SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT AUTHORITY

THEMATIC RESEARCH PLAN

FOR

BIOASSESSMENT

Last Revised May 2016

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Introduction

Biological assessment, or bioassessment, is the science of evaluating the health of an ecosystem by examining the organisms that live within it. Unlike chemistry- and toxicology-based monitoring methods, bioassessment is able to integrate the cumulative effects of all stressors on an ecosystem and the organisms in it, including contaminants, altered physical habitat, and changing hydrological flow patterns. While traditional chemical and toxicology-based methods are typically restricted to monitoring at a discrete point in time, a single bioassessment sampling event can produce integrative data on all stressors over the organism's full lifespan. Consequently, bioassessment is intrinsically linked to the beneficial-use goals that are the focal point of water-quality improvement plans, and has become the cornerstone of Southern California's two premier regional monitoring programs: the Southern California Bight Regional Monitoring Program and its freshwater counterpart, the Southern California Stormwater Monitoring Coalition Regional Watershed Monitoring Program. While the use of bioindicators such as algae, invertebrates, and fish as biological indicators of ecosystem health in certain water body types are well-established, SCCWRP's goal is to build a comprehensive bioassessment program that eventually encompasses all water body types in Southern California and utilizes organisms across all levels of aquatic food webs, enabling environmental managers to better protect aquatic ecosystems and foster healthy, sustainable biological communities (Figure 1).

Conceptual Model

SCCWRP's conceptual model for bioassessment research is driven by a series of beneficial-use goals that environmental managers are legally mandated to protect. These goals form the foundation of a robust bioassessment monitoring program that comprises three distinct research areas, which work in coordination to seamlessly transition science into managerially relevant products optimized for widespread adoption (Figure 1). These three stages are assessing waterbody condition (**Condition Assessment**), assessing causes of waterbody impairment (**Causal Assessment**), and setting expectations and measuring progress toward achieving beneficial-use goals (**Management Action**).

Figure 1. SCCWRP's bioassessment research is driven by the need to achieve beneficial-use goals for waterbodies. SCCWRP works across three main areas – condition assessment, causal assessment, and management application – to design managerially relevant approaches and tools that help achieve these beneficial-use goals.

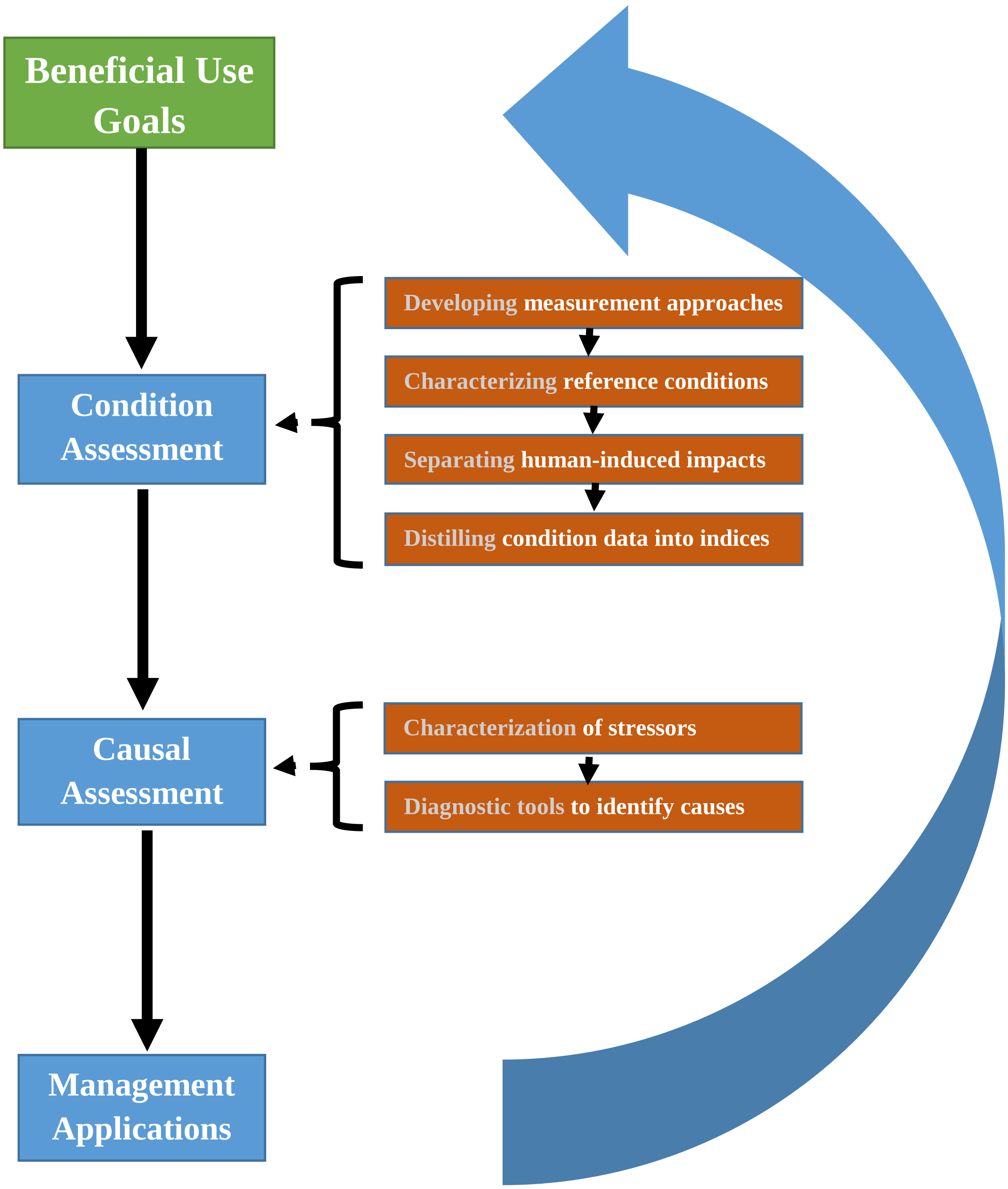

Figure 2. SCCWRP is working to incrementally build its bioassessment program to eventually encompass all stages of bioassessment research and multiple condition indicators for all major water body types in Southern California. The components of SCCWRP's program fall on a continuum, starting with the nascent stages (i.e., collection of baseline biological, physical, and chemistry data) and ending with the stages that demonstrate full program maturity (i.e., incorporation of bioassessment into management programs). This figure presents the state of SCCWRP's bioassessment program to date.

