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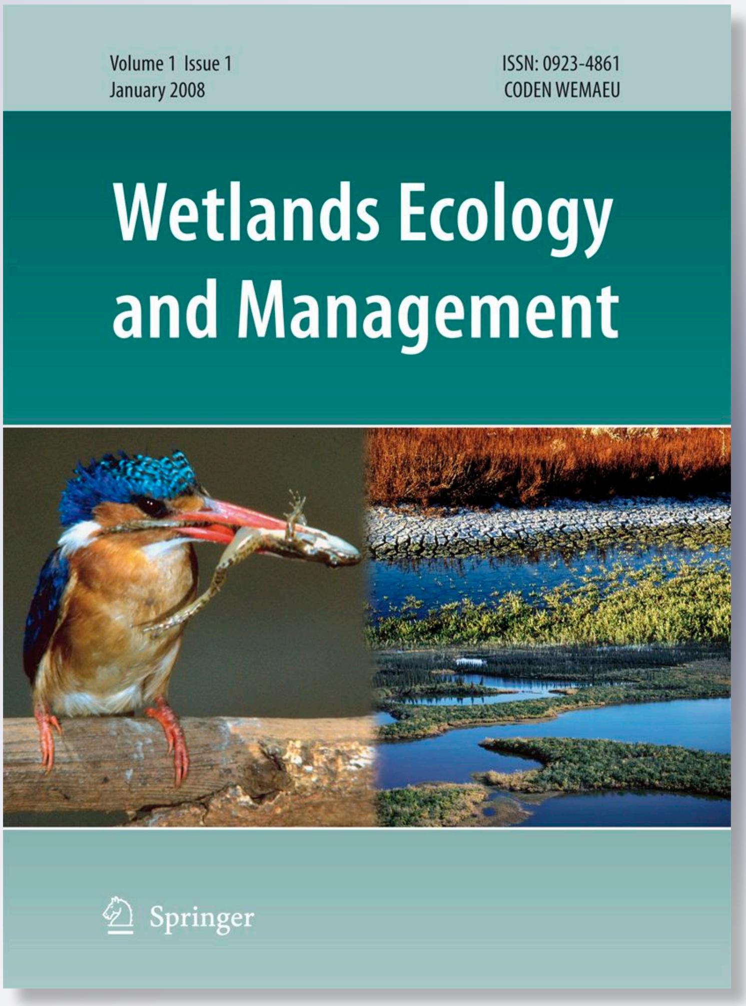
Wetlands Ecology and Management

ISSN 0923-4861
Volume 19
Number 5

Wetlands Ecol Manage (2011)
19:459-474
DOI 10.1007/s11273-011-9230-6



Springer

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ORIGINAL PAPER

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

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Received: 1 February 2010 / Accepted: 23 August 2011 / Published online: 3 September 2011

Abstract Watersheds are useful templates for wetland protection and land use planning because they integrate cumulative effects that better inform site-specific management decisions. The goal of this study was to demonstrate application of a three-tiered assessment paradigm in the San Gabriel watershed (Los Angeles County, California) that incorporates monitoring at varying spatial scales and intensities. 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 indicator 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. 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, (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 prioritize management activities.

Keywords Wetland assessment · Watershed · Level 1-2-3 · CRAM · San Gabriel River

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Introduction

Holistic methods of watershed assessment can maximize the effectiveness of wetland resource management (Reinhardt et al. 2007; Thomas and Lamb 2005); however, achieving this goal is often intractable for several reasons. First, most watershed assessments are based on singular objectives (e.g., regulatory compliance) or specific indicators (e.g., benthic macroinvertebrates). Second, most assessments typically fail to provide a comprehensive inventory of all wetland resources within the watershed based on a common classification system. Third, monitoring efforts often target specific sites within the watershed (e.g., restoration or mitigation project sites), but neglect to incorporate an overall assessment of ambient watershed condition to provide context for interpreting site-specific assessment results (Fennessy et al. 2007; Brooks et al. 2006). Fourth, the general lack of historical information on wetland extent and distribution makes it difficult to establish a meaningful baseline for assessing wetland change within a watershed (Bedford and Preston 1988). Ultimately, resource managers need a means to integrate various types of spatial and temporal watershed data to make more informed management decisions.

Recognizing these challenges, the U.S. Environmental Protection Agency (USEPA) has proposed a three-tiered monitoring paradigm (Level 1-2-3; USEPA 2006; Stein et al. 2007) that provides a structured framework for conducting more integrated assessments of wetland resources across multiple scales. Level-1 analysis consists of resource inventories and maps that address questions about the extent and distribution of wetlands and other aquatic resources at the landscape-scale. Level-2 consists of rapid assessment methods that use cost-effective, field-based diagnostic indicators to assess wetland condition. Level-3 consists of intensive assessment methods that provide detailed information on functionality of specific wetland sites.

Watersheds provide a useful organizational template for application of the Level 1-2-3 monitoring and assessment framework (Kentula 2007). Although the benefits of a tiered approach to monitoring are recognized, there are relatively few examples of actual implementation at the programmatic level (e.g., Wardrop et al. 2007). Therefore, demonstration projects are relevant not only as tangible, real-world examples of the approach, but they provide the empirical basis for determining how multiple data types can be integrated and analyzed to provide more comprehensive assessment of aquatic resource condition.

