluation of central California projects using these curves supported their applicability in that region, a conclusion that could be strengthened with additional data.

Now is an appropriate time to develop these ecologically comprehensive performance curves because regulatory agencies are implementing performance measures for compensatory mitigation projects that encompass a range of environmental components. The US Army Corps of Engineers-South Pacific Division (SPD) recently issued performance guidelines that include ecological function and condition assessment methods including CRAM (US Army Corps of Engineers 2013). They also provided a new suite of uniform performance standards for mitigation project managers (US Army Corps of Engineers 2012a). As restoration projects are increasingly judged by overall ecological performance, these curves could be powerful tools in restoration management.

Improve and expand performance curves

We generated performance curves using the available relevant data for southern California stream restoration projects. As data for additional projects becomes available, future research can validate the curves produced here with more intensive data and refine them with longer term data. In addition, curve development could be expanded to include additional restoration types. While CRAM evaluates overall ecological condition, intensive measurements of ecological components such as macroinvertebrates, algae, and soil lend different insight into stream development. Because intensive metrics have varying units of measurement (e.g., Craft *et al.* 2002), mature at different rates (e.g., Morgan & Short 2002; Craft *et al.* 2003), and have not been integrated into an ecologically comprehensive index in California, metric selection and interpretation of results should be conducted thoughtfully.

Including longer term data from projects 10-30 years old would provide several benefits. First, it may establish that physical structure reaches reference standards within 30 years, versus the ten year period used for our curves. Second, data from older projects may change some of the polynomial-shaped metric curves to be power-shaped, reflecting long-term stability rather than deteriorating conditions. Finally, older project data could anchor the right ends of curves that rose above reference ranges or off the range of CRAM to level more reflective of a quasi-stable mature wetland condition.

As this study demonstrated the development and application of curves based on the concepts of Kentula *et al.* (1992), an appropriate next step would be to expand the application range of this tool to a larger suite of restoration approaches and wetland types. Projects with complex time-zero conditions and those with passive vegetation restoration are candidate categories for curve development. CRAM modules exist for other wetlands in addition to riverine: estuarine (tidal marsh), bar built estuarine, individual vernal pool, vernal pool systems, depressional (pond), and slope wetlands, so similar performance curves could be developed for those wetland types.

Tables

Table 3.1. Sources used to locate stream restoration projects for curve development.

Restoration Project Sources	**URL**
CalFish Projects	www.calfish.org
California Coastal Conservancy	scc.ca.gov
California Department of Fish and Game Cal Fed Ecosystem Restoration Program	www.dfg.ca.gov
California State Parks Project Inventory	www.parks.ca.gov
California Wildlife Conservation Board	www.wcb.ca.gov
EcoAtlas (formerly the California Wetland Tracker)	www.ecoatlas.org
National Oceanic and Atmospheric Administration Restoration Atlas	restoration.atlas.noaa.gov
Natural Resource Project Inventory	www.ice.ucdavis.edu
Southern California Wetland Recovery Project	scwrp.org
US Army Corps of Engineers Los Angeles District, Regulatory Division	www.spl.usace.army.mil

Table 3.2. CRAM attributes, metrics, and sub-metrics. Numbers in parenthesis indicate the range of scores available for each data type (California Wetlands Monitoring Workgroup 2013).

Attribute	Metric	Submetric
Buffer and Landscape Context (25-100)	Stream Corridor Continuity (3-12)	
	Buffer (6-24)	Percent of AA with Buffer (3-12)
		Average Buffer Width (3-12)
		Buffer Condition (3-12)
Hydrology (25-100)	Water Source (3-12)	
	Channel Stability (3-12)	
	Hydrologic Connectivity (3-12)	
Physical Structure (25-100)	Structural Patch Richness (3-12)	
	Topographic Complexity (3-12)	
Biotic Structure (25-100)	Plant Community Composition (3-12)	Number of Plant Layers (3-12)
		Number of Co-dominant Species (3-12)
		Percent Invasion (3-12)
	Horizontal Interspersion (3-12)	
	Vertical Biotic Structure (3-12)	

Table 3.3. Performance curve summary: mathematical functions of the curves, regression for curves r-squared values, and the years that curves and upper error band boundaries reached the reference zone if this occurred within 30 years (rounded to the nearest year). CRAM attributes are underlined. Raw reference data were not available. CRAM parent components are underlined and italicized.

Curve Metric	**Curve Function**	**R^2**	**Curve Crosses Reference Mean (year)**	**Error Envelope Crosses Reference Band (year)**
CRAM Index	$y = 60.613x^{0.0542}$	0.848	> 30	27
Hydrology	$y = 73.18x^{0.0523}$	0.531	14	1
Channel Stability	$y = 7.3536x^{0.1163}$	0.544	> 30	1
Hydrologic Connectivity	$y = 8.5922x^{0.145}$	0.869	< 1	0
Physical Structure	$y = 41.499x^{0.0642}$	0.32	> 30	> 30
Structural Patch Richness	$y = -0.068x^2 + 0.711x + 3.2656$	0.099	never	never
Raw Patch Count	$y = 3.9973x^{0.1943}$	0.71	n/a	n/a
Topographic Complexity	$y = -0.1331x^2 + 0.9544x + 5.5039$	0.364	never	1
Biotic Structure	$y = 59.149x^{0.124}$	0.934	7	1
Number of Plant Layers	$y = 7.1872x^{0.1189}$	0.739	> 30	1
Number of Co-dominant Species	$y = -0.1567x^2 + 1.4427x + 3.4344$	0.384	2	11
Raw Co-dominant Species Count	$y = 1.1335x^{0.985}$	0.957	n/a	n/a
Percent Invasion	$y = -0.212x^2 + 2.6412x + 3.6755$	0.826	5	10
Raw Invasive Species Percentage	$y = 0.0272x^2 - 0.3265x + 1.3878$	0.059	n/a	n/a
Raw Invasive Species Count	$y = 0.008x^2 - 0.0923x + 0.3039$	0.281	n/a	n/a
Plant Community Composition	$y = 6.8447x^{0.113}$	0.794	18	0
Horizontal Interspersion	$y = -0.1884x^2 + 2.1533x + 2.7442$	0.621	never	1
Vertical Biotic Structure	$y = 7.2688x^{0.1246}$	0.974	4	0

Figures

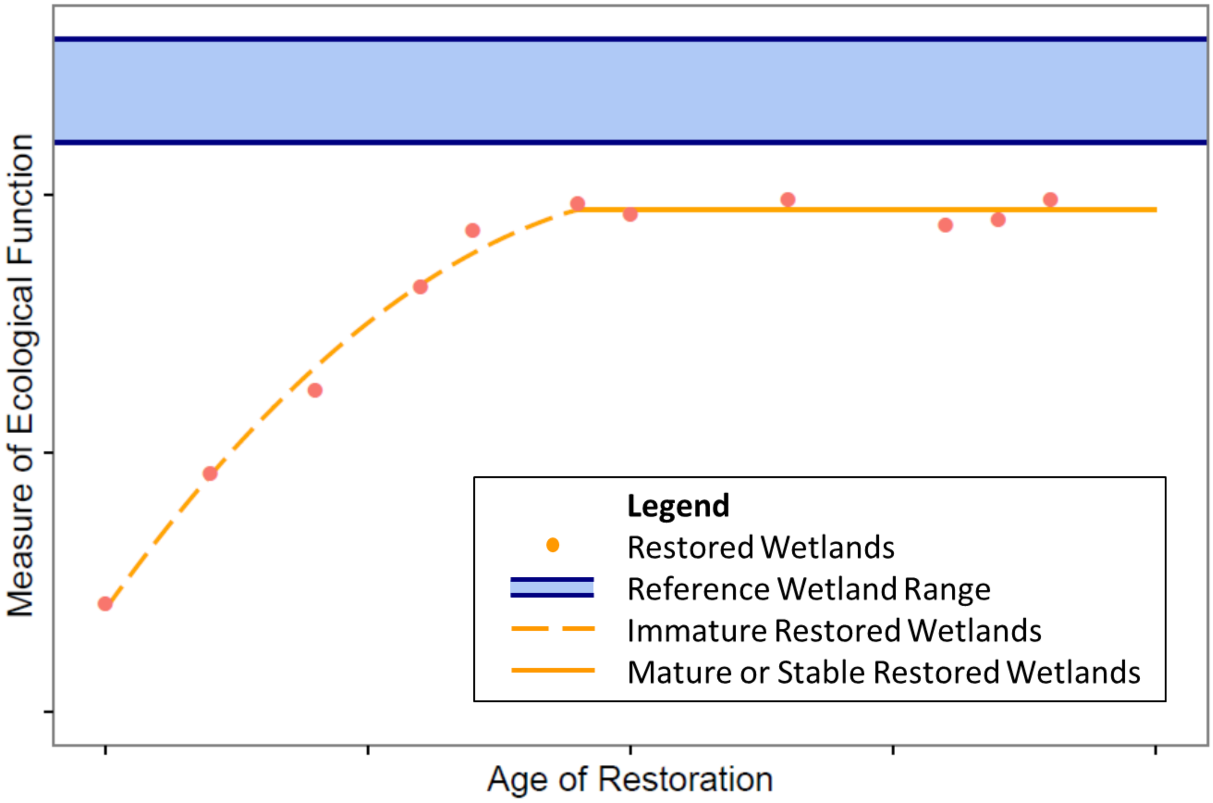


Figure 3.1. Hypothetical performance curve (Kentula *et al.* 1992). The restored wetland improves until a time point where it reaches a mature or stable condition. The curve is based on the chronosequence approach, where data from multiple restoration projects of different ages are used to illustrate the development of a hypothetical project. Data that approximate the range of natural or near-natural conditions at minimally disturbed reference wetlands are used to determine whether the curve reaches reference-level performance.

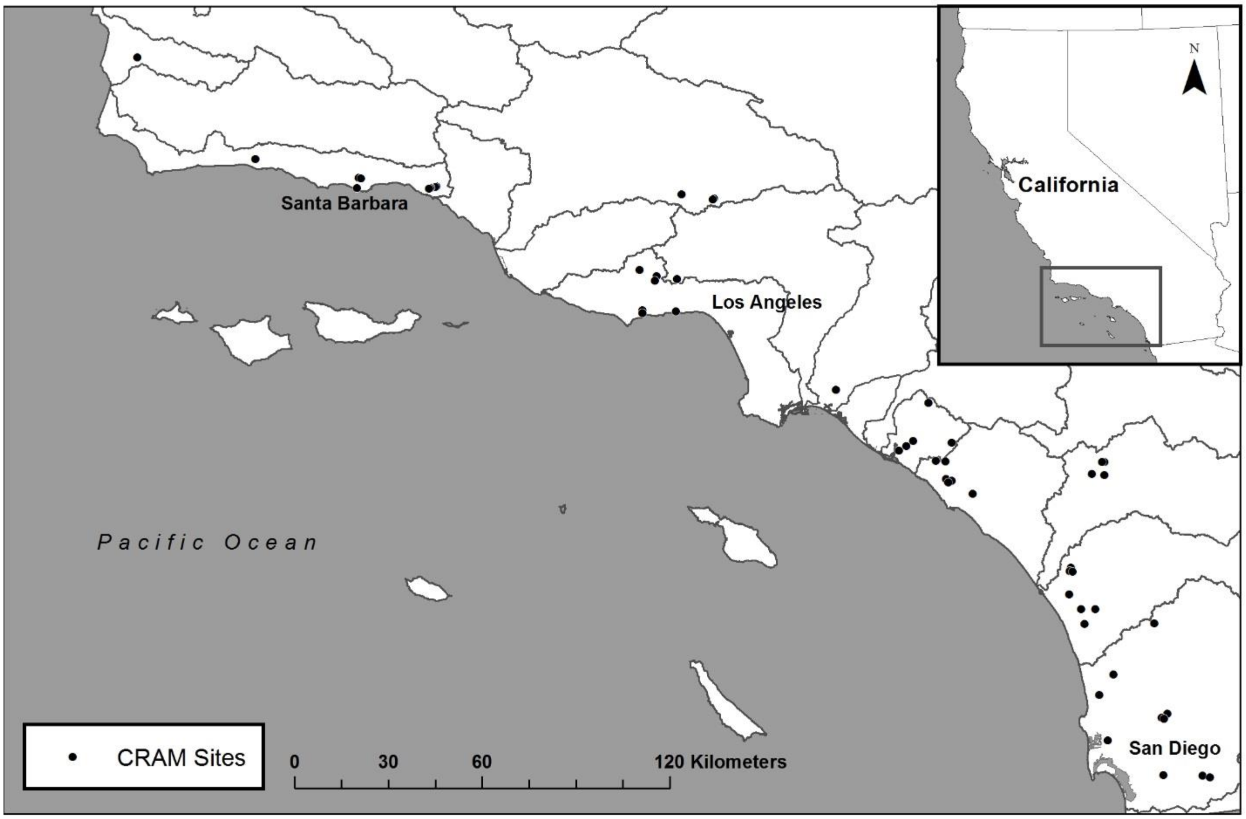


Figure 3.2. Restoration project sites where CRAM assessments were conducted in 2012-2013 for performance curve development. All projects were located in coastal-draining watersheds in southern California. Black lines are watershed boundaries.

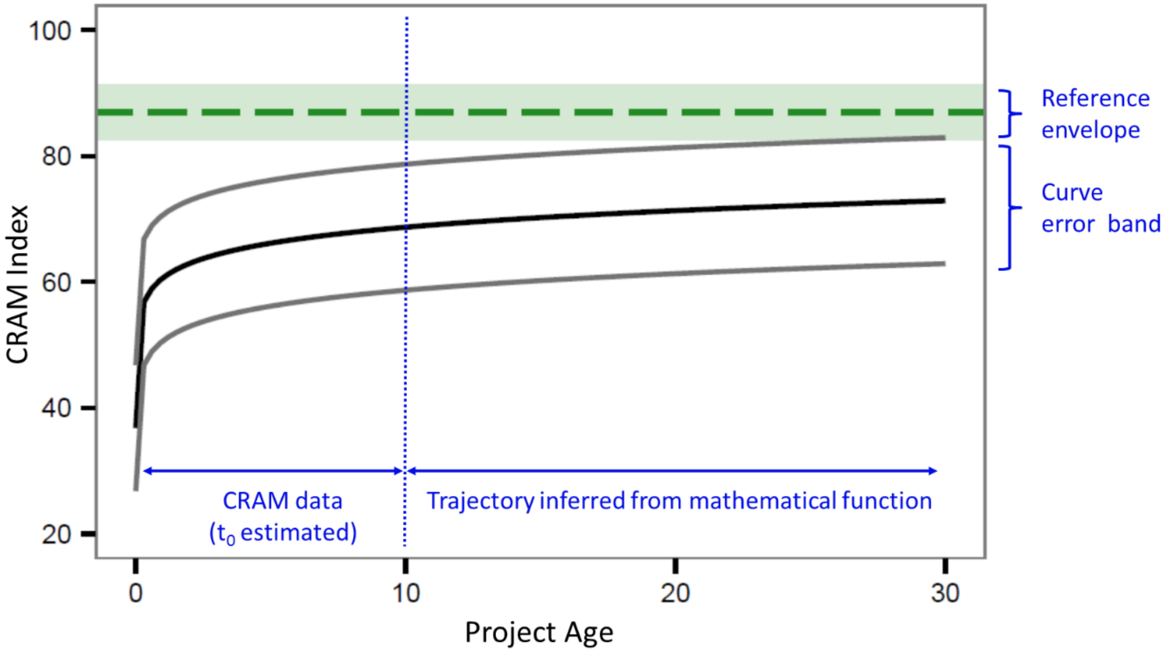


Figure 3.3. The performance curve (center of the error band) illustrating the hypothetical CRAM achievement of a high-performing restored stream. This performance curve was formed using the mathematical function best fit to actual CRAM data from projects 2-10 years old and an estimated data value at time-zero. The reference envelope is composed of the 95% confidence interval around the mean reference value, which is indicated by the dashed line. The curve error band is ± the CRAM index error around the curve.

