Demonstration of an integrated watershed assessment using a three-tiered assessment framework

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ABSTRACT

Watersheds are useful templates for wetland protection and land use planning because they integrate cumulative effects and spatial patterns that better inform site-specific management decisions. Taking advantage of this template requires the ability to integrate assessments over multiple spatial scales. The goal of this study was to demonstrate the application of a three-tiered assessment paradigm that incorporates monitoring at varying spatial scales and intensities in the San Gabriel River watershed (Los Angeles County, California). Data on wetland extent and distribution, habitat condition using rapid assessment, and intensive site monitoring were used to show how different levels of assessment can be used together to provide a deeper contextual understanding of overall wetland condition. Wetland sites in the less developed portions of the watershed were of higher overall condition compared to sites located in the more urbanized portions of the watershed. GIS analysis revealed that percent impervious surface is a useful landscape-scale predictor of riverine wetland condition. Furthermore, rapid assessment metrics were significantly correlated with stressors found at sites. Significant correlations also existed between riverine habitat condition, water chemistry, and benthic macroinvertebrate communities across streams in this watershed. Results indicate that rapid assessment can be an efficient, cost-effective surrogate for intensively collected data. This study highlights the following key concepts: 1) application of a multiple indicator approach at different spatial scales and sampling intensities promotes a better understanding of the causal relationships between land use, wetland condition, and anthropogenic stress operating within a watershed; 2) a multi-tiered monitoring approach can provide a cost-effective means of integrating wetland status and trends assessments into routine watershed monitoring programs; and 3) a three-tiered approach to monitoring provides wetland managers with an effective organizational tool that can be used to make well-informed management decisions and prioritize management activities.

INTRODUCTION

Holistic watershed condition is often recommended as a strategy to maximize the effectiveness of wetland management (Thomas and Lamb 2005, Reinhardt *et al*. 2007). However, the goal of a holistic, integrated assessment is often difficult to meet for several reasons. First, most watershed monitoring and assessment is currently based on singular objectives (e.g., regulatory compliance) or indicators (e.g., benthic macroinvertebrates). Consequently, a comprehensive perspective of wetland condition is frequently not possible. Second, the foundation of any monitoring program is a wetland inventory, yet comprehensive inventories using common classification systems are typically lacking. Third, wetland monitoring often focuses on specific projects or sites (i.e., restoration, mitigation, acquisition) but neglects assessment of ambient (or general background) condition. Without information on the overall condition of wetlands throughout the region, there is no ecological context for interpreting the results of project-based assessments (Brooks *et al*. 2006, Fenessey *et al*. 2007). Fourth, limited historical information on historical extent makes it difficult to establish a meaningful baseline for assessing wetland change (Bedford and Preston 1988). Ultimately, resource managers will need a means to integrate various types of data collected at multiple tiers of assessment in order to make more informed management decisions.

Recognizing these challenges, the United States Environmental Protection Agency (USEPA) developed the Level 1-2-3 Framework and its ten basic elements of monitoring and assessment (USEPA 2006). The Level 1-2-3 paradigm moves beyond single dimension assessment toward a more integrated assessment of wetland resources across multiple scales. The information derived from these three monitoring tiers is complementary and interdependent.

Watersheds provide an excellent organizational template for application of the Level 1-2-3 toolkit at the state or regional scale (Kentula 2007). Because watershed-scale monitoring often involves multiple entities with variations in data collection and assessment methods, watersheds provide opportunities to integrate multiple objectives of disparate programs and policies in a coordinated way, leverage resources of a broad range of assessment efforts, and concurrently track ambient conditions and the performance of wetland projects. Although the benefits of applying these tools in programmatic watershed monitoring are recognized, there are relatively few examples of actual implementation (e.g., Wardrop *et al*. 2007). Therefore, demonstration projects are needed as tangible, real-world applications of this framework. In addition, demonstrations provide the empirical basis for determining how to most effectively integrate multiple layers of data into watershed assessment to guide future refinement of the process and methodologies used.

An opportunity for such demonstration exists in California because the tools for each of the three levels have been developed and applied in a series of related studies over the past three years: Standardized wetland and riparian mapping methodologies, methods to assess stressors on wetlands at a landscape scale (Level-1), the California Rapid Assessment Method (CRAM; Collins *et al*. 2007a) for wetlands (Level-2), and standardized, site-specific monitoring protocols (Level-3). Stein *et al*. (2007a) provide a detailed examination of the Level 1-2-3 framework for wetland monitoring and assessment and discuss how it can be integrated into the context of state and federal wetland programs in California.

In this paper, we present a demonstration of the Level 1-2-3-assessment framework and associated wetland monitoring tools in the San Gabriel River watershed (Los Angeles County, California) by compiling results of several recently completed studies into an integrated watershed assessment. Our overall objectives were to: 1) apply a multi-tiered data collection process within the Level 1-2-3 framework, 2) integrate three intensities of wetland monitoring data to identify possible causal relationships of riverine wetland condition, and 3) provide conclusions on how multiple tiers of monitoring data can be used to prioritize management activities within a watershed context.

Framework for Level 1-2-3 Monitoring

Level-1 analysis consists of resource inventories and maps that address questions about the extent and distribution of wetlands and other aquatic resources. Associated tools include standardized protocols for mapping modern and historic wetland and riparian habitats, land use, and land cover.

Level-2 consists of rapid wetland condition assessment, which uses cost-effective, field-based diagnostic tools to assess the overall condition and functional capacity of wetland and riparian areas using relatively simple field indicators. Rapid assessment can include the characterization of stressors (e.g., road crossings, tile drainage, ditching) known to limit wetland services.

Level-3 consists of intensive assessment that provides detailed information on wetland condition or specific functionality. Level-3 data can be used to validate landscape and rapid methods and diagnose the causes of wetland condition observed in Levels 1 and 2. This often involves the development of indices of biological integrity (IBIs).

Application of the three tiers can occur concomitantly and be integrated through different monitoring approaches. For example, the wetland and riparian inventories generated at Level-1 can be used to select sites for Level-2 and -3 assessments, either through probability-based surveys or targeted sampling approaches. Rapid assessment and intensive monitoring data can be collected at the same sites within a single monitoring program. Level-3 information is typically more meaningful when a baseline of regional wetland condition is available. This baseline can be generated through a survey of ambient wetland condition that employs a probabilistic sampling design.

METHODS

Study Area

The San Gabriel River watershed is approximately 689 mi^2 (1,785 km^2) and is the third largest coastal catchment in Los Angeles County, California. The basin is bound by the San Gabriel Mountains to the north, the San Bernardino Mountains to the east, the watershed divide with the Los Angeles River to the west, and the Pacific Ocean to the south. The headwaters originate at 444 m the San Gabriel Mountains and the main channel flows for 60 km through the heavily urbanized San Gabriel Valley and Los Angeles basin before entering the Pacific

Ocean in San Pedro Bay (Figure 1). Like most watersheds located in urbanized regions, wetlands and riparian areas in the San Gabriel River basin have been severely impacted by development and other forms of anthropogenic disturbance.