In this paper, we discuss an application of the Level 1-2-3-assessment framework in the San Gabriel River watershed (Los Angeles County, California). By compiling the results of several types of studies that include historical ecology, contemporary wetland mapping, rapid assessment, and site-specific monitoring, our objectives were to (1) integrate various types of data collected at three intensities of monitoring effort in order to identify possible causal relationships affecting overall wetland condition, and (2) provide conclusions on how multiple tiers of monitoring data can be used to target and prioritize wetland management activities at the watershed-scale.

Methods

Study area

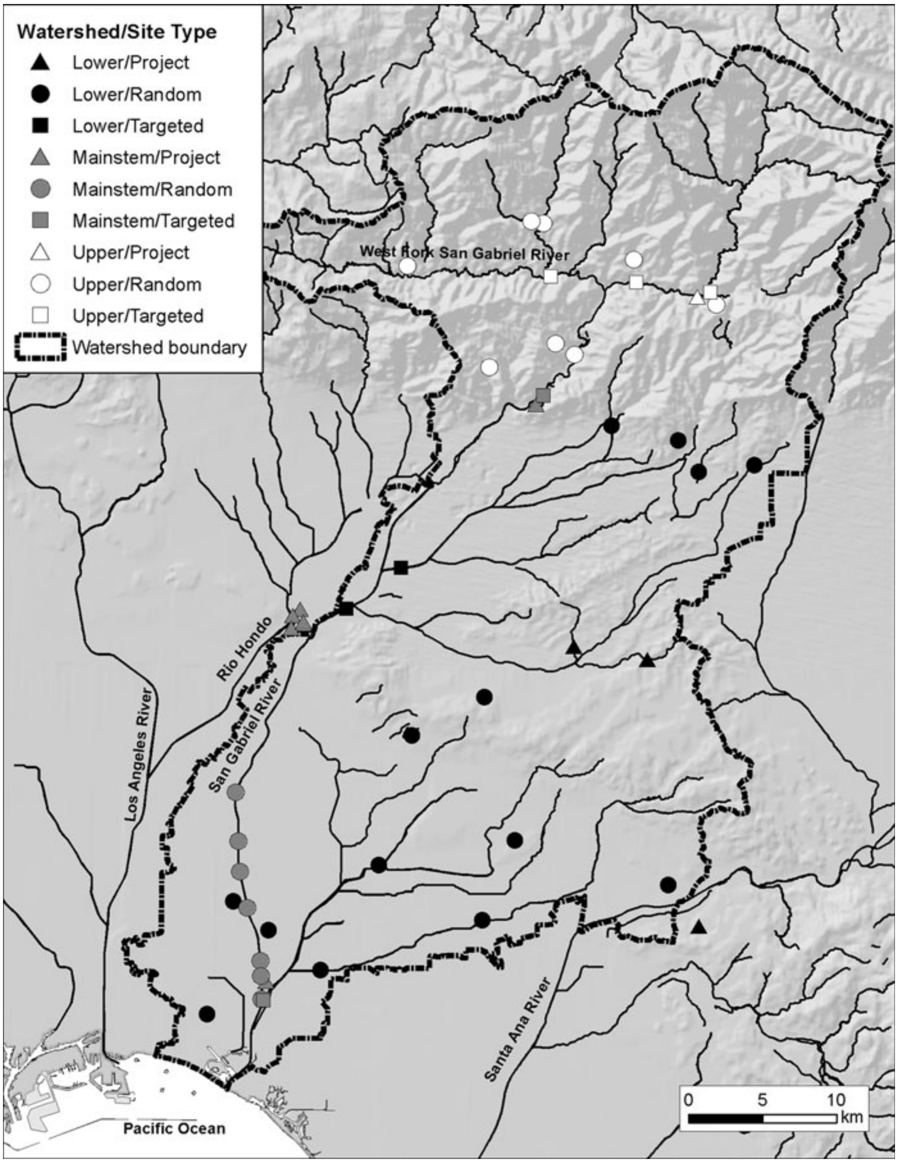
The San Gabriel River watershed is approximately 1,785 km^2 (689 mi^2) and is the third largest coastal catchment in Los Angeles County, California. The basin is defined by the San Gabriel Mountains to the north, the San Bernardino Mountains to the east, the watershed divide with the Los Angeles River to the west, and the Pacific Ocean to the south (Fig. 1). The watershed can be roughly divided into two broad segments based on land use and population density: the upper third (upper watershed) that is within the San Gabriel Mountains and Angeles National Forest with population densities fewer than 38 people/km^2 (100/mi^2), and the remaining two-thirds (lower watershed), which lie within the heavily urbanized Los Angeles basin and have population densities in excess of 2,300 people/km^2 (6,000/mi^2). The net effect of these land use disparities has created vast differences in the hydrologic, physical, and biotic character between streams that comprise the upper and lower portions of the watershed.

