Ecosystem response to regulatory and management actions: The southern California experience in long-term monitoring

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ABSTRACT

Billions of dollars have been invested over the past 35 years in reducing pollutant emissions to coastal environments. Evaluation of the effectiveness of this investment is hampered by the lack of long-term consistent data. A rare opportunity exists in southern California to evaluate the effectiveness of management actions by analyzing long-term monitoring of effluent, sediment, benthos, and fish and comparing this trend data to periodic regional surveys of environmental condition. In this paper, we ask the question "have improvements in effluent quality in response to environmental regulation translated into improvements in the receiving environment?" Results indicate that management actions directed at reducing mass emissions from wastewater treatment plants (i.e., POTWs) have resulted in substantial improvement in aquatic communities. However, the magnitude and timing of response varies by indicator, suggesting that use of multiple assessment endpoints is necessary to adequately interpret trends. Reductions in the effect of POTW effluent have allowed managers to shift resources to address a wider range of contaminant sources, including stormwater and resuspension of legacy pollutants.

INTRODUCTION

Over $500 billion has been spent in the United States in the past 30 years to reduce pollutant discharge to the ocean (Knopman and Smith 1993, Copeland 2002. US PIRG 2007). Much of this effort has been directed toward reducing contaminant levels in discharges to the ocean from wastewater treatment facilities, commonly referred to as publicly owned treatment works (POTWs). The primary regulatory mechanism for reducing pollutant levels has been compliance with requirements of the Federal Clean Water Act (CWA). Since 1972, the CWA has mandated technology based effluent limits for point source dischargers and has provided funding for major infrastructure improvements to help achieve those endpoints (Copeland 2002). Under the CWA, POTW discharges are required to be permitted under the National Pollutant Discharge Elimination System (NPDES).

There have been few attempts to comprehensively assess the effect of CWA mandated management action on environmental quality. Most evaluations of the effect of management actions rely on either an assessment of permit compliance or retrospective analysis. For example, the recent report *Troubled Waters* stated that nationally, more than 3,600 major facilities (57%) exceeded their Clean Water Act permit limits at least once/year (US PIRG 2007). Such process based performance measures do not measure environmental endpoints. Although they can be considered a measure of CWA effectiveness, such evaluations do not account for the environmental effects of permit-driven reductions in pollutant discharge, and thus are not a true measure of the effect of management action.

The most common way to assess historic changes in pollution levels for a specific area is sediment core analysis (Valette-Silver 1992). These analyses rely on examining pollution levels at various depths within the core, then approximating the corresponding exposure date based on radioactive

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signatures, such as those from ^{210}Pb or ^{137}Cs (Valette-Silver 1992). The approximate historical time period of various pollution levels can be compared to known anthropogenic activities in the contributing drainage area (or other sources, such as air) to relate changes in pollution to changes in land use and management practices. Coring studies are most effective where the sediment is undisturbed, fine-grained, and subject to relatively rapid sedimentation rates. Although valuable, such analysis has its limitations. First, numerous factors, including weather patterns and dredging, can affect the integrity of the sediment core. Second, dating relies on clear detectable radioactive signatures, which may or may not be present. Third, the temporal resolution of the dating is relatively coarse and is generally reliable on a decadal scale. Finally, analysis of sediment cores relies on inferences about relationships between the historical pollution record and what is known about local or regional management practices, making conclusions about the connection between these two somewhat speculative.

Long-term monitoring data offers an alternative or complementary analysis to sediment cores (Schiff *et al.* 2000, Bernstein and Weisberg 2003, Lyon and Stein 2009). Long-term consistent monitoring allows for direct analysis of the relationship between changes in environmental quality and changes in land use or management actions. Maintenance of such long-term data sets can be expensive and difficult to sustain; consequently, direct analysis of the effect of management actions via environmental monitoring is seldom documented. When available, long-term monitoring data can provide additional insight (above and beyond that provided by sediment cores) on the relationship between management actions and environmental effects.