Bioassessment Program Components

	Initial Data/Reference Characterization			***Condition Assessment***				***Causal Assessment***		***Management Response***		
Research Elements	Habitat Data	Biological Data	Stressor / Pressure Data	Rapid Assessment	Single Assemblage	Multi-Assemblage	Ecosystem Function/Services	Screening	Comparative	Condition Thresholds	Implementation Support	Spatial / Temporal Integration
Arid Washes	■		■	■								
Seeps/Springs												
Depressional Wetlands	■	■	■	■								
Lakes												
Wadeable Streams[1] §	■	■	■	■	■	■		■	■		■	■
Rivers												
Estuaries	■	■		■								
Nearshore Soft Bottom[2]	■	■	■	■	■	■				■	■	■
Nearshore Hard Bottom[3]	■	■	■			■						
Shelf Benthic[2]	■	■	■		■					■	■	■
Shelf Pelagic												
Slope/Abyssal	■	■	■									

Cell shading: Indicates an element for which SCCWRP is working on or has completed a research project that allows SCCWRP to conduct or inform that element

§: Denotes a water body type for which a robust definition of reference conditions has been developed

Underlined water body types: Denotes water body types with an associatedm ongoing ambient assessment program that provides much of the data necessary to advance the research element

[1]Southern California Stormwater Monitoring Coalition (SMC) Regional Watershed Monitoring Program

[2]Southern California Bight Regional Monitoring Program

[3]Marine Protected Areas (MPA) Monitoring Enterprise

Condition Assessment

All water-quality management programs across California are founded on the expectation that they will protect and restore the many beneficial uses that waterbodies provide, from recreation to industrial uses to providing drinking water. Environmental managers are tasked with maintaining cold (COLD) and warm (WARM) freshwater habitats at their respective temperatures, protecting estuarine (EST) and marine (MAR) habitats from human-triggered encroachment and damage, and preserving ecologically sensitive biological habitats (BIOL). What these goals have in common is that they depend upon a manager's ability to accurately and comprehensively assess the biological condition of each waterbody.

SCCWRP builds capacity for environmental managers to assess the condition of a waterbody type via a four-step development process: First, SCCWRP **develops and standardizes assessment approaches** to measure condition. Second, SCCWRP **characterizes reference conditions** to understand the condition of a waterbody relative to what it would look like without human-induced impacts. Third, SCCWRP works to **assess the range of human impacts** that potentially have altered the condition of the waterbody from its reference state. Fourth, SCCWRP collects and analyzes data on the waterbody's condition in an effort to **distill condition data into indices** that can be readily interpreted by managers.

- **Developing and standardizing measurement approaches**: Before waterbody condition can be assessed using one or more biological indicators, a standardized approach to sampling and measuring condition must be developed and vetted for each indicator. Because the best condition assessments include multiple indicators (i.e., microbes, plants, invertebrates, and vertebrates), there is a persistent need to develop and standardize measurement approaches to enable use of additional indicators.
  Challenges: Individual measurement approaches alone cannot provide a comprehensive, accurate picture of waterbody condition, necessitating development of multiple measures, which then must be integrated into a single index-based scoring tool.
- **Characterizing reference condition**: To ascertain what condition a waterbody *should* be in if not for human impacts, scientists must assess the waterbody's reference condition. Because not all degradation of a waterbody can be attributed to human-induced impacts, it is essential to analyze how variations in physical gradients affect reference biological expectations. This natural variability can dramatically affect composition and condition of biological communities, driving changes to breeding success, recruitment/settlement, survival, and competition/predation. Natural variability encompasses factors like water depth, substrate type, water temperature, and time, including short-term temporal cycles such as seasonality, and long-term cycles such as extended wet/dry or warm/cool periods (i.e., El Niño/La Nina). In freshwater systems, natural variability also includes altitude.
  Challenges: Conceptually, establishing reference condition is a relatively straightforward task that involves finding remote, undisturbed locations, but in practice, finding sufficient numbers of minimally disturbed sites across major ecosystem gradients is challenging because many of these habitats have been pervasively altered. Also, long-term monitoring is required to be able to appropriately integrate the impacts of temporal variability. For example, the reference condition for the California Stream Condition Index scoring tool was established over a 10-year period, which means the index may be biased against climatic patterns that span more than 10 years.

- **Separating human-induced impacts from natural variation**: Once reference conditions have been established, the full range of impacts to the site of interest must be captured and analyzed, with a goal to understand which impacts are triggered by human activity and which are the result of natural variation. To make this determination, scientists must characterize natural and stressor gradients in physical habitats (i.e., change to habitat structure), flow changes (i.e., hydromodification), chemical contamination (i.e., toxics), and biogeochemical elements (i.e., nutrients).
  Challenges: Condition is affected by multiple stressors and natural variability that collectively can exert synergistic impacts. Thus, indices and causal assessment tools must be developed that are diagnostic of (i.e., sensitive to) specific stressors to more reliably connect condition with potential causes of degradation. For example, some environmental settings are so pervasively altered that it may be impossible to find and sample an adequate number of minimally altered reference sites. In these situations, alternative approaches for separating natural and anthropogenic biological variation may be required, such as modeling of historic conditions, or using "best observed" condition in place of "minimally altered". If an alternative reference definition is used, ensuring comparability with assessments based on traditional reference definitions will require careful study.
- **Distilling condition data into indices**: Because bioassessment generates a wealth of data – for example, a single sample from one square meter of ocean bottom may yield over 100 species and thousands of individual organisms – this information must be distilled into findings that can be readily interpreted by water-quality managers, not all of whom are trained biologists/ecologists. The solution is environmental scoring tools known as biological indices that can transform a wealth of raw data into simple numerical scores corresponding to overall environmental condition. When properly contextualized with relevant information about natural condition and the range of human impacts, these numerical representations allow managers to compare condition to reference expectations, and to understand where along a condition gradient a given site falls.
  Challenges: Because natural variability may bias index scores, calibration of useful assessment indices may require considerable amounts of data that may take considerable resources (both time and money) to collect. Furthermore, although the value of multiple indicators is undisputed, there also is a need for a framework for integrating them into a single condition assessment; this is the only effective way to fully realize the potential of bioassessment data and to effectively connect bioassessment with management actions.