Level 1: resource inventories and maps

Documenting wetlands in the historical landscape

The San Gabriel River was the subject of a historical ecology study that estimated wetland extent and distribution (circa 1870) along a portion of the San Gabriel River floodplain from the base of the San Gabriel Mountains to its boundary with the historic San Gabriel and Los Angeles River estuaries (Stein et al. 2010). Primary and secondary sources of historical data included Mexican land grant sketches, U.S. General Land Office maps, topographic maps, aerial photographs, oral histories, and essays, among other sources. The concordance between these multiple data sources and collective "weight of evidence"

Fig. 1 The San Gabriel River watershed showing the locations of the 29 probabilistic (random), seven targeted, and ten project sites assessed for this study



were used to support inferences about the historical extent and distribution of wetland types in the San Gabriel River watershed.

Once assembled, these data were digitized, georeferenced, and overlaid in GIS to produce historical wetland polygons that were classified post hoc using the National Wetland Inventory (NWI) system (Cowardin et al. 1979) to facilitate comparison with contemporary conditions. The resulting maps were then compared to contemporary wetland maps to assess wetland loss and type conversion. Stein et al. (2010) provide a complete discussion of the approach and methods used for historical wetland mapping.

Contemporary wetland inventory and mapping

An inventory of contemporary wetlands, riparian areas, and drainage networks within the San Gabriel River watershed was produced using a base layer of digital aerial imagery and various types of collateral data. The mapped area included the portions of the San Gabriel River floodplain that were included in the historical analysis. Contemporary wetlands and drainage networks were mapped using established federal and state standards, as defined by the NWI and the California Statewide Wetlands Inventory (Dark et al. 2006). Draft mapping standards developed for the State of California, under consideration of the Riparian Habitat Joint Venture, were used to map riparian areas (Collins et al. 2007b). Classification of wetland habitats was based on NWI, but augmented with hydrogeomorphic (HGM) modifiers (Brinson 1993). Dark et al. (2006) provide a detailed description of the methods used to map contemporary wetlands in the San Gabriel River watershed.

Level 2: rapid assessment of stream condition

Ambient watershed assessment with CRAM

An ambient survey of streams in the San Gabriel River watershed was conducted in the spring and summer of 2005. Twenty-nine (29) stream sites were probabilistically selected from the upper, lower, and main stem portions of the watershed using the sample frame developed as part of the Level 1 assessment. This sample draw was weighted by proportion of watershed area to ensure adequate distribution of sites, with eight (8) sites located in the upper watershed, 14 in the lower watershed, and seven (7) along the river's main stem (Fig. 1). In addition to the probabilistically selected sites, seven key confluence points and areas of unique habitat value were targeted for assessment (LASGRWC 2007). Three (3) targeted sites were located in the upper watershed, two (2) in lower watershed, and two (2) along the river's main stem (Fig. 1).

We used the riverine module of the California Rapid Assessment Method for Wetlands (CRAM ver. 5.01; Collins et al. 2007a) to assess the condition of all but one of the 29 probabilistically selected points and the seven targeted locations. CRAM was not conducted at one of the upper watershed sites. CRAM assesses four overarching attributes of wetland condition: buffer and landscape context, hydrology, physical structure, and biotic structure. Each of these attributes is comprised of a number of metrics and submetrics that are evaluated in the field for a prescribed assessment area. CRAM attribute scores are averaged to produce an overall index score ranging from 25 (lowest possible) to a maximum of 100. CRAM also identifies key anthropogenic stressors that may be affecting wetland condition with a checklist. CRAM assessment areas were determined using the recommended guidelines provided in Collins et al. (2007a).

Project assessment with CRAM

In 2007, the riverine module of CRAM (ver. 5.01; Collins et al. 2007a) was used to evaluate the condition of ten (10) stream-based project sites distributed throughout the San Gabriel River watershed. One (1) project site was located in the upper watershed, three (3) were located in the lower watershed, and six were located (6) along the river's main stem (Fig. 1). These ten sites represented a range of project types (restoration, enhancement, compensatory mitigation) in various stages of development (planned, on-going, or completed projects). Assessment areas were determined using the recommended guidelines provided in Collins et al. (2007a).

Assessment of stressors

We evaluated the effects of anthropogenic 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. Sites were selected in conjunction with a CRAM validation study that documented relationships between CRAM results and independent, intensive measures of condition (Stein et al. 2009). Derived LDI values were then compared with CRAM overall index and attribute scores. In addition, we evaluated the performance of LDI compared to USGS derived percent imperviousness and regional land use data (SCAG 2003).

In addition to generating numeric condition scores, CRAM also lists the variety of possible stressors within a wetland or its landscape setting (Table 1). Stressors were evaluated for sites in the upper, lower, and main stem portions of the San Gabriel River watershed as defined by the 2005 probabilistic survey. Stressor types 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

Table 1 List of all possible stressors for each of the four CRAM attributes in the CRAM stressor checklist (Collins et al. 2007a)

Hydrology attribute
Point source discharges (publicly owned treatment works, other non-stormwater discharge)
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)
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
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
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)

* Not applicable to restoration areas, ** Includes point-source or non-point source pollution

and likely to cause a significant impact to the CRAM assessment area.