The San Gabriel River watershed can be roughly divided into two broad segments based on population density and landcover types. The upper third of the watershed is within the San Gabriel Mountains and National Forest with less than 100 people/mi^2. Consequently, this portion remains relatively undeveloped and the vegetation consists of extensive areas of undisturbed riparian, chaparral, and woodland habitats (Stephenson and Calcarone 1999), although the river channel itself has been modified with a series of flood control and water conservation dams. The remaining two-thirds of the drainage basin lie within the heavily urbanized San Gabriel Valley and Los Angeles basin with population densities in excess of 6,000 people/mi^2. Throughout this portion of the watershed, most of the river's main stem and tributaries have been confined within concrete channels for flood control. The net effect of these land use disparities, impoundments, and water diversions has been the loss of hydrologic connectivity between the upper and lower portions of the watershed.

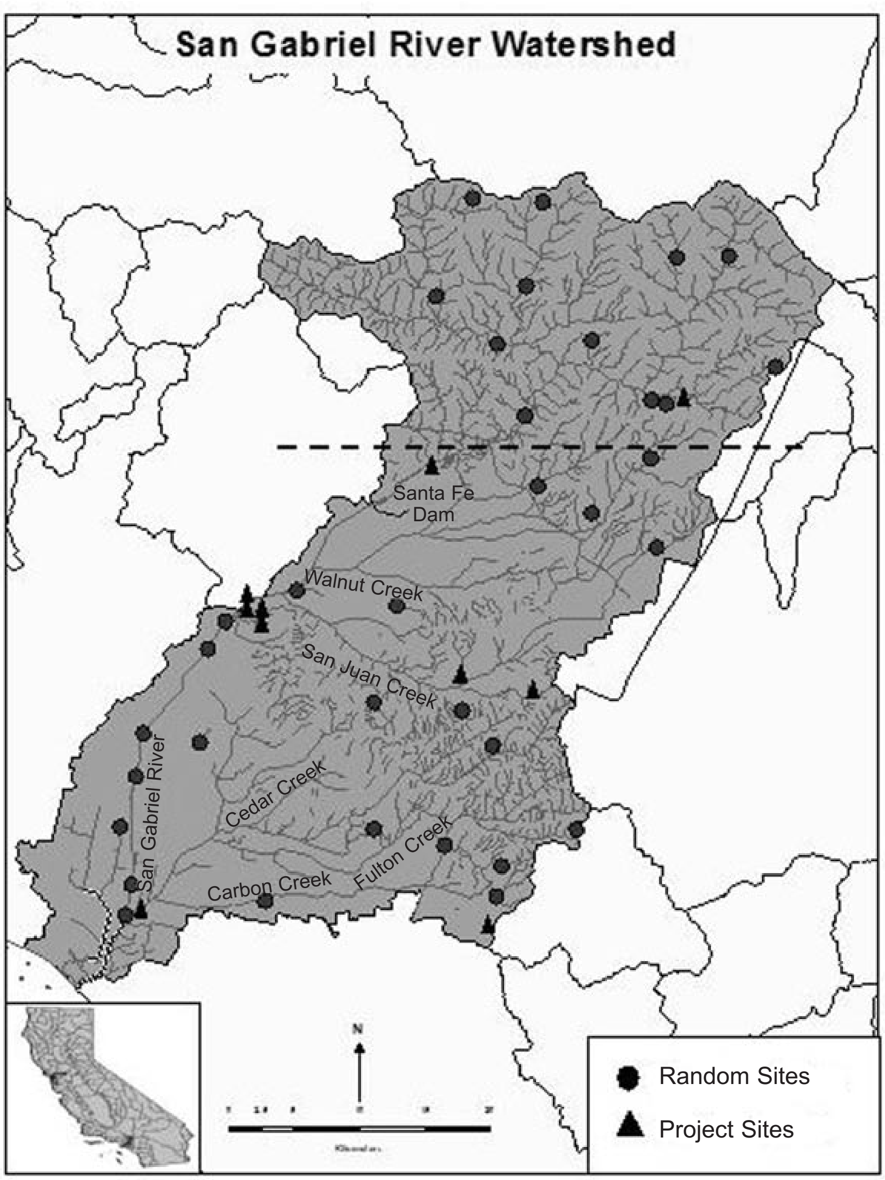

Figure 1. The San Gabriel River watershed in southern California; the approximate division between the upper and lower portions of the watershed is denoted by the dotted line.

Level 1: Resource Inventories and Maps

Documenting Wetlands in the Historical Landscape

The San Gabriel River and its floodplain was the subject of an in-depth historical ecology and landscape study (Stein *et al*. 2007b). Analysis focused on estimating historical wetland extent and distribution along the San Gabriel River floodplain (circa 1870) from the base of the San Gabriel Mountains to the boundary with the historic San Gabriel/Los Angeles River estuary. Primary historical data sources included Mexican land grant sketches (for former Mexican territories), United States General Land Office maps, irrigation maps, topographic maps, soil surveys, and aerial photographs. Secondary data sources included oral histories, essays, ground photographs, and field notes. The concordance between these multiple data sources allowed conclusions based on the collective "weight of evidence" to support inferences about historical condition in the San Gabriel River watershed.

Once assembled, these data sources were digitized, georeferenced, and overlaid in GIS to produce historical wetland polygons that were later classified using the National Wetland Inventory (NWI) system to facilitate comparison with contemporary conditions. The NWI uses the standard classification developed by Cowardin *et al*. (1979), but adds a set of modifiers based on the hydrogeomorphic approach (HGM) classification system (Brinson 1993). Historical herbaria records and bird observations were used to confirm the results of the GIS analysis and provided further insight into the composition of historical wetland communities of the watershed. The resulting maps were then compared to contemporary wetland maps to assess wetland loss and type conversion. See Stein *et al*. (2007b) for a complete discussion of the methods used to assess historical wetland loss in the San Gabriel River watershed.

Contemporary Wetland Inventory and Mapping

Contemporary wetland extent and the drainage network of the entire San Gabriel River watershed were mapped using established federal and state standards, as defined by the NWI and the California Statewide Wetlands Inventory (see Dark *et al*. 2006). This area incorporates the portions of the San Gabriel River floodplain in the San Gabriel Valley and Los Angeles basin that were included in the historical analysis. Draft mapping standards developed for the State of California under the consideration of the Riparian Habitat Joint Venture were used to map riparian areas (Collins *et al*. 2007b). The California Statewide Wetlands Inventory is the primary wetland inventory for the State and is used to update the NWI of the US Fish and Wildlife Service (USFWS) and the National Hydrography Dataset (NHD) of the US Geological Survey (USGS).

The process of inventorying wetlands, riparian areas, and drainage networks in the San Gabriel River watershed began with the creation of a geodatabase containing base digital aerial imagery and collateral data within the study area. Baseline imagery consisted of 1-m resolution color infrared USGS digital orthophoto quads (DOQs) from year 2000 or later. Collateral data sources included old NWI wetland maps where available, 10-m digital elevation models (DEMs), quadrangle boundaries of the area to be mapped, land use data (SCAG 2000), pre-existing National Hydrography Data (USGS 2004), hydric soils data (NRCS 2005), and USGS topographic maps (1:24,000).

Classification of wetland habitats followed the standard guidelines of the USFWS method for "Classification of Wetlands and Deepwater Habitats" (Cowardin *et al*. 1979), augmented with HGM modifiers (Brinson 1993). HGM classifications are applied after the Cowardin classifications are applied via an automated process. This layer was first overlaid onto the classified NWI wetlands and a post-classification performed by translating the NWI classification and its geomorphic location into the HGM classification. See Dark *et al*. 2006 for a detailed description of the methods used to map and classify wetlands in the San Gabriel River watershed.