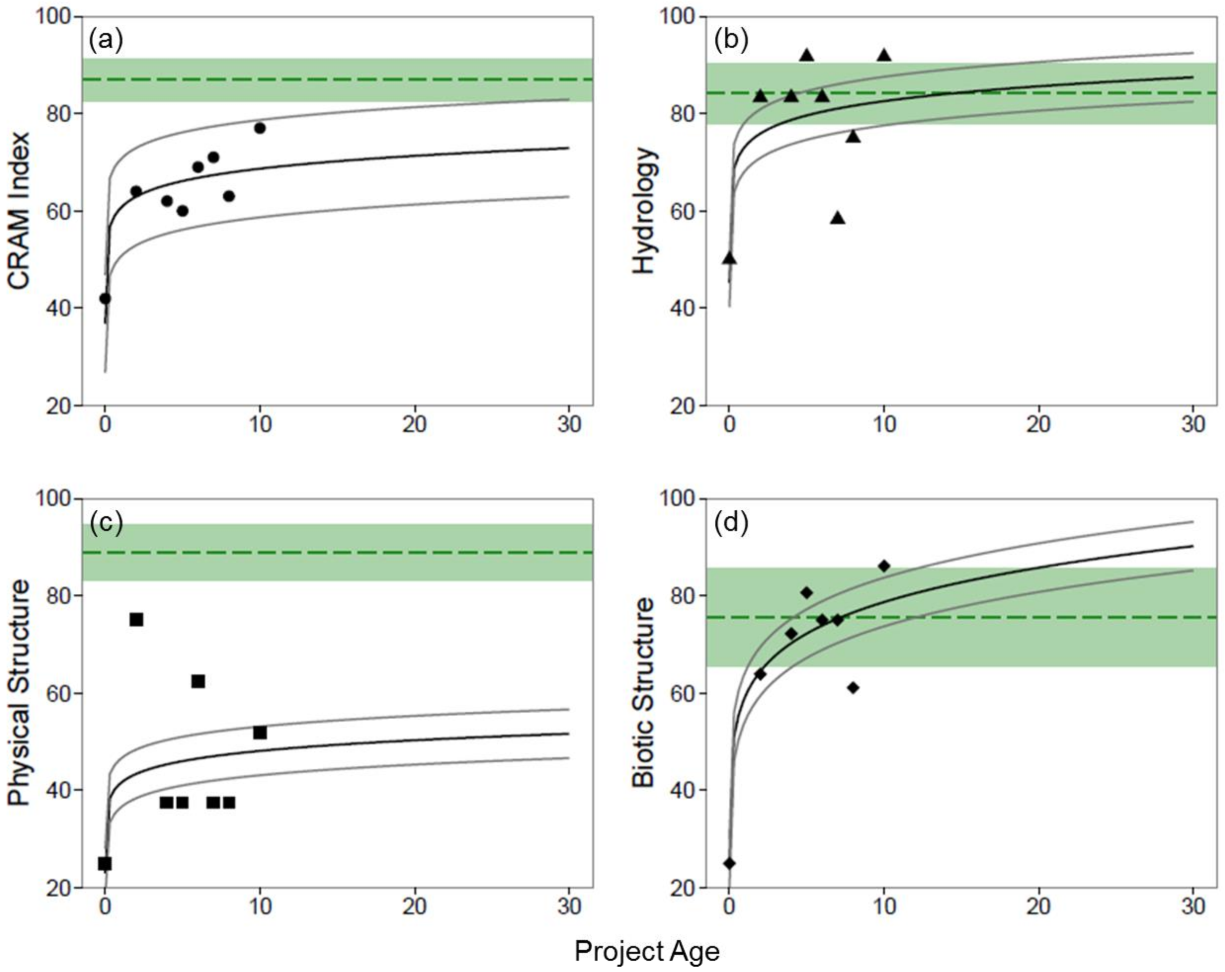


Figure 3.4. Hypothetical stream restoration performance curves for CRAM (a) index (●), (b) Hydrology (▲), (c) Physical Structure (■), and (d) Biotic Structure (♦) attributes. Curves were developed with CRAM data from best-performing restoration projects. The curve error band (gray) is ± CRAM error values around the curve. Reference envelopes (green) are composed of the 95% confidence intervals around mean reference values, indicated by dashed lines.

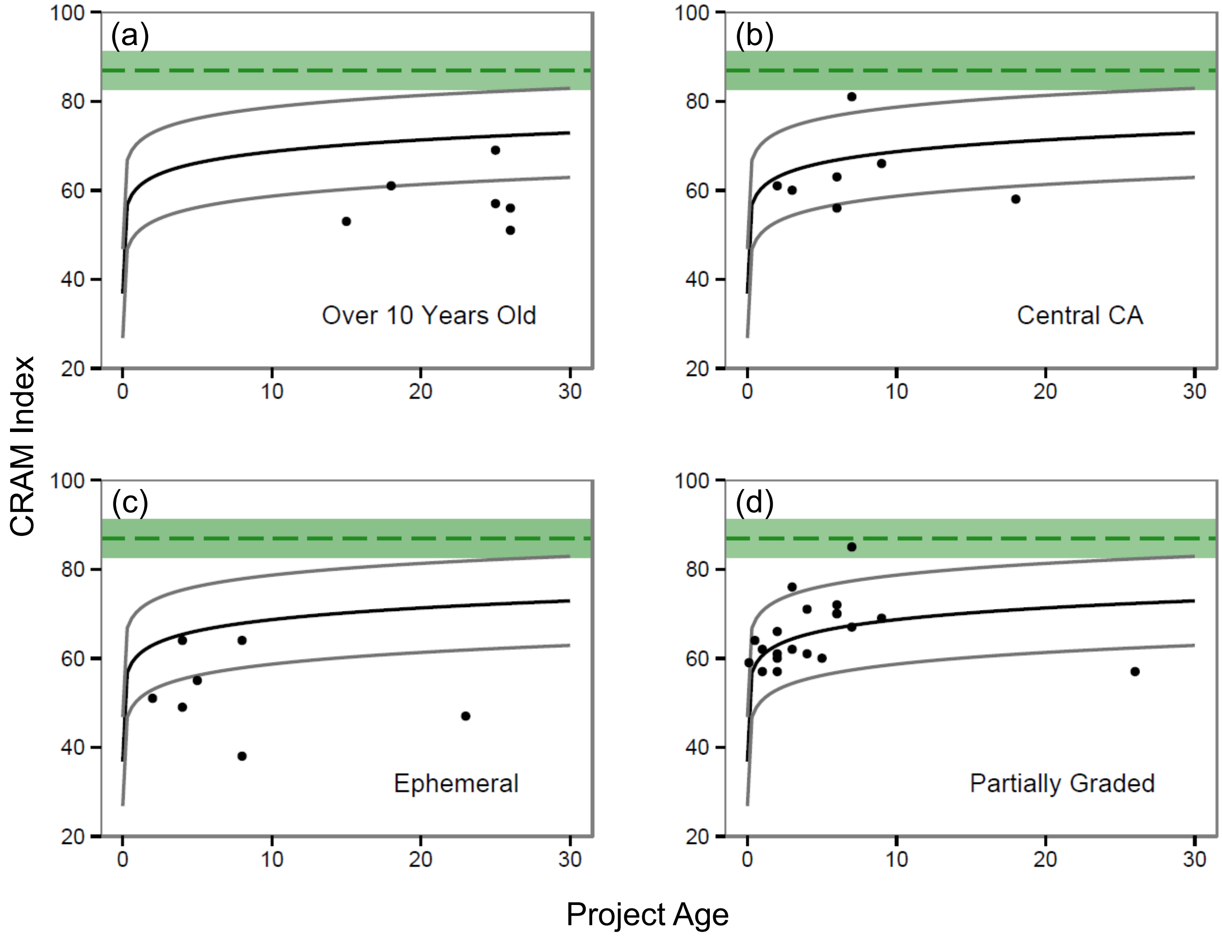


Figure 3.5. Performance curves superimposed on CRAM index scores from (a) projects over 10 years old (n = 6), (b) projects from the California central coast (n = 7), (c) ephemerally flowing projects (n = 7), (d) projects partially graded prior to restoration (n = 20). Only 19 partially graded site scores are visible because points overlap in year six where two projects scored 70.

Appendices

Appendix 3A: Performance Curve Study Site Information

Geographic coordinates of select sites not included due to requests from restoration practitioners or land managers. **(*)** Due to limited project information, restoration year was estimated as the Clean Water Act § 404 permit year.

Site	**Latitude**	**Longitude**	**Watershed**	**Hydrologic Regime**	**Restoration Category**	**AA Entirely Graded**	**Restoration Year**
San Antonio Creek Site 1	37.77681	-120.49756	San Antonio Creek	perennial	Compensatory Mitigation	yes	2010
San Antonio Creek Site 3	34.77991	-120.50688	San Antonio Creek	perennial	Compensatory Mitigation	yes	2010
South Coast Habitat Restoration (SCHR) 5			Santa Barbara Channel	intermittent	Fish Passage	no	2011
SCHR 6			Santa Barbara Channel	perennial	Fish Passage	no	2011
Upper Las Positas Creek	34.43325	-119.73519	Santa Barbara Channel	ephemeral	City Improvement	yes	2010
Mission Creek SB	34.43214	-119.72687	Santa Barbara Channel	intermittent	Fish Passage	no	2012
SCHR 7			Santa Barbara Channel	intermittent	Fish Passage	no	2012
SCHR 3			Santa Barbara Channel	intermittent	Fish Passage	no	2010
SCHR 2			Santa Barbara Channel	intermittent	Fish Passage	no	2010
Mesa Creek (Arroyo Burro)	34.40490	-119.73994	Santa Barbara Channel	perennial	City Improvement	yes	2006
SCHR 1			Santa Barbara Channel	intermittent	Fish Passage	no	2010

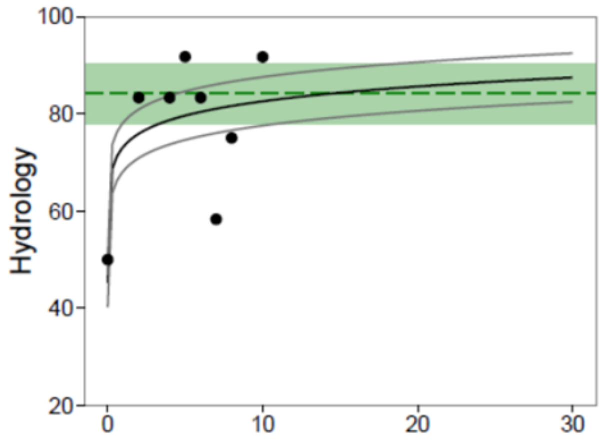
SCHR 7			Santa Barbara Channel	intermittent	Fish Passage	no	2010
Pico Creek	34.37824	-118.61166	Santa Clara River	intermittent	Mitigation Bank	yes	2005
Whitney Canyon	34.36561	-118.49792	Santa Clara River	intermittent	Mitigation Bank	yes	2010
Elsemere Canyon	34.36249	-118.50202	Santa Clara River	intermittent	Mitigation Bank	no	2009
Medea Creek	34.16298	-118.76118	Santa Monica Bay	perennial	Other	yes	1994
Las Virgenes Creek-Agoura Rd/Starbucks	34.14440	-118.70125	Santa Monica Bay	perennial	City Improvement	yes	2007
Dry Canyon Creek	34.13564	-118.63187	Los Angeles River	intermittent	Other	yes	2007
Las Virgenes Creek-Lost Hills	34.13131	-118.70748	Santa Monica Bay	perennial	Other	yes	1997
Solstice Creek-AC2 to AC3	34.04570	-118.75356	Santa Monica Bay	perennial	Fish Passage	no	2005
Las Flores Creek	34.04145	-118.63759	Santa Monica Bay	intermittent	City Improvement	yes	2008
Solstice Creek-D1 to D3	34.03813	-118.75211	Santa Monica Bay	perennial	Fish Passage	no	2005
El Dorado Nature Center	33.80737	-118.08752	San Gabriel River	perennial	Other	yes	2010
Peters Canyon Wash Mitigation*	33.76469	-117.77029	Newport Bay	intermittent	Compensatory Mitigation	yes	1987
Pacific Commerce / Mason Regional Park*	33.65627	-117.82522	Newport Bay	perennial	Compensatory Mitigation	yes	1988

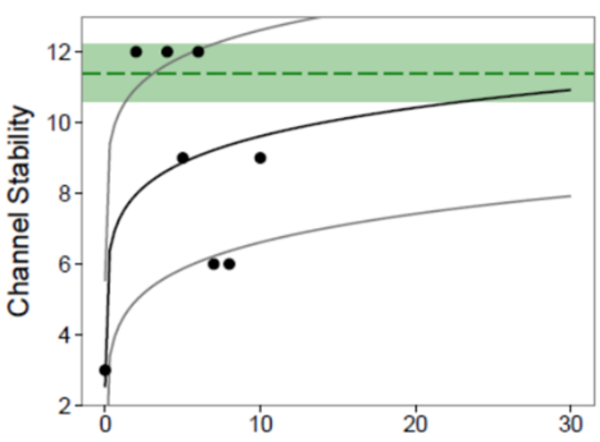
Serrano Creek	33.64835	-117.69308	Newport Bay	perennial	Other	yes	2002
Bison/Berkeley Mitigation*	33.64140	-117.84937	Newport Bay	ephemeral	Compensatory Mitigation	yes	1990
Big Canyon Country Club	33.62918	-117.87398	Newport Bay	perennial	Compensatory Mitigation	yes	2006
El Toro Rd/Tentative Tract Mitigation*	33.59655	-117.74805	Aliso Creek	perennial	Compensatory Mitigation	no	1987
Dairy Fork	33.59415	-117.71555	Aliso Creek	perennial	Compensatory Mitigation	yes	1987
Murrieta 2			Santa Margarita River	ephemeral	Compensatory Mitigation	yes	2008
St. Martha's Mitigation	33.58006	-117.17602	Santa Margarita River	perennial	Compensatory Mitigation	yes	2004
Murrieta 1			Santa Margarita River	perennial	Compensatory Mitigation	yes	2006
WetCat West/Country Village Mitigation*	33.54399	-117.71582	Aliso Creek	perennial	Compensatory Mitigation	yes	1988
Arboretum Mitigation	33.54247	-117.17068	Santa Margarita River	intermittent	Compensatory Mitigation	yes	2002
Sulphur Creek-Crown Royale Area	33.53907	-117.69650	Aliso Creek	perennial	City Improvement	yes	2006
Sulphur Creek-ACOE	33.53429	-117.70715	Aliso Creek	perennial	City Improvement	no	2008
Whispering Hills Mitigation	33.49982	-117.62405	Aliso Creek	ephemeral	Compensatory Mitigation	yes	2007
Wilmont Mitigation	33.27811	-117.29455	San Luis Rey	intermittent	Compensatory Mitigation	no	2007

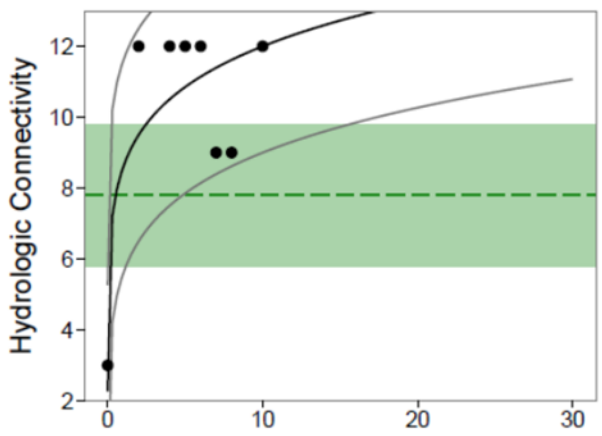
Morro Hills West Parcel	33.26990	-117.29768	San Luis Rey	ephemeral	Compensatory Mitigation	no	2004
Morro Hills East Parcel	33.26732	-117.28859	San Luis Rey	ephemeral	Compensatory Mitigation	no	2004
Rancho del Oro	33.20275	-117.30207	San Luis Rey	perennial	Compensatory Mitigation	no	2006
Rosemary's Mountain Quarry	33.15870	-117.26234	San Luis Rey	perennial	Compensatory Mitigation	no	2009
Future Elementary School	33.15662	-117.21360	San Luis Rey	intermittent	Compensatory Mitigation	yes	2007
La Costa	33.11615	-117.25332	San Luis Rey	perennial	Compensatory Mitigation	yes	2004
Cloverdale Creek	33.11113	-117.01348	San Diego River	perennial	Compensatory Mitigation	yes	2006
McGonigle Canyon	32.96739	-117.15842	San Diego River	perennial	Compensatory Mitigation	no	2003
Los Penasquitos	32.90956	-117.20982	San Diego River	perennial	Compensatory Mitigation	no	2006
Santee Town Center	32.84922	-116.98005	San Diego River	ephemeral	Compensatory Mitigation	yes	2008
Forester Creek DOT	32.83920	-116.99893	San Diego River	perennial	Compensatory Mitigation	no	2006
Forester Creek Improvement	32.83499	-116.99158	San Diego River	perennial	City Improvement	yes	2008
Tecolote-Tecolote Canyon Mitigation	32.77794	-117.18539	San Diego River	perennial	Compensatory Mitigation	no	2008
Bonita Meadows	32.67273	-116.99900	San Diego River	perennial	Compensatory Mitigation	yes	2006
Jamul Creek	32.66835	-116.86584	San Diego River	perennial	Mitigation Bank	yes	2002