A rare opportunity exists in southern California to directly assess effects of management actions because of the existence of several long-term monitoring data sets and regional analysis dating back to 1970. Since the early 1970s, major POTW dischargers have been conducting ongoing monitoring of both effluent and indicators of environmental quality surrounding outfalls, including sediment, benthos and fish (CLA 2007, OCSD 2007, CSD 2008, LACSD 2008). Much of this regional data has been periodically compiled and analyzed for regional status and trends by the Southern California Coastal Water Research Project (SCCWRP; Schiff *et al.* 2000, Raco-Rands and Steinberger 2001, Lyon *et al.* 2006, Allen 2006). Finally, since the early 1990s, a broad suite of local, State, and Federal agencies have been participating in SCCWRP's Bight Regional Monitoring Program. This program is a cooperative effort in which the partner agencies implement an integrated regional assessment of the condition of environmental resources in the Southern California Bight (SCB). The program occurs approximately every five years and focuses on answering questions about water chemistry, sediment contamination, benthic infauna, fish, and other organisms. Subsequently, results of the Bight Regional Monitoring Program are used to inform and adjust local management actions.

The goal of this paper is to synthesize data from the long-term regional monitoring programs and studies conducted in the SCB over the past 35 years to assess the effect of changes in regulatory and management practices on a portion of the SCB. This study builds on the earlier assessment of the SCB by Schiff *et al.* (2000) by providing a more in-depth case study of monitoring associated with the area's largest single discharger, the Los Angeles County Sanitation Districts (LACSD) Joint Water Pollution Control Plant (JWPCP). The LACSD monitoring program provides an excellent case study because monitoring around this discharge has remained largely unmodified between 1972 and today. In addition to continuous effluent monitoring, samples of sediments, benthic infauna, and fishes are taken from depths of 23, 61, 137 (fish), 152, and 305 m along transects perpendicular to the shoreline. Eleven benthic transects and four trawl transects have been conducted either annually or biannually since 1972, allowing for direct evaluation of changes in environmental quality over the past 35 years.

THE SOUTHERN CALIFORNIA BIGHT (SCB)

The Southern California Bight is an 80,000-km^2 body of water consisting of more than 300 km of shoreline, associated continental shelf, slope, and basins, extending from Point Conception, California, in the north, to Cabo Colnett, Baja California, Mexico, in the south (Figure 1). This area is a unique and important ecological and economic resource for southern California. The SCB includes diverse habitats for a broad range of marine life, including more than 2,000 species of invertebrates, 500 species of fish, and many marine mammals and birds (Dailey *et al.* 1993). High biological productivity in the SCB is derived from its relatively unique oceanographic