Level 2: Rapid Assessment of Riverine Wetland Condition

Ambient Watershed Assessment with CRAM

In the San Gabriel River watershed, Level-2 monitoring consisted of a probabilistic survey of ambient riverine wetland condition using the CRAM (Collins *et al*. 2007a). Sample points were probabilistically selected using the sample frame developed as part of the Level-1 assessment. The sample draw was weighted by proportion of watershed area to ensure adequate distribution of sites throughout the three main portions of the watershed: upper watershed above Morris Dam, lower watershed (tributaries entering the river below Morris Dam), and the main stem river below Whittier Narrows. Thirty sites were assesssed over a six-week period during the spring and summer of 2005. Potential sites were rejected if they could not be legally or safely accessed or did not contain surface flow to allow collection of the Level-3 indicators (typically through late June). If a site was rejected it was replaced with the next sequential site from the sample draw. In addition to the probabilistic survey, CRAM was conducted at seven targeted locations that included key confluence points and areas of unique habitat value within the watershed (LASGWC 2007).

Project Assessment with CRAM

In 2007, CRAM was used to evaluate habitat condition at ten riverine project sites distributed throughout the San Gabriel River watershed. Nine of the ten project sites were located in the lower portion of the watershed and one project was located in the upper watershed. Although no projects were located directly along the river's main stem, one site was in very close proximity. These ten sites were identified and selected based on input from various public agencies operating within the watershed and represented a range of project types (i.e., restoration, enhancement, mitigation) in various stages of progress (planned, on-going, or completed projects). Assessment areas were determined using the recommended guidelines for riverine wetlands provided in Collins *et al*. (2007a). To evaluate the types and severity of stressors impacting CRAM assessment areas at project sites, the CRAM stressor checklist was used to determine the types and number of these stressors that could influence CRAM index and attribute scores.

Assessment of Stressors

We evaluated the effects of anthropogenic perturbations (stressors) at the landscape scale using two types of data. First, a Landscape Development Index (LDI) was developed for the San Gabriel River watershed using the procedure described by Brown and Vivas (2005). Riverine wetland sites were selected across a range of land use types to generate a broad range of LDI values and wetland condition scores as assessed by the CRAM. Sites were selected in conjunction with a CRAM validation study that documented relationships between CRAM results and independent, Level-3 measures of condition (see Stein *et al*. 2009). The National Land Cover Dataset (NLCD 2001) at 30-m resolution was used to develop the LDI. ArcGIS was used to input land cover and polygon datasets and to calculate LDI values at various spatial scales (catchment basin and buffer zone) for each riverine CRAM site. Derived LDI values were then compared with CRAM overall index and attribute scores to serve as an indicator of riverine wetland condition for the watershed. In addition, we evaluated the performance of LDI compared to USGS derived percent imperviousness and regional data from the Southern California Association of Governments (SCAG) data as a predictor of wetland condition.

We also evaluated the presence and severity of stressors at the buffer and landscape scale using stressor presence/absence data collected via 2005 probabilistic survey of ambient riverine wetland condition with CRAM (LASGWC 2007). In addition to generating numeric condition scores, CRAM provides a “stressor checklist” that lists the variety of possible stressors within a wetland or its landscape setting (Table 1). The checklist does not influence the numeric CRAM condition score, but can be used to help explain the scores and identify possible management actions to improve condition. Stressors are represented as categorical scores ranging from “0”, indicating no stressor was present; “1”, indicating that the stressor is present but unlikely to cause significant impact; and “2”, indicating that the stressor is present and likely to cause a significant impact on the functional capacity of a CRAM assessment area. The CRAM stressor checklist assumes: 1) wetland condition declines as the number of stressors acting on the wetland increases (there is no assumption that the decline is additive (linear), non-linear, or multiplicative); 2) increasing the intensity or the proximity of the stressor results in a greater decline in condition; and 3) continuous or chronic stress increases the decline in condition (Collins *et al*. 2007a).

Stressors were evaluated for the upper, lower, and main stem portions of the San Gabriel River watershed as defined by the 2005 probabilistic survey. Three types of data from the NLCD (vegetation type, percent impervious surface, and population density distribution) were used to visually depict land cover in the watershed to provide context to the types of stressors recorded. Percent impervious surface was based on land cover imagery with values representing the percent of impervious surface within each cell of the raster image (30 x 30 m). The population data was generated from Topologically

Table 1. List of all possible stressors for each of the four CRAM attributes in the CRAM stressor checklist. *not applicable to restoration areas. ** includes point-source or non-point source pollution.

HYDROLOGY ATTRIBUTE:

Non-point Source discharges (urban runoff, farm drainage)
Dredged inlet/channel
Dike/levees
Groundwater extraction
Weir/drop structure, tide gates
Dams (reservoirs, detention basins, recharge basins)
Flow diversions or unnatural inflows
Flow obstructions (culverts, paved stream crossings)
Engineered channel (riprap, armored channel bank, bed)
Point Source discharges (publicly owned treatment works, other non-stormwater discharge)

BIOTIC STRUCTURE ATTRIBUTE:

Predation and habitat destruction by non-native vertebrates
Biological resource extraction or stocking (fisheries, aquaculture)
Treatment of non-native and nuisance plant species
Removal of woody debris
Tree cutting/sapling removal
Mowing, grazing, excessive herbivory (within assessment area)
Pesticide application or vector control
Excessive human visitation

PHYSICAL STRUCTURE ATTRIBUTE:

Filling or dumping of sediment or soils*
Plowing/discing*
Grading/ compaction*
Resource extraction (sediment, gravel, oil and/or gas)
Excessive sediment or organic debris from watershed
Vegetation management
Excessive runoff from watershed
Pesticides or trace organics impaired**
Heavy metal impaired **
Nutrient impaired**
Bacteria and pathogens impaired**
Trash or refuse

BUFFER AND LANDSCAPE CONTEXT ATTRIBUTE:

Urban residential
Industrial/commercial
Dryland farming
Intensive row-crop agriculture
Dairies
Rangeland (livestock rangeland also managed for native vegetation)
Military training/Air traffic
Commercial feedlots
Ranching (enclosed livestock grazing or horse paddock or feedlot)
Orchards/nurseries
Transportation corridor
Active recreation (off-road vehicles, mountain biking, hunting, fishing)
Sports fields and urban parklands (golf courses, soccer fields, etc.)
Passive recreation (bird-watching, hiking, etc.)
Physical resource extraction (rock, sediment, oil/gas)
Biological resource extraction (aquaculture, commercial fisheries)

Integrated Geographic Encoding and Referencing System (TIGER) census data.