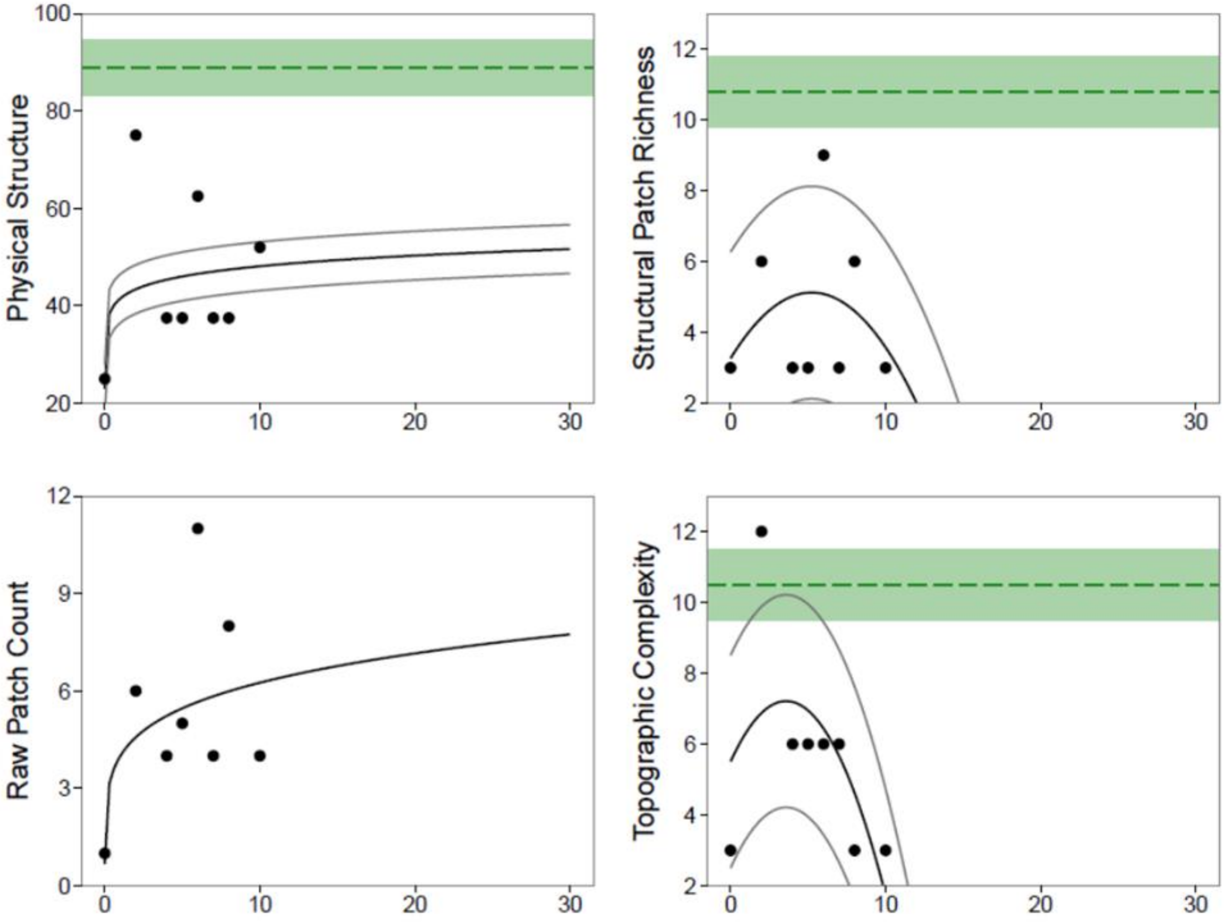
Dulzura Creek	32.66273	-116.84097	San Diego River	perennial	Mitigation Bank	yes	2002
Bear Creek	34.2692	-117.8913	San Gabriel River		Reference	na	na
San Gabriel River, West Fork	34.2406	-117.8831	San Gabriel River		Reference	na	na
SMC00476	33.9551	-117.9054	San Gabriel River		Reference	na	na
SMC00480	33.9823	-117.8157	San Gabriel River		Reference	na	na
SMC01040	33.8263	-117.7009	Santa Ana River		Reference	na	na
Little Mill Creek	34.1642	-117.1419	Santa Ana River		Reference	na	na
South Fork Santa Ana River	34.1328	-116.8429	Santa Ana River		Reference	na	na
Noble Canyon	32.8641	-116.5085	Tijuana River		Reference	na	na
SMC01161 (Sandia Creek)	33.4418	-117.2557	Santa Margarita River		Reference	na	na
SMC00827	34.2724	-119.2502	Ventura River		Reference	na	na

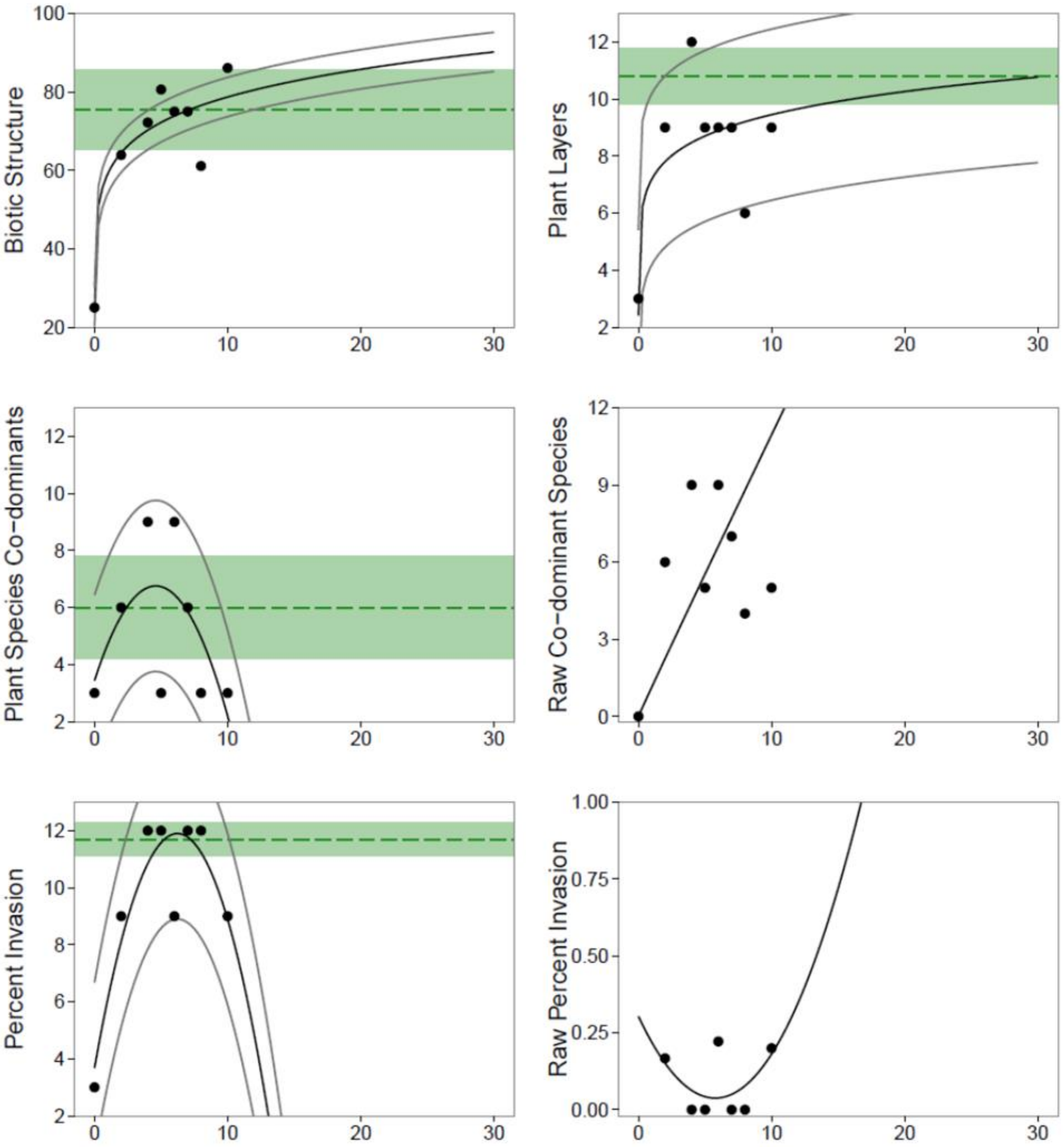
Appendix 3B: California Rapid Assessment Method (CRAM) Attribute, Metric, Sub-Metric, and Raw Data-based Hypothetical Performance Curves

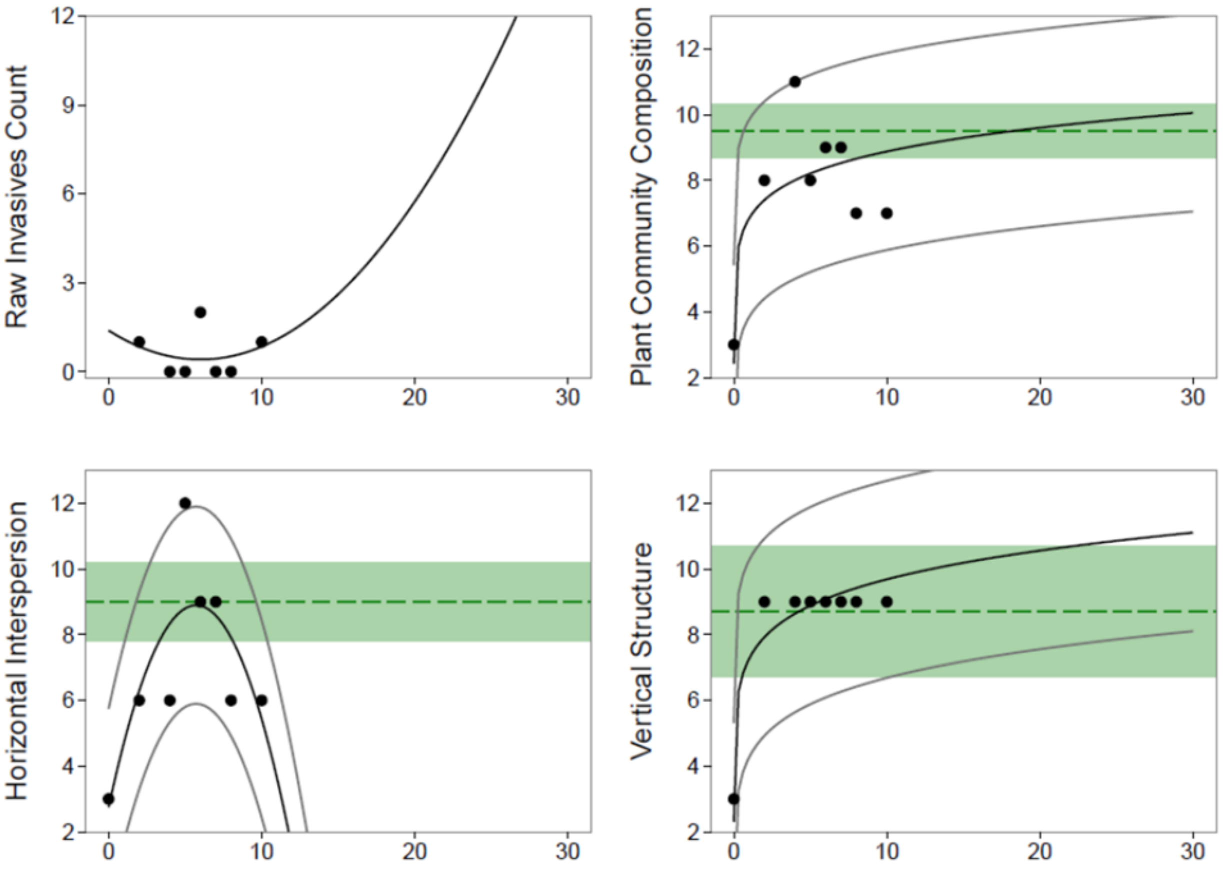







Physical Structure
100
80
60
40
20
0
10
20
30
Structural Patch Richness
12
10
8
6
4
2
0
10
20
30
Raw Patch Count
12
9
6
3
0
0
10
20
30
Topographic Complexity
12
10
8
6
4
2
0
10
20
30


Biotic Structure
100
80
60
40
20
0
10
20
30
Plant Layers
12
10
8
6
4
2
0
10
20
30
Plant Species Co−dominants
12
10
8
6
4
2
0
10
20
30
Raw Co−dominant Species
12
9
6
3
0
0
10
20
30
Percent Invasion
12
10
8
6
4
2
0
10
20
30
Raw Percent Invasion
1.00
0.75
0.50
0.25
0.00
0
10
20
30


Raw Invasives Count
12
9
6
3
0
0
10
20
30
Plant Community Composition
12
10
8
6
4
2
0
10
20
30
Horizontal Interspersion
12
10
8
6
4
2
0
10
20
30
Vertical Structure
12
10
8
6
4
2
0
10
20
30

CHAPTER FOUR: DEVELOPMENT AND DEMONSTRATION OF AN AERIAL IMAGERY ASSESSMENT METHOD FOR RESTORED STREAM CONDITION

Abstract

Remote sensing is an excellent resource for assessing the changing condition of streams and wetlands. Several studies have measured large-scale changes in riparian condition indicators, but few have remotely applied multi-metric assessments on a finer scale to measure changes, such as those caused by restoration, in the condition of small riparian areas. We developed an aerial imagery assessment method (AIAM) that combines landscape, hydrology, and vegetation observations into one index describing overall ecological condition of non-confined streams. Verification of AIAM demonstrated that sites in good condition (as assessed on-site by the California Rapid Assessment Method) received high AIAM scores (AIAM was not verified with poor condition sites). Spearman rank correlation tests comparing AIAM and the field-based California Rapid Assessment Method (CRAM) results revealed that some components of the two methods were highly correlated. The application of AIAM is illustrated with time-series restoration trajectories of three southern California stream restoration projects aged 15 to 21 years. The trajectories indicate that the projects improved in condition in years following their restoration, with vegetation showing the most dynamic change over time. AIAM restoration trajectories also overlapped to different degrees with CRAM chronosequence restoration performance curves that demonstrate the hypothetical development of high-performing projects. AIAM has high potential as a remote ecological assessment method and effective tool to

determine restoration trajectories. Ultimately, this tool could be used to further improve stream and wetland restoration management.

Introduction

In light of direct anthropogenic impacts to wetlands, such as land conversion, and anticipated indirect impacts, such as those due to climate change, there is much attention on their changing extent and condition (e.g., World Resources Institute 2005; Zedler & Kercher 2005; Dahl 2011). Remote sensing is a key resource for addressing these concerns, and is particularly useful when it is not financially or logistically feasible to collect data on the ground. Field data acquisition may be limited or impossible because areas of interest are extensive, inaccessible (Haack 1996), or ecologically sensitive (Phinn, Stow & Zedler 1996). Furthermore, collections of remote sensing data are important information sources for ecological change detection studies when other forms of historical data are not available. Use of aerial and satellite images is advantageous for ecological studies due to the relative ease of collection, ease of tailoring to specific spatial and temporal needs, and long time-series recordings (Morgan, Gergel & Coops 2010). For stream and wetland management and research, remote imagery has several applications. For example, it has been used to estimate change in riparian forest buffer (Claggett, Okay & Stehman 2010), wetland extent (Kent & Mast 2005b), coastal wetland restoration (Shuman & Ambrose 2003), spatial distribution of mangroves (Lee & Yeh 2009), and barrier island area (Thomas *et al.* 2011).

Studies have used remote imagery to roughly measure large-scale (e.g., one or more catchments) changes in ecological indicators such as landscape (Apan, Raine & Paterson 2002; Goetz *et al.* 2003), buffers (Goetz 2006), and vegetation (Sever, Leach & Bren 2012). Many of these studies involved quantitative analyses of multi-spectral imagery. Few studies have conducted remote multi-metric assessments through visual observations of aerial images to capture changes in the overall ecological condition of smaller riparian areas.

Chung (2006) developed the Aerial Photography Based Assessment Methodology (APBAM), a riparian condition measurement that relied only on aerial imagery, and with it demonstrated loss and decline of riparian wetlands in two southern California watersheds attributed to cumulative impacts. APBAM was based on five metrics from assessment methodology of the Middle River Neck Peninsula Special Area Management Plan of Baltimore County, Maryland. McMeechan (2009) adapted seven metrics from the California Rapid Assessment Method (CRAM) v.5.0.2 (Collins *et al.* 2008) to demonstrate via remote, aerial image-based assessment that impacts from Clean Water Act §404 permitted projects reduced the ecological condition of certain California wetlands, and that the restoration efforts of compensatory mitigation projects failed to fully replace lost ecological function. CRAM is a multi-metric field assessment that evaluates the overall ecological condition of a walkable area. It is a performance measure recommended for compensatory mitigation project assessment by the US Army Corps of Engineers South Pacific Division (US Army Corps of Engineers 2013).

A remote ecological assessment tool for small projects would be useful in stream and wetland restoration program evaluation, as monitoring is essential to evaluate restoration progress and inform project management planning (Kondolf 1995; Palmer *et al.* 2007), and managers want to know whether restoration goals are met and projects can be considered successful. Our objective was to develop a multi-metric assessment based on data from aerial imagery to assess the change in ecological condition over time of small stream restoration projects (< 200 meters long). We targeted a product with higher resolution than what was previously developed, and that could be conducted quickly and with few resources. To accomplish this, we addressed two questions:

- What are the best metrics to include in this method?
- Does the new aerial imagery assessment method (AIAM) accurately measure ecological condition?