Level 3: intensive site assessment

Intensive site assessment was conducted at the 29 probabilistically selected and seven targeted sites included in the 2005 ambient survey. Monitoring included measures of water column chemistry, aquatic toxicity, the benthic macroinvertebrate community, and stream physical habitat (Los Angeles and San Gabriel Rivers Watershed Council 2007). This suite of indicators provided an opportunity to assess whether there are apparent linkages between observed levels of chemicals of concern, toxicity, and/or changes to physical habitat and impacts on the benthic community. Water chemistry measurements included general constituents, metals, and nutrients sampled at all sites using standard grab samples (Los Angeles and San Gabriel Rivers Watershed Council 2007; Table 2). Water column toxicity was assessed based on the survival and reproduction of the water flea (*Ceriodaphnia dubia*) for freshwater sites or a 7-day survival test of the silver sides (*Menidia beryllina*) for estuarine sites (Johnson 2007).

Benthic macroinvertebrates collected from each site were identified to the lowest specified taxonomic level, and biological metrics including diversity, average tolerance scores, relative abundance of aquatic macroinvertebrate species among categories of distinct

Table 2 List of water chemistry parameters measured in the San Gabriel River for the 2005 probabilistic survey (Los Angeles and San Gabriel Rivers Watershed Council 2007)

Category	Parameters
General characteristics	Hardness
	Alkalinity
	Total dissolved solids (TDS)
	Total suspended solids (TSS)
	Dissolved oxygen (DO)
	pH
	Total and dissolved organic carbon
Metals	Total and dissolved for ICP* list of 34 metals
Nutrients	Ammonia
	Nitrate
	Nitrite
	Total Kjeldahl nitrogen
	Total phosphate
	Orthophosphate
Organophosphate pesticides	ICP list for 19 pesticides (including chlorpyrifos, diazinon, malathion)

* Industry Cooperative Program

functional feeding groups (e.g., predators, grazers) were calculated (Harrington 2003). Next, a multi-metric Southern California benthic IBI (B-IBI) was calculated for each site (Ode et al. 2005). The B-IBI score derived allows the water quality conditions found there to be compared against reference site conditions in southern California. For the southern California B-IBI, five equal condition score categories (0–19 = "very poor", 20–39 = "poor", 40–59 = "fair", 60–79 = "good", and 80–100 = "very good") were determined using B-IBI = 39 as an impairment threshold that defined the boundary between "fair" and "poor" conditions (Ode et al. 2005).

The Level-2 and Level-3 data collected at ambient and targeted sites were summarized using histograms and box and whisker plots to enable comparisons of constituent concentrations and condition scores between the upper, lower, and main stem portions of the watershed. Scatter plots and linear regression were used to examine relationships between the various data sets (Zar 1996). Hierarchical cluster analysis was conducted on the benthic macroinvertebrate species data (based on the number of species present at a site) to elucidate relationships between the benthic community composition and watershed location.

Results

Wetland extent and distribution

A total of 5,395 ha of existing wetland habitat were mapped in mountain, foothill, and valley areas of the San Gabriel River Watershed (Dark et al. 2006). The vast majority of this area is comprised of riverine (2,286 ha) and palustrine wetland types (2,054 ha; Fig. 2). A summary by HGM category indicates that fluvial systems, including streams and flow-through palustrine wetlands confined to a channel, dominate in this watershed. Most of these fluvial features are located in canyon areas, with smaller amounts in valley areas. Stein et al. (2010) estimated the greatest losses to wetlands of the San Gabriel River floodplain have been associated with streams in the upper floodplain and palustrine wetlands in the tidal fringe since the 1870s.

It is estimated that over 4,000 ha of small tributary streams, creeks, and associated riparian habitat existed in the San Gabriel River floodplain circa 1870 (Stein et al. 2010). Since that time, approximately 75% of this area has been lost or extensively modified by a series of dams, diversions, and channels. The greatest proportional loss of riverine and riparian habitat has occurred in the upper floodplain due to the conversion of the broad alluvial floodplain 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 (Stein et al. 2010).

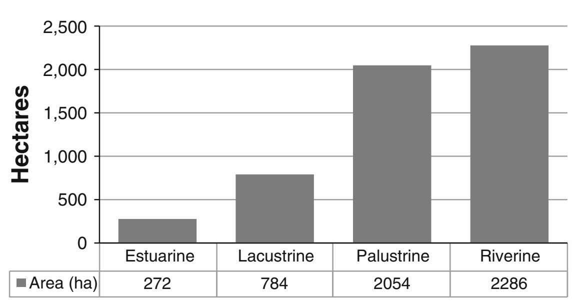


Fig. 2 Amount of wetland area (in hectares) by wetland type (Cowardin class) in the San Gabriel River watershed (Stein et al. 2010)

Rapid assessment

CRAM index scores from the probabilistically selected sites ranged from 35 to 91 (Table 3; Fig. 3). The seven sites in the upper watershed that were assessed with CRAM were comprised of mostly natural streams and had the highest mean CRAM scores overall. The seven sites located in the main