Level 3: Intensive Site Assessment

Level-3 monitoring was conducted at the same 30 probabilistically selected and seven targeted sites included in the 2005 ambient survey. Level-3 monitoring was based on a “triad” approach and included benthic macroinvertebrate bioassessment (and its associated suite of physical habitat measurements), aquatic toxicity, and water column chemistry (LASGWC 2007). Bioassessment procedures were based on the draft California Surface Water Ambient Monitoring Program (SWAMP) protocols (Harrington 2003). These consisted of the manual collection of composite benthic macroinvertebrate samples using a D-shaped kick net and a modified measure of the instream physical habitat (PHAB) as originally developed by the USEPA. Water chemistry included the manual collection of grab water samples using specified container types as defined in the SWAMP protocols. Water chemistry was sampled at all sites. The list of constituents differed somewhat depending on the specific goals of each program component, but typically included general water chemistry, trace metals, and nutrients. Water column toxicity sampling included the manual collection of grab water samples using a one-gallon wide mouth carboy at each of the monitoring locations. To test water toxicity, survival and reproduction of the water flea (*Ceriodaphnia dubia*) was used at each freshwater sampling site, and a seven-day survival test of the silver sides (*Menidia beryllina*) was used at estuary sites. See Johnson (2007) for a complete description of the laboratory and field methods.

Benthic macroinvertebrates collected from each site were identified to the lowest specified taxonomic level, and then biological metrics including diversity, average tolerance scores, relative abundance of aquatic macroinvertebrate species among distinct functional feeding group (FFG) categories (e.g., predators, grazers), and others were calculated. Next, the multi-metric Southern California IBI was calculated for each site (Ode *et al*. 2005). The IBI score derived for each site allows the water quality conditions found there to be compared against reference site conditions in southern California. Scores below 39 (on a scale of 100) represent "poor" conditions.

The data collected at ambient and targeted sites were summarized and analyzed using cumulative frequency distributions (CFD) and box and whisker plots. The CFDs illustrate the distribution of values from 0 to 100% for various indicators measured. The box and whisker plots show the median and range of the different indicators measured. In addition to comparing mean concentrations of the constituents sampled at individual sites, CFDs were used to compare data from targeted and permit-mandated stations to the ambient condition for the watershed as established by the random sites. Analysis of variance (ANOVA) was used to determine whether differences between sampling strata in the ambient survey were statistically significant.

RESULTS

Because this study is based on a synthesis of various, previously completed efforts, we present the results in four parts. First, the Level-1 information on historical and current wetland extent and distribution, with a focus on riverine wetlands, is presented. Second, we report the results of the Level-2 studies, which include the probabilistic and targeted survey of riverine wetlands using rapid assessment, the survey of riverine project sites using rapid assessment, and the analysis of stressors. Third, we present a subset of the intensive monitoring data (Level-3) collected from the probabilistically selected and targeted sites (intensive data were not collected at the riverine restoration/mitigation project sites). Finally, we report on the relationships observed between the various tiers of monitoring data to describe the overall ecological condition of riverine wetlands in the San Gabriel River watershed.

Wetland Extent and Distribution

A total of 5,395 ha of wetland habitat were mapped in mountain, foothill, and valley areas of the San Gabriel River Watershed (Dark *et al*. 2006). Based on total wetland acreage by Cowardin class, the vast majority of wetlands in the San Gabriel River watershed are comprised of riverine (2,286 ha) and palustrine wetlands (2,053 ha). A summary by HGM category indicates that fluvial systems (including both riverine wetlands and flow-through palustrine wetlands confined to a channel) dominate in this watershed. Most of these fluvial systems were found in canyon areas, with smaller amounts in valley areas. The greatest losses to wetlands of the San Gabriel River floodplain have been to riverine wetlands of the upper floodplain and palustrine wetlands in the tidal fringe (Stein *et al*. 2007b; Figure 2).

Almost all of the wetlands mapped in the San Gabriel Valley exhibit some form of anthropogenic impact. It is estimated that over 4,000 ha of riparian habitats and other fluvial features (i.e., small tributary stream and creeks) existed in the San Gabriel River floodplain circa 1870 (Stein *et al*. 2007b). Since that time, approximately 75% of this wetland

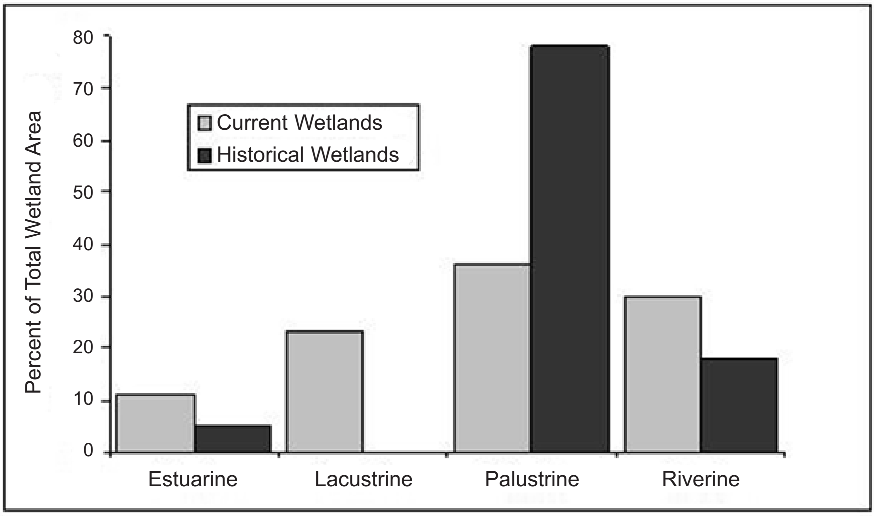

Figure 2. Percentage of wetland area within the San Gabriel River floodplain comprised of each wetland type (Cowardin class) under current and historical conditions (Stein *et al.* 2007b).

area has been lost or extensively modified by a series of dams, diversions, and channels. The greatest proportional loss of riverine wetlands has occurred in the upper floodplain. The most dramatic changes to the landscape are evidenced in the conversion of the broad alluvial floodplains of the upper watershed and the meandering streams of the southern floodplain to flood control channels. Today, the southern San Gabriel River floodplain has been entirely converted to urban land uses. Present-day land use maps illustrate the dramatic land use disparities between the upper (undeveloped) and lower (developed) portions of the watershed.

Rapid Assessment

The results of the ambient assessment of riverine wetland condition with CRAM document a broad range of conditions between the upper, mainstem, and lower portions of the San Gabriel River watershed in terms of overall integrity of riverine wetland (Figure 3). CRAM scores ranged from 35 to 91 (with a possible range of 25 to 100). Overall CRAM scores varied by a site's location and illustrated clear patterns between the upper (undeveloped) and lower (developed) portions of the watershed. The upper watershed, which is comprised of mostly natural streams, has the highest mean CRAM score. The main stem of the river, which was predominantly channelized, had the lowest mean CRAM scores (approximately half the mean score as the upper watershed). The lower watershed, which was comprised of a mix of semi-natural and channelized systems, had intermediate scores that were comparable to mean values for the overall watershed condition.

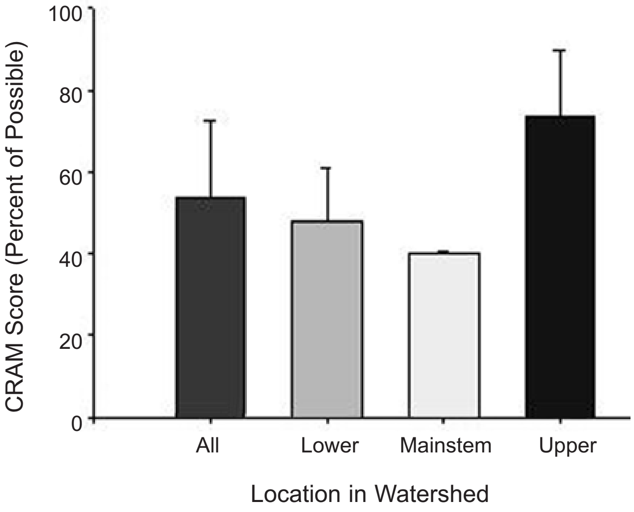

Figure 3. Mean scores for CRAM assessment areas in the San Gabriel River based on watershed position. Bars represent 95% confidence limits.