To illustrate the use of AIAM, we assessed time-series images of three restoration projects and produced developmental trajectories showing the ecological change over time of each project. From the trajectories, we determined when each project reached its present condition and the pattern of its recovery. We also assessed how the hypothetical chronosequence CRAM performance curves from the preceding chapter compared to the development of these real projects.

Methods

AIAM development

We constructed AIAM primarily using metrics found in existing literature and riparian assessment methods. To identify potential assessment techniques that could be observed or measured remotely, we surveyed peer-reviewed literature, graduate theses, and ecological assessments. Through this initial search, we found 44 remotely observed metrics that could be used to assess riparian condition in seven peer-reviewed studies, two graduate theses, and CRAM. We compiled the metrics into four categories that reflected general ecological attributes:

Surrounding Landscape, Hydrologic Structure, Physical Habitat, and Vegetation Structure (Table 4.1).

For a method that was simple to conduct with limited resources, we further selected metrics that could be assessed with aerial imagery by someone without imagery analysis training. This process eliminated metrics such as ‘tree crown size’ and ‘willow canopy width’, which should be measured by a well-trained assessor, or using additional software such as that for pixel-based or object-oriented classification. We identified ten metrics that could be easily observed visually in aerial images, and that measured different features (Table 4.2). These metrics comprised AIAM. Observation methods for eight of ten total metrics were adopted from existing assessments (Chung 2006; McMeechan 2009; California Wetlands Monitoring Workgroup 2013). We developed methods to measure the other two (“Average Riparian Zone Width” and “Percent Tree and Shrub Cover” metrics; see below).

To score AIAM, metrics are graded A, B, C, or D. The letters are transposed into numerical values, which are inserted into algorithms to calculate attribute scores (Table 4.3). The attributes represent overarching ecological components: Landscape Structure, Hydrologic Structure, and Vegetation Structure. They are averaged to produce an index that ranges from 25 to 100. There is no attribute describing physical habitat because we could not identify relevant observations that were consistently obtainable via aerial imagery.

We developed and demonstrated AIAM for non-confined streams. We adopted the guideline for determining stream confinement from CRAM: non-confined streams are in a location where “the width of the valley across which the system can migrate without encountering a hillside, terrace, or other feature that is likely to prevent further migration is at least twice the average bank full width of the channel” (California Wetlands Monitoring Workgroup 2013).

The AIAM evaluation area is termed the Riparian Area (RA), and includes the entire apparent riparian corridor around the channel. The RA hosts vegetation visibly influenced by the stream channel, and its outer boundaries are drawn where the vegetation community visually differs from that in the riparian corridor. The RA length is 100 – 200 meters that excludes hydrologic or geomorphic features that correspond to significant changes in flow or sediment regime. These features were adopted from CRAM; see Table 4.4 for examples.

The AIAM Landscape Structure attribute is comprised of the same four metrics as the CRAM “Buffer and Landscape Context” attribute. “Stream Corridor Continuity, “Percent of Area with Buffer,” and “Average Buffer Width” are measured around the RA as outlined for CRAM in its Riverine Field Book v.6.1 (Appendix 4A; www.cramwetlands.org). “Buffer Condition” is assessed in AIAM similarly to McMeechan (2009), with no reference to native and non-native vegetation because it is difficult to distinguish between the two in aerial and satellite images.

The AIAM Hydrologic Structure attribute includes four metrics: “Water Source,” “Average Riparian Zone Width” (RZ Width), “Lateral Hydrologic Connectivity” (LHC), and “Evidence of Channel Alteration” (ECA). “Water Source” is measured as in the CRAM v.6.1, evaluating direct water inputs and diversions within 2 kilometers upstream of a RA that affect its dry season hydrologic condition. We defined the RZ Width as the width influenced by the presence of the channel, not including the visible channel width. It is measured:

$$RZ\ Width = \frac{Riparian\ Area - Channel\ Area}{Riparian\ Area\ Length}$$

The RZ Width scoring scheme is based on width ranges of protective zones around riparian areas recommended for the restoration of beneficial functions in watersheds with listed anadromous salmonids in the California Forest Practice Rules 2014. This is a reasonable guide for aerial assessment riparian width scoring as the range of the fish is extensive in California (California Department of Forestry and Fire Protection 2014).

LHC is adopted from McMeechan (2009) with no alterations to the method or scoring. It assesses the presence of features within five meters of the RA boundary that suggest a break in hydrologic connectivity. Paved roads, paths, trails, and other features associated with levees are considered connectivity break indicators. The metric is measured as the percent of the RA sides (parallel to stream flow direction) where unnatural levee indicators are present.

ECA is adapted from Chung (2006), and measures the amount of permanent, human-induced channel alteration in a riparian area. The metric is assessed by calculating the percent of RA length that features permanent alteration such as rip-rap, concrete channel lining, and road or trail crossings. We combined the top two of five original score categories (originally (1) no channelization is evident and (2) minor alteration present, usually piers of bridges on span crossings or unpaved trail/road crossings) into one so that ECA could be scored on a four-grade scale. By describing the connection of water flow to the natural floodplain, and the potential for it to naturally shape the channel and floodplain, LHC and ECA collectively capture human-induced impacts affecting flow in and around the RA.

The AIAM Vegetation Structure Attribute is comprised of two metrics that collectively describe the height and maturity of the vegetation community: “Vegetation Development”, and “Percent Tree and Shrub Cover” (Percent TSC). Vegetation Development is adapted from Chung (2006), and measures the amount of long-lived vegetation in the riparian area. We simplified the original metric’s four categories, which referenced specific trees and shrubs (e.g., willows, sycamores, alders, mulefat), to involve only general vegetation types (i.e., trees, shrubs, and herbs). Percent TSC assesses the amount of non-channel area covered by trees or shrubs. It is calculated:

$$Percent\ TSC = \frac{Cumulative\ Area\ Covered\ by\ Trees\ or\ Shrubs}{Riparian\ Area - Visible\ Channel\ Area}$$

The Percent TSC scoring system is based on the distribution of AIAM data collected from 30 southern California stream sites with conditions ranging from poor to good. More details about these sites are below. The lowest (D; 0-59%) scoring range of this metric is the range of percentages in the lowest quartile of Percent TSC scores. To assign the percentages associated with A (91-100%), B (76-90%), and C (60-75%), they were separated into ranges that seemed reasonable based on the greater range of the upper three quartiles.

Imagery source

We used Google Earth^{TM} Pro to obtain images and conduct AIAM. This is an excellent tool for remote imagery ecological assessment because it is readily available and provides both recent and historical satellite images free of charge. For an assessment like AIAM, images need no additional processing, which removes the burden of avoiding common aerial imagery processing errors (Morgan *et al.* 2010) from the user. Furthermore, it features functions that allow users to draw, measure, and save lines and polygons quickly and easily. AIAM data were collected using only this program.

Testing AIAM

To test AIAM's ability to measure ecological condition, we used it to assess 30 southern California stream sites that ranged from poor to good condition as measured by CRAM (Figure 4.1, Appendix 4B). With the resulting scores, we conducted correlation analyses between AIAM and CRAM scores from the sites. CRAM was developed with its own set of constraints, so it does not include all important aspects of ecological condition. However, it has been extensively validated as a tool for assessing riparian ecosystems (Stein *et al.* 2009). CRAM data were readily available and therefore a practical choice to involve in our development and evaluation of AIAM. CRAM is based on 16 metric and sub-metrics observations that comprise four attributes: Buffer and Landscape Context, Hydrology, Physical Structure, and Biotic Structure. The overall CRAM index is the average score for those attributes (Table 4.5).

Sites and CRAM data were obtained from the California Statewide CRAM Database (www.cramwetlands.org). The CRAM data from each site were obtained with CRAM v.6.1. All sites were located in southern California and featured perennial or intermittent flow. We selected images and CRAM data from 2013 because imagery available for this year through Google Earth^{TM} Pro was generally clear. For sites where quality 2013 images were not available, we used images from the closest year (either before or after) possible.

AIAM and CRAM data were compared using a Spearman's rank correlation. We focused the analyses on potential AIAM-CRAM analogues. These analogues measured the same general ecological components (e.g., vegetation, hydrology); however, some analogues measured different specific items within those general themes (e.g., vegetation maturity in AIAM vs. vertical biotic structure in CRAM). Correlation coefficients and p-values were derived in SPSS 23.

If AIAM appropriately measures ecological condition, sites in good condition should receive high scores. To verify AIAM by demonstrating its ability to give high scores to good sites, we conducted AIAM on images of six California stream and river Reference Condition Management Program (RCMP) reference sites. These reference sites had relatively un-impacted surrounding landscapes and displayed high biotic integrity. We determined whether AIAM produced high scores for the sites, and also related AIAM scores to CRAM scores for the reference sites. We did not verify that sites in poor condition receive low AIAM scores, as an appropriate pool of poor condition sites was not readily available.

AIAM-based restoration trajectories

We demonstrated the ability of AIAM to detect stream restoration recovery by using it to determine time-series stream restoration trajectories of three projects. The restoration projects are over ten years old and geographically dispersed throughout southern California. Medea Creek was restored in 1994 and is in Los Angeles County; Serrano Creek was restored in 2002 and is in Orange County; and Dulzura Creek was restored in 2002 and is in San Diego County (Figure 4.1). Each project was entirely graded at restoration time-zero and featured perennial flow. To determine the trajectories, we collected AIAM data from 9 to 11 time-series images of each project site. Imagery dates ranged from 1989 to 2015, and one image per project showed site conditions either five or eight years before restoration. We graphed the index and attribute data against project age.

We compared the real AIAM restoration trajectories to hypothetical CRAM performance curves. The AIAM index, Hydrologic Structure, and Vegetation Structure scores were overlaid on corresponding CRAM performance curves and reference envelopes from the preceding chapter. Landscape Structure trajectories were not compared to a performance curve because a curve was not developed for its analogue, CRAM Buffer and Landscape Context. The CRAM curves illustrate the hypothetical achievement of high-performing restoration projects. They were developed by fitting mathematical curves to CRAM data from high-scoring restoration projects aged two to ten years (see preceding chapter). The curves were complemented by performance curve error bands that were ± the CRAM index or attribute errors around the curve, and reference envelopes that were composed of 95% confidence interval values around mean reference values of each score type. Reference envelopes were based on CRAM data from ten RCMP reference sites. A few real CRAM data points collected for the projects in 2012 were also included in the graphic to see whether AIAM and real CRAM scores for the projects were within the same range.

Results

Testing AIAM

Comparisons between AIAM and CRAM data produced a range of relatively strong (e.g., AIAM vs. CRAM Buffer Width $r_s = 0.796$, $p = 0.000$) to very weak (e.g., AIAM Vegetation Development vs. CRAM Biotic Structure $r_s = -0.007$, $p = 0.972$) correlation relationships (Table 4.6; Appendix 4C). The AIAM index data were more highly correlated to the average scores of the three CRAM attributes with measurements most similar to the AIAM attributes (Buffer and Landscape Context, Hydrology, and Biotic Structure; $r_s = 0.437$,

$p = 0.016$) than with the CRAM index (r_s = = 0.367, $p = 0.046$), which is the average of four attributes (those three plus Physical Structure). Among the attributes, AIAM Landscape Structure and CRAM Buffer and Landscape Context ($r_s = 0.659$, $p = 0.000$) were the most highly correlated, followed by AIAM Hydrologic Structure and CRAM Hydrology ($r_s = 0.543$, $p = 0.002$). AIAM Vegetation and CRAM Biotic Structure correlation results suggested no relationship between the two ($r_s = -0.024$, $p = 0.901$).

As anticipated, AIAM produced high scores for RCMP reference sites and was thus verified. The score distribution ranged from 71 to 92, with an 82 mean value. Also, the AIAM and CRAM index scores of the RCMP reference areas were very similar, with overlapping distributions. The CRAM distribution ranged from 72 to 94 with an 85 mean.

AIAM-based restoration trajectories

The AIAM trajectories varied between data types (i.e., index, attribute), and also between restoration projects (Figure 4.2; Appendix 4D). Vegetation Structure changed the most, with net improvement at all projects from time-zero to 2015 (Figure 4.2d). Vegetation Structure displayed plateaus with different scores and at different times at Medea and Serrano Creeks. At Medea Creek, the attribute reached 100 in year 17 and did not regress in following years. At Serrano Creek, it initially plateaued at 88 in year five, then rose to 100 in year 13. There, the Vegetation Structure score was also 100 eight years before restoration, though it did not return to 100 until 13 years post-restoration.

The index trajectories were similar to the Vegetation Structure trajectories, but with less dramatic changes because they were subdued by their more static Landscape and Hydrologic Structure components (Figure 4.2a). Neither Landscape nor Hydrologic Structure changed substantially over time at Serrano and Dulzura Creeks (Figure 4.2b, c). These attributes were more dynamic at Medea Creek, where Landscape Structure fluctuated and Hydrologic Structure improved from time-zero to 2015. Among the three sites, the attributes' trajectories were similar between Serrano and Dulzura Creeks, where Landscape and Hydrologic Structure showed little to no change, Vegetation Structure changed substantially, and the index changed to a lesser extent in the post-restoration period.

The AIAM index trajectory of every project was within or above the CRAM performance curve envelope through the entire period from time-zero and 2015. Medea Creek's AIAM Hydrologic Structure trajectory closely followed the shape of the CRAM Hydrology performance curve, but Serrano and Dulzura Creeks' Hydrologic Structure trajectories did not. Six Dulzura Creek AIAM index scores exceeded the upper performance curve error boundaries; two of those scores were within the CRAM reference envelope.

None of the Vegetation Structure time-series trajectories displayed the rapid and early increase exhibited by the corresponding CRAM Biotic Structure performance curve. The Vegetation Structure trajectories for Medea and Serrano Creeks rose quickly during years 10-15 and 3-5, respectively, to eventually exceed the corresponding CRAM reference envelope. Dulzura Creek's Vegetation Structure trajectory neither met the CRAM performance curve, nor displayed a similar shape.

There were varied levels of correspondence between the CRAM 2012 data points and AIAM scores at similar project ages (Figure 4.2). CRAM index scores were within (at Serrano Creek) or slightly below (at Medea and Dulzura Creeks) the ranges of AIAM index scores. CRAM Buffer and Landscape Context scores were in close proximity to AIAM Landscape

Structure scores at all three projects. CRAM Hydrology and Biotic Structure scores did not correspond closely to AIAM Hydrologic and Vegetation Structure of the same project ages.

Discussion

AIAM is a valid method for assessing ecological condition that potentially has higher resolution than previously developed remote multi-metric assessments. However, the breadth of ecological components it measures is still limited. This is because it is designed to use only two-dimensional aerial or satellite images for data collection. Despite these limitations, we successfully applied AIAM to demonstrate riparian development patterns of restoration projects over periods longer than a decade. Because the information for conducting an AIAM analysis is readily available and free, AIAM holds high potential as a tool that informs riparian restoration management.

AIAM

AIAM potentially has a higher resolution than either APBAM developed by Chung (2006), or the remote CRAM adapted by McMeechan (2009). More non-overlapping metrics are involved in AIAM than in the two previously developed methods. For example, remote CRAM features only one vegetation metric that is based on the percent coverage of expected vegetation in the assessment area. In contrast, AIAM includes two vegetation metrics that observe percent cover and vegetation development (maturity). This difference of AIAM can be attributed to our approach of involving remote sensing metrics from several sources, rather than adapting methods from one field-based method for remote application. Whether the additional metrics included in AIAM add value by making the method more sensitive or comprehensive than APBAM or remote CRAM has yet to be seen. This could be explored in the future by comparing AIAM, APBAM, and remote CRAM results to each other, and to other ecological indicators.

AIAM is an effective tool for determining restoration trajectories. The AIAM trajectories share similarities in shape and timing with other wetland restoration performance curves that were based on both single-site, time-series (Craft *et al.* 2002) and multi-site, chronosequence (Morgan & Short 2002; Craft *et al.* 2003; Matthews *et al.* 2009) field data. AIAM Vegetation Structure trajectories demonstrate the strongest examples of these similarities: the rise and stabilization of vegetation condition at our restoration projects resembled the post-creation development curves of aboveground biomass in eastern U.S. saltmarshes (Morgan & Short 2002; Craft *et al.* 2003) and Floristic Quality Index (FQI) data from Illinois wetlands (Matthews *et al.* 2009). Aboveground biomass and FQI assess vegetation development, so the agreement of curves also supports AIAM's ability to accurately capture vegetation condition. Stream restoration activities affect the Vegetation Structure attribute more than the others (Table 4.7). Restoration is typically implemented in and around the channel, so restoration mostly occurs in the riparian zone, where the AIAM vegetation metrics are observed. Among AIAM hydrologic metrics, RZ Width might increase if there is channel or floodplain development, and ECA conditions might improve if channel alteration structure removal occurs. However, Water Source and LHC would not be influenced by stream restoration. Those metrics are measured outside of the riparian zone, so their improvement through stream restoration projects is not expected.