Table 3 Final attribute and index scores for the probabilistically selected (random) and targeted sites assessed with CRAM in the San Gabriel River watershed

Site ID	Site type	Watershed location	Buffer/ landscape	Hydrology	Physical structure	Biotic structure	CRAM index score
SGLR004	Random	Lower	39	42	38	58	44
SGLR007	Random	Lower	45	83	38	75	60
SGLR015	Random	Lower	25	67	25	21	34
SGLR017	Random	Lower	33	67	38	46	46
SGLR018	Random	Lower	62	88	88	38	69
SGLR022	Random	Lower	25	67	25	38	39
SGLR025	Random	Lower	25	67	25	42	40
SGLR036	Random	Lower	57	58	50	46	53
SGLR039	Random	Lower	25	67	25	25	35
SGLR041	Random	Lower	25	67	25	46	41
SGLR043	Random	Lower	25	67	25	21	34
SGLR047	Random	Lower	25	67	25	21	34
SGLR055	Random	Lower	25	58	25	21	32
SGUR051	Random	Lower	28	58	25	38	37
SGMR011	Random	Mainstem	28	58	25	29	35
SGMR016	Random	Mainstem	28	58	25	21	33
SGMR027	Random	Mainstem	28	58	25	21	33
SGMR031	Random	Mainstem	28	58	25	21	33
SGMR059	Random	Mainstem	28	58	25	33	36
SGMR073	Random	Mainstem	28	58	25	21	33
SGMR079	Random	Mainstem	28	58	25	21	33
SGUR003	Random	Upper	64	100	100	71	84
SGUR006	Random	Upper	67	100	75	54	74
SGUR010	Random	Upper	49	67	63	29	52
SGUR042	Random	Upper	62	100	88	71	80
SGUR065	Random	Upper	67	100	63	63	73
SGUR070	Random	Upper	64	100	75	50	72
SGUR083	Random	Upper	67	100	63	54	71
SGLT506	Targeted	Lower	25	67	63	71	56
SGLT507	Targeted	Lower	42	67	38	58	51
SGLT508	Targeted	Mainstem	25	67	25	21	34
SGUT505	Targeted	Mainstem	60	67	63	63	63
SGUT501	Targeted	Upper	62	100	75	67	76
SGUT502	Targeted	Upper	67	100	100	46	78
SGUT504	Targeted	Upper	62	92	88	71	78

CRAM index scores are the average of the final four attribute scores. Scores can range from 25 to 100. Sites are arranged by type and watershed location. Note that one of the probabilistically selected sites (upper watershed) was not assessed with CRAM and is not listed

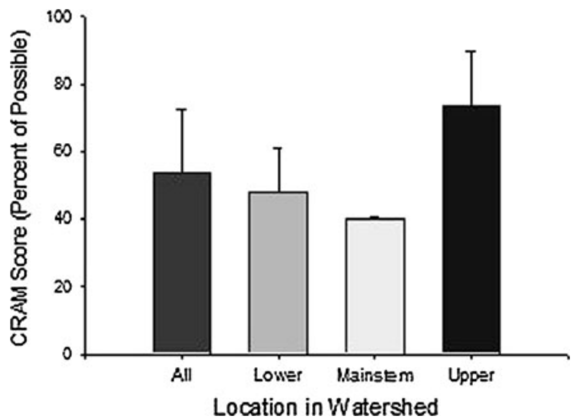


Fig. 3 Mean scores for CRAM assessment areas in the San Gabriel River based on watershed position. *Bars* represent 95% confidence limits

stem of the river, which has been predominantly channelized, had the lowest mean CRAM scores (approximately half the mean score as the upper watershed). The 14 lower watershed sites, which are comprised of a mix of semi-natural and channelized tributaries, had intermediate scores that were comparable to mean values for the overall watershed condition.

CRAM index scores for the ten project sites ranged from 54 to 84 (Table 4), and spatial patterns in stream condition were similar to those observed among the probabilistic sites. The single project located in the upper, less developed portions of the watershed (Cattle Canyon) had one of the highest CRAM index scores (83) of all the projects assessed, whereas projects in the lower and main stem sections tended to have lower CRAM index and attribute scores. For example, 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 index score (54). An exception to this was the Oak Canyon project site which received the highest CRAM index score (84) of all the projects assessed. Although this site was in the lower portion of the watershed, it is located within a relatively isolated, 58-acre natural park.

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 score 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 the Cattle Canyon site was located in the least developed portion of the watershed, it probably began with higher condition scores than sites in the lower watershed regardless of project status (i.e., planned, on-going, or completed) at the time of assessment. The small project sample size and lack of standardization among projects by type and age limited additional data comparability.

