Evolution of monitoring program design for marine outfalls in the Southern California Bight

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Abstract

Southern California is one of the most populated urban coastal regions in the United States with roughly 17 million residents and 19 publicly owned treatment works that discharge about 53.7 m^3/s (1,226 mgd) of treated wastewater through ocean outfalls (Lyon *et al*. 2006, Lyon and Stein 2008). Each discharger monitors their effluent quality as well as the effects of discharge on the ambient environment. The effluent monitoring component of these programs has remained relatively static over the past 40 years; however, the receiving water monitoring component has evolved significantly. These changes occurred in three phases characterized by differing monitoring questions and associated sampling designs. In the early years, starting around 1970, monitoring designs were focused on assessing differences between outfall sites and outlying reference sites. These programs succeeded at documenting differences and driving enhanced water quality engineering. Yet, as monitoring data accumulated and understanding of the marine environment grew, two serious flaws became apparent: 1) reference sites were not well-matched in all physical parameters, and 2) managers needed more context to interpret the ecological relevance of observed differences. The second phase of monitoring, beginning in the mid-1980s, focused on development of assessment tools to determine if differences between outfall and reference sites were meaningful to environmental managers. This was accomplished through development of new data interpretation tools that matched results to a scale of values ranging from severely to minimally affected sites. While the new tools better distinguished anthropogenic effects from natural variation, they lacked an integrated regional context to assess whether commingled discharges and other pollution sources might together lead to regional degradation. In the later years, the relevant monitoring question changed from "Is the area around my outfall degraded" to "How much area in the Southern California Bight (SCB) is degraded?" and "How does the area around my outfall compare to the rest of the Bight?" Consequently, monitoring locations were redesigned to achieve wider and more representative coverage. In addition, methods were standardized among organizations to ensure that data were comparable and could be regionally integrated. This evolution in monitoring has culminated in the establishment of a model monitoring program (MMP) framework for wastewater dischargers in southern California (Schiff *et al*. 2002a). The adaptive and flexible mindset espoused in the MMP will be key to meeting the challenges posed by emerging issues in coastal environmental management.

Introduction

The SCB is a 400 km (250 mile) stretch of recessed coastline from Point Conception to the United States-Mexico International Border (Figure 1). This bend in the coast, where warm equatorial waters flow north and mix with southward-flowing subarctic waters, supports one of the most biologically diverse oceanic regions in the world (Dailey *et al*. 1993). The SCB sustains approximately 500 marine fish species and more than 5,000 invertebrate species (Dailey *et al*. 1993, Bight 2003 Steering Committee 2007). SCB habitats range from dense forests of giant kelp (*Macrocystis pyrifera*) to ocean basins over 1000 m deep. Twenty species of marine mammals can be found there, including the Blue whale

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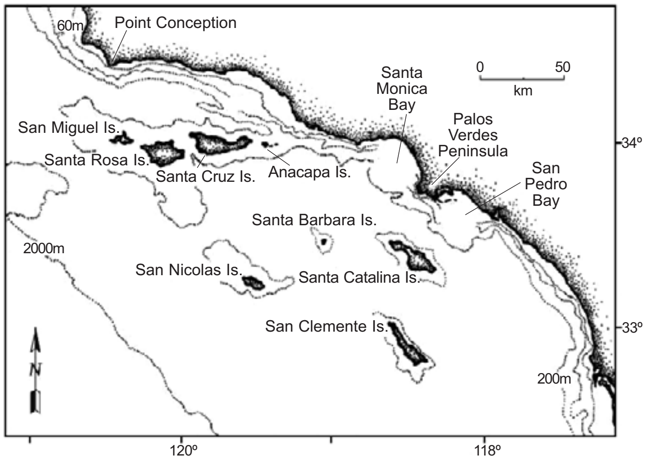

Figure 1. Map of the SCB (Dailey *et al.* 1993).

(*Balaenoptera musculus*), the largest of all marine mammals (Cal-Atlas 2009). In addition, the SCB is a primary stop on the Pacific flyway, a major north-south migration route for seabirds.

The SCB is also a rich economic resource. More than 17 million residents inhabit the SCB, making it one of the most populated coastal regions in the United States (US Census Bureau 2004). Southern California's ocean-related activities contribute over $25 billion to the gross state product, and directly support about 187,000 jobs (Kildow and Colgan 2005). Commercial fishing lands about 91,000 tons per year, while recreational fishermen in southern California catch about 21.1 million ocean fish annually (Cal DFG 2009, NOAA 2002). Beach visitors to this region number about 175 million every year (USLA 2009). In addition, the SCB is home to the largest commercial port complex (ports of Los Angeles and Long Beach), which moves about 120 million tons of freight valued at approximately $200 billion annually (Kildow and Colgan 2005). Finally, San Diego Bay houses the second largest Navy complex in the United States.

While the SCB showcases ecological richness and economic development, its ecosystems are not immune to the byproducts of intense urbanization. The coastal ocean is subject to pollution through a number of pathways, including point source discharges such as publicly owned treatment works (POTWs), power generating stations, and industrial facilities. Additionally, there are numerous nonpoint pollution sources, such as urban and agricultural runoff, shipping activities, and atmospheric deposition. Coastal POTWs have historically been a primary source of contaminants to the SCB, discharging large volumes of treated municipal and industrial wastewater directly to the ocean (Lyon *et al*. 2006, Lyon and Stein 2008; Table 1). There are 19 POTW outfalls along the SCB coast (the four largest outfalls align with major population centers and account for about 85% of the total discharge volume.