Causal Assessment

While condition assessment reveals the degree to which a waterbody is impacted by human and natural processes, and the limitations of the waterbody's ability to support biological communities and beneficial-use goals, it cannot answer questions about the underlying causes of impact. Hence, researchers need a methodology to identify, evaluate, and quantify potential stressors on a waterbody, a research area known as causal assessment. Causal assessment relies on the biological data generated through condition assessment to establish what biological impacts have occurred, and to identify what stressors should be remediated to improve biological condition. In practice, causal assessments also serve to highlight gaps in routine monitoring data.

SCCWRP builds capacity for environmental managers to conduct causal assessments by focusing its research around two main areas: First, SCCWRP works to **characterize stressors** by identifying all potential pressures on a biological community and how they relate to observed biological degradation. Second, SCCWRP develops **diagnostic tools to identify causes**, a multi-tiered assessment process that starts with rapidly eliminating potential causes and ends with detailed, in-depth assessments that include confirmatory follow-ups.

- **Stressor characterization**: In the first main stage of causal assessment, all potential stressors at a site are listed, defined and characterized as to how they could be contributing to the degradation observed in a biological community. Accurate stressor characterization is essential for obtaining unbiased causal assessment results.
  Challenges: Across Southern California's highly developed watersheds and coastal habitats, it is common to find multiple, commingled stressors that exert cumulative impacts on biological communities. Dominant stressors affecting a given waterbody must be documented in terms of their intensity, persistence, and reversibility.
- **Diagnostic tools to identify causes**: The multi-tiered process to identify causes of a waterbody's impairment begins by rapidly screening to eliminate major classes of stressors from consideration. If biological response patterns do not match any of the characterized stressors, then these stressors can be eliminated from future consideration, greatly simplifying and reducing the cost of the subsequent analysis. Identifying and confirming causal stressor(s) require the use of numerous stressor evaluation tools that consistently point to the same stressor(s), essentially building a weight-of-evidence approach for causation. Confirmation studies, including manipulative studies and focused monitoring, round out the stressor identification process.
  Challenges: Causal assessment screening tools must be developed and adapted for each waterbody type of interest in Southern California. Furthermore, the most effective route to take requires developing tools can be applied at both local and regional scales to identify both local and landscape-scale factors that could be managed to improve condition.

Bridging these two research areas is SCCWRP's ongoing work to quantify the relationship between stressor and response, which informs an understanding of how stressors trigger biological impacts and how to interpret causation data.

Management Applications

Underlying all bioassessment research is a need to design tools and collect data that inform management decisions. Thus, SCCWRP's bioassessment program aims to connect the findings of condition and causal assessments to regulatory, restoration, and management programs, and to beneficial-use endpoints. The solution is a single, unified integrated framework with custom-designed management tools that integrates a full suite biological indicators and can be applied to any waterbody type. SCCWRP is working to incrementally build this management framework by focusing on three areas: First, SCCWRP is working to simplify and streamline biological index calculations by **bringing automation to assessment tools**. Second, SCCWRP is laying a scientific foundation to **support management interpretation of tools**. And third, SCCWRP is **using case studies to demonstrate application** of its assessment tools in management settings.

- **Bringing automation to assessment tools**: To support a manager's ability to implement both condition and causal assessments in a consistent, streamlined and unbiased manner, a variety of protocols must be developed to bring automation and user-friendliness to the bioassessment process. These protocols help users compile large data sets and conduct detailed and complex analyses with them, then facilitate interpretation of scores by non-technical experts. Products include user manuals, training programs, quality assurance procedures, automated scoring tools (i.e., calculators), and data management infrastructure. ***Challenges***: Although the State of California has developed a data management infrastructure with some ability to support bioassessment, little automation exists, particularly for condition and causal assessment tools. Thus, there remains a need to commit time and resources toward programming complex ecological algorithms, design intuitive user interfaces, and developing comprehensive technical transfer training documents and workshop curricula.

- **Supporting management interpretation of bioassessment tools**: For bioassessment tools to be useful in a management context, the scientific data generated by bioassessments must be translatable into appropriate thresholds, regulatory targets, and compliance goals. Managers need to know how to interpret tools, integrate various condition indices and scoring data, rank sites along a conceptual condition gradient, apply the results of causal assessments, and have assurances regarding reliability and confidence estimates. Thus, interpretive frameworks must be developed to contextualize and inform issues such as comparing alternative management actions, setting performance or compliance targets, evaluating progress toward achieving those targets, and calibrating and validating biological response models aimed at informing management action.
  Challenges: There are a number of different viable approaches to set appropriate thresholds; the key is to link them to management priorities, a connection that requires a considerable investment of time and energy to execute effectively.
- **Using case studies to demonstrate application**: To demonstrate that condition and causal assessment tools can be effectively implemented in the regulatory and management sectors, case studies are needed. Case studies provide an opportunity to test-drive the bioassessment tools and identify barriers to implementation.
  Challenges: Case studies require extensive partnerships with and buy-in from the end-user management community. Thus, before tools can be widely implemented, relationships must be cultivated to support execution of case studies. Also, a single case study often isn’t enough; several case studies are typically required to ensure tools are universally applicable across waterbody types and management scenarios, and to verify improvements are being observed in response to management decisions.

Research Directions

Bioassessment pervades multiple disparate areas of SCCWRP's research. It forms the underlying science that helps drive regional monitoring programs in both marine and freshwater environments, and serves as the technical foundation for a wide range of policy-setting and permitting decisions in areas like biological objectives, sediment quality, stormwater management, nutrient control, and minimum flow criteria. SCCWRP is vested both in building bioassessment tools for every major aquatic habitat type of management concern, as well as in developing integrated frameworks that allow managers to effectively and efficiently synthesize results from multiple tools to assess and manage overall waterbody health – and to relate those results to beneficial-use attainment goals.