Table 4 CRAM final Attribute and Overall Index scores for ten project sites assessed with CRAM in the San Gabriel River 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

Projects are ranked from highest to lowest overall index score. Overall index scores are the average of the final four attribute scores. Scores can range from 25 to 100

U upper watershed, *M* main stem, *L* lower watershed

Table 5 Frequency of occurrence of landscape stressor types within 500 m of sites assessed with CRAM in the San Gabriel River watershed

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

The most frequently recorded severe landscape stressors are noted in parentheses

Stressor analysis

A total of 12 different types of landscape stressors (operating within 500 m of the assessment area; Table 5) and 26 types of hydrologic, physical, and biotic stressors (operating within 50 m of the assessment area; Table 6) were recorded at the random and targeted sites included in the ambient survey. CRAM index scores were significantly correlated with the number of stressors and severe stressors found at each random site (non-parametric Spearman's rank correlation for the buffer and landscape context attribute of CRAM ($r = -0.54$ and -0.32, respectively; $P < 0.05$). A similar trend was observed for the hydrologic, physical, and biotic (non-parametric Spearman's rank correlation $r = -0.41$ and -0.42, respectively; $P < 0.01$).

Urban residential land use was considered the most common landscape stressor affecting stream sites throughout the watershed in terms of presence (46%) and severity of impact (32%). Transportation corridors and industrial/commercial land use were also among the most frequently cited severe stressors at the landscape scale (Table 5). Nutrient impairment was the most common physical stressor throughout the watershed, recorded at 67% of the sites visited. Other physical and hydrologic stressors, including 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 (Table 6).

The three portions of the watershed (upper, lower, and main stem) differed in the presence and severity of stressors at the 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, stressors at the buffer/landscape scale only impacted 60% of the upper watershed sites. 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.

A similar trend was found for stressors operating within 50 m of the assessment area. The 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 (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. In contrast, the upper watershed had few recorded occurrences of stressors and severe stressors (11 and 15%, respectively).

Table 6 Frequency of occurrence of stressor types within 50 m of sites assessed with CRAM in the San Gabriel River watershed

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

The most frequently recorded severe stressors are noted in parentheses

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 prevalent 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. Furthermore, 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 (Fig. 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 (Fig. 4b). Toxicity was observed during the ambient assessment at only 2 of the 29 random sites sampled (7% of total samples). 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

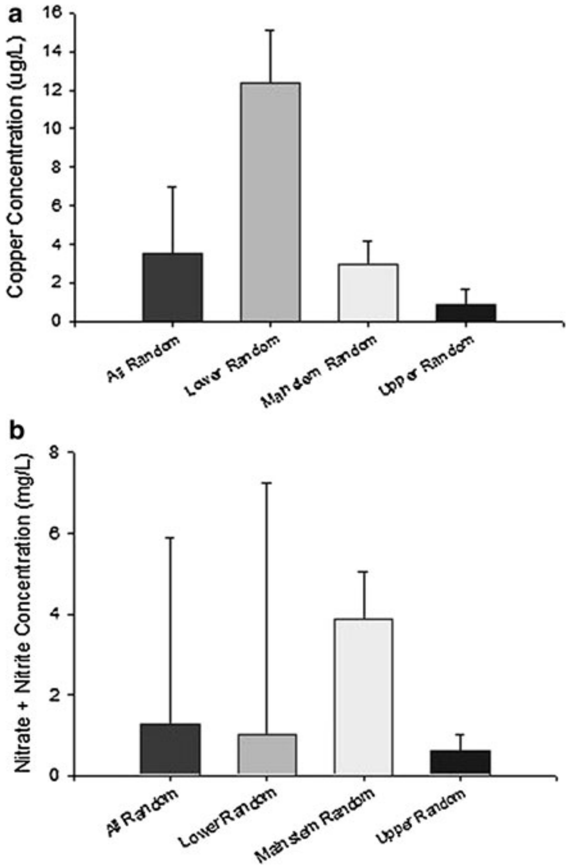


Fig. 4 **a** Total copper concentrations and **b** nitrate + nitrite concentrations at random sites by position across the San Gabriel River watershed. *Bars* represent 95% confidence limits

than at the random sites. In contrast, total iron was higher at the targeted sites.

Benthic macroinvertebrate species data collected from the 2005 random and targeted 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 (Fig. 5). 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, and sites located in the upper watershed had the highest IBI scores (Fig. 6). A subset of sites from the lower watershed and main stem grouped together and received similar IBI scores. Similar patterns among the major portions of the watershed were also apparent when species in the three subsets of the watershed are combined into ecological groupings. 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 (Fig. 5).

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 ($r = 0.78$; Fig. 7). 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 ($r = -0.87$; $P < 0.001$), followed by the National Landcover Data ($r = -0.86$; $P < 0.001$). The overall CRAM index score consistently had the strongest relationship with the LDI whereas relationships at the CRAM attribute level were not as strong.