Schiff *et al*. (2002b) estimated that $31 million is spent annually on monitoring in the SCB. To protect the ocean environment, state and federal regulatory agencies mandate two types of ocean outfall monitoring via National Pollutant Discharge Elimination System (NPDES) perts which account for approximately three-quarters of this annual expenditure (Schiff *et al*. 2002b). The first type is effluent monitoring, which measures flow and constituent concentrations coming from each facility just prior to discharge. Effluent monitoring has existed in some form since the 1940s. It was initially used to assess plant operation rather than to determine regulatory compliance. In the early 1970s, effluent monitoring became a key component of regulation with passage of California's Porter-Cologne Water Quality Control Act in 1969 and the federal Clean Water Act in 1972. Oversight agencies rely on effluent monitoring to demonstrate compliance with water quality standards, which are based on laboratory-developed relationships between chemical concentrations and toxicity to sensitive marine organisms.

Effluent monitoring has been effective at documenting how management actions taken by southern California's POTWs have reduced the total contaminant load to the southern California coastal ocean over time (Figure 2). Monitoring data shows how reclamation and re-use strategies have kept total water discharge volume relatively stable in spite of the dramatic rise in the southern California population. More importantly, these programs have also demonstrated drastic declines in contaminant mass emissions to the ocean owing to increased treatment, pre-treatment, and source control.

Nonetheless, effluent monitoring has remained relatively static over the years, reflecting a fixed regulatory structure and a compliance-oriented approach. The frequency, parameters and, in some cases, even methods of effluent monitoring have not changed significantly over the last few decades. POTWs rely on a list of 126 priority pollutants issued by the federal government, while also measuring total suspended solids (TSS), biological oxygen demand (BOD), flow rate, and toxicity. Considering the compliance aspect of effluent monitoring, along

Table 1. Description of the POTW outfalls in the SCB (Hauser 2005, Lyon *et al.* 2006, Lyon and Stein 2008).

POTW	Treatment Level	Discharge (m^3/s)	Discharge (mgd)	Outfall Distance (m)	Outfall Depth (m)
Goleta Wastewater Treatment Plant	Advanced Primary / Secondary	0.20	4.50	1,802	27
El Estero Wastewater Treatment Plant	Secondary	0.36	8.22	2,658	21
Montecito Wastewater Treatment Plant	Secondary	0.05	1.14	472	7
Summerland Wastewater Treatment Plant	Tertiary	0.01	0.19	226	6
Carpinteria Wastewater Treatment Plant	Secondary	0.07	1.58	305	8
Oxnard Wastewater Treatment Plant	Secondary	1.07	24.48	1,814	18
Hyperion Treatment Plant 1-mile Outfall[1]	Secondary	--	--	1,600	15
Hyperion Treatment Plant 5-mile Outfall	Secondary	13.99	319.39	8,100	57
Joint Water Pollution Control Plant Outfall 001[2]	Secondary	14.00	319.65	2,268	58
Joint Water Pollution Control Plant Outfall 002[2]	Secondary	14.00	319.65	2,433	64
Terminal Island Wastewater Treatment Plant	Tertiary	0.70	15.96	274	10
Avalon Wastewater Treatment Facility	Secondary	0.02	0.51	122	40
San Clemente Island Wastewater Treatment Plant	Secondary	0.0009	0.02	457	unknown
Orange County Sanitation District	Primary / Secondary	10.32	235.62	8,047	61
Aliso Creek Ocean Outfall	Secondary	0.67	15.32	2,408	59
San Juan Creek Ocean Outfall	Secondary	0.93	21.27	3,216	30
Oceanside Ocean Outfall	Secondary / Tertiary	0.68	15.49	2,697	30
Encina Ocean Outfall	Secondary	1.08	24.67	2,377	46
San Elijo Ocean Outfall	Secondary	0.73	16.74	2,438	45
Point Loma Wastewater Treatment Plant	Advanced Primary	7.62	173.89	7,242	98
South Bay Ocean Outfall	Advanced Primary / Secondary	1.21	27.58	7,193	28
TOTAL		53.72	1,226.22		

[1] Emergency discharge only

[2] Both outfalls discharge during normal operation, these locations are averaged

with its significant contribution to tracking trends, effluent monitoring will likely continue to be performed for many years to come.

The second type of required monitoring is ambient monitoring, which assesses how discharge affects the chemical, physical, and biological condition of the environment. Instead of comparing effluent concentrations to thresholds that predict biological effects, ambient monitoring examines *in-situ* conditions for actual effects. Ambient monitoring is used to evaluate the effectiveness of pollution control programs, track changes in environmental condition due to unmeasured pollution sources, and assess cumulative effects from multiple discharges. Some examples of ambient monitoring include: shoreline bacterial measurements to assess the risk of swimming-related illness; physical oceanography to assess wastewater plume effects on dissolved oxygen, pH, and water clarity; kelp bed monitoring to assess habitat alteration; benthic macrofauna sampling to assess sediment condition; fish and invertebrate trawls to assess fundamental alterations in community structure; and tissue bioaccumulation to evaluate seafood safety.

In contrast to effluent monitoring, ambient monitoring has evolved considerably as management issues have changed over the last four decades. There have been notable advances in the questions asked by coastal managers, approaches to monitoring design, environmental assessment tools, and ways of interpreting data. These changes can be characterized over three general time periods: the early years of monitoring (ca. 1970-1985), the middle years (ca. 1985-1998), and the later years (ca. 1998-2010). This paper describes the evolution in ambient ocean monitoring, focusing on two major monitoring program elements (sediment chemistry and benthic infauna) that provide a paired measure of exposure and biological response. Similar changes in monitoring approaches have also occurred for other ambient monitoring elements (e.g., fish communities, water column parameters, and sediment toxicity), but will not be extensively discussed.