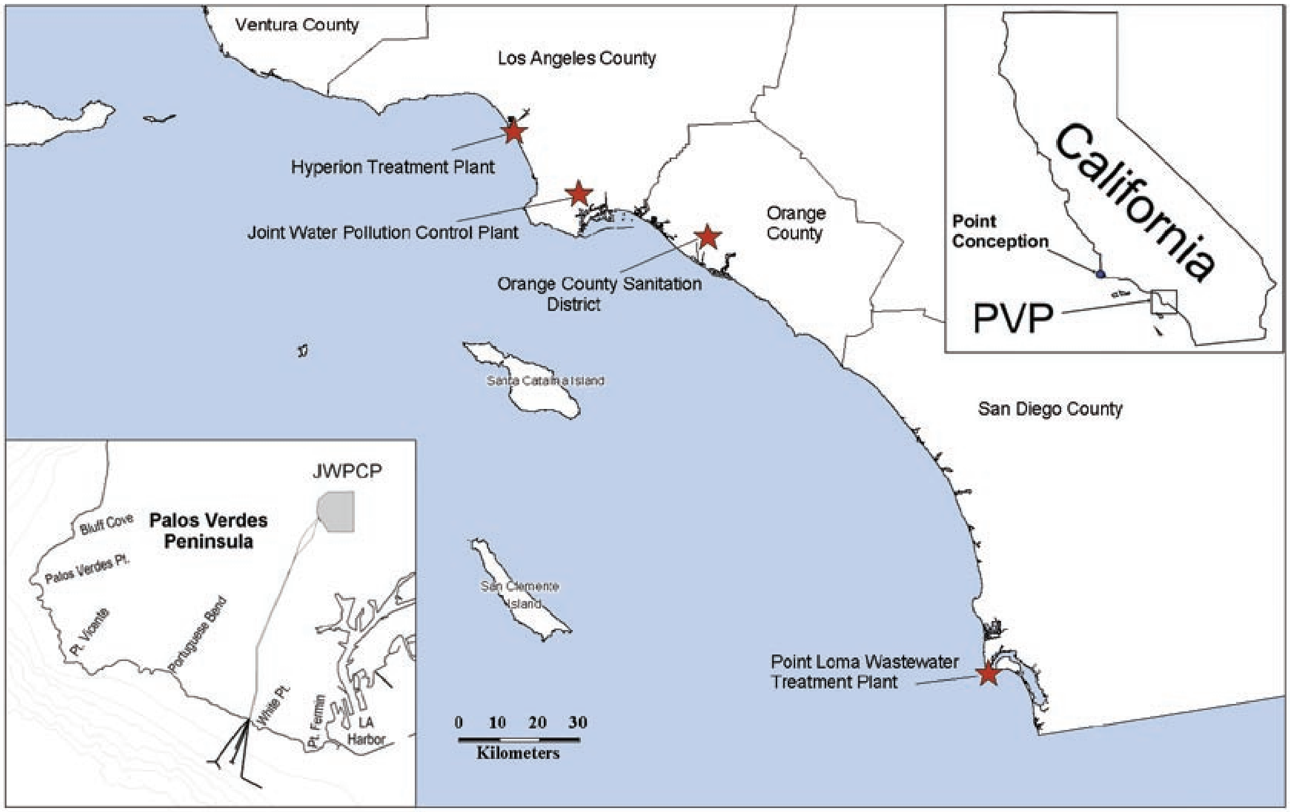

Figure 1. The Southern California Bight (SCB) with the locations of major POTW discharges, and configuration of Joint Water Pollution Control Plant (JWPCP) discharges off the Palos Verdes Peninsula (PVP).

position. The nearshore waters of the SCB are positioned in a confluence of currents flowing from the north and south, termed the California Transition Zone (Newman 1979). The relative influence of the currents varies over time, producing a complex pattern of nutrient availability and larval supply. Northern waters are cold and typically richer in nutrients than southern waters. The relative balance of oceanographic influence changes with alterations of the sea-surface pressure in the central Pacific, reversing northern flow to southern counterflow in a cycle of varying intensity at a periodicity of three to seven years; this cycle is commonly known as the El Nino Southern Oscillation (ENSO; Wolter, 1987). The ENSO is overlain by a multi-decadal regime shift between cool and warm conditions that originates in the North Pacific Ocean; the regime shift is referred to as the Pacific Decadal Oscillation (PDO; Chavez *et al.* 2003). The aggregate effect of these cycles is considerable variability in the base state of ecological communities in the area, which increases the importance of long-term data in interpreting environmental trends.

The coastal region along the SCB is one of the most densely populated coastlines in the United States. The five coastal counties bordering the SCB are home to over 17 million people (US Census Bureau 2002). More than 175 million beach-goer days occur annually, helping to drive a tourism industry that generates an estimated $9 billion in ocean related activities each year (Schiff *et al.* 2002). The significance of the coastal ocean as a recreational resource is balanced by its necessity for other purposes, many of which result in the discharge of pollutants to coastal waters. More than 60 point sources discharge over 4.7 billion liters of treated effluent per day into the coastal ocean (Lyon and Stein 2009). The major point sources of pollutant discharge to the SCB are four large POTWs managed by the City of Los Angeles, Los Angeles County Sanitation Districts, Orange County Sanitation Districts, and City of San Diego, respectively, each discharging over 3.8×10^8 liters/day (100 million gallons/day). These four facilities account for approximately 60% of the volume and 90% of the point-source pollutant mass discharged annually (Lyon and Stein 2009). Routine monitoring of the discharge from these facilities and the surrounding environmental condition has been ongoing since 1971.

REGIONAL TRENDS IN MASS EMISSIONS

Between 1970 and 2002 the population of the five coastal counties bordering the SCB increased 65% (US Census Bureau 2002). During that time the total annual POTW volume discharged to the SCB increased 31%, however, mass emissions of nearly all constituents decreased (Figure 2). Reductions in mass emissions resulted from improved treatment practices mandated under the CWA and source control measures that restricted increases in effluent volume to more than 20% less than corresponding increases in population. Bans on the use of DDTs and PCBs, and strict regulation of heavy metals such as lead and mercury over the study period have also contributed to the decline. Cessation of sludge discharges to the ocean in the 1980s and increased secondary treatment capacity by POTWs in response to CWA requirements have also contributed to significant effluent quality improvements (Raco-Rands and Steinberger 2001, Steinberger and Schiff 2003).