There was a positive correlation ($r = 0.64$; $P < 0.01$) between benthic macroinvertebrate communities (as measured by IBI) and habitat condition (as measured by CRAM) across streams in this watershed (Fig. 8). Furthermore, a comparison of habitat condition as assessed through rapid assessment and three types of Level-3 data (copper concentration, aquatic toxicity, and benthic macroinvertebrates) provided insight in how percentage of watershed area meeting target conditions can vary depending on the standard and type of indicators used (Fig. 9a). If based on total copper concentrations, 15% of the watershed area does not meet target conditions for current copper standards. For toxicity, 5% of the area does not meet target conditions. For the benthic macroinvertebrates, 44% of the area does not meet target conditions based on the current benthic IBI for southern California. For overall habitat condition, 62% of the area does not meet target conditions based on CRAM overall index scores. The minimum acceptable condition for CRAM was assumed to be represented by the 25th

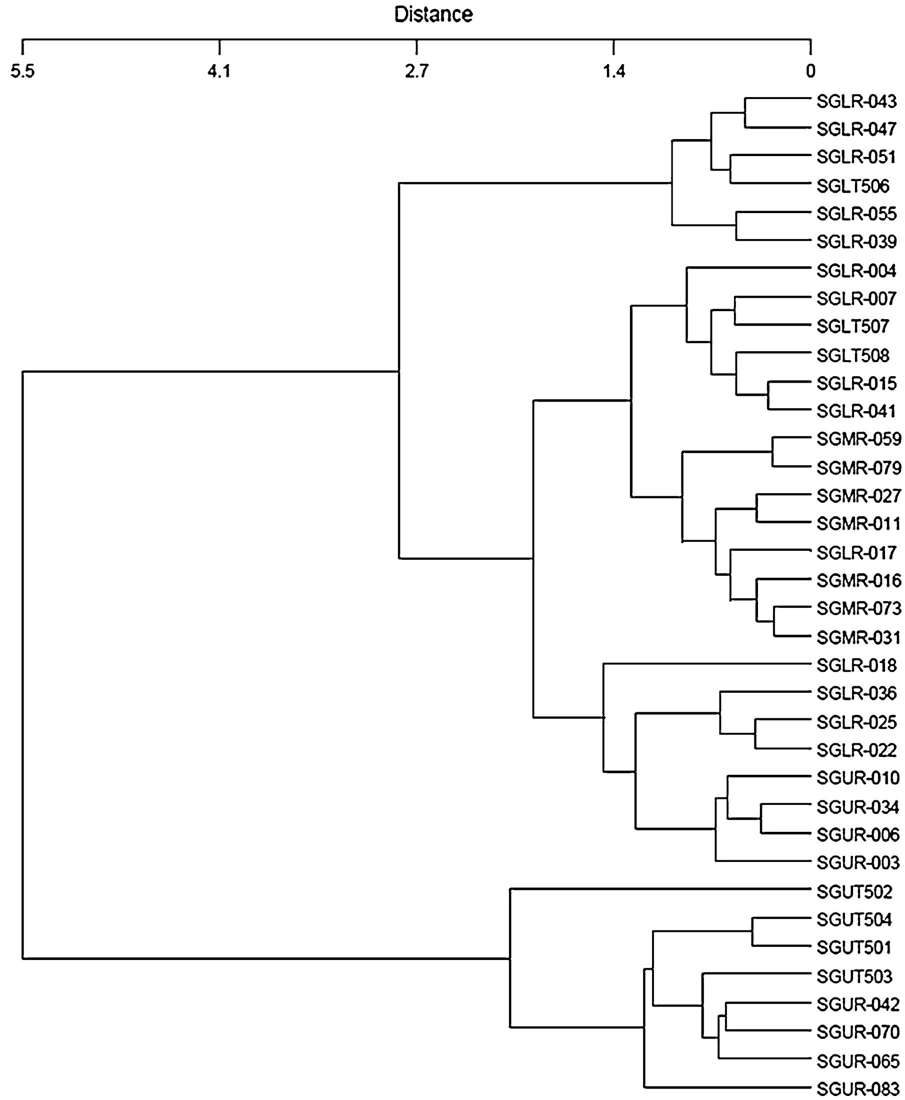


Fig. 5 Cluster analysis of benthic macroinvertebrate species data from the random and targeted sites in the San Gabriel River watershed. L refers to sites in the lower watershed, M to sites along the main stem, U to sites in the upper watershed, and T to targeted sites

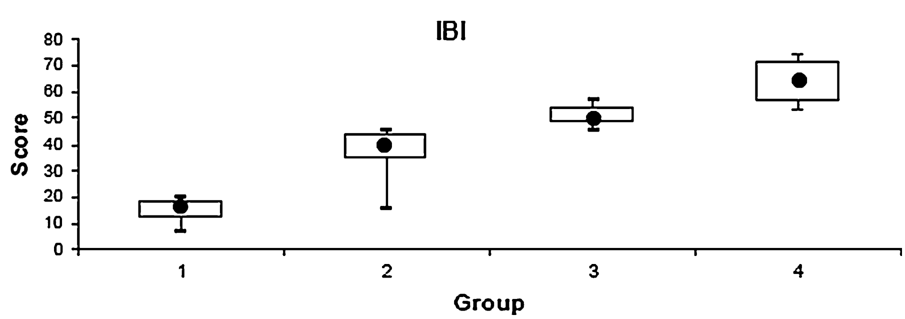


Fig. 6 *Box* and *whisker plots* showing the median and range of IBI scores in each of the four site groups from the cluster analysis. Site group 1 contains only lower watershed sites; site group 2 contains the main stem sites; and site groups 3 and 4 contain the upper watershed sites

percentile of index scores based on the statewide ambient survey for all indicators combined. When condition is inferred based on multiple indicators, conclusions about the percent of area not meeting target conditions also varies based on the number of indicators used (Fig. 9b).