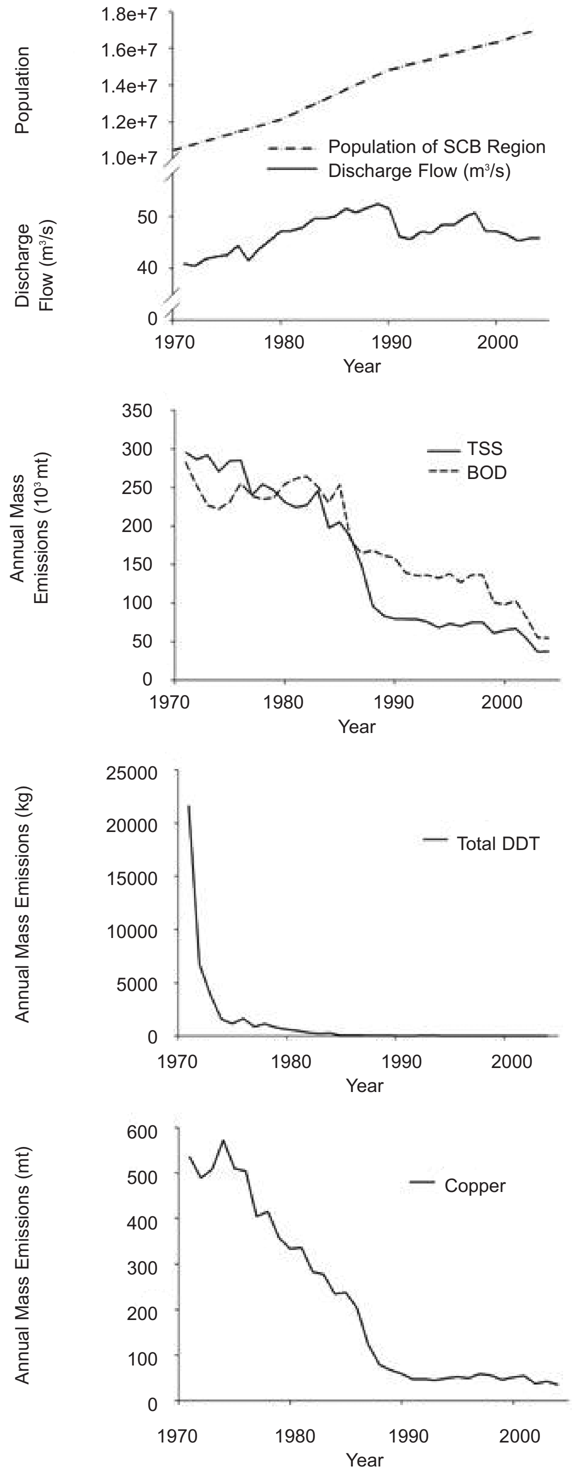

Figure 2. Trends over time in population of five coastal counties in the SCB and effluent volume from the four major POTWs in the SCB between 1971 and 2000 (top), as compared to mass emissions of BOD, TSS, DDT, and copper from 1971-2004 (Lyon and Stein 2009, Lyon *et al.* 2006, Steinberger and Schiff 2003, US Census Bureau 2004). mt = metric tons.

Early Years

Ambient monitoring programs from the late 1960s into the mid-1980s focused on addressing a relatively simple question: "Is there a difference between an outfall site(s) and a nearby reference site(s)?" This approach was consistent with the U.S. Environmental Protection Agency's guidance at the time (Tetra Tech 1982). To determine compliance with Section 301(h) of the Clean Water Act and state water quality standards, POTWs were required to document water quality "in the vicinity of the Zone of Initial Dilution (ZID) boundary, at control or reference stations, and at areas beyond the ZID where discharge impacts might reasonably be expected."

This approach to monitoring involves comparing conditions at sites near outfalls with reference sites distant from outfalls. The intent was to select reference sites that are similar in all other respects to the outfall sites, but without anthropogenic influence. The prevailing thought was that the two sites would respond similarly to natural cycles, and that any differences measured between sites would be attributable to anthropogenic changes in water quality caused by outfall discharges. Data analyses during the early years typically took the form of pairwise testing (t-tests) and/or analysis of variance to determine if differences between the outfall and reference sites were statistically significant.

At one level, these early monitoring programs were successful at documenting differences, and served as the technical justification for enhanced water quality engineering. Noticeable differences in environmental quality usually did exist between discharge sites and reference sites in the early 1970's (Stein and Cadien 2009). Sediment contamination, for example, clearly decreased at a distance from the outfall (Figure 3). Similarly, there were clear patterns of biological community improvement away from the outfalls (Figure 4).

As monitoring data accumulated and understanding of the marine environment grew, though, a number of serious flaws with the early monitoring design became apparent. First, it was difficult to identify appropriate reference sites. Since these were some of the earliest examinations of the southern California coastal ocean, there was incomplete knowledge about how factors such as sediment grain size, depth, and current velocity affected chemical deposition and biological communities. The results shown in Figure 4, for instance, illustrate a mix of