Condition Assessment

Developing and Standardizing Measurement Approaches

Accomplishments

The robust set of bioassessment tools developed by SCCWRP already has been integrated into management decision-making, including regulatory-based comparisons for NPDES monitoring and reporting requirements. SCCWRP also has invested heavily in taxonomy, a fundamental building block of standardizing assessment methods. Given that there are an estimated 5,000 species of invertebrates in our coastal ocean and another 2,000 different species of invertebrates in our streams, SCCWRP has taken a lead on supporting taxonomic resolution and standardization – that is, making sure each scientist calls the same organism by the same name. SCCWRP has helped found and run multiple professional societies that maintain taxonomic standardization for freshwater and marine invertebrates, including the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT), Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT), and Southern California Association of Ichthyological Taxonomists and Ecologists (SCAITE).

Ongoing Research

The approach to conducting bioassessments is undergoing a revolution as traditional taxonomic identification gives way to novel molecular methods that use unique genetic signatures from each species to rapidly analyze bioassessment samples (Stein et al. 2014). Known as DNA barcoding, this technology has presented SCCWRP with an unprecedented opportunity to develop next-generation biological indicators that can be applied to additional waterbody types.

> ***Project:* Using molecular tools to develop ichthyoplankton as a bioindicator**
> SCCWRP is developing molecular tools to allow ichthyoplankton to serve as a condition indicator for the marine pelagic zone. Ichthyoplankton, or fish larvae, are used to assess environmental impact, but historically have not been developed as a bioindicator because of challenging taxonomic identification and a dearth of properly trained taxonomists. DNA barcoding offers the potential to develop ichthyoplankton as a sensitive indicator of condition, particularly for California's recently established Marine Protected Areas (MPAs), which are subject to stresses from land-based discharges.

> ***Project*: Developing capacity for algae-based bioassessments**
> SCCWRP is part of a team that is working to build capacity to conduct algae-based

bioassessments in California streams. The ultimate endpoint is to be able to develop a predictive, statewide freshwater index of biotic integrity that uses algae as the indicator of waterbody condition; it would serve as a complement to the California Stream Condition Index, which uses benthic macroinvertebrates as the bioindicator. With this endpoint in mind, SCCWRP is building up taxonomic capacity to analyze the assemblage, composition and structure of algae, as well as measure biomass (e.g., ash-free dry mass or chlorophyll-a) and eutrophic condition. SCCWRP also developing standardized approaches that include quality assurance protocols.

Priorities for Future Research

Recent advances in molecular technology are paving the way for SCCWRP to move into environmental metagenomics, in which DNA representing an entire biological community is extracted and analyzed from a single environmental sample, such as water or sediment. Metagenomics could enable SCCWRP to expand routine monitoring programs into any number of waterbody types, including streams, nearshore soft-bottom waterbodies, wetlands and estuaries. As the number of available indicators expands, more data will be amassed during routine data collection efforts that can then be used as the foundation for future indices development.

***Future focus area*: Using eDNA to characterize community structure**
The ability to use molecular data to characterize community structure and composition would be particularly advantageous for routine monitoring because it could streamline data production for information that has been difficult to collect through traditional means. For example, molecular barcoding might support data production for hard-to-resolve species, such as oligochaetes or microcrustacea. Analysis of eDNA may allow for rapid detection of species of concern (both invasive and protected species). Additionally, next-generation sequencing (i.e., non-targeted) opens the door to new ways of assessing broad suites of taxa across multiple trophic levels (e.g., fish and amphibians), which might otherwise be too difficult to sample within a rapid monitoring framework.

***Future focus area*: Developing standardized taxonomic effort levels for soft algae and diatoms**
SCCWRP is interested in harmonizing taxonomy for soft algae and diatoms. Currently, very few labs are able to produce algal taxonomic data that is comparable to the data produced by state labs, and dischargers may have difficulty conducting permit-required monitoring. Standardized taxonomy is a critical element to ensure comparability across multiple state labs. Taxonomic standardization is maintained for freshwater and marine invertebrates by professional societies that SCCWRP helped found and run, and similar successes with algal taxonomy are anticipated.

Characterizing Reference Condition

Accomplishments

SCCWRP has long invested in reference condition monitoring, starting with the agency's 1976 "reference surveys" (Word et al. 1979) and continuing with the Reference Condition Management Program (Ode and Schiff 2009, Ode et al. 2016). This reference monitoring has paved the way for development of numerous biological indices – notably, the benthic invertebrate index for perennial streams and soft-bottom marine and estuarine habitats. Reference conditions also have been studied for other biological indicators, including freshwater algae (both diatoms and soft algae).

Ongoing Research

Reference condition has only been examined for a handful of biological indicators and waterbody types, so this work is being incorporated into a variety of ongoing projects where appropriate.

Priorities for Future Research

In addition to continuing to expand the number of bioindicators and waterbody types for which reference condition has been characterized, SCCWRP intends to increasingly weave into its research an improved understanding of the impacts of climate change on reference condition. Climate change could potentially trigger a need to incorporate shifting baselines into bioassessment tools if it is confounding managers' ability to interpret condition assessment data.

Separating human-induced impacts from natural variation

Accomplishments

SCCWRP's research to understand the full range of human impacts has focused extensively on wadeable streams and marine/estuarine soft-bottom habitats. Much of this work has been conducted through site-specific studies and regional monitoring programs. Because much less effort has been spent on other waterbody types, SCCWRP has been one of the driving forces in integrating new habitats – including rocky reefs, wetlands, and nonperennial streams – into regional monitoring programs. In some cases, these efforts have required development of new biological indicators, such as riparian habitat using CRAM (Collins et al. 2008), new stressors such as hydromodification (Stein et al. 2013), and constituents of emerging concern (Dodder et al. 2013).