Similar spatial trends in riverine wetland condition were evident from the project assessments with CRAM in the San Gabriel River watershed (Table 2). Overall CRAM index scores for the ten project sites assessed ranged from 54 to 84. Although project sites were assessed using a later version of CRAM and direct comparisons with the sites probabilistically selected for the 2005 ambient assessment were not possible, projects located in the upper or less developed portions of the watershed generally had the highest overall CRAM scores and those in the lower portions of the watershed and along the main stem of the river had the lowest overall CRAM scores. For example, the Cattle Canyon project is located in the San Gabriel Mountains along an unregulated tributary stream and received one of the highest overall CRAM index scores (83) of all the projects assesed. The El Dorado Nature Center project, located near the main stem of the river and in one of the most urbanized portions of the watershed, received the lowest CRAM score (54). However, the Oak Canyon site, located in the lower portion of the watershed, but within a 58 acre natural park, received a CRAM score comparable to the Cattle Canyon site (84). Although some sites scored similarly for overall CRAM index scores, attribute scores occasionally differed. For example, the Cattle Canyon project received a high overall index scores as well as high attribute scores for the buffer/landscape and hydrology attributes, but scored low for physical and biotic structure, whereas the opposite was true of the of the Oak Canyon site. Because projects sites in the San Gabriel Mountains were located in the least developed portion of the watershed, these probably began with higher condition scores than those in the lower watershed regardless of project status (i.e., planned, on-going, completed) at the time of assessment.

Stressor Analysis

A total of 12 different types of landscape stressors (operating within 500 m of the assessment area) were recorded at the probabalistic and targeted sites included in the ambient survey (Table 3). CRAM index scores for the buffer and landscape context attribute of CRAM were significantly correlated with the number of stressors and severe stressors found at each random site (non-parametric spearman's rank correlation r = -0.54 and -0.32, respectively; p-value

Table 2. CRAM raw attribute and index scores for the the ten project sites assessed with CRAM in the San Gabriel River watershed. Projects are ranked from highest to lowest overall index score. Overall index scores are the average of the final four attribute scores. Scores range from 25 to 100. U = upper watershed, M= main stem, L = lower watershed.

Project Name	Project Type	Project Status	Buffer/ Landscape	Hydrology	Physical Structure	Biotic Structure	Overall Index Score
Cattle Canyon (U)	Enhancement	planned	100	100	75	58	83
Oak Canyon (L)	Restoration	on-going	88	67	100	83	84
Sycamore Canyon (L)	Mitigation	completed	42	58	88	75	66
Azusa Canyon (M)	Enhancement	planned	79	67	50	56	63
Crossover Channel (L)	Restoration	on-going	92	67	50	47	64
Lario Creek (L)	Restoration	planned	96	58	25	53	58
Bosque del Rio Hondo (L)	Restoration	completed	46	42	50	89	57
Lemon Creek (L)	Mitigation	completed	38	75	63	53	57
Mission Creek (L)	Restoration	on-going	83	42	50	61	59
El Dorado Nature Center (L)	Restoration	planned	46	75	38	58	54

<0.05). Urban residential land use was considered the most common landscape stressor on riverine wetlands throughout the watershed in terms of presence (47%) and severity of impact (33%). Transportation corridors and industrial/commercial land use were also among the most frequently cited severe stressors at the buffer/landscape scale (see Table 3).

The three portions of the watershed (upper, lower, and main stem) differed in the presence of severity of stressors at the buffer/landscape scale. Sites in the lower watershed and main stem were the most impacted, with 100% of the lower watershed sites and 80% of main stem sites experiencing at least one type of stress. In contrast, 60% of the upper watershed sites were not impacted by any type of stressor at the buffer/landscape scale. Urban residential land use, passive recreation, transportation corridors, and industrial commercial land use were among the most common types of landscape stressors affecting the lower and main stem sites (Table 4). In the upper watershed, landscape stressors were less frequently recorded, with only transportation corridors cited more than once. A single upper watershed site accounted for most of the stressors and severe landscape stressors (operating within 500 m of the assessment area) that were

Table 3. Frequency of occurrence of landscape stressor types within 500 m of sites assessed with CRAM in the San Gabriel River watershed. The most frequently recorded severe landscape stressors are noted in parentheses.

Stressor Type	Total	Lower Watershed	Mainstem	Upper Watershed
Urban residential	17(12)	11(8)	5(3)	1(1)
Passive recreation	14	5	7	2
Industrial/commercial	9(7)	2(2)	6(4)	1(1)
Transportation corridor	9(7)	6(4)	1(1)	2(2)
Sports fields and urban parklands	7	6	0	1
Orchards/nurseries	3	1	2	0
Active recreation	3	2	0	1
Rangeland	1	1	0	0
Ranching	1	0	0	1
Physical resource extraction	1	1	0	0
Military training/Air traffic	1	1	0	0
Commercial feedlots	1	1	0	0

Table 4. Frequency of occurrence of stressor types within 50 m of sites assessed with CRAM in the San Gabriel River watershed. The most frequently recorded severe stressors are noted in parentheses.

Stressor Type	Total	Lower Watershed	Mainstem	Upper Watershed
Nutrient impaired	24	13	8	3
Bacteria and pathogens impaired	23	13	8	2(2)
Trash or refuse	22	12	8	2(2)
Non-point Source discharges	22(19)	11(10)	9(8)	2
Heavy metal impaired	20	11	8	1
Pesticides or trace organics impaired	18	13	4	1
Flow obstructions	15	10	2	3(3)
Excessive runoff from watershed	15(10)	11(8)	2	2(2)
Engineered channel	14(11)	10(8)	2(2)	2
Flow diversions or unnatural inflows	12	9	2(2)	1
Point Source discharges	12(10)	2	9(8)	1
Excessive human visitation	11	6	2	3
Grading/ compaction	8	7	1	0
Dams	8	5	2(2)	1
Pesticide application or vector control	6	5	1	0
Excessive sediment/organic debris from watershed	5	4	0	1
Vegetation management	5	4	1	0
Groundwater extraction	4	1	2	1
Weir/drop structure, tide gates	4	1	2	1
Mowing, grazing, excessive herbivory	3	3	0	0
Dike/levees	3	3	0	0
Plowing/Discing	2	1	1	0
Tree cutting/sapling removal	2	1	1	0
Treatment of non-native/nuisance plant species	1	0	1	0
Filling or dumping of sediment or soils	1	0	0	1
Removal of woody debris	1	0	1	0

recorded in this portion of the drainage.

A total of 26 types of hydrologic, physical, and biotic stressors (operating within 50 m of the assessment area) were recorded at the random and targeted sites (Table 4). Overall CRAM assessment area scores were significantly correlated with the number of stressors and severe stressors found at each site (non-parametric spearman's rank correlation $r = -0.41$ and -0.42, respectively; p-value <0.01). Nutrient impairment was the most common stressor impacting riverine wetlands throughout the San Gabriel River watershed, recorded at 67% of the sites visited. Non-point source discharges, engineered channels, and excessive runoff from watershed were among the most frequently cited severe stressors, present at 53, 31, and 28% of all sites visited, respectively.