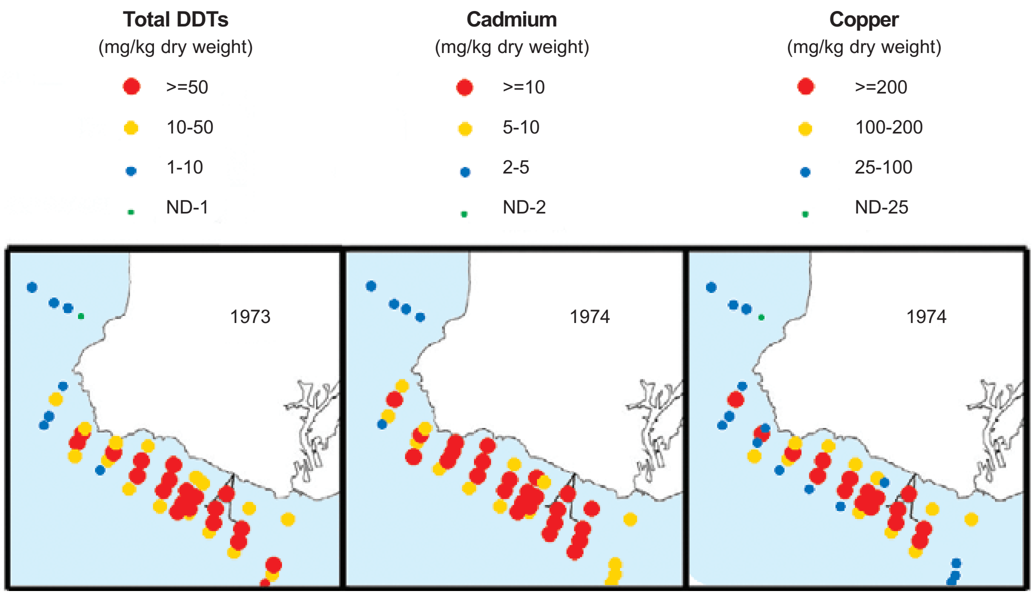

Figure 3. Total DDTs, Cadmium, and Copper (mg/kg dry weight) in surface sediments around the Los Angeles County Sanitation Districts' Joint Water Pollution Control Plant in 1973 and 1974 (Stein and Cadien 2009). ND = non-detect.

natural and anthropogenic effects. In relatively short order, the scientists responsible for interpreting these data began to doubt the underlying premise that differences between reference and potentially affected sites were entirely due to outfall effects, instead attributing some of them to underlying physical habitat differences. This type of concern undermined the ability to use data for making management decisions.

Another concern was that while reference sites were located away from outfalls, they were still subject to influences from other pollution sources. In San Pedro Bay, for example, environmental quality could have also been affected by storm water discharge from the Los Angeles and San Gabriel Rivers, shipping activities in the nearby Ports of Los Angeles and Long Beach, past military activities, oil spills, invasive species, ocean dumping sites, and/or deposition of airborne pollutants. This potential source of error concerned managers because comparison to an already disturbed "reference" site could lead them to underestimate outfall effects.

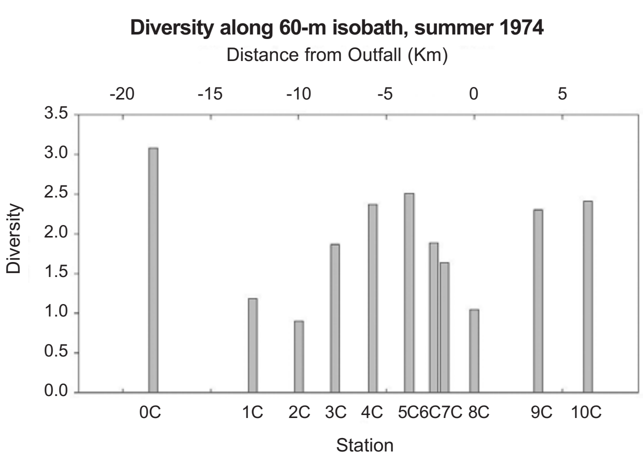

Figure 4. Example of benthos results from the early years: benthic infaunal diversity (H') along the 60 m isobath on Palos Verdes, CA, in 1974. The Joint Water Pollution Control Plant outfall is located near station 8C. Low benthic infaunal diversity at stations 1C and 2C, located away from the outfall, was attributed to increased sediment grain size from localized relic red sands.

Finally, the early monitoring design focused on identifying differences, but failed to provide sufficient context for interpreting their importance. Even after accounting for differences that were attributable to poorly matched reference sites, managers needed to place potential human impacts into the context of natural variability, such as that caused by periodic El Niño and La Niña anomalies. In the early years of the program, there was simply not enough data available to clarify when a difference from reference conditions was meaningful.

Middle Years

From the mid-1980s to the late 1990s, monitoring approaches were refined to better characterize the significance of results and the severity of impacts. The monitoring question shifted from "Is there a difference from a reference site?" to "Are conditions degraded near an outfall?" Differences found in reference-outfall site comparisons were no longer adequate to address concerns about marine pollution. Environmental managers needed to know instead whether their outfall caused a problem that required remediation.

The hallmark of the middle years was the advent of better data interpretation tools whereby conditions could be matched to a scale of values ranging from severely to minimally affected sites. This scaled approach recognized that true reference sites were difficult to locate, and that a difference from reference conditions did not necessarily imply poor environmental quality. These assessment tools also allowed data from multiple outfalls and regions to be compared against the same standards, enabling managers to gauge relative environmental disturbance. Scaled results likewise increased the ease and clarity of communication to environmental managers, regulators, and the public.

One such assessment tool for evaluating trace metal sediment contamination is iron normalization. This approach recognizes that many trace metals occur naturally in the environment as part of the earth's crust, and that measurable concentrations of metals in sediments do not always indicate human impact (Schiff and Weisberg 1999). Normalization looks not at the bulk concentration of metals in sediments, but rather at the ratio of their concentrations to the presence of a reference element, such as iron. Because iron is so abundant in the earth's crust (ca. 10,100 mg/dry g in SCB sediments), any anthropogenic additions have a minimal effect on its concentration. In contrast, trace metals (such as cadmium, copper, lead, or zinc) are naturally present at low levels and show a distinct change when anthropogenic additions are present. Looking at data with a reference element allowed visualization of which sites were anthropogenically enriched, and moreover, by how much they were enriched (Figure 5). Other common normalizing parameters included grain size, total organic carbon, aluminum, lithium, rare elements, and radioisotope tracers.