AIAM is an alternative, but not an equivalent substitute, for field-based monitoring methods. Significant benefits of AIAM are the low-cost and rapidity with which it is conducted. Even rapid assessment methods, which were developed to assess ecological condition and function in the field quickly in lieu of intensive data collection, require more time and resources to conduct than AIAM. For example, CRAM recommends at least two practitioners complete the assessment in two to three hours on-site (plus travel time to and from the site). The Hydrogeomorphic (HGM) classification assessment method (Brinson 1993; Smith *et al.* 1995), which was developed for the US Army Corps of Engineers Section 404 Regulatory Program to assess wetland functions, requires a half-day in the field per site. In contrast, AIAM can be conducted in the office by one person in as few as ten minutes per site or time period. AIAM also offers the distinct advantage of assessing prior condition of a site, which of course cannot be accomplished with a field-based assessment method. This allows pre-impact and pre-restoration assessments as well as the developmental trajectories illustrated here.

AIAM's primary disadvantage is its limited ecological scope. For example, it does not measure any physical features (e.g., riffles, pools, undercut banks) that indicate habitat sources. Neither does it capture certain aspects of vegetation community, such as plant species diversity, which indicate community robustness and resilience, or prevalence of non-native species. Inclusion of metrics such as these in multi-metric assessment methods make them more comprehensive tools for evaluating stream and wetland condition. Field-based assessments such as HGM and CRAM observed these types of data. AIAM's limitations are due to its basis in the use of easily obtainable aerial or satellite images that only provide a two-dimensional, nadir perspective. More involved remote sensing methods can be used to collect data beyond what AIAM is currently designed to observe. For example, Gillan *et al.* (2014) demonstrated capabilities of measuring rangeland shrub heights using digital stereo aerial photographs. Johansen *et al.* (2010) verified that object-based image analysis of airborne Light Detection and Ranging (LiDAR) data could to be used to remotely measure streambed width, riparian zone width, plant projective cover (PPC), longitudinal continuity, coverage of large trees, vegetation overhang, and stream bank stability in an Australian sub-tropical savannah stream. Both of the approaches of Gillan *et al.* (2014) and Johansen *et al.* (2010) involved remote data collection via aircraft flyover and additional data processing measures. Remote methods like these are more costly and time-intensive than this initial version of AIAM, but can provide valuable information without necessitating field visits. One or more of these could be applied to a later version of AIAM in the future, should there be a desire to increase its resolution.

Next steps in the development of AIAM would be to validate and calibrate the method. Both validation and calibration have been applied to field-based rapid assessment methods (e.g., CRAM, HGM, Ohio Rapid Assessment Method) to determine whether metrics, attributes, and overall index scores are good predictors of wetland condition as measured against more intensive indicators of ecological condition such as birds, benthic macroinvertebrates, plants, soil, and human alteration (Hruby 2001; Stapanian *et al.* 2004; Sutula *et al.* 2006; Stander & Ehrenfeld 2009; Stein *et al.* 2009). Calibration is intended to optimize the correlations between the assessment method data and quantitative data representing a gradient of wetland condition. Validation is used to assure that the calibration applies broadly to many wetlands, and is a long-term, ongoing process that makes an assessment method more robust (Sutula *et al.* 2006). We could use our results from the AIAM to CRAM correlations to inform calibration of AIAM scores. We noted that some of the metrics we labeled as conceptual analogues correlated poorly because they actually measured very different aspects of the ecological components to which they were both connected. If we used CRAM data to calibrate AIAM, we would need to be discerning about which CRAM metrics are involved. Ideally other intensive data would also be involved in these steps.

Management implications

AIAM can be applied in at least two ways to help address monitoring challenges. First, AIAM can be employed to supplement existing monitoring efforts and support extended monitoring periods. AIAM might be used to measure natural variability to inform expectations for restored systems. For example, it could be applied to time-series of natural reference sites to capture the natural ecological fluctuations. AIAM could also be applied to capture responses to adaptive management, quickly indicating whether changes in project management have resulted in improved condition. Additionally, AIAM could be used to acquire a continuous thread of project condition information throughout monitoring periods if they become longer than the current norm. Five years is the minimum monitoring period currently recommended for compensatory mitigation projects in the United States (US Army Corps of Engineers & US Environmental Protection Agency 2008). González *et al.* (2015) found in a review of international stream restoration literature spanning 1990 to 2015 that monitoring beyond six years is rare. Studies have demonstrated that wetland restoration projects do not reach functional equivalency within five or six years. Vegetation conditions at the southern California stream restoration projects in this study did not stabilize until year five or later. Craft *et al.* (2003) and Osland *et al.* (2012) observed that the recovery period of wetland vegetation was shorter than that of hydric soils in constructed wetlands in North Carolina and Louisiana. Furthermore, Osland *et al.* (2012) observed that both vegetation and hydric soils in created wetlands required over ten years to reach functional equivalence with natural reference wetlands. Longer monitoring periods for wetland restoration have been considered appropriate from a scientific perspective (Mitsch & Wilson 1996). Kondolf (1995) thought at least a decade would be an appropriate length of time to evaluate stream restoration project success and suggested, as an alternative to typical annual stream restoration monitoring, that data be collected at five time points over a ten-year monitoring period. AIAM could easily be conducted annually, and at low cost, if field monitoring events were temporally spread out.

Second, AIAM is a tool that can fill restoration project monitoring gaps and overcome barriers to monitoring. A large proportion of restoration projects do not collect baseline or monitoring data, preventing the determination of project success from being quantitatively confirmed. In a survey of 94 stream restoration project managers in Washington State, Bash & Ryan (2002) observed that only about half of their projects involved collection of baseline data and one or more ecological measure for monitoring. The managers listed lack of funding, time, and personnel as barriers to restoration monitoring. Bernhardt *et al.* (2007) found through a survey of 317 restoration project managers across the United States that 83% collected project monitoring data, and 59% used quantitative data to evaluate project success. Bernhardt *et al.* (2007) estimated that the national monitoring rates are lower than their observations because their sample pool was skewed by a high representation of expensive and large restoration efforts performed by long-term restoration practitioners. AIAM can be applied to historical imagery to assess ecological condition prior to restoration in the absence of baseline data collection, and to collect quantitative restoration project recovery data where monitoring has been completely absent. With the availability of free imagery through sources such as Google Earth^{TM}, AIAM requires no additional material cost beyond a computer and internet connection.

Final thoughts

In recent decades, many approaches to field-based ecological assessment have been developed and strengthened. This has been driven by intent to assess the function and condition of ecological resources, including streams and wetlands, for management purposes. On a parallel timeline, remotely sensed data have improved in quality and become easier to obtain. The development of AIAM is an effort to apply remote sensing resources to the concept of a multi-metric ecological assessment method for streams. Remote sensing capabilities will continue to improve and expand in the future. Exploring ways to integrate remote sensing into stream and wetland assessment is an investment of effort that will benefit the field of ecological restoration management both now and in the long term. AIAM is not intended to replace field-based monitoring, but to supplement existing monitoring efforts for stronger stream and wetland restoration management programs.

Tables

Table 4.1. Aerial imagery-based riparian metrics proposed by past studies to assess ecological condition.

Ecological Attribute	Congalton *et al*. 2002	Chung 2006	Goetz 2006
Surrounding Landscape		• Aerial Photography Based Assessment Methodology connectivity (dams, roads, trails, dirt roads, maintenance roads, span crossings, drop structures, impoundments, fill); • Vegetation buffer	• Buffer assessment
Hydrologic Structure		• Watershed land cover (adapted from Brown and Vivas 2000); • Channel alteration	
Physical Habitat		• Sinuousity (from Middle Neck River Peninsula Special Area Management Plan)	
Vegetation Structure	• Riparian structure classification (hardwood, brush and recent clear-cut, large conifers, closed canopy conifer, sparse conifer/seed-sap-pole, persistent brush, grass/pasture/open or agricultural)	• Vegetation development; • Abundance of very mature trees; • Contiguous vegetation cover	• Vegetation mapping via high spatial-resolution imagery

Table 1 *continued*

Ecological Attribute	Johansen and Phinn 2006	Booth *et al*. 2007	Johansen *et al.* 2008
Surrounding Landscape			
Hydrologic Structure		• Riparian width	• Exposed stream banks; • Bank stability and flood damage; • Riparian zone width
Physical Habitat	• Leaf area index		• Water bodies; • Exposed stream banks
Vegetation Structure	• Tree crown size; • Vegetation species composition	• Willow canopy widths; • Willows present; • Riparian vegetation patch widths	• Percent canopy cover; • Map riparian vegetation, water, transition zone, cleared areas, exposed stream banks

Table 1 *continued*

Ecological Attribute	McMeechan 2009	Stromsoe and Callow 2011	Goforth and Bain 2012
Surrounding Landscape	• Development or human visitation in immediate drainage basin; Landscape continuity		• Dominant, sub-basin, and riparian riparian land cover; • Presence of roads; • Estimated percent land cover beyond riparian zone as cropland, pasture/forest or brush; • Existence of conservation activity
Hydrologic Structure	• Lateral hydrologic connectivity	• Hillslope erosion; • In-channel and floodplain gross planform changes; • Connected sheetwash	• Point source pollution; • Presence of roads; • Upstream subbasin and riparian land cover; • Width of riparian area
Physical Habitat		• Gullies and minor tributaries; • Hillslope, floodplain, and bare channel mapping	• Presence of wetlands
Vegetation Structure	• Vegetation presence		• Dominant riparian land cover • Riparian canopy continuity

Table 4.2. Metric scoring guidelines for AIAM. The letters are transposed into numerical values (A = 12, B = 9, C = 6, and D = 3), which are inserted into algorithms to calculate attribute and index scores. Observation methods for eight metrics were adopted from existing assessments; (*) denotes methods were adopted from CRAM with little or no alteration.

Aerial Image Assessment Method Metric	A	B	C	D
Stream Corridor Continuity *	The combined total length of all nonbuffer segments is less than 100 m for a distance of 500 m both upstream AND downstream of RA	The combined total length of all nonbuffer segments is less than 100 m for a distance of 500 m upstream of RA AND the combined total length of all non-buffer segments is between 100 m and 200 m for a distance of 500 m downstream of RA OR vice versa	The combined total length of all nonbuffer segments is between 100 m and 200 m for a distance of 500 m upstream AND downstream of RA	The combined total length of non-buffer segments is greater than 200 m for a distance of 500 m upstream AND/OR downstream of RA
Percent AA with buffer *	Buffer is 75 - 100% of RA perimeter	Buffer is 50 – 74% of RA perimeter	Buffer is 25 – 49% of RA perimeter	Buffer is 0 – 24% of RA perimeter

Table 2 *continued*

Aerial Image Assessment Method Metric	**A**	**B**	**C**	**D**
Average Buffer Width *	Average buffer width is 190 – 250 m	Average buffer width is 130 – 189 m	Average buffer width is 65 – 129 m	Average buffer width is 0 – 64 m
Buffer Condition *	Buffer for RA has undisturbed soils, and is apparently subject to little or no human visitation.	Buffer for RA is characterized by mostly undisturbed soils and is apparently subject to little or low impact human visitation OR Buffer for AA shows some soil disturbance and is apparently subject to little or low impact human visitation.	Buffer for RA is characterized by a moderate degree of soil disturbance/compaction, and/or there is evidence of at least moderate intensity of human visitation.	Buffer for RA is characterized by barren ground and/or highly compacted or otherwise disturbed soils, and/or there is evidence of very intense human visitation, or there is no buffer present.

Table 2 *continued*

Aerial Image Assessment Method Metric	A	B	C	D
Water source *	Freshwater sources that affect the dry season condition of the RA, e.g., flow characteristics, hydroperiod, or salinity regime, are precipitation, snow melt, groundwater, and/or natural runoff, or natural flow from an adjacent freshwater body, or the AA naturally lacks water in the dry season. There is no indication that dry season conditions are substantially controlled by artificial water sources.	Freshwater sources that affect the dry season condition of the RA are mostly natural, but also obviously include occasional or small effects of modified hydrology. Indications of such anthropogenic inputs comprise less than 20% of the immediate drainage basin within about 2 km upstream of the AA. No large point sources or dams control the overall hydrology of the RA.	Freshwater sources affecting the dry season conditions of the RA are primarily artificial hydrology or substantially controlled by diversions of water or other withdrawals directly from the RA, its encompassing wetland, or from its drainage basin. Indications of artificial hydrology (e.g., urban runoff, directed irrigation) comprise more than 20% of the immediate drainage basin within 2 km upstream of the RA, or major point source discharges exist.	Natural, freshwater sources that affect the dry season conditions of the AA have been eliminated based on the following indicators: impoundment of all possible wet season inflows, diversion of all dryseason inflow, predominance of xeric vegetation, etc.
Average Riparian Zone Width	Average riparian zone width is greater than 80 m	Average riparian zone width is 20 - 80 m	Average riparian zone width is 10 - 20 m	Average riparian zone width is less than 10 m

Table 2 *continued*

Aerial Image Assessment Method Metric	**A**	**B**	**C**	**D**
Evidence of Channel Alteration	No channelization is evident OR minor alteration present, usually piers of bridges on span crossings or unpaved trail/road crossings	Some channelization present, usually in areas of bridge abutments and riprap placement of road crossings. About 1 - 40% channelized or altered.	Channelization is moderately extensive. About 40 - 80% of the riparian reach is channelized or altered. Some instream habitat still present.	Extensive channelization is present; over 80% of the riparian reach is channelized or altered. No instream habitat is present.
Lateral Hydrologic Connectivity	No unnatural levee indicators	Less than 50% of RA boundary comprised of unnatural levee indicators	50 - 90% of RA boundary comprised of unnatural levee indicators	Over 90% of RA boundary comprised of unnatural levee indicators
Vegetation Development	RA dominated by trees	RA dominated by trees and shrubs	RA dominated by shrubs and herbs	No vegetation
Percent Tree and Shrub Cover	91 - 100% of non-channel riparian area covered by trees and shrubs	76 - 90 % of non-channel riparian area covered by trees and shrubs	60 - 75 % of non-channel riparian area covered by trees and shrubs	0 - 59 % of non-channel riparian area covered by trees and shrubs

Table 4.3. Methods for calculating AIAM scores. Letters in parentheses after Landscape Structure metrics indicate variables in algorithm for calculating corresponding raw score.

Attribute:	*Landscape Structure*	*Hydrologic Structure*	*Vegetation Structure*
Metrics:	Stream Corridor Continuity (D)	Water source	Vegetation Development
	Percent AA with buffer (A)	Average Riparian Zone Width	Percent Tree and Shrub Cover
	CRAM Average Buffer Width (B)	Evidence of Channel Alteration	
	Buffer Condition (C)	Lateral Hydrologic Connectivity	
Raw Score:	= D + [C x (A x B)^(½)]^(½)	= sum of numeric scores	= sum of numeric scores
Attribute Score:	= (Raw Score/24) x 100	= (Raw Score/48) x 100	= (Raw Score/24) x 100
Overall AIAM Index Score = Average of Three Attribute Scores			

Table 4.4. Examples of features that should and should not be used to establish RA boundaries for Riverine wetlands. Content is from CRAM Riverine Field Book v. 6.1 (California Wetlands Monitoring Workgroup 2013).

Features that should be used to establish RA boundaries	**Features that should not be used to establish RA boundaries**
• major changes in riverine entrenchment, confinement, degradation, aggradation, slope, or bed form • major channel confluences • diversion ditches • end-of-pipe large discharges • water falls • open water areas more than 30 m wide on average or broader than the wetland • transitions between wetland types • weirs, culverts, dams, drop- structures, levees, and other flow control, grade control, or water height control structures	• at-grade, unpaved, single-lane, infrequently used roadways or crossings • bike paths and jogging trails at grade • bare ground within what would otherwise be the AA boundary • equestrian trails • fences (unless designed to obstruct the movement of wildlife) • property boundaries, unless access is not allowed • riffle (or rapid) – glide – pool transitions in a riverine wetland • spatial changes in land cover or land use along the wetland border • state and federal jurisdictional boundaries

Table 4.5. CRAM attributes, metrics, and sub-metrics. Numbers in parenthesis indicate the range of scores available for each data type (California Wetlands Monitoring Workgroup 2013). The CRAM Assessment Area (AA) is 100-200 meters long and includes the channel and adjacent riparian area that accounts for allochthonous input to the channel and its immediate floodplain.

Attribute	Metric	Submetric
Buffer and Landscape Context (25-100)	Stream Corridor Continuity (3-12)	
	Buffer (6-24)	Percent of AA with Buffer (3-12)
		Average Buffer Width (3-12)
		Buffer Condition (3-12)
Hydrology (25-100)	Water Source (3-12)	
	Channel Stability (3-12)	
	Hydrologic Connectivity (3-12)	
Physical Structure (25-100)	Structural Patch Richness (3-12)	
	Topographic Complexity (3-12)	
Biotic Structure (25-100)	Plant Community Composition (3-12)	Number of Plant Layers (3-12)
		Number of Co-dominant Species (3-12)
		Percent Invasion (3-12)
	Horizontal Interspersion (3-12)	
	Vertical Biotic Structure (3-12)	

Table 4.6. Spearman’s Rank correlation coefficients indicating the correlation of AIAM to CRAM data. Analyses are based on stream reaches in southern California (n = 30). AIAM attributes are bold. Asterisks (*) denote that items being compared are measured the same way in both methods.