Ongoing Research

***Project:* Developing bioindicators for depressional wetlands**

SCCWRP is developing bioindicator tools to support a regional assessment of depressional wetland condition in Southern California – notably, using benthic macroinvertebrates and algae. SCCWRP has developed sampling protocols to collect benthic macroinvertebrates and algae, and used them collect data from more than 50 sites. Ongoing work focuses on more data collection, development of models to set site-specific biological expectations, and, eventually, creation of new indices that measure departure from reference-based expectations. Depressional wetlands have become a scarce but important freshwater habitat in Southern California, supporting both aquatic and terrestrial wildlife and playing key roles in moderating floods and improving water quality.

***Project:* Mapping and characterizing the natural hydrology of nonperennial streams**

Because one of the greatest difficulties of examining the range of human impacts in nonperennial streams is the anthropogenic addition of water, this project is using state-of-the art statistical models to estimate the probability of flow at any stream segment for any month based on catchment characteristics, such as size, slope, geology, and rainfall, among others. Many streams exhibit increased flows largely because of runoff from excess irrigation and discharge of treated wastewater. Managers struggle, however, with determining, how much discharge should occur naturally, and if this extra discharge alters the biological communities living there.

Priorities for Future Research

Given that biological condition assessments are only possible in waterbody types where tools have already been developed, SCCWRP intends to broaden its reach into other priority waterbody types. Unquestionably, assessments using multiple indicators should be the standard for all priority waterbodies, as multiple lines of evidence provide a better reflection of condition. SCCWRP intends to continue work on perennial and ephemeral streams by developing sampling protocols for vertebrates, soil microbes, and terrestrial arthropods. Other priority waterbodies include lakes, brackish estuaries, lagoons, and rocky reefs and intertidal habitats.

> ***Future focus area*: Developing bioindicators for coastal lagoons**
> Focusing bioassessment in coastal lagoons will be especially valuable as watershed managers continue to implement water-quality improvements. Coastal lagoons are unique habitats that serve as an important natural resource at the land-sea interface, supporting endangered species and providing nursery/breeding habitat for a variety of coastal organisms. Yet there are few biological indicators for these understudied systems. Moreover, potential human stressors can be intense, as this is the first coastal waterbody that receives much of the pollutants from land-based runoff.

Distilling Condition Data into Indices

Accomplishments

SCCWRP began developing biological indices in marine habitats in the 1970s (Word et al. 1979) and introduced a new, more powerful approach in the 1990s (Smith et al. 2001). SCCWRP's index development work with marine benthic infauna has since been incorporated into sediment quality objectives (alongside sediment chemistry and sediment toxicity), marking the first regulatory criterion based on biological condition in California (SWRCB 2009). These biological indices are now routinely used in the Southern California Bight Regional Monitoring Program and nearly all regulatory-based marine monitoring programs in California.

Fully functional biological indices for perennial wadeable streams are used in routine monitoring efforts throughout the region, most notably through the ongoing Southern California Stormwater Monitoring Coalition Regional Watershed Monitoring Program (Mazor 2015). The SMC uses three main indices: (1) benthic algae indices, which are used to make assessments based on diatom and soft-bodied algae (Fetscher et al. 2013), (2) the California Stream Condition Index for benthic macroinvertebrates (Mazor et al. 2016), and (3) the California Rapid Assessment Method riverine module, which is used to riparian condition (Collins et al. 2008). The CSCI also is a cornerstone of both the nutrient and biointegrity policy that the State is developing for wadeable streams. Finally, SCCWRP has explored the transferability of its stream indices to novel settings, including low-gradient streams (Mazor et al. 2010) and nonperennial streams (Mazor et al. 2014).

Ongoing Research

SCCWRP's biological index development work is now focused around nonperennial streams, which comprise 50% to 95% of stream lengths in Southern California watersheds (Mazor 2015) and provide a range of beneficial uses, including support for aquatic life/wildlife and protection of downstream waters. Despite the prevalence of nonperennial streams, the applicability of available biological indices (specifically, the CSCI and algae IBIs) is not yet clear because hydrologic permanence is known to affect stream biota, potentially yielding misleading results for nonperennial streams.

***Project*: Adapting assessment indices to nonperennial streams**
SCCWRP is working to validate or refine assessment indices developed for perennial streams for use in nonperennial streams. Preliminary research has shown that a traditional, non-predictive index of biotic integrity (IBI) provides valid measurements of condition of nonperennial streams in the San Diego region (Mazor et al. 2014), but this study was limited to a small number of reference sites and did not investigate the condition indices that are directly related to management needs (specifically, the CSCI and algae IBIs). SCCWRP is testing these indices in a wide variety of high-quality (i.e., reference) nonperennial streams across Southern California to assess whether they're biased to give incorrect scores to nonperennial streams, and to identify the limits of index applicability along a gradient of hydrologic permanence.

Although a number of algae indices are available for use in Southern California wadeable streams (Fetscher et al. 2013), they are based on traditional (i.e., non-predictive) approaches that set uniform expectations for all streams in the region. Predictive indices are preferred in many instances because they establish site-specific expectations that take into account major natural gradients, which can influence the biota observed at a site. In Southern California, these gradients have relatively small effects on scores generated with traditional indices, but the bias may have a more dramatic effect in certain regions outside Southern California, which would call into question the reliability of using benthic algae to make statewide estimates of stream condition.

***Project:* Developing a predictive stream algae index with statewide applicability**
SCCWRP is developing a predictive index for statewide use that is based on benthic algae data. Although traditional indicator-based indices (IBIs) have proven essential in assessing condition for Southern California, they are most applicable in Southern California habitats only. A predictive index is needed for assessing sites that incorporates site-specific natural gradients with statewide consistency. SCCWRP intends to follow a similar process used to develop the CSCI for benthic macroinvertebrates. An index with this power could be used in setting future statewide management goals or nutrient policies.

Because a robust bioassessment toolkit contains multiple indices for different assemblages, such as benthic algae and macroinvertebrates, these individual tools must ultimately be integrated into frameworks that link different indices together, as well as link them to ecosystem functions that support management objectives. Thus, for the mature wadeable streams program, SCCWRP is beginning to develop frameworks designed to help managers understand and interpret scores from multiple indices.