Another tool developed in the middle years was the benthic response index (BRI; Smith *et al*. 2001), which provides a standardized approach for interpreting benthic invertebrate community samples with a single index value that communicates the level of impact at that site. The index value is calculated using an abundance-weighted average pollution tolerance of the different species found in the sample (Bergen *et al*. 1998). If most of the species found at

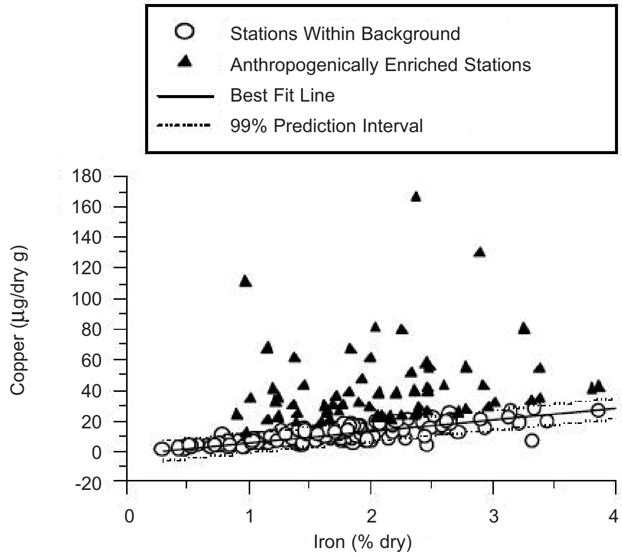

Figure 5. Example of a copper versus iron plot overlain with reference element baseline relationships (Schiff and Weisberg 1999). Sites that fall within the prediction interval are considered natural; sites that lie above the prediction interval are considered anthropogenically enriched.

a site are pollution tolerant, the index value is elevated. Lower BRI scores indicate fewer pollution tolerant species. Five categories of impact are defined by the BRI (Figure 6), including three corresponding to biological responses in which key community attributes are lost (i.e., loss of biodiversity, loss of community function, and defaunation; Smith *et al*. 2001).

These new assessment tools allowed managers to accurately assess whether there was degradation in the vicinity of their outfalls. Still, managers lacked the ability to place local conditions into an integrated regional context, in order to prioritize management action. Most monitoring was still clustered around outfalls, which covered only a small fraction of the SCB, and did not provide adequate information to describe the overall health of the SCB ecosystem (NRC 1990). It could not be told whether areas near outfalls represented the worst sites or if other perturbations demanded more immediate attention. Regional information was also needed to assess whether commingled pollutant sources might cumulatively lead to regional environmental degradation.

To address these shortcomings, sampling layouts needed to be redesigned to go beyond local reference sites. Scientists required an understanding of the entire range of natural variability among the least impacted sites in the region. In this way, they would be able to distinguish normal and allowable differ-

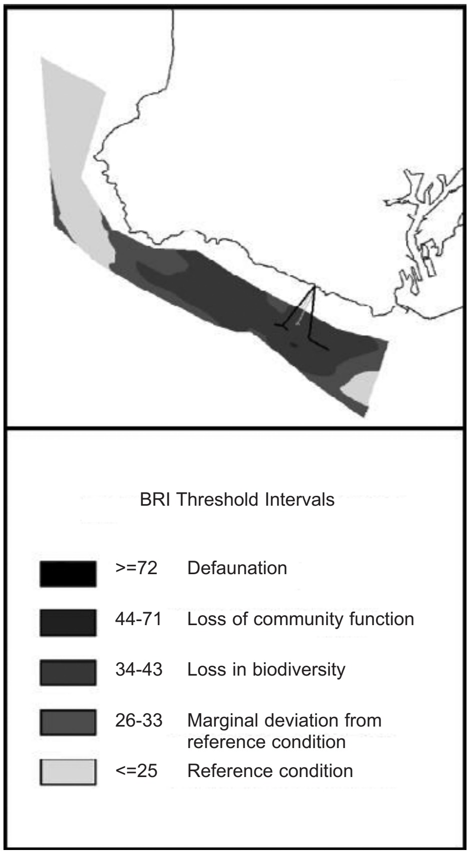

Figure 6. Example of results using the benthic response index: classification of infaunal community condition off the Palos Verdes shelf in 1994 (LACSD 2008).

ences from those that were "unnatural" and presumably anthropogenic. Monitoring designs shifted back into an investigative mode and special sampling programs were conducted to gather the needed data. Initially the regional reference condition was studied using reference surveys located as far as possible from the influence of outfalls. The earliest of these was the Southern California Coastal Water Research Project (SCCWRP) 60 meter survey in 1977, which sampled at 10 km intervals from Point Conception to the border with Mexico along the 60 m depth contour off the coast (Word and Mearns 1979). Similar reference surveys were repeated in 1985 and 1990, adding sites at the 30 m and 150 m contours (Thompson *et al*. 1987, 1993).

Later Years

In the later years, the relevant monitoring question changed from "Is the area around my outfall degraded" to "How much area in the Southern California Bight is degraded?" and "How does the area around my outfall compare to the rest of the Bight?" Substantive design changes were needed to address these questions. The first involved a change in sampling locations to achieve wider and more representative coverage. The second was standardization of methods to ensure that data collected by different organizations were comparable and could be integrated within a regional assessment.

Both of these needs were addressed through the development of a cooperative regional monitoring program, the Southern California Bight Regional Monitoring Program, beginning with a 1994 Pilot Project and subsequently continued on a semi-decadal basis in 1998, 2003, and 2008 (SCBPP Steering Committee 1998, Bight '98 Steering Committee 2003, Bight 2003 Steering Committee 2007). The program was based on newly developed probability-based sampling designs (Stevens 1997) in which sites are selected randomly from a grid to ensure unbiased estimates of areal extent with known levels of confidence. To improve the comparative value, the grid was stratified by different habitat types such as the continental shelf, estuaries and bays, and offshore islands as well as areas influenced by differing degrees of human activities such as POTWs, ports and marinas, and urban river mouths (Figure 7). A number of different indicators, including sediment chemistry, water quality, benthic infauna, and fish trawls, were included to provide a multi-faceted picture of marine environmental quality.