AIAM Component	*CRAM Component*	r_s	p
AIAM Index	CRAM Index	0.367	0.046
	Average of Buffer and Landscape Context, Hydrology, and Biotic Structure Scores	0.437	0.016
Landscape Structure	Buffer and Landscape Context*	0.659	0.000
Stream Corridor Continuity	Stream Corridor Continuity*	0.452	0.012
Percent AA with Buffer	Percent AA with Buffer*	0.378	0.039
Buffer Width	Buffer Width*	0.796	0.000
Buffer Condition	Buffer Condition*	0.420	0.021
Hydrologic Structure	Hydrology	0.543	0.002
Water Source	Water Source*	0.775	0.000
Average Riparian Zone Width	Hydrology	0.334	0.071
	Hydrologic Connectivity	0.585	0.001
Evidence of Channel Alteration	Hydrology	0.487	0.006
	Hydrologic Connectivity	0.291	0.119
Lateral Hydrologic Connectivity	Hydrology	0.420	0.021
	Hydrologic Connectivity	0.213	0.259
Vegetation Structure	Biotic Structure	0.185	0.901
Vegetation Development	Biotic Structure	-0.007	0.972
	Vertical Biotic Structure	0.220	0.242
Percent Tree and Shrub Cover	Biotic Structure	-0.019	0.921
	Vertical Biotic Structure	0.117	0.538

Table 4.7. Anticipated response of AIAM metrics to riparian restoration efforts.

AIAM Attribute	AIAM Metric	Anticipated Restoration Response
Landscape Structure	Stream Corridor Continuity	none
	Percent AA with buffer	none
	CRAM Average Buffer Width	none
	Buffer Condition	none
Hydrologic Structure	Water source	none
	Average Riparian Zone Width	Increased width
	Evidence of Channel Alteration	Reduced channel alteration
	Lateral Hydrologic Connectivity	none
Vegetation Structure	Vegetation Development	Maturation of vegetation over time
	Percent Tree and Shrub Cover	Increase in cover area

Figures

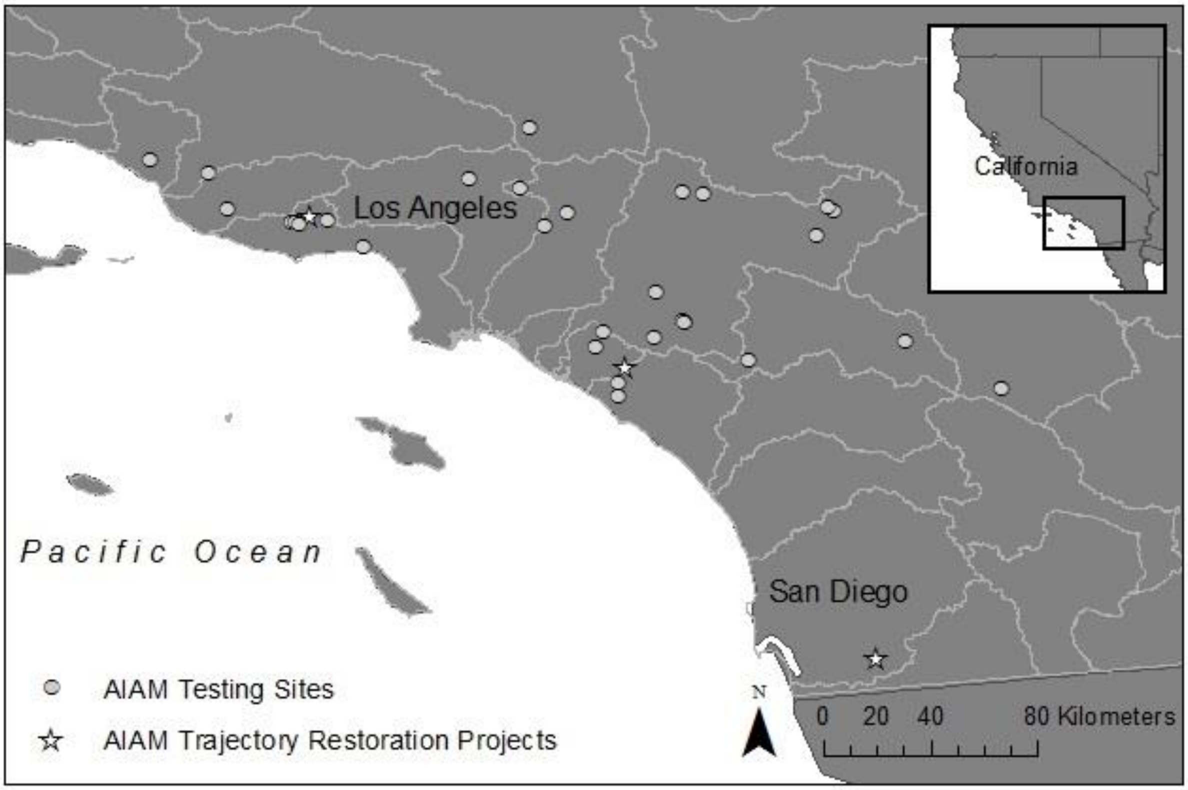


Figure 4.1. Locations of sites used to test AIAM and determine AIAM-based stream restoration trajectories. Area watersheds are outlined in gray.

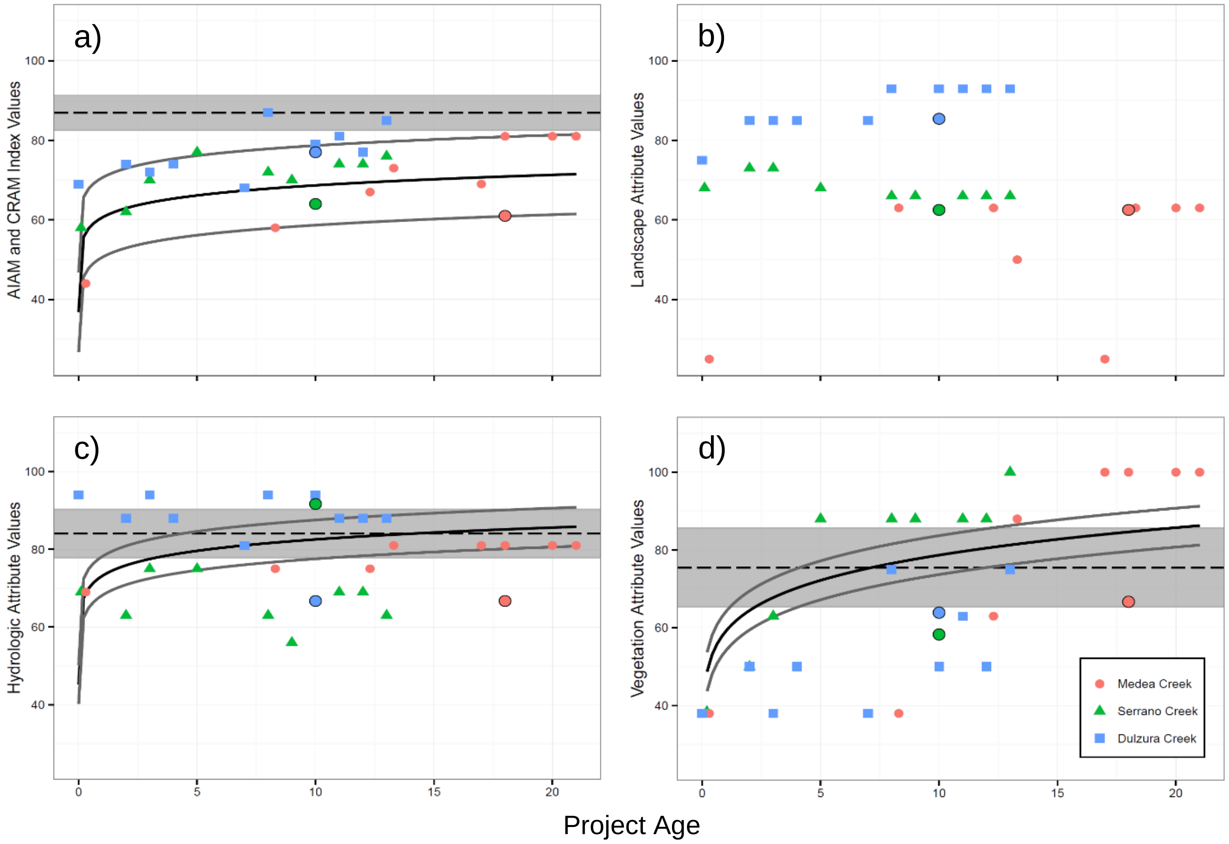
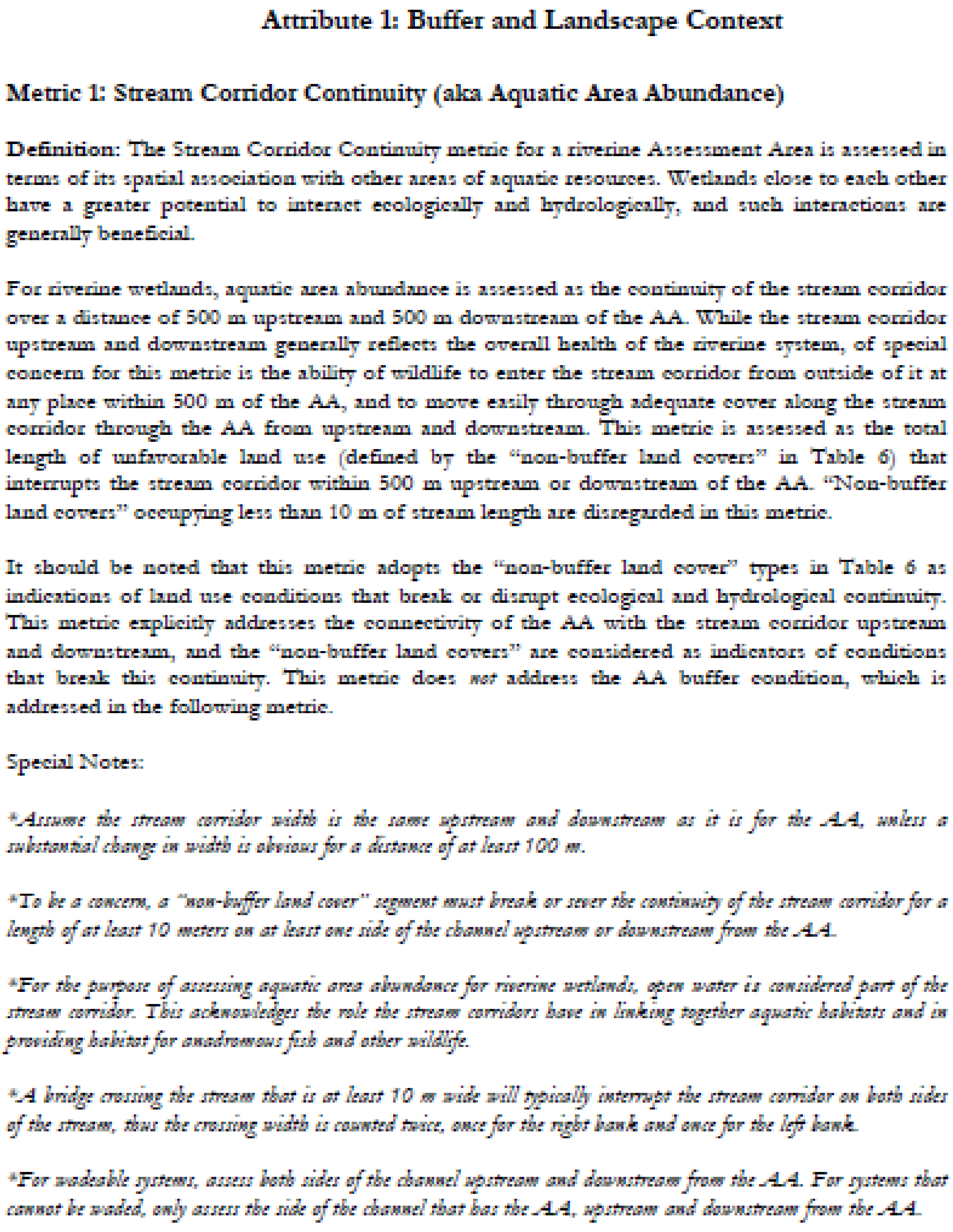


Figure 4.2. AIAM time-series, single-site performance trajectories and CRAM chronosequence hypothetical performance curves (solid black line) with CRAM reference envelopes (gray band). CRAM performance curves include error bands (solid gray line) of ± 10 for the index ± 5 for attributes. The CRAM reference envelopes (gray band) are composed of the 95% confidence interval around the mean reference value (dashed black), and represent high stream conditions in southern California. Graphs juxtapose analogous components: a) AIAM and CRAM indices, b) AIAM Landscape Structure and CRAM Buffer and Landscape Context (no Buffer and Landscape Context performance curve was developed), c) AIAM Hydrologic Structure and CRAM Hydrology, and d) AIAM Vegetation Structure and CRAM Biotic Structure. Circles outlined in black represent CRAM scores measured in 2012. Some points overlap.

Appendices

Appendix 4A: Buffer and Landscape Context Assessment Guidelines from CRAM Riverine Field Book v. 6.1 (pp. 11-19)



Attribute 1: Buffer and Landscape Context

Metric 1: Stream Corridor Continuity (aka Aquatic Area Abundance)

Definition: The Stream Corridor Continuity metric for a riverine Assessment Area is assessed in terms of its spatial association with other areas of aquatic resources. Wetlands close to each other have a greater potential to interact ecologically and hydrologically, and such interactions are generally beneficial.

For riverine wetlands, aquatic area abundance is assessed as the continuity of the stream corridor over a distance of 500 m upstream and 500 m downstream of the AA. While the stream corridor upstream and downstream generally reflects the overall health of the riverine system, of special concern for this metric is the ability of wildlife to enter the stream corridor from outside of it at any place within 500 m of the AA, and to move easily through adequate cover along the stream corridor through the AA from upstream and downstream. This metric is assessed as the total length of unfavorable land use (defined by the "non-buffer land covers" in Table 6) that interrupts the stream corridor within 500 m upstream or downstream of the AA. "Non-buffer land covers" occupying less than 10 m of stream length are disregarded in this metric.

It should be noted that this metric adopts the "non-buffer land cover" types in Table 6 as indications of land use conditions that break or disrupt ecological and hydrological continuity. This metric explicitly addresses the connectivity of the AA with the stream corridor upstream and downstream, and the "non-buffer land covers" are considered as indicators of conditions that break this continuity. This metric does *not* address the AA buffer condition, which is addressed in the following metric.

Special Notes:

**Assume the stream corridor width is the same upstream and downstream as it is for the AA, unless a substantial change in width is obvious for a distance of at least 100 m.*

**To be a concern, a "non-buffer land cover" segment must break or sever the continuity of the stream corridor for a length of at least 10 meters on at least one side of the channel upstream or downstream from the AA.*

**For the purpose of assessing aquatic area abundance for riverine wetlands, open water is considered part of the stream corridor. This acknowledges the role the stream corridors have in linking together aquatic habitats and in providing habitat for anadromous fish and other wildlife.*

**A bridge crossing the stream that is at least 10 m wide will typically interrupt the stream corridor on both sides of the stream, thus the crossing width is counted twice, once for the right bank and once for the left bank.*

**For wadeable systems, assess both sides of the channel upstream and downstream from the AA. For systems that cannot be waded, only assess the side of the channel that has the AA, upstream and downstream from the AA.*

Table 4: Steps to assess Stream Corridor Continuity for riverine wetlands.

Step 1	Extend the average width of the AA 500 m upstream and downstream, regardless of the land cover types that are encountered (see Figure 4).
Step 2	Using the site imagery, identify all the places where "non-buffer land covers" (see Table 6) at least 10 m long (measured parallel to the stream channel) interrupt the stream corridor within the average width of your AA on **either side of the channel** in the extended AA. Disregard interruptions of the stream corridor that are less than 10 m wide. Do not consider open water as an interruption. It is possible for a non-buffer segment to cross one or both sides of a two-sided AA (see Figure 4). If a non-buffer segment crosses both sides it must be counted twice (one time for each side of the stream corridor). For one-sided riverine AAs, assess only one side of the system.
Step 3	Estimate the length of each "non-buffer" segment identified in Step 2, and enter the estimates in the worksheet for this metric.

Figure 4: Diagram of method to assess Stream Corridor Continuity of riverine wetlands. This example shows that about 400 m of "non-buffer land cover" disrupts the stream corridor within 500 m downstream of the AA. This is due to the large parking lot that impinges on the south side of the stream in addition to two bridge crossings that disrupt the buffer on both sides of the stream. There is a 10 m non-buffer segment in the stream corridor upstream of the AA due to a bridge crossing (10 m for each side of the stream, adding up to a 20 m break total). The upstream segment of the stream has an intact stream corridor (green stream reach) upstream from the AA, except for the bridge directly upstream (black area).