The presence of stressors operating within 50 m of the assessment area and degree of severity was highest in the lower portion of the watershed (59 and 64%, respectively), followed by the main stem of the river (30 and 21%, respectively) based on the total number of observations at all sites. Although non-point source discharges were among the most frequently cited severe stressor in both the lower watershed and main stem sites (67 and 72 % of sites, respectively), point source discharges were also considered severe at main stem sites only (72% of sites). Engineered channels and excessive runoff from the watershed were also among the most common severe stressors at lower watershed sites. Overall, stressors that impaired the wetland physical structure attribute (e.g., bacteria, heavy metals, nutrient enrichment, and trash) were more frequently recorded in the lower watershed compared to main stem sites (see Table 4). In contrast, the upper watershed had few recorded occurrences of stressors and severe stressors (11 and 15%, respectively). A single upper watershed site, located below a major dam, accounted for the majority of the stressors and severe stressors (operating within 50 m of the assessment area) that were recorded in this portion of the drainage.

No significant correlation was found between CRAM index scores and the number of stressors and severe stressors found at project sites. Non-point source discharges and flow obstructions were the two most stressors on riverine wetlands, affecting 70% of the sites visited. Flow diversions, excessive human visitation, and transportation corridors were also among the most common stressors recorded at all project sites. In addition, no trends in CRAM scores were detected among sites based on project type (i.e., restoration, enhancement, or mitigation) or status (planned, in-progress, or completed).

Intensive Site Assessments

Comparison of data collected for a suite of general water quality constituents, metals, and nutrients from the three subregions of random sites indicated differences in water chemistry based on watershed position. For all constituents sampled, the lowest concentrations were found in the upper watershed. For metals (except zinc) and organic carbon, the highest levels were observed in the lower watershed, as shown in the representative pattern for total copper (Figure 4a). Zinc concentrations were generally highest in the river's main stem. For nutrients, the highest levels were along the main stem of the San Gabriel River, as shown in the representative pattern for nitrate + nitrite (Figure 4b). Little toxicity was observed during the ambient assessment. Only 2 of the 30 random sites sampled (7% of total samples) exhibited toxicity. Both samples were from the lower watershed. These findings are consistent with other studies (Schiff *et al*. 2006). In general, the mean values for general constituents, metals, and nutrients measured at the targeted sites were comparable to the random sites with a few notable exceptions. Chloride and orthophosphate levels were substantially lower at the targeted sites than at the random sites. In contrast, total iron was higher at the targeted sites.

Benthic macroinvertebrate species data collected from the 2005 random watershed sites identified groupings of sites that were similar in terms of composition and ecological groupings of the benthic community based on the location in the watershed. Benthic macroinvertebrate IBI scores also differ based on watershed position. Sites located in the lower, most developed portion of the watershed, had the lowest overall IBI scores. Sites located in the upper watershed and had the highest IBI scores. A subset of sites from the lower watershed and main stem grouped together and received similar IBI scores.

Differences among the major portions of the watershed were also apparent when species in the three subsets of the watershed are combined into ecological groupings. The upper watershed contained larger proportions of collectors/filterers, shredders, and predators. The lower watershed and main stem communities contained more generalist feeders, and were dominated by collectors/gatherers, with the lower watershed community having a slight-

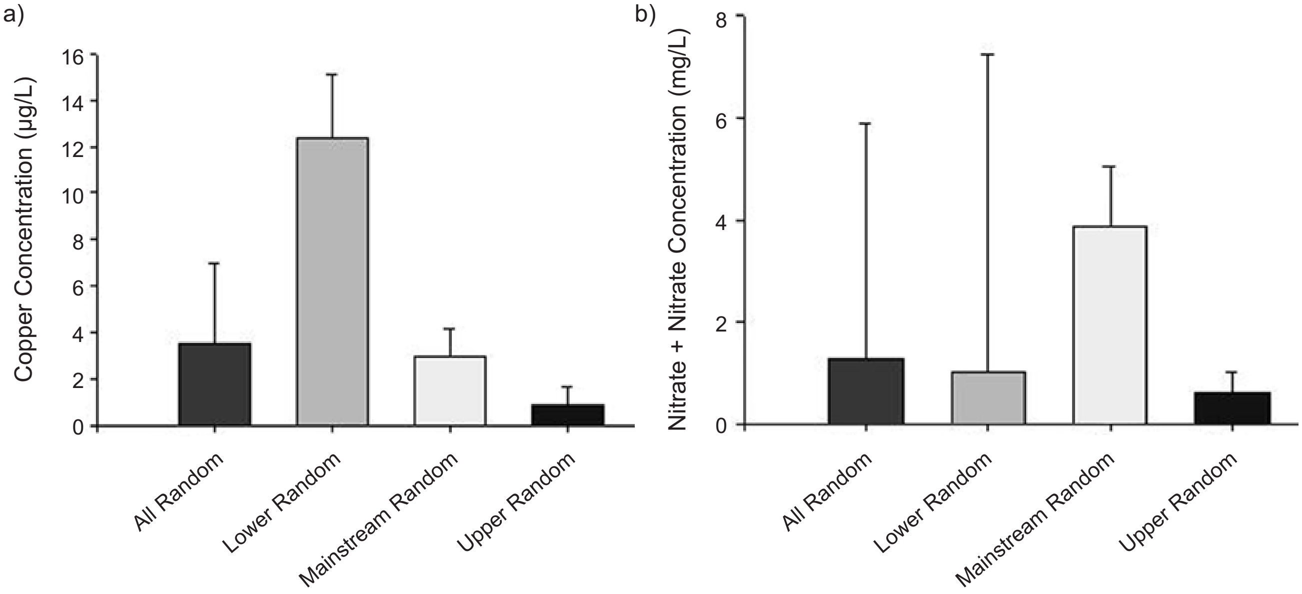

Figure 4. Total copper concentrations (a) and nitrate+nitrite concentrations (b) at random sites by position across the San Gabriel River watershed. Bars represent 95% confidence limits.

ly larger proportion of collectors/gatherers than the main stem. Based on taxonomic evaluation, the lower watershed included a number of species that rarely occur at either the main stem or upper watershed sites, and tended to be the most tolerant to habitat degradation. Targeted sites had IBI scores that span the full range of scores observed in the random sites, but a similar trend, with upper watershed targeted sites tending to group with upper watershed random sites, was observed in the cluster analysis for these sites.

Assessing Watershed Condition Using Multi-level Data

In general, riverine wetlands scored higher with CRAM when located in portions of the watershed with a higher percentage of open space ($R^2 = 0.61$; Figure 5). Significant correlations were also detected between CRAM scores (overall index and attribute scores) and the intensity of surrounding landscape based on the derived LDI values for the San Gabriel River watershed. The correlations were significant based on all three land use data sets and at all scales at which the analysis was conducted. The strongest negative relationship was detected between the overall CRAM index score and the percent impervious cover layer at the 100 m buffer scale ($r = -0.87$; p-value <0.001), followed by the National Landcover Data ($r = -0.86$; p-value <0.001). The overall CRAM index score consistently had the strongest relationship with the LDI whereas relationships at the CRAM attribute level were not as strong.