The Regional Monitoring Program also served as a focal point for standardizing sampling methods, quality assurance procedures, and data sharing protocols among more than 50 organizations that routinely collect ambient data in the SCB. Standard operating procedure (SOP) manuals from the various participating organizations were merged into common regional documents, and cross-training exercises were conducted to ensure consistent execution of sampling techniques. In addition, intercalibration efforts were organized to promote consistency in laboratory analyses for parameters such as chemistry (Gossett *et al*. 2003), toxicity, microbiology (Noble *et al*. 2003, Griffith *et al*. 2006), and benthic infaunal identification (Ranasinghe *et al*. 2003). Perhaps the greatest challenge, consistent data management, was addressed by a shared regional information management plan.

This new sampling approach allowed managers for the first time to make summary statements about the extent of regional effects, which were easy to communicate to policy-makers and the public. For

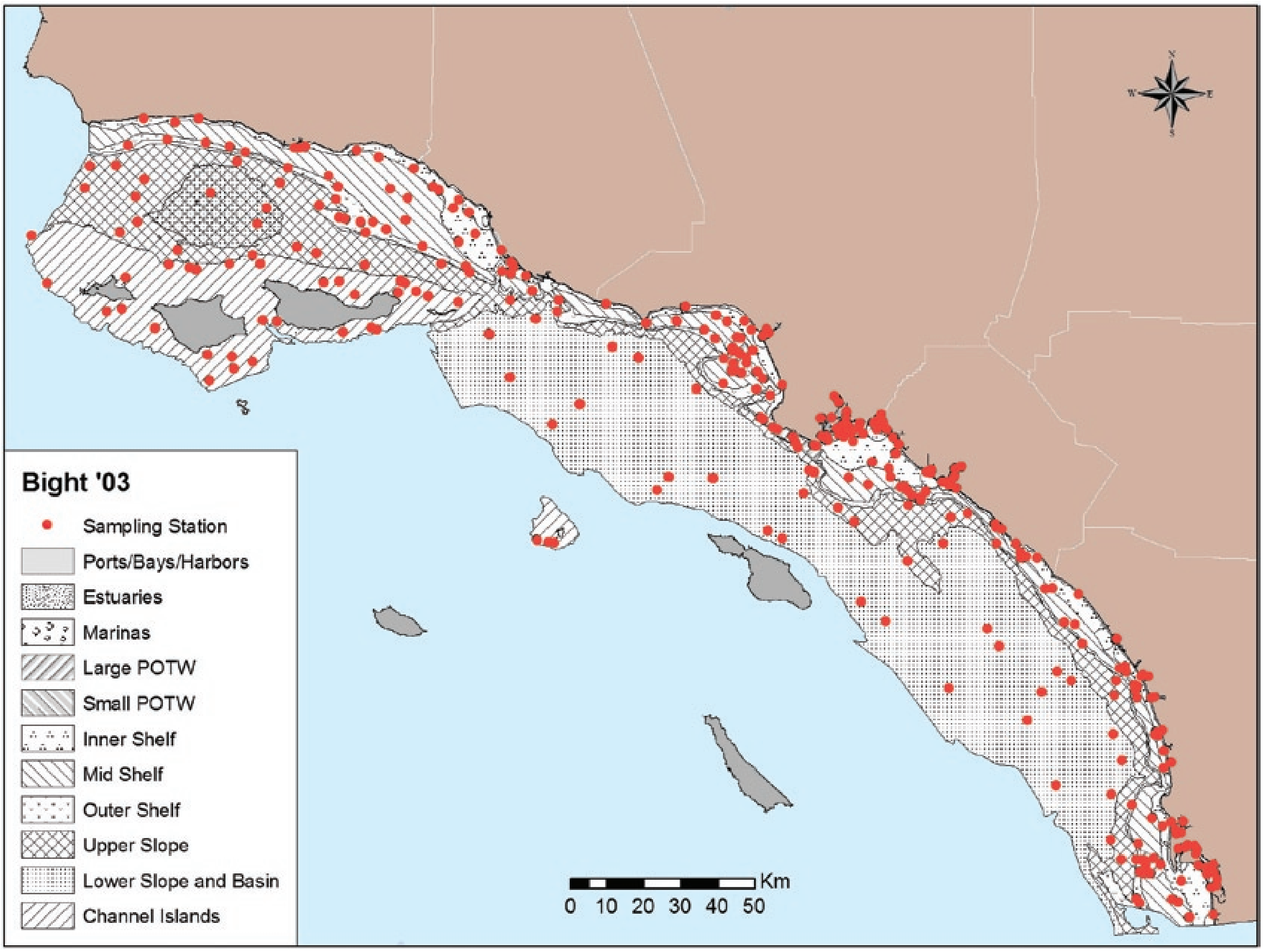

Figure 7. Example of the SCB divided into various strata with sampling locations overlain, for use in the Bight 2003 Regional Monitoring Program.

example, the most recent regional monitoring findings showed that only 2% of the SCB had moderately or highly disturbed benthic communities (Figure 8; Ranasinghe *et al*. 2007). Among the various strata, bays and estuaries were in the worst condition, with 12.6% of the area showing clear evidence of disturbance. POTW strata, however, had no area in the moderately or highly disturbed categories.