The greatest reductions in contaminant loading have been from POTWs. Many of the contaminant loads from POTWs were reduced by at least 90% from pre-CWA levels (Lyon *et al.* 2006). Major reductions in mass emissions from POTWs occurred from 1971 to 1989, with further reductions between 1989 and 2000. Combined POTW flow volumes have remained high, but decreased from 1,658 billion liters in 1989, to 1,426 billion liters in 2002. Combined total suspended solid (TSS) emissions decreased 83% between 1982 and 2004, while oil and grease emissions declined 80% over the same period. Annual chromium emissions in 1971 were 666 mt, but dropped to 23 and 4.9 mt by 1989 and 2000, respectively. Suspended solids, biological oxygen demand, cyanide, several heavy metals, and total DDT all follow this general trend. Reductions in regional mass emissions generally correspond to increases in the percentage of total combined discharge volume treated at the secondary level, which has incrementally increased from 0% prior to 1982, to 76% in 2004 (Lyon *et al.* 2006).

CASE STUDY: THE HISTORY OF DISCHARGE MODIFICATION AND ENVIRONMENTAL RESPONSE AT A LARGE POTW

Discharge History

The LACSD JWPCP is one of the two largest discharges to the SCB (along with the City of Los Angeles' Hyperion Treatment Plant) and accounts for

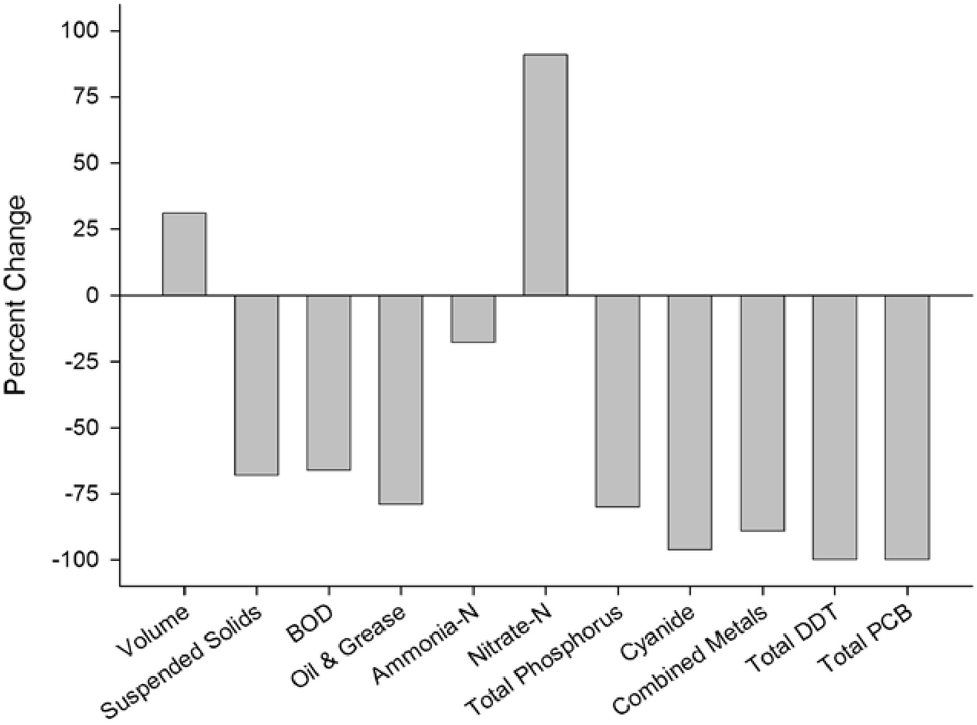

Figure 2. Percent change in total discharge volume and mass emissions of selected constituents to the Southern California Bight (SCB) from 1970 to 2002.