A comparison of CRAM index scores and benthic macroinvertebrate data for the San Gabriel River watershed reveals a positive correlation between benthic macroinvertebrate communities (as measured by IBI) and habitat condition (as measure by CRAM) across streams in this watershed (Figure 6). This provides a weight of evidence to suggest that biotic integrity is higher at sites with more intact wetland and riparian communities.

A comparison of habitat condition assessed through rapid assessment and three types of Level-3 data (copper concentration, aquatic toxicity, and benthic macroinvertebrates) revealed that meeting target conditions in the San Gabriel River watershed varied based on the standard and type of indicators used (Figure 7a). Based total copper concentrations, 15% of cases would not meet target conditions for current copper standards. For toxicity, 5% of cases do not meet target conditions based on survival and reproduction of *Ceriodaphnia dubia*. For the benthic macroinvertebrates, 44% of cases do not meet target conditions based on the current benthic IBI for southern California. For overall habitat condition, 62% of cases do not meet target conditions based on CRAM overall index scores. The minimum acceptable condition for CRAM, was assumed to be represented by the 25th percentile of index scores based on the statewide ambient survey for all indicators combined. If looked at in a different way, the percent of cases not meeting target conditions also varies based on the number of indicators used (Figure 7b). In general, the percent of cases that

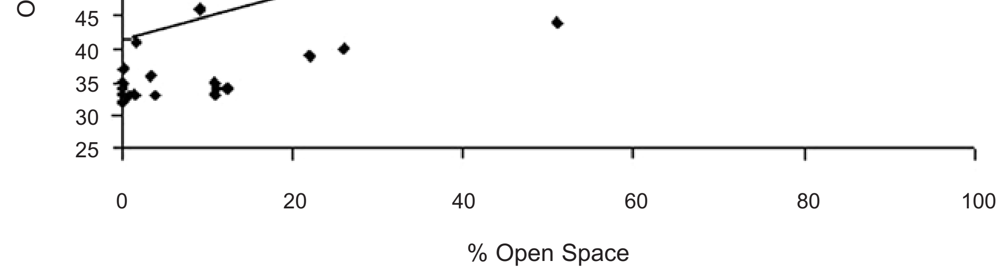

Figure 5. Scatter plot and linear regression between overall CRAM scores and the percent of open space in the San Gabriel River watershed.

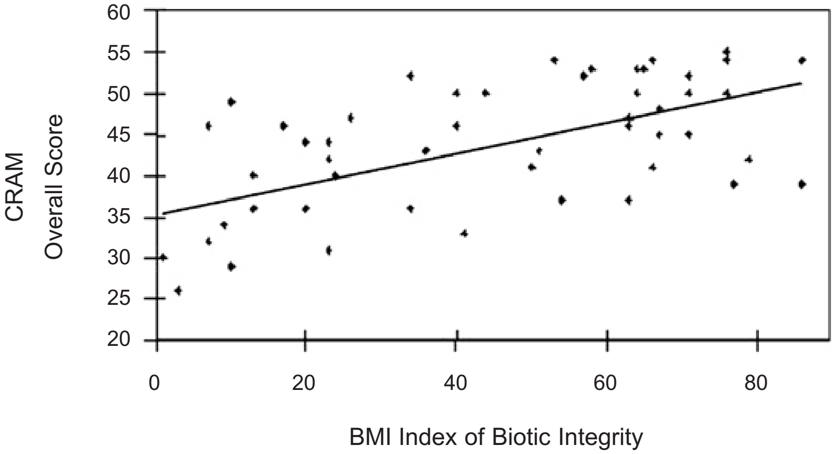

Figure 6. Scatter plot and linear regression between overall CRAM scores and IBI scores from the 2005 ambient survey of riverine wetland condition in the San Gabriel River watershed.

meet target conditions improves if more indicators are used in the assessment.

DISCUSSION

Four broad conclusions about integrating Level 1-2-3 monitoring into a comprehensive watershed assessment framework arise from this demonstration project:

- The Level 1-2-3 approach provides managers with a flexible assessment program where the intensity of the assessment can be matched to the importance of the management question.
- Application of a multiple indicator approach at different spatial scales and sampling intensities promotes a better understanding of the relationships between land use, wetland condition, and anthropogenic stress operating within a watershed.
- A multi-tiered monitoring approach can provide a cost-effective means of integrating wetland status and trends assessments into routine watershed monitoring programs
- A multi-level approach to monitoring and assessment provides wetland managers with an effective organizational tool that can be used to make well-informed management decisions and prioritize management activities.

A multi-tiered monitoring framework that integrates data collection at different spatial scales and sampling intensities provides watershed managers more flexibility in how they assess wetland condition. This approach can be applied to a variety of local, state, and federal wetland programs in conjunction with existing tools for managing wetlands. For example, monitoring under a variety of state programs, including the National Pollutant Discharge Elimination System (NPDES), CWA 401 Certification and Waste Discharge Requirements, and the Streambed Alteration (1600) Permits under California's Fish and Game Code, could be coordinated in such as manner to minimize redundancies, maximize comparability of data, and maximize the geographic coverage of the data (Sutula *et al*. 2008).

The significant relationship between CRAM and intensive physical habitat metrics suggest redundancies between the various tools. These redundancies can be taken advantage of to augment monitoring programs when/where resources are limited. For example, both rapid assessment and intensive studies corroborate that biotic integrity is higher at sites with more intact wetland and riparian communities (LASGWC 2007). Taken together, the positive correlation between the two intensities of assessment provides weight of evidence to indicate that biotic integrity is strongly dependent on habitat condition. Therefore, rapid assessment can be used as a cost-effective screening tool to help identify wetlands where more intensive assessments are warranted or attributes of a wetland that require improvement through corrective management actions. This further demonstrates how coarse scale rapid assessment data and finer scale intensive monitoring data can complement each