Early on, the SCB Regional Monitoring Program focused on the offshore marine environment, but it led to expansion of similar regional monitoring activities in other southern California habitats, such as rocky subtidal reefs, streams, wetlands, kelp beds, and rocky intertidal habitats (SMC 2007, SCWRP 2001, MBC 2008, CCKA 2008, MARINe 2010). Looking back, the success of the SCB Regional Monitoring Program was contingent on three factors: 1) the desire and commitment of both regulated and regulatory environmental managers to gather the information necessary for decision-making; 2) the ability to substitute inefficient or overly repetitive ambient monitoring requirements for a statistically-defensible regionwide monitoring design; and 3) the help of an independent agency to coordinate and facilitate the numerous agencies that would participate in the Regional Monitoring Program, in this case SCCWRP.

Bringing It All Together: Southern California's Model Monitoring Program

Monitoring of the SCB has evolved significantly over the past few decades. These changes were driven by a growing understanding of the SCB ecosystem and the emergence of new questions with examination of earlier work. This evolution culminated in development of the southern California model monitoring program (MMP) for POTWs (Schiff *et al*. 2002a). The MMP formally standardized both ocean

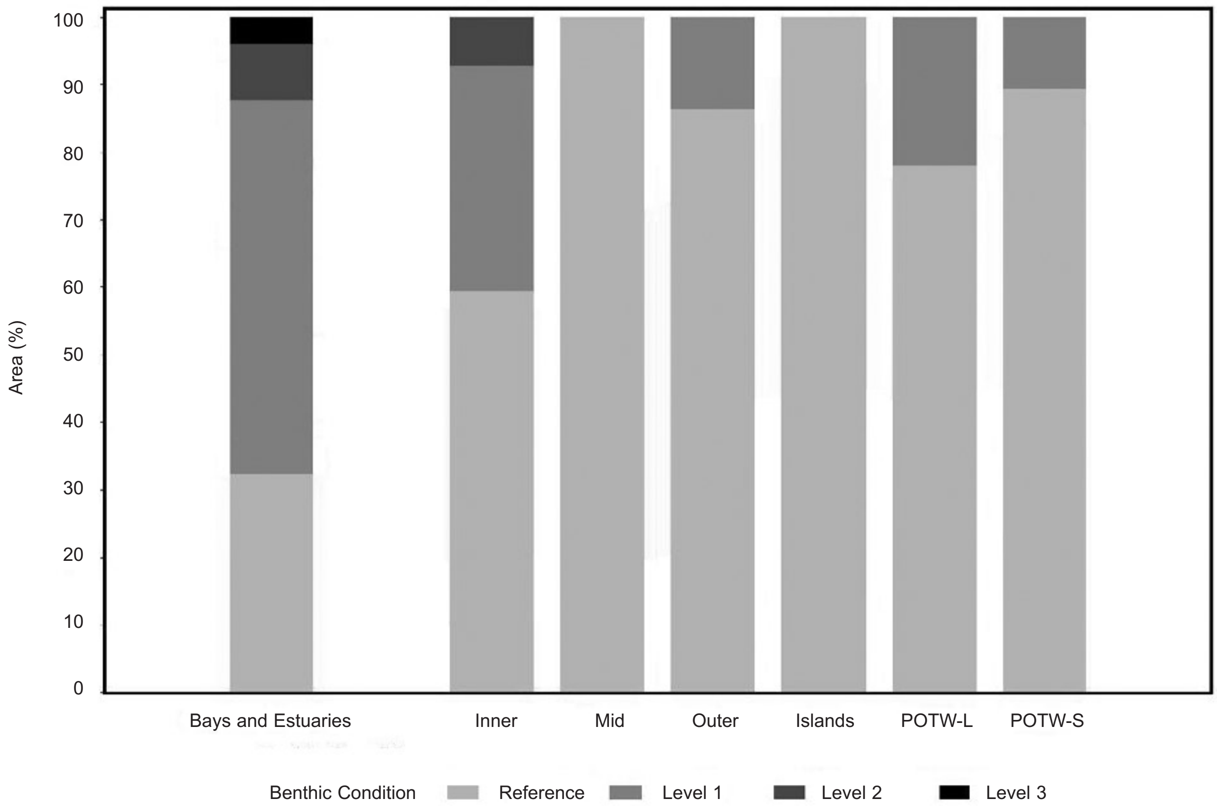

Figure 8. Benthic condition in strata sampled for Bight '03, including bays and estuaries, inner, middle, and outer shelf, islands, and large and small POTW areas (Ranasinghe *et al.* 2007). Level 1 (low disturbance) corresponds to a marginal deviation from reference, Level 2 (moderate disturbance) corresponds to biodiversity loss, and Level 3 (high disturbance) corresponds to community function loss or defaunation. Response Levels 2 and 3 are considered clear evidence of disturbed benthic communities.

outfall monitoring programs and participation in regional monitoring efforts, in order to increase applicability, comparability, and equitability among POTWs.

The MMP is guided by four philosophies (Schiff *et al*. 2002a). First, discharging treated wastewater to the ocean is considered a privilege, not a right, and therefore monitoring is a central responsibility to ensure that environmental degradation is not occurring. Second, monitoring should be question-driven and not conducted just for the sake of collecting data. A corollary to this philosophy is that all monitoring questions should have an explicit action(s) when answered. Third, discharging agencies must work together to address public concerns about the health of the environment at different spatial scales, including both the vicinity of their outfall and the wider region. Lastly, monitoring effort should be proportional to the level of environmental impact. This final point ensures that adaptive monitoring triggers go into effect if the environmental impact increases or decreases.

The MMP contains three central monitoring elements derived from the evolution in SCB monitoring that differ in their spatial and temporal focus (Figure 9). Core monitoring focuses on repetitive measures for compliance and trend assessments at the local discharger scale. Core monitoring has been part of discharge monitoring programs since the early years, but the level of effort allocated toward this element in the MMP has been scaled back by some agencies compared to the early years, partly because some of the core monitoring questions have been largely addressed. For instance, effluents often failed to meet standards in the early years, but improved treatment technology consistently led to better water quality, resulting in reduction of monitoring intensity. Similarly, improved conditions in the ambient environment lessened the need for frequent trend monitoring.