Worksheet for Stream Corridor Continuity Metric for Riverine Wetlands

Lengths of Non-buffer Segments For Distance of 500 m Upstream of AA		**Lengths of Non-buffer Segments For Distance of 500 m Downstream of AA**	
Segment No.	Length (m)	Segment No.	Length (m)
1		1	
2		2	
3		3	
4		4	
5		5	
Upstream Total Length		Downstream Total Length	

Table 5a: Rating for Stream Corridor Continuity for Wadeable Riverine Wetlands.

Rating	For Distance of 500 m Upstream of AA:	For Distance of 500 m Downstream of AA:
A	The combined total length of all non-buffer segments is less than 100 m.	The combined total length of all non-buffer segments is less than 100 m.
B	The combined total length of all non-buffer segments is less than 100 m.	The combined total length of all non-buffer segments is between 100 m and 200 m.
	OR	
	The combined total length of all non-buffer segments is between 100 m and 200 m.	The combined total length of all non-buffer segments is less than 100 m.
C	The combined total length of all non-buffer segments is between 100 m and 200 m.	The combined total length of all non-buffer segments is between 100 m and 200 m.
D	The combined total length of non-buffer segments is greater than 200 m.	any condition
	OR	
	any condition	The combined total length of non-buffer segments is greater than 200 m.

Table 5b: Rating of Stream Corridor Continuity for Non-wadeable Riverine (1-sided AAs).

Rating	For Distance of 500 m Upstream of AA:	For Distance of 500 m Downstream of AA:
A	The combined total length of all non-buffer segments is less 50 m.	The combined total length of all non-buffer segments is less than 50 m.
B	The combined total length of all non-buffer segments is less than 50 m.	The combined total length of all non-buffer segments is between 50 m and 100 m.
	OR	
	The combined total length of all non-buffer segments is between 50 m and 100 m.	The combined total length of all non-buffer segments is less than is less than 50 m.
C	The combined total length of all non-buffer segments is between 50 m and 100 m.	The combined total length of all non-buffer segments is between; 50 m and 100 m.
D	The combined total length of non-buffer segments is greater than 100 m.	any condition
	OR	
	any condition	The combined total length of non-buffer segments is greater than 100 m.

Metric 2: Buffer

Definition: The buffer is the area adjoining the AA that is in a natural or semi-natural state and currently not dedicated to anthropogenic uses that would severely detract from its ability to entrap contaminants, discourage forays into the AA by people and non-native predators, or otherwise protect the AA from stress and disturbance.

To be considered as buffer, a suitable land cover type must be at least 5 m wide starting at the edge of the AA extending perpendicular to the channel and extend along the perimeter of the AA (measured parallel to the channel) for at least 5 m. The maximum width of the buffer is 250 m. At distances beyond 250 m from the AA, the buffer becomes part of the landscape context of the AA.

Special Notes:

**Any area of open water at least 30 m wide that is adjoining the AA, such as a lake, large river, or large slough, is not considered in the assessment of the buffer. Such open water is considered to be neutral, and is neither part of the wetland nor part of the buffer. There are three reasons for excluding large areas of open water (i.e., more than 30 m wide) from Assessment Areas and their buffers.*

1) *Assessments of buffer extent and buffer width are inflated by including open water as a part of the buffer.*
2) *While there may be positive correlations between wetland stressors and the quality of open water, quantifying water quality generally requires laboratory analyses beyond the scope of rapid assessment.*
3) *Open water can be a direct source of stress (i.e., water pollution, waves, boat wakes) or an indirect source of stress (i.e., promotes human visitation, encourages intensive use by livestock looking for water, provides dispersal for non-native plant species), or it can be a source of benefits to a wetland (e.g., nutrients, propagules of native plant species, water that is essential to maintain wetland hydroperiod, etc.).*

**However, any area of open water that is within 250 m of the AA but is not directly adjoining the AA is considered part of the buffer.*

Submetric A: Percent of AA with Buffer

Definition: This submetric is based on the relationship between the extent of buffer and the functions provided by aquatic areas. Areas with more buffer typically provide more habitat values, better water quality and other valuable functions. This submetric is scored by visually estimating from aerial imagery (with field verification) the percent of the AA that is surrounded by at least 5 meters of buffer land cover (Figure 5). The upstream and downstream edges of the AA are not included in this metric, only the edges parallel to the stream.

Figure 5: Diagram of approach to estimate Percent of AA with Buffer for Riverine AAs. The white line is the edge of the AA, the red line indicates where there is less than 5 meters of buffer land cover adjacent to the AA, while the green line indicates where buffer is present. In this example 55% of the AA has buffer.

Table 6: Guidelines for identifying wetland buffers and breaks in buffers.

**Please refer to the CRAM Photo Dictionary at www.cramwetlands.org for photos of each of the following examples.*

Examples of Land Covers Included in Buffers	**Examples of Land Covers Excluded from Buffers** Notes: buffers do not cross these land covers; areas of open water adjacent to the AA are not included in the assessment of the AA or its buffer.
• at-grade bike and foot trailswith light traffic • horse trails • natural upland habitats • nature or wildland parks • range land and pastures • railroads (with infrequent use: 2 trains per day or less) • roads not hazardous to wildlife, such as seldom used rural roads, forestry roads or private roads • swales and ditches • vegetated levees	• commercial developments • fences that interfere with the movements of wildlife (i.e. food safety fences that prevent the movement of deer, rabbits and frogs) • intensive agriculture (row crops, orchards and vineyards) • golf courses • paved roads (two lanes or larger) • active railroads (more than 2 trains per day) • lawns • parking lots • horse paddocks, feedlots, turkey ranches, etc. • residential areas • sound walls • sports fields • urbanized parks with active recreation • pedestrian/bike trails (with heavy traffic)

Percent of AA with Buffer Worksheet.

In the space provided below make a quick sketch of the AA, or perform the assessment directly on the aerial imagery; indicate where buffer is present, estimate the percentage of the AA perimeter providing buffer functions, and record the estimate amount in the space provided.

Percent of AA with Buffer: ________ %

Table 7: Rating for Percent of AA with Buffer.

Rating	Alternative States (not including open-water areas)
A	Buffer is 75 - 100% of AA perimeter.
B	Buffer is 50 – 74% of AA perimeter.
C	Buffer is 25 – 49% of AA perimeter.
D	Buffer is 0 – 24% of AA perimeter.

Submetric B: Average Buffer Width

Definition: The average width of the buffer adjoining the AA is estimated by averaging the lengths of eight straight lines drawn at regular intervals around the AA from its perimeter outward to the nearest non-buffer land cover or 250 m, whichever is first encountered. It is assumed that the functions of the buffer do not increase significantly beyond an average width of about 250 m. The maximum buffer width is therefore 250 m. The minimum buffer width is 5 m, and the minimum length of buffer along the perimeter of the AA is also 5 m. Any area that is less than 5 m wide and 5 m long is too small to be a buffer. See Table 6 above for more guidance regarding the identification of AA buffers.

Table 8: Steps to estimate Buffer Width for riverine wetlands

Step 1	Identify areas in which open water is directly adjacent to the AA, with <5 m between the edge of the AA and the open water. **These areas are excluded from buffer calculations.**
Step 2	From the previous sub-metric, identify the areas that have buffer adjacent to the AA.
Step 3	For the area that has been identified as having buffer, draw straight lines 250 m in length perpendicular to the axis of the stream channel at regularly spaced intervals starting at the AA boundary. For one-sided riverine AAs, draw four lines; for AAs that include both sides of the stream draw eight lines (see Figure 6 below).
Step 4	Estimate the length of each of the lines as they extend away from the AA. Record these lengths on the worksheet below.
Step 5	Calculate the average buffer width. Record this width on the worksheet below.

Figure 6: Diagram of approach to estimate Average Buffer Width for Riverine AAs. Continuing with the example from above, draw 8 lines evenly distributed within the buffer (red lines indicate where no buffer is present). The lines end in this example when they encounter active row crop agriculture, a lawn, and some fencing that restricts wildlife movement.

Worksheet for calculating average buffer width of AA

Line	Buffer Width (m)
A	
B	
C	
D	
E	
F	
G	
H	
Average Buffer Width *Round to the nearest integer*	

Table 9: Rating for average buffer width.

Rating	Alternative States
A	Average buffer width is 190 – 250 m.
B	Average buffer width 130 – 189 m.
C	Average buffer width is 65 – 129 m.
D	Average buffer width is 0 – 64 m.

Submetric C: Buffer Condition

Definition: The condition of a buffer is assessed according to the extent and quality of its vegetation cover, the overall condition of its substrate, and the amount of human visitation. Buffer conditions are assessed only for the portion of the wetland border that has **already been identified as buffer** (i.e., as in Figure 7). Thus, evidence of direct impacts (parking lots, buildings, etc.) by people are excluded from this metric, because these features are not included as buffer land covers; instead these impacts are included in the Stressor Checklist. If there is no buffer, assign a score of D.

Figure 7: Diagram of method to assess Buffer Condition for Riverine AAs. Continuing with the example from above, this submetric assesses the condition of the buffer only where it was found to be present in the two previous steps (the shaded areas shown).

Table 10: Rating for Buffer Condition.

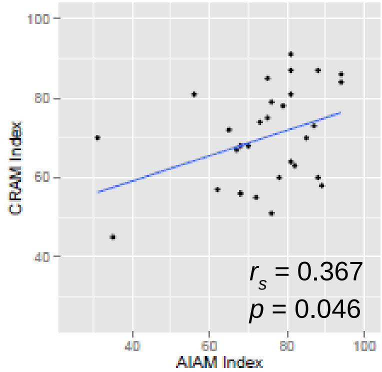
**Please refer to the CRAM Photo Dictionary at www.cramwetlands.org for photos of each of the following ratings.*

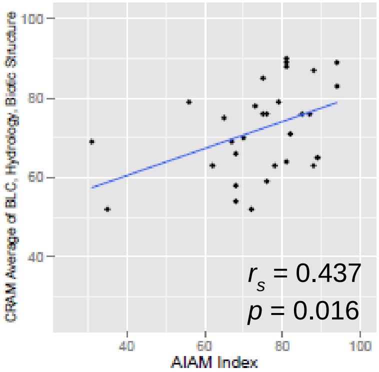
Rating	Alternative States
A	Buffer for AA is dominated by native vegetation, has undisturbed soils, and is apparently subject to little or no human visitation.
B	Buffer for AA is characterized by an intermediate mix of native and non-native vegetation (25% to 75% non-native), but mostly undisturbed soils and is apparently subject to little or low impact human visitation.
	OR
	Buffer for AA is dominated by native vegetation, but shows some soil disturbance and is apparently subject to little or low impact human visitation.
C	Buffer for AA is characterized by substantial (>75%) amounts of non-native vegetation AND there is at least a moderate degree of soil disturbance/compaction, and/or there is evidence of at least moderate intensity of human visitation.
D	Buffer for AA is characterized by barren ground and/or highly compacted or otherwise disturbed soils, and/or there is evidence of very intense human visitation, or there is no buffer present.

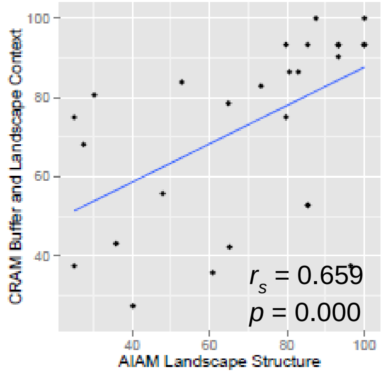
Appendix 4B: Names and Locations of Sites in AIAM-CRAM Correlation Analyses

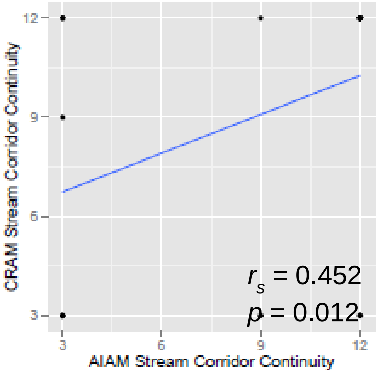
eCRAM ID	AA Name	latitude	longitude
2986	SMC09091	33.71374	-117.7954
2906	Peters Canyon Wash Mitigation	33.76429	-117.77043
3135	Corona-Rincon CRAM Area 2	33.89906	-117.58989
2832	Dairy Fork Tributary, Aliso Creek	33.5935	-117.71533
3510	Triunfo Creek	34.13221	-118.82049
2919	Wet Cat West/Country Village Mitigation	33.54442	-117.71606
3019	SGLT510	34.12102	-117.96335
3511	Triunfo Creek	34.1329	-118.81177
3323	San Jacinto River	33.66509	-117.27621
3358	Mill Creek	34.08873	-117.04233
3337	Lytle Creek	34.23759	-117.4983
3170	Deleo 1	33.7938	-117.49276
3187	Silverado Creek	33.74626	-117.59282
3174	Cajon Wash	34.23288	-117.42958
3204	Las Virgenes 37670	34.14132	-118.70116
3116	Santa Clara River	34.30159	-119.10426
3111	Ventura River	34.34639	-119.30023
3028	Deer Creek 0674	34.17588	-116.98454
2875	Lee Lake CRAM 1	33.80203	-117.49641
3213	Topanga Canyon 23297	34.05028	-118.58105
3335	Strawberry Creek	33.7296	-116.74715
3020	SMC00428	34.24704	-118.04915
3167	Bear Creek	34.1832	-117.00963
3316	Horse Thief Creek	33.57434	-116.41685
2834	Little Rock Creek 1195	34.45388	-118.01704
3011	SMC05640	34.28405	-118.22214
3171	Potero Valley Creek	34.12742	-118.79659
3114	Calleguas Creek	34.1797	-119.04045
3203	Deleo 3	33.79735	-117.49336
3018	SGUT505	34.1689	-117.88866

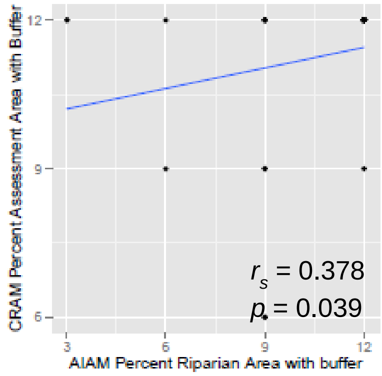
Appendix 4C: Scatterplots Comparing Select AIAM and CRAM Components

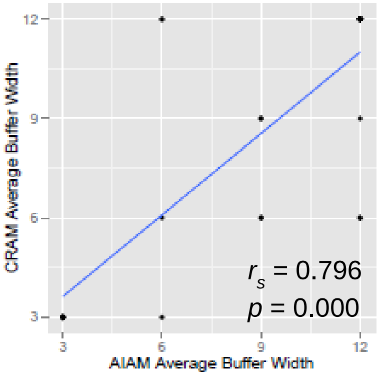


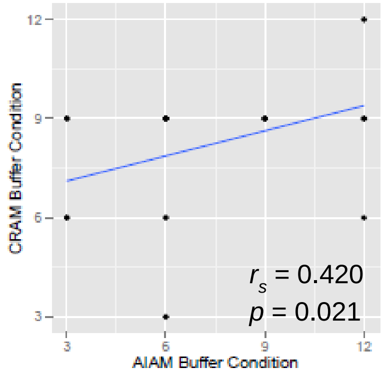


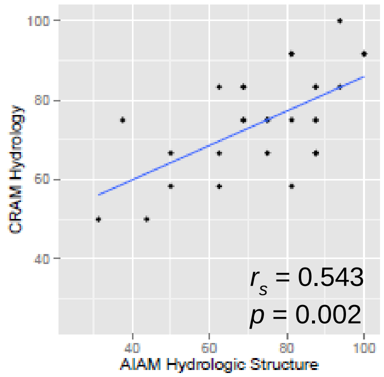


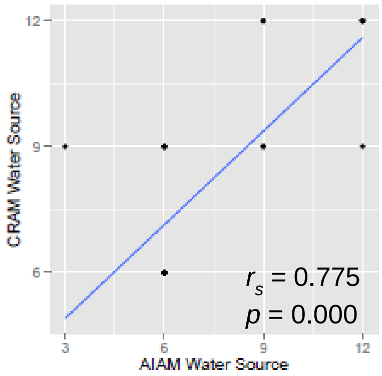


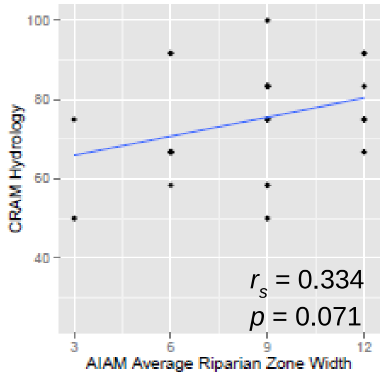


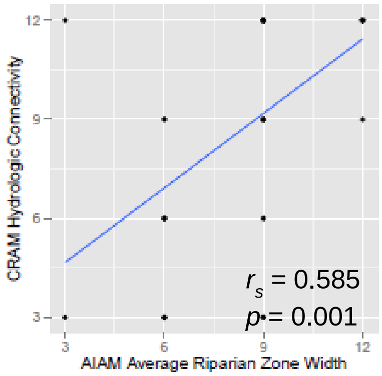


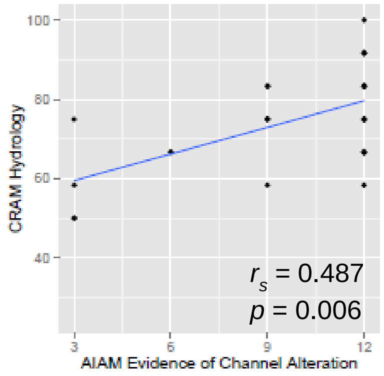


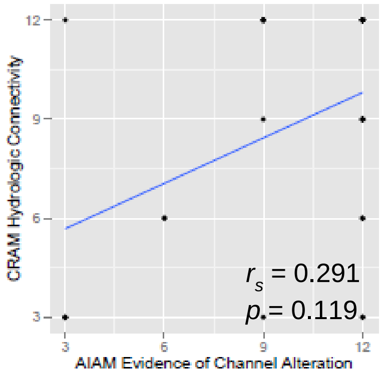

CRAM Hydrology
100
80
60
40
AIAM Hydrologic Structure
40
60
80
100
r_s = 0.543
p = 0.002