***Project:* Multi-indicator integration for wadeable streams**
As part of regional assessments, SCCWRP is working to integrate multiple indicators of wadeable stream condition, including indicators still under development, so that watershed managers will have a convenient, meaningful way to synthesize different measures of stream health. Multi-indicator integration has the potential to, among other things, improve robustness, increase responsiveness to different stressor types, and enhance diagnostic ability. SCCWRP's previous exploratory studies that involved sampling multiple indicators (specifically, benthic invertebrates, algae, and riparian wetlands) have focused the multi-indicator integration work around how conflicting indicators should be weighed and whether poor condition reflected by one indicator trumps good condition reflected by others. Expected products include

guidance on interpreting multiple indicators for wadeable streams (potentially including a multi-indicator index of stream condition) and an application to an ambient stream survey.

Priorities for Future Research

A high priority for future SCCWRP research is continued integration of indicators that span multiple trophic levels. For a single waterbody, integration of multiple indicators is necessary for a comprehensive understanding of the waterbody's health; however, SCCWRP's only preliminary integration work has been in the context of a regional monitoring program. At the level of multiple samples over time or space, integration of multiple indicators is needed to understand where and when beneficial uses are attained; however, understanding of temporal variability is limited to just a few indicators in certain waterbody types in certain environmental settings (e.g., CSCI in perennial wadeable streams), and the spatial extent of poor condition that can be inferred from a single site is unknown. At the level of comprehensive assessments of ecosystem health, integration of measures of condition for multiple waterbody types is needed to provide a complete evaluation. For example, a watershed assessment needs to incorporate wadeable streams, large rivers, and estuaries to provide a truly integrated assessment. Also, understanding how condition relates to beneficial-use attainment is limited, as this framework has not yet been built.

Causal Assessment

Causal assessment, a fundamental tool that identifies what stressors are causing biological impacts, is the principal tool that managers use to remediate streams. It remains a vastly underdeveloped area and a focal point of bioassessment research. SCCWRP has been conducting casual assessments since the 1970s in a number of different ways, including examining biological-stressor relationships, looking at changes in biological community composition, measuring physical and biochemical responses within the organisms themselves, and creating new toxicity identification evaluation (TIE) treatments.

The development of CADDIS (Causal Analysis/Diagnosis Decision Information System) by the U.S. EPA has added a structural framework for causal assessment, with the actual link to causation contained in the diagnostic tools used to support or refute individual stressors (or stressor combinations). SCCWRP was the first to evaluate CADDIS in California, conducting four case studies that showed the framework is useful, but requires additional research and development to be effective in the region (Schiff et al. 2015). Specifically, more work is needed to characterize stressors and develop diagnostic tools to identify causes. While SCCWRP's causal assessment research is initially being built using data primarily from freshwater habitats, the expectation is that the approaches can be adapted and expanded to other waterbody types across Southern California, especially estuarine and marine systems.

Stressor Characterization

Accomplishments

SCCWRP's work to characterize stressors on Southern California streams has revealed that the risks from traditional water chemistry stressors are less widespread than non-traditional stressors, especially habitat, nutrients, and flow modification risks. This finding has helped drive much of SCCWRP's research to understand physical habitat alterations, hydromodification, nutrient sources and biogeochemical cycling, and constituents of emerging concern (including current-use pesticides).

Similarly, SCCWRP has helped compile information on dozens of human activities (land use, roads, gravel mines, etc.) across California into a single GIS library that has provided researchers with a reasonably comprehensive inventory of anthropogenic pressures to which different stream systems across the state are exposed. Not only does this help define non-impacted reference sites, but it also provides the range of human activities that impact these systems at non-reference sites. As a result, scientists have been able to generate a more comprehensive data set on the ambient level of "natural" stressors (e.g., conductivity, nutrients, habitat) and quantify the relationships between in-stream stressors and the extent of anthropogenic alterations (Ode et al. 2016).

Ongoing Research

Given that physical habitat and flow are two of the most widespread risks to stream biota in Southern California, SCCWRP is focused on expanding the toolbox for these stressors. In general, scientists know what constitutes "good" habitat, based largely on routine but labor-intensive physical habitat measurements taken at reference sites. SCCWRP is focused on combining these multiple physical habitat measurements into meaningful information for causal assessment. SCCWRP, however, isn't as far advanced in its understanding of what constitutes "good" flow, as long-term flow measurements at reference sites are rare. Thus, SCCWRP's ongoing research focuses on defining flow conditions at reference sites. More information about this research area can be found in the Ecohydrology research theme.

Priorities for Future Research

Because impacted biological communities can be a trigger for failing sediment quality objectives, there is a need to use causal assessment in estuaries and bays. SCCWRP is aiming to transfer the approaches and tools learned in stream applications to these waterbody types. Separately, SCCWRP is interested in continuing to collect additional geographic data on stream stressors that, while not well-characterized, are thought to be having potential impacts on resident biota, according to evidence from scientific literature (e.g., pesticide applications).

> ***Future focus area*: Expanded collection of hydromodification data**
> SCCWRP is interested in collecting additional hydromodification data to better understand how altered hydrology can be a stressor on streams. Although SCCWRP has the ability to measure evidence of altered hydrology in a stream, the only such measurements have been done in studies specifically targeting hydromodification.
>
> ***Future focus area*: Expansion of GIS stressor inventories**
> While researchers have developed a GIS library of human activities for all of the wadeable stream watersheds across California, the GIS layers may now be old and out of date or may be missing key stressor information. SCCWRP is interested in improving new landscape-scale information using remotely sensed data, especially new satellites with improved resolution and multi-spectral sensors. Inclusion of these data into a spatial database will greatly improve identification of potential stressors to a system, quickly eliminating low-likelihood stressors from the list of reasonable candidate causes.

Diagnostic Tools to Identify Causes

Accomplishments

SCCWRP's evaluation of CADDIS remains the seminal work for California (Schiff et al. 2015). The biggest lesson learned was that the regional monitoring programs provide an unparalleled opportunity to evaluate stressor responses and to create new diagnostic tools, partly because there are so many sites with bioassessment data matched to stressor data, and partly because many of the current diagnostic tools provided by the USEPA were not relevant to Southern California stream conditions. Furthermore, the data necessary to study stressor relationships and develop diagnostic tools are being generated by the region's large-scale monitoring programs (i.e., Southern California Stormwater Monitoring Coalition Regional Watershed Monitoring Program, Southern California Bight Regional Monitoring Program).