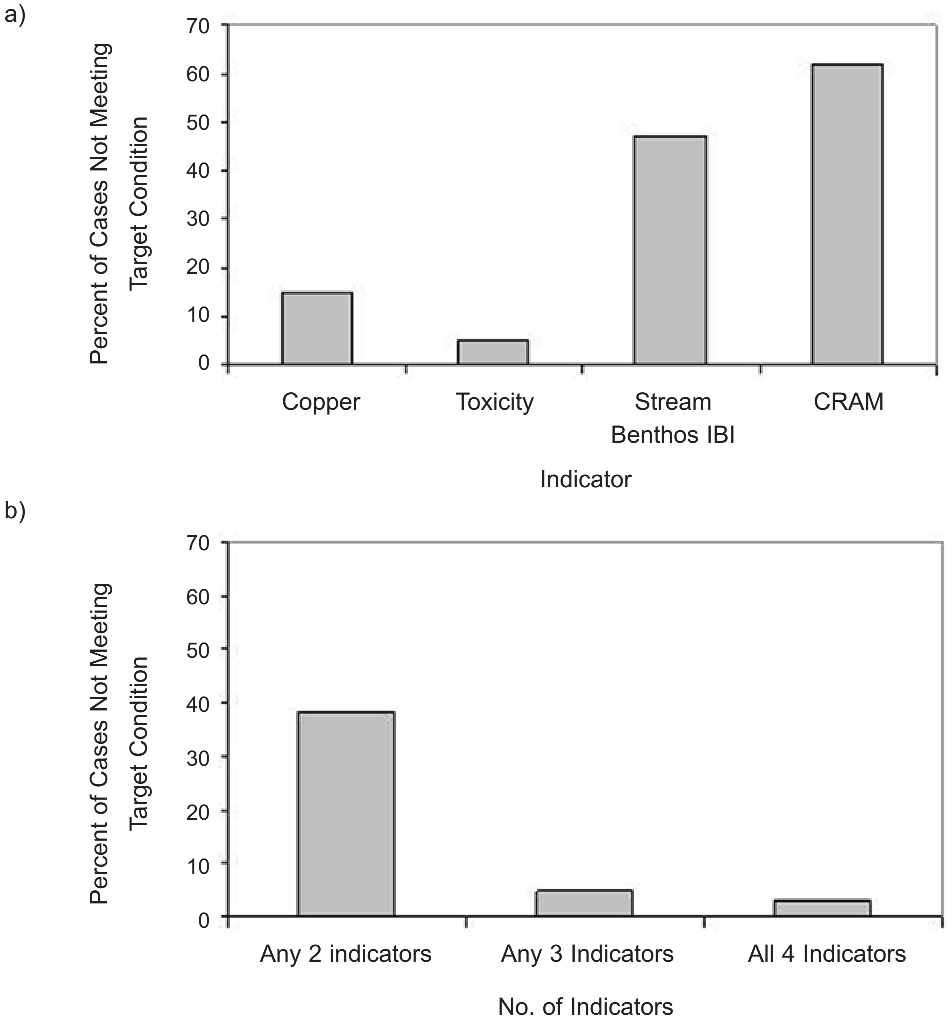

Figure 7. Indicators used in the San Gabriel River watershed to assess riverine-riparian condition relative to different environmental policies and programs (a), the same data relative to the number of indicators used to assess riverine-riparian condition (b).

other to provide a more refined understanding of factors that affect wetland condition.

The information generated through integrated assessments provides transparent linkages between wetland inventories, land use, and wetland condition data. Changes in land use ultimately affect wetlands receiving water from an urbanizing drainage basin (Kentula *et al*. 2004). It is evident that the broad range of habitat conditions existing in the San Gabriel River watershed along with a site's relative position in the watershed are important determinants of overall condition. This relationship can be extrapolated to a wide range of management concerns and activities. Different land uses, imperviousness, and vegetative cover produce unique combinations of factors that directly affect watershed hydrology and wetland condition. Other studies in southern California indicate that the extent of developed land may be strongly associated with the poor biological condition of stream ecosystems in the region (Mazor and Schiff 2008). Similar relationships have been reported in other parts of the world (e.g., Hatt *et al*. 2004, Walsh *et al*. 2007).

A further advantage of using a multi-tiered monitoring approach is the ability to integrate multiple indicators that represent different spatial scales and monitoring intensities to elucidate the factors that contribute to poor wetland condition. For example, there was a lack of significant correlation between heavy metal concentrations and nutrients with IBI scores in the San Gabriel River watershed. This would indicate that water quality is negligible as a stressor on benthic macroinvertebrate communities in the watershed. However, the strong relationship observed between CRAM index scores (Level-2) and IBI scores (Level-3) indicate that stressors affecting the physical structure of the habitat (as measured by CRAM) can have a significant influence on these communities. Other studies have shown that benthic macroinvertebrates are particularly sensitive to hydrologic and habitat modification that accompanies watershed urbanization (Sonneman *et al*. 2001, Walsh *et al*. 2001, Mazor *et al*. 2006), but may not be sensitive to other stressors, such as nutrient enrichment (Mazor and Schiff 2008).

Using multiple lines of evidence together provides a more complete understanding of the factors affecting overall stream condition in the San Gabriel River watershed. Although the use of multiple lines of evidence can provide greater sensitivity to more types of impacts, different indices do not always agree on the general level of impairment or condition. Therefore, any conclusions based on these indices need to consider the type and number of indicators used in the assessment. For example, had assessment in the San Gabriel River relied only on total copper concentrations as an indicator of condition, the target condition based on the current standard for copper would be achieved less than 20% of the time. If based solely on toxicity standards, this percentage would be even lower because little aquatic toxicity was observed in the watershed. However, if viewed from the aspect of biological condition using benthic macroinvertebrate IBI or CRAM scores, the percentage of cases not meeting target conditions would be considerably higher. This indicates that different indices can provide different types of information and address different aspects of the waterbody being monitored. The use of multiple indicators provides a way to integrate different types of information collected at varying intensities of assessment to better inform on the condition of the waterbody and prioritize management actions.

A coordinated approach using standardized tools for data collection and information management can minimize the aggregate costs for multiple programs while improving public access to monitoring and assessment results that better reflect management priorities. For example, prior to application of the 1-2-3 Framework, most monitoring in the San Gabriel River watershed was permit-driven and focused on point-source discharges to the river. As a result, some portions of the watershed were monitored intensively, while others were never (or very rarely) monitored. Consequently, there was a considerable amount of intensive data available for a small number of targeted sites, but limited ambient context for interpreting this data.

Decisions on wetland restoration projects, proposed development impacts on wetlands, and performance criteria for compensatory mitigation should be guided in part by an understanding of landscape-scale issues and the ambient condition of wetlands within the entire watershed. The integration of Level-1 and -2 would facilitate the development of realistic performance targets for wetland-based projects at the watershed scale. For example, wetlands located in heavily urbanized portions of the San Gabriel River watershed may never achieve a condition comparable to that of similar natural wetlands in the region, even with intensive site management. The coupling of landscape and habitat condition data fosters a better understanding of the “best achievable” conditions for a particular wetland site by relating local site condition to its landscape perspective. The knowledge gained from Level-1 and -2, in turn, provides greater interpretive power for the intensive, Level-3 data collected at project sites.

Systematic monitoring of Level-3 indicators is an important consideration for project-based evaluations. A standardized, rapid assessment method, such as CRAM, provides an efficient, cost-effective means to collect habitat condition data. However, rapid assessment methods are based on relatively simple field indicators and only provide a coarse-scale assessment of wetland condition. Intensive data will always be needed to validate Level-1 landscape and Level-2 rapid methods and develop biologically based criteria in order to diagnose the causes of wetland condition. For example, several of the projects we assessed for our demonstration in the San Gabriel River watershed received mid-range CRAM index scores, and, consequently, the habitat condition data for these sites were difficult to interpret based on rapid assessment alone. Although we did not collect Level-3 data at our project sites, Level-3 information would help to discern subtle differences in wetland condition in these instances. Furthermore, standardized protocols and methodologies for monitoring of indicators at project sites would allow site managers to better determine what their monitoring data represent from a watershed perspective and how the data compares to other wetlands or sites in the region.

A coordinated approach using standardized tools for data collection and information management can minimize the aggregate costs for multiple programs while improving public access to monitoring and assessment results. Whether Level-2 or Level-3 methods are used to collect data will depend on case-specific circumstances. However, the efficacy of using the less expensive Level-2 methods should be carefully considered before Level-3 methods are employed. In many cases, Level-2 methods can be used augment the Level-3 assessments of specific wetland functions or aspects of condition to provide more robust evaluations of overall functional capacity or health at little additional cost.

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