To varying degrees depending on the agency, effort that previously focused on the core program has been redirected toward the second element of the MMP, which is regional monitoring. Regional moni-

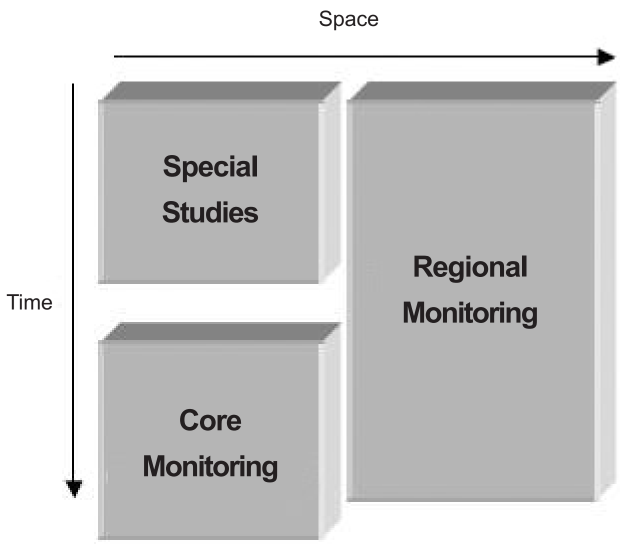

Figure 9. Framework for the MMP (Schiff *et al.* 2002a).

toring provides a big picture assessment. This element took on increasing interest as local-scale effects were found to decline. The third element of the MMP is special studies, which are exemplified by forays into assessment tool development and reference surveys during the middle years. Special studies are designed to provide an adaptive monitoring tool to investigate new ideas, research needs, or potential problem areas (perhaps derived from findings during the other core or regional elements) without being saddled by the ongoing repetitive requirements of a core monitoring program.

All of the regulated POTW dischargers and their regulatory agency counterparts working in coastal southern California have adopted the principles of the MMP framework, which are often specifically cited in federal and state NPDES permits. The guiding philosophies and monitoring elements of the MMP are utilized widely enough that the California State Water Resources Control Board is in the process of adopting the MMP as the framework for all ocean monitoring programs across the state, via amendments to the California Ocean Plan. The Ocean Plan is the state's principal legislation regarding water quality objectives to protect beneficial uses of the ocean.

Future Years

When looking at the past, it is easy to imagine that the future of environmental monitoring will bring new revelations, questions, and solutions. This section considers three pertinent issues that may affect POTW monitoring approaches in southern California in the coming years. The first is contaminants of emerging concern (CECs). This group of substances includes pharmaceuticals, personal care products, current-use pesticides, and newly manufactured industrial chemicals for which the fates and effects are largely unknown (California Ocean Science Trust *et al*. 2009). Whereas present monitoring programs are focused on the Environmental Protection Agency's 126 priority pollutants, several thousand new chemicals are introduced into use each year and measurement methods are not available for many of them. Moreover, CECs could potentially cause reproductive effects that manifest in the next generation, but are not captured by current testing methods focused on short-term acute and chronic biological effects. Therefore, more sensitive sampling devices and new types of toxicity tests that evaluate molecular responses are needed. Cost-efficient measurement techniques for detecting CECs in the environment are being developed by researchers to address these needs, but a comprehensive plan for monitoring and regulating CECs is still several years away.

A second future monitoring issue is assessing biological responses to increased nutrient levels. Whereas nutrients have become a focal point of POTW monitoring in other parts of the world, monitoring in southern California has continued to focus on priority pollutants because the SCB does not exhibit large hypoxic zones. In addition, natural sources of nutrients from coastal upwelling have been assumed to overwhelm any anthropogenic signals. Currently, though, eutrophication of coastal wetlands and increased ambient levels of harmful algal bloom toxins, such as domoic acid (Schnetzer *et al*. 2007), are leading to heightened interest in the local ecosystem effects of nutrient pollution. The 2008 SCB Regional Monitoring Program is beginning to examine the relationship between nutrient inputs and algal blooms, and seeks to quantify nutrient sources to the SCB.

A third issue is understanding how climate change affects monitoring, since data interpretation is limited by the ability to distinguish natural conditions from those influenced by other variables. The effects of climate change are intricately intertwined and often synergistic. For example, the Intergovernmental Panel on Climate Change expects increasing atmospheric CO_2 to increase wildfire occurrence in southern California (IPCC 2007), which could in turn affect contaminant release into the atmosphere and storm runoff. More importantly, scientists are concerned about how higher levels of CO_2 in the atmosphere can alter ocean acidity and impact marine organisms, especially those at the base of the food chain. Ocean acidification could have profound effects on marine food webs and population dynamics. Long-term environmental monitoring data sets will become important for isolating, tracking, and interpreting the effects of climatic shifts.

New technologies that enhance monitoring capabilities are already being developed to match these new challenges. Ocean observing systems provide continuous measurements that better allow managers to assign causes to observed effects. Gene microarrays allow examination of more subtle physiological responses in marine organisms. Other rapid molecular technologies for water and tissue monitoring are ready for pilot use. For example, quantitative polymerase chain reaction (qPCR) technologies can detect fecal contamination at beaches and provide a measure of health risk within a few hours, compared to the one- or two-day response given by present culture based techniques (Noble and Weisberg 2005). Similarly, automated devices may be mounted on southern California piers in the near future to detect genetic material from harmful algal species and telemeter this information to the laboratory. Clearly, current monitoring frameworks will need to be modified and refined in the future to adapt to new technology, better methodologies, and emerging environmental management questions. The adaptive and flexible mindset espoused in the MMP will make it possible to meet the challenges posed by these emerging issues.

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