Ongoing Research

Based on lessons learned during the CADDIS evaluation, SCCWRP research has turned to using regional data sets to examine biological responses to various stressors in new waterbody types.

> ***Project*: Developing new tools for selecting multiple test and comparator sites**
> SCCWRP is working toward being able to conduct an assessment over multiple, adjacent sites at one time. Many of California's urbanized watersheds are ubiquitously impacted, creating challenges for managers using the existing CADDIS framework, which was built for single test sites and single comparator sites. California watershed managers also experience difficulties selecting nearby (i.e., upstream-downstream) comparator sites recommended by CADDIS; thus, SCCWRP is developing a new assessment framework that enables the use of many comparator sites outside the watershed, each with potentially differing stressor values but similar in natural gradients to the test site(s). Expected products are a rule set for interpreting statistical evaluations of similarity among test sites prior to combining them for causal assessment, and an algorithmic process for selecting multiple comparator sites based upon environmental gradients and predicted biological similarity.

> ***Project:* Developing new diagnostic tools for conductivity and pyrethroid pesticides**
> SCCWRP is developing new stressor response diagnostic tools and creating species sensitivity curves, both of which can be used in future causal assessments in other watersheds. This project builds upon SCCWRP's work conducting the first causal assessments using CADDIS in Southern California, including for the San Diego River. Potential stressors of conductivity and pyrethroids pesticides were identified, but the strength of inference was relatively low. Thus, there's interest in developing new lines of evidence based on key taxa responses in the regional monitoring data and supporting studies from the scientific literature.

> ***Project:* Evaluating the response of marine organisms to ocean acidification**
> SCCWRP is evaluating a potential biological stressor relationship for benthic infauna most susceptible to reduced ocean acidification – namely, shelled organisms, particularly those with shells made of calcium carbonate. The causal assessment challenge is that small pH changes are hard to measure, making stressor response relationships difficult to evaluate. SCCWRP will determine if further enhancements to regional marine monitoring are necessary to support causal assessment.

Priorities for Future Research

Developing rapid screening tools to identify cause represents perhaps the biggest near-term opportunity for SCCWRP's future causal assessment research. Rapid screening tools, which are designed around the broad categories into which stressors fall (e.g., flow/habitat-related, chemical/toxicant-induced, nutrient-mediated), use observed patterns in stressor distribution and biological community profiles to quickly eliminate a wide universe of potential causes of stress and narrow the cause down to a short list of probable stressors and associated management options/expectations. Thus, rapid screening tools serve as a critical early step of causal assessment and pave the way for subsequent causal assessment efforts to be targeted toward the most likely causes. SCCWRP has identified a number of strategies for building up its causal assessment rapid-screening capabilities.

> ***Future focus area*: Developing indicator taxa or trait-based screening tools**
> SCCWRP intends to develop suites of indicator taxa linked to information about their biological stressor responses. As this library is amassed, screening tools will need to be developed. These tools, which will be based upon the presence/absence or relative abundance of these taxa or of taxa with specific traits (or sensitivities), could be applied to samples of invertebrates and algae collected during the condition assessment process, providing rapid-screening insights about the stressors the samples might have been exposed to.

> ***Future focus area*: Grouping stream stressors into typologies**
> Given that the anthropogenic pressures that Southern California's systems are exposed to are typically very similar, streams and reaches of streams could be classified by their stressor exposure (including GIS layers from stressor characterization), which would create a framework to allow for rapid predictions regarding which candidate causes are most likely for a given set of observed impacts to the resident biota. This will follow more causal assessment case studies that are being conducted across this region, establishing patterns that make it possible to analyze the similarities and differences among them.

> ***Future focus area*: Evaluation of CRAM as a screening tool**
> SCCWRP is interested in adapting California Rapid Assessment Method (CRAM) evaluation processes to serve as a rapid screening tool for causal assessments. CRAM modules have already been developed for numerous waterbody types, serving as a relatively quick, field-based evaluation of a site's condition. The CRAM modules ae composed of different attributes designed to evaluate different aspects of the site (e.g., habitat, biology, or invasive species), so they might prove effective as rapid screening tools for broad classes of stressors.

> ***Future focus area*: Developing "smart indices" for causal screenings**
> As biological indices are developed for new waterbody types and new biological indicators, an opportunity is potentially created to incorporate stressor-specific responses into the normal measures of overall biological condition. Incorporation of stressor-specific biological indicators into condition assessments would allow these "smart indices" to do double duty, bridging the link between condition and causal assessments and automatically generating potentially useful causal screening-level information.

While CADDIS has provided a general framework for conducting causal assessments of aquatic systems, the causal relationships remain associative in nature. Thus, there remains a need to establish causal pathway linkages to confirm these associative relationships.

> ***Future focus area*: Using mesocosms to study biological responses to stressor(s)**
> Mesocosm experiments will provide a more controlled environment in which to measure indicator taxa and community assemblage responses following exposure to

known stressor(s) in increasing quantities. Although field-based observations of biological responses to stressors can quantify all responses collectively, there are typically multiple stressors involved that need to be analyzed individually.

Management Applications

To help mangers apply condition and causal assessment results to management decisions, a range of tools must be developed that allows end users to readily access data and tools, easily perform computations with environmental scoring tools, and visualize bioassessment data in ways that support regulatory requirements and advance beneficial uses.

Bringing Automation to Assessment Tools

Accomplishments

SCCWRP has developed an initial round of widely used, automated scoring tools and calculators for nearshore soft-bottom benthic invertebrate assessments (i.e., the Benthic Response Index, or BRI) and other sediment quality assessments. SCCWRP also has developed standardized data visualization methods for the Stormwater Monitoring Coalition Regional Watershed Monitoring Program and the Southern California Bight Regional Marine Monitoring Program.

Ongoing Research

***Project*: Building a calculator for the California Stream Condition Index (CSCI)**
SCCWRP is working to automate a multi-step process required to produce index scores from raw data for the California Stream Condition Index. As originally developed, the CSCI relies on the users' ability to integrate raw benthic community data, GIS data, and habitat data through use of watershed delineation, modeling and statistical analysis. The CSCI calculator will allow users to upload raw community data and sampling locations, improving speed, ease, accuracy, and consistency.