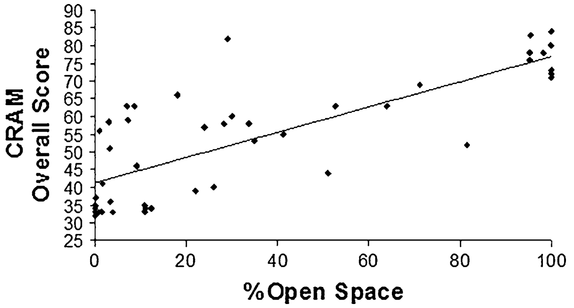


Fig. 7 Scatter plot and linear regression between overall CRAM scores and the percent of open space in the San Gabriel River watershed

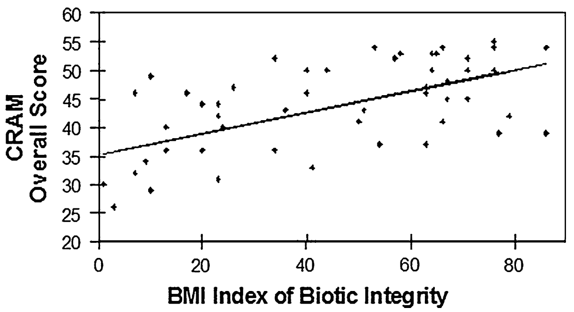


Fig. 8 Scatter plot and linear regression between overall CRAM scores and IBI scores from the 2005 ambient survey of riverine wetland condition in the San Gabriel River watershed

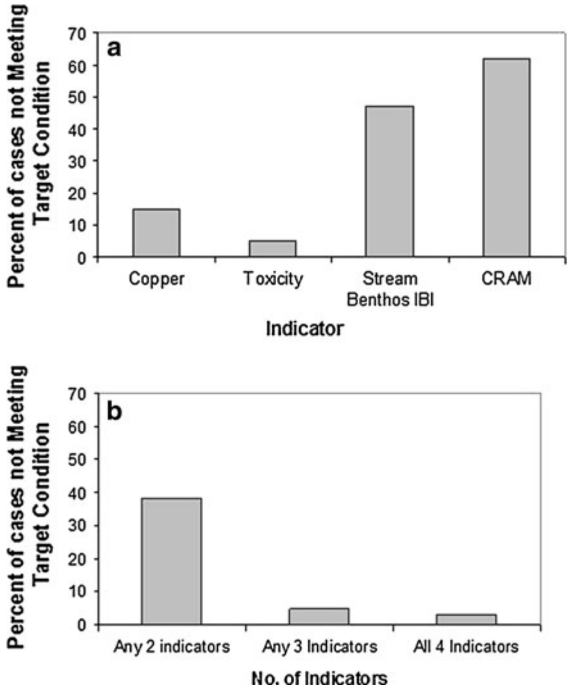


Fig. 9 **a** Indicators used in the San Gabriel River watershed to assess riverine-riparian condition relative to different environmental policies and programs, **b** the same data relative to the number of indicators used to assess riverine-riparian condition

Discussion

A three-tiered monitoring framework provides a flexible assessment approach where the intensity of the assessment can be matched to the importance of the management question. This approach could be applied to a variety of local, state, and federal wetland programs (e.g., National Pollutant Discharge Elimination System) in a manner that leverages existing tools to minimize redundancies, maximize data comparability, and maximize the geographic coverage of the data (Sutula et al. 2008). The results of the rapid assessment and intensive studies both indicate that biotic integrity is highest at sites with intact wetland and riparian communities (Los Angeles and San Gabriel Rivers Watershed Council 2007). Therefore, rapid assessment can be used as a cost-effective screening tool to help identify sites where more intensive assessments are warranted or to identify specific attributes of a wetland that require improvement through corrective management actions. Furthermore, the significant relationship between CRAM and intensive physical habitat metrics suggests redundancies that can be eliminated if resources are limited.

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. Watershed position was shown to be an important determinant of overall stream 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 (Mazor and Schiff 2008), as well as other parts of the world (e.g., Hatt et al. 2004; Walsh et al. 2007), indicate that the extent of developed land is strongly associated with the poor biological condition of stream ecosystems. Changes in land use are known to particularly affect wetlands receiving water from an urbanizing drainage basin (Kentula et al. 2004).

A further advantage of a multi-tiered monitoring approach is the ability to integrate multiple indicators at 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. 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).

Multiple lines of evidence together provide a more complete understanding of the factors affecting overall stream condition in the San Gabriel River watershed. Although this 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 understand the condition of the waterbody and prioritize management actions.

Another benefit of a multi-level approach to monitoring and assessment is that it provides wetland managers with an effective organizational tool that can be used to make well-informed management decisions and prioritize management activities. 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, this 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 compare to other wetlands or sites in the region.

Finally, a multi-tiered monitoring approach can provide a cost-effective means of integrating wetland status and trends assessments into routine watershed monitoring programs. 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 these data.

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 augment the Level 3 assessments of specific wetland functions or aspects of condition to provide more robust evaluations of overall health at little additional cost.

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