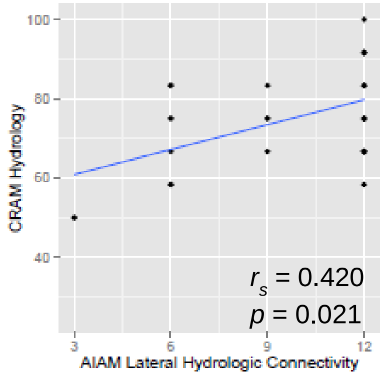

CRAM Water Source
12
9
6
AIAM Water Source
3
6
9
12
r_s = 0.775
p = 0.000

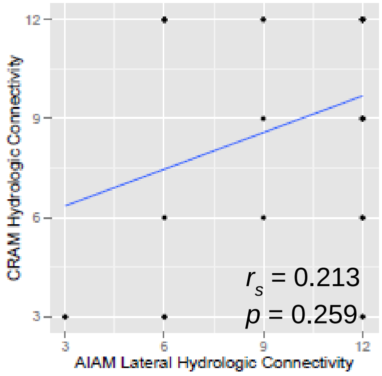

CRAM Hydrology
100
80
60
40
AIAM Average Riparian Zone Width
3
6
9
12
r_s = 0.334
p = 0.071

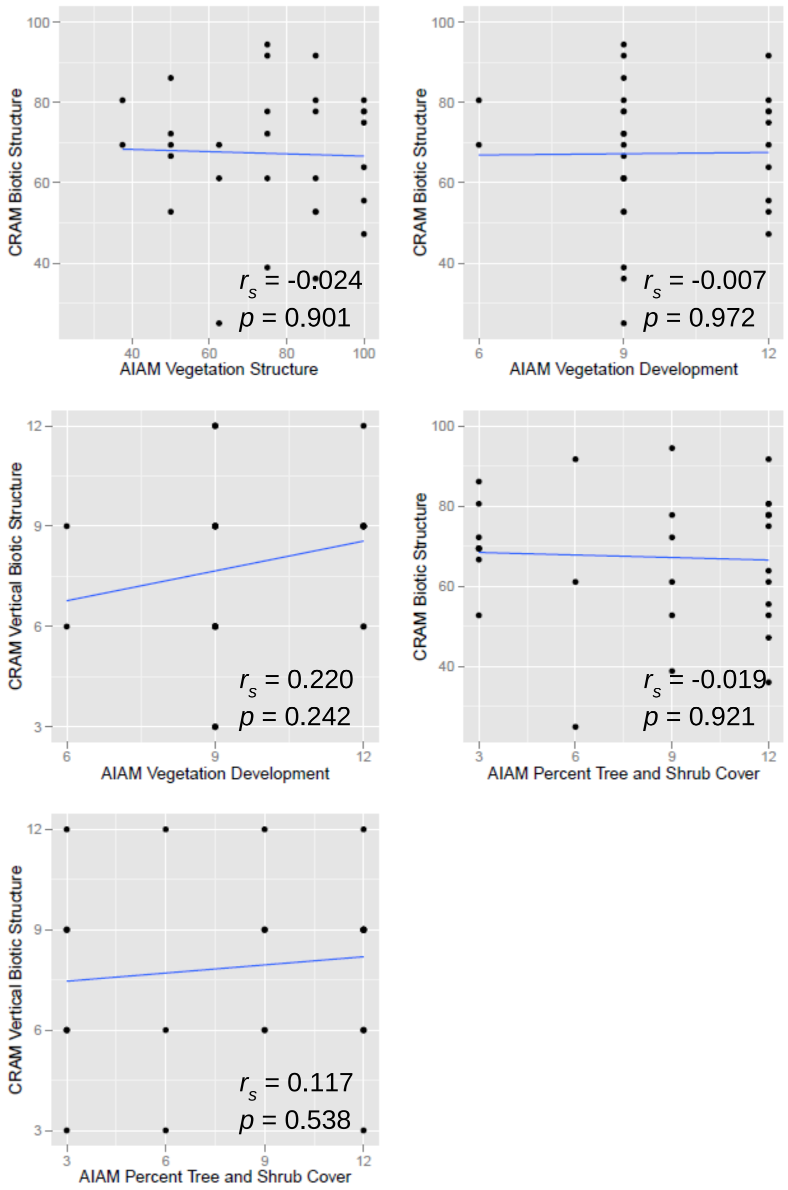

CRAM Hydrologic Connectivity
12
9
6
3
AIAM Average Riparian Zone Width
3
6
9
12
r_s = 0.585
p = 0.001


CRAM Hydrology
100
80
60
40
AIAM Evidence of Channel Alteration
3
6
9
12
r_s = 0.487
p = 0.006


CRAM Hydrologic Connectivity
12
9
6
3
AIAM Evidence of Channel Alteration
3
6
9
12
r_s = 0.291
p = 0.119

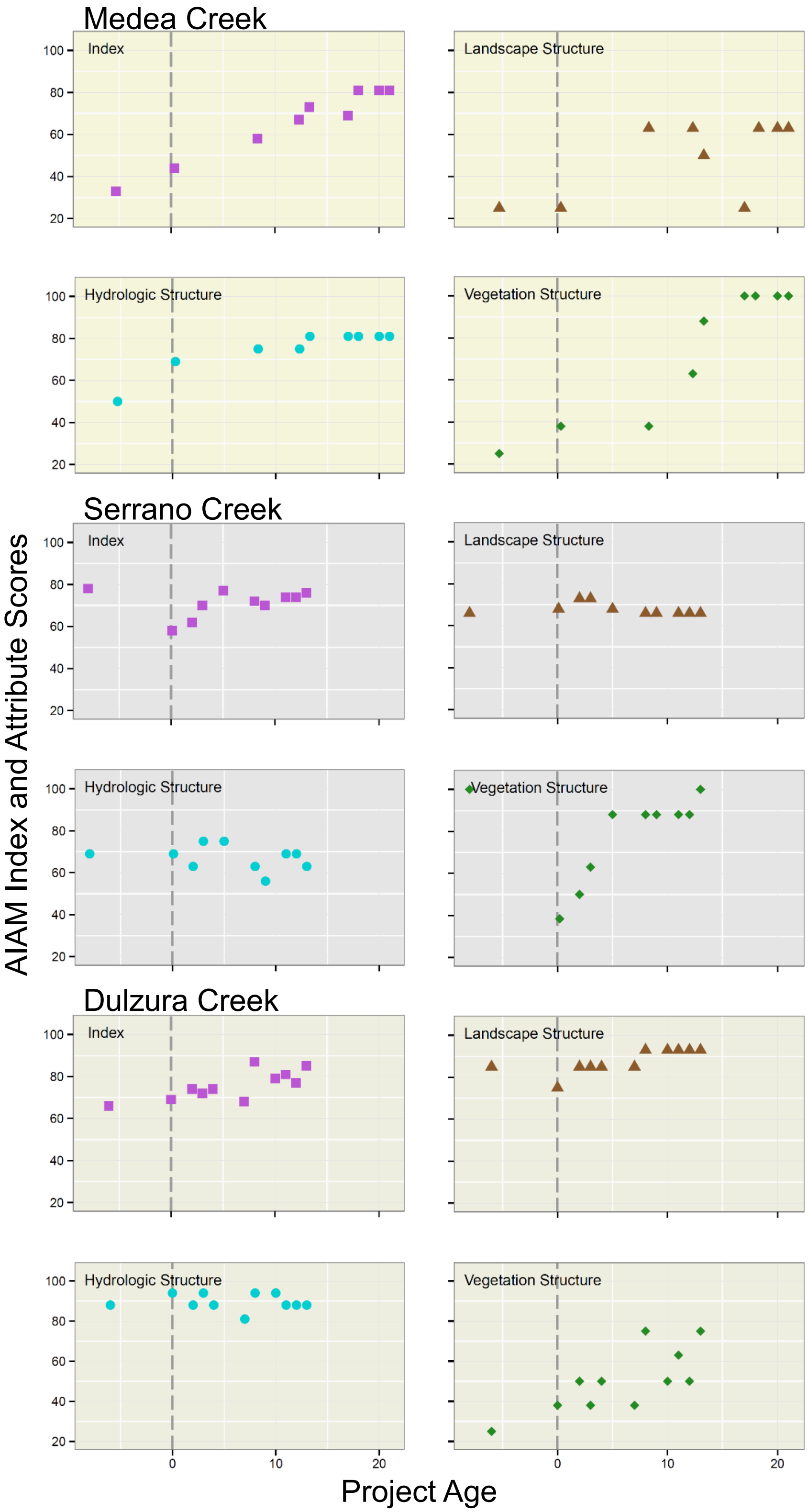

CRAM Hydrology
100
80
60
40
AIAM Lateral Hydrologic Connectivity
3
6
9
12
r_s = 0.420
p = 0.021


CRAM Hydrologic Connectivity
12
9
6
3
AIAM Lateral Hydrologic Connectivity
3
6
9
12
r_s = 0.213
p = 0.259



Note: Blue lines are linear regression

Appendix 4D: AIAM-based Restoration Trajectories of Three Projects



CHAPTER FIVE: CLOSING

This dissertation contributed to compensatory mitigation by assessing its implementation and producing tools that can be used for mitigation project management. The analysis of compensatory mitigation in southern California revealed a shift in compensation practices from before to after the 2008 Final Rule. Mitigation through third party credit purchase did not increase as expected, and off-site permittee-responsible mitigation increased to be the most prevalent choice. These patterns may have been influenced by multiple factors including the compensation hierarchy introduced by the Final Rule, and economic dynamics. We developed stream restoration performance curves that illustrate the hypothetical development of high performing projects using the California Rapid Assessment Method (CRAM). The curves imply that the CRAM index and hydrology and biotic structure attributes reach reference levels within 30 years following restoration, but that the physical structure attribute will not. The curves can be used by restoration practitioners and project managers to forecast restoration development and set performance standards. We also developed a remote aerial imagery assessment method (AIAM) that captures the ecological condition of small riparian areas quickly and inexpensively. AIAM can record the changing condition of real restoration projects over time, and may be used to supplement project monitoring practices.

While this dissertation focused primarily on compensatory mitigation, the ultimate national goal is to cease the net loss of aquatic resources. Due in part to the §404 program, the loss of these resources in the United States has been mitigated. A series of national Wetland Status and Trends reports have revealed that national wetland acres and rates of loss decreased from the 1950's to present (Frayer *et al.* 1983; Dahl & Johnson 1991; Dahl 2000, 2006, 2011). Dahl (2006) even reported an annual net gain in wetland acres between 1998-2004, and attributed the increase to creation, enhancement, and restoration through both regulatory and non-regulatory restoration programs. However, pond construction by agricultural conservation programs provided the acres that set gains above losses during that time period. Dahl (2006) highlighted that the replacement of vegetated wetlands with ponds results in a change of wetland classification, and that ponds do not provide the same values and functions as vegetated wetlands. Furthermore, the report also emphasized that the quality of existing wetlands nationwide was unknown, and underscored the need to assess their condition. The Status and Trends report for 2004-2009 indicated that annual net loss resumed (Dahl 2011). A look into wetland replacement and compensatory mitigation outcomes reveals continued loss of both area and functions (Turner, Redmond & Zedler 2001). Studies of created wetland function have concluded that replacement wetlands fall short of natural wetland quality (Zedler & Callaway 1999; Hossler *et al.* 2011). Studies evaluating compensatory mitigation project success have documented projects failing in several respects, including ecological and area replacement (Sudol & Ambrose 2002; Ambrose, Callaway & Lee 2007). Achievement of the "no net loss" goal continues to evade our efforts. I will briefly discuss two approaches to pursuing this goal and how the work of this dissertation connects to each.

A first approach to halting net loss is to optimize the methods and mechanisms of wetland replacement through compensatory mitigation. The results of this dissertation primarily contribute to this approach. The analysis of compensatory mitigation in southern California provides a snapshot of how regulations intended to address wetland loss by improving compensation have been enacted. The 2008 Final Rule attempts to better compensatory mitigation by elevating the watershed approach and mechanisms of compensation thought to have lower risks of failure (i.e., third party mitigation). The shift in mitigation types observed was not in complete agreement with the predicted patterns based on the compensation hierarchy. Our results can help regional compensatory mitigation project managers and watershed planners decide what additional mitigation information to evaluate, and whether to seek adjustments to local compensation mechanisms, such as more availability of third party credits. The performance curves and aerial imagery assessment method are tools to better the management of aquatic resource replacement projects. They can be used for project monitoring, site selection, and other facets of stream restoration. Although the services provided by naturally occurring aquatic resources are not fully replaced in created wetlands, it is important to improve compensation and restoration for the best results possible.

A second approach to achieving “no net loss” is to reduce or eliminate impacts. Within the mitigation sequence, this can be accomplished by focusing on avoidance and minimization. The connection between avoidance and “no net loss” is simple: without impacts to resources, there is theoretically no loss. Little is known about the frequency and extent of avoidance and minimization. They are difficult to assess because a uniform process to measure them has not been coordinated. Perhaps their implementation should be documented in a consistent manner as part of the §404 permitting process. While current regulations merely recommend (i.e., do not require) avoidance and minimization, additional efforts can promote this practice. Clare *et al.* (2011) suggested promoting avoidance through watershed planning to inform land management, through wetland valuation, and by increasing public appreciation. Bronner *et al.* (2013) suggested protecting streams through local zoning and floodplain regulations, and through financial incentives to re-use already developed sites. Also, permittees might lean more towards avoidance and minimization if compensatory mitigation becomes more expensive. Studies have indicated that five years is not long enough to know how well a project will perform and be sustained, and that compensatory mitigation does not fully compensate for lost aquatic resources. Longer required monitoring, higher mitigation ratios, higher ecological standards in mitigation planning, and more rigorous requirements for allowed forms of mitigation are ways to address these concerns, but also increase the cost and burden of responsibility connected with compensatory mitigation.

Impacts can also be eliminated through regulated preservation. Many are concerned that preservation is not compensation (and I agree). However, preservation is a powerful way to protect existing aquatic resources, thereby preventing future impacts. Efforts to conserve aquatic resources would benefit from required preservation acres in addition to compensation through restoration, enhancement, and creation. These acres should be above and beyond the conservation easements often placed on compensation projects. Mitigation banks are potentially good mechanisms to coordinate preservation, should this practice be elevated. They identify and obtain strategic parcels of property. Some already generate credits through preservation that could be specifically applied to meet preservation requirements, rather than to offset the loss of real wetlands.

Under the current regulatory system, District engineers are given latitude to determine what compensatory mitigation decisions are “appropriate” and “practicable” in multiple scenarios, including application of the watershed approach and avoidance and minimization. Critics of the Final Rule view this latitude as negative, fearing that regulatory officials will permit impacts without requiring sufficient mitigation. However, officials can also use this freedom to reduce potential impacts by promoting avoidance and minimization. They can also increase compensation project effectiveness by raising standards and requirements, with acceptable rationale. For example, the Final Rule specifies a minimum project monitoring period of five years, and gives district engineers the ability to reduce or extend the requirement. The restoration science community has established that restored wetlands do not reach maturity within five years, and recommended longer monitoring periods. Although this has not resulted universally in more monitoring, there have been cases where regulatory officials required additional monitoring time to see if adaptive management efforts were successful. We should continue to focus on establishing knowledge connected to the mitigation sequence so that regulators are well-informed to set requirements for, and propose alternatives to, compensatory mitigation.

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