***Project*: Creating a selection tool for choosing CADDIS comparator sites**
SCCWRP is building a site selection tool to provide a standardized process for identifying and selecting appropriate comparator sites for both regional ambient and targeted causal assessments. Selecting appropriate comparator sites is crucial because causal assessment results are most robust when a broad suite of comparator sites are used to capture a range of biotic conditions and stressor exposures. These sites must still be ecologically similar enough to the test site of interest to allow meaningful comparisons (e.g., coastal-plain streams should be compared to other coastal-plain streams, not mountain streams).

***Project*: Automating physical habitat (PHAB) data processing**
SCCWRP is building automated data reporting and scoring tools to make it easier and more efficient to incorporate PHAB results into ambient monitoring and causal assessment studies. Physical habitat data collected as part of routine bioassessments include large quantities of qualitative and quantitative observations at several different spatial scales. Data for each site must be aggregated to produce standard metrics and indices.

Priorities for Future Research

Nearly all scoring tools and indices produced will eventually need to be automated prior to widespread adoption and incorporation into policies and programs. SCCWRP's main priorities are to (1) structure tools to facilitate direct import of raw data and rapid index calculation, (2) incorporate error-tracking functions to improve quality control and document tool performance, and (3) develop data visualization tools and/or dynamic linkages with existing data systems, so results can be explored and communicated in accessible ways.

Supporting Management Interpretation of Tools

Accomplishments

SCCWRP has provided the broad spatial and temporal data and analysis necessary for managers to establish and defend a number of thresholds for regional monitoring programs. Regional monitoring also has generated potential regional comparator sites for conducting causal assessments. In the regulatory arena, the State's sediment quality objectives program is based in part on soft-bottom benthic bioassessment indices developed by SCCWRP. Furthermore, stream biointegrity programs under development at both the state and regional levels are based on benthic invertebrate and algae bioassessment tools and data sets produced by SCCWRP.

Ongoing Research

SCCWRP is continuing to work toward informing threshold setting for regional monitoring programs, and applying this approach to modified landscapes.

> ***Project*: Informing threshold-setting in modified channels**
> SCCWRP is developing approaches for determining alternative biological expectations that may provide more realistic management objectives for these modified streams. Although the intention of most water quality programs is to maintain streams at reference condition, this goal may not be realistic for streams that have been modified to maximize other services. For example, where physical habitat has been altered for flood conveyance or other purposes, a stream may not be able to support the expected biological conditions. Thus, SCCWRP is developing a biological condition gradient model for wadeable streams that links bioassessment metrics to independent measures of ecosystem function (specifically, benthic biomass production). The expected product is a model that allows assignment to these tiers based on algae metrics (and possibly benthic macroinvertebrate), which will enable managers to set ecologically meaningful objectives in streams.

As new indicators are developed and new waterbody types are assessed, SCCWRP is continuing to place a priority on informing threshold-setting, including for anti-degradation policies, future basin plan amendments related to protecting ecosystem health, additional TMDLs, hydromodification management, and wetland restoration performance assessments (e.g., Section 401 certifications).

> ***Project*: Assessing spatial and temporal fidelity of bioassessment scores**
> SCCWRP is pursuing a multi-pronged strategy to understand the temporal and spatial fidelity of a bioassessment score for perennial and nonperennial streams and how it can inform threshold-setting. These issues are being explored in greater depth using historical and newer data sets collected via ongoing regional monitoring programs as well as targeted special studies. The goal is to answer questions including: When examining a bioassessment score, how large or small of an area around the sampling site can be inferred to have similar conditions? Over what time period can a score be

inferred to be representative of, and how consistent does a score need to be over time to determine whether it meets the threshold value?

Priorities for Future Research

SCCWRP also intends to improve managers' ability to confidently and cost-effectively implement a range of restoration project options. Restoration is one of the commonly used management options for achieving aquatic life beneficial uses, yet restoration projects have had spotty track records.

***Future focus area*: Developing a predictive model for remediation effectiveness**
SCCWRP is interested in developing an analytical framework/model to predict the effectiveness of different remediation actions on the condition and composition of the biological community. Although a number of potential remediation options are available, a predictive framework is needed to measure the confidence that any particular option will succeed in improving biological condition of a waterbody.

Using Case Studies to Demonstrate Management Application

Accomplishments

SCCWRP has already conducted a number of case studies to demonstrate regulatory application of bioassessment, including early regional assessments for 305(b) reporting (Mazor and Schiff 2008), TMDL support for the Malibu and Chollas Creeks (Brown and Bay 2011), and as part of building a technical foundation for the State's stream biointegrity policy.

Ongoing Research

SCCWRP is working on multiple case studies to demonstrate how causal assessment results can be used to inform management actions, including selection and placement of BMP, which could support compliance efforts associated with TMDLs and stormwater permits.

***Project*: Causal assessment case study in San Diego Creek**
SCCWRP is conducting a case study in San Diego Creek in Orange County in collaboration with regulators and local regulated agencies to support technical transfer of the CADDIS framework using local bioassessment and stressor monitoring data. SCCWRP also is testing new diagnostic tools developed for conducting a causal assessment across multiple adjacent sites, and for using comparator sites outside the watershed.

***Project*: Causal assessment case study in Marina del Rey**
SCCWRP is using benthic community composition and environmental data to diagnose whether the potential cause(s) for the degraded condition of the biological community in Marina del Rey Harbor is related to contaminants or to some other broad class of stressors (e.g., nutrients, water quality, physical disturbance). SCCWRP anticipates refining a set of diagnostic tools for identifying contaminant vs. non-contaminant causes that can inform guidelines for similar analyses in other coastal embayments.

Priorities for Future Research

SCCWRP will take on case studies in the future that: (1) prioritize conservation and management areas through anti-degradation policies, grant programs, etc., (2) support setting achievable regulatory limits/standards, (3) inform BMP design and placement, (4) develop ways to assess BMP performance based on biological endpoints and the condition of receiving waters, and (5) develop a more robust approach to accommodate shifting expectations over time due to climate change.

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