over 30% of the total annual POTW discharge. Discharge through the JWPCP outfalls off White Point (Figure 1) has a history similar to that of other major point-source discharges in the SCB. Discharge began in 1937, increasing in volume and particulate load during the period of rapid population growth in the region which followed. The discharge point also moved seaward as new outfalls came on line; currently, the depth of this point is 61 m, approximately 2.8 km (1.75 miles) from shore. Maximal discharge volume was reached in 1970, with volume gradually decreasing to date as a result of water conservation and water reclamation efforts (Figure 3). In 1970, primary treatment level improvements began to be implemented in response to the impending passage of the CWA. The JWPCP was the first large POTW to implement secondary treatment. In 1983, the JWPCP began treating 3% of its effluent at the secondary level, and increased secondary treatment capacity in each of the subsequent three years; by 1986, 54% of the facility's total volume received secondary treatment. By the end of 2002, 100% of the effluent was receiving secondary treatment. Improved treatment practices translated to reduced emissions. For example, as the percentage of secondary treatment increased, TSS emissions declined 49% between 1982 and 1986, and 67% between 2002 and 2003 (Figure 4). By 2007, solids discharged to the ocean decreased 96% from 1971 levels (LACSD 2008). This is a substantially larger reduction than the regional average of 68% associated with all facilities combined (Lyon and Stein 2009) and reflects the comprehensive change in treatment level undertaken by LACSD.

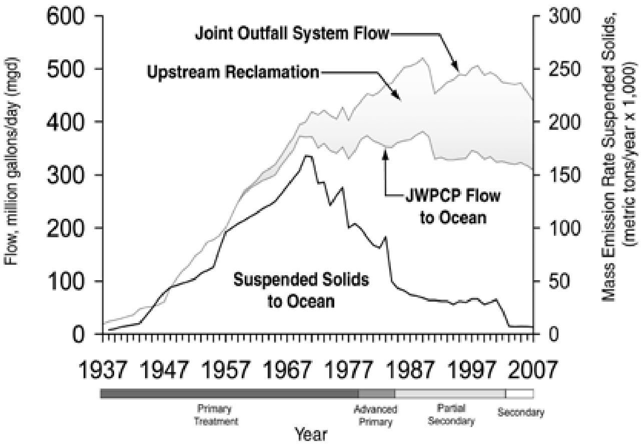

Figure 3. Joint Water Pollution Control Plant (JWPCP) discharge history 1937 to 2007. Separation of the flow line into two lines in 1960 reflects water reclamation; the upper line represents system flow, the lower discharge flow to the ocean. Mass emission rate of suspended solids (metric tons/year x 1,000) is also presented. System treatment levels are indicated below the time line to indicate periods of changing treatment intensity.

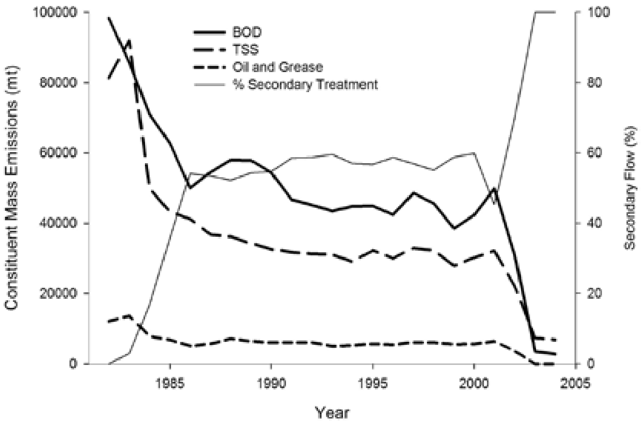

Figure 4. Comparison of secondary treatment and constituent mass emissions from the Joint Water Pollution Control Plant (JWPCP) between 1982 and 2004.

Trends in Sediment Contamination

Studies beginning in 1972 show improvement in sediment quality near the JWPCP outfalls. Reductions in effluent inputs were directly traceable as reductions in both labile (i.e., nutrient) and refractory (i.e., metal and organic pollutant) sediment loads (LACSD 2006, 2008). Patterns of sediment concentration of organic nitrogen (Figure 5) and total DDTs over time (Figure 6) mirror decreases in effluent concentrations and reflect increased efficiency of particle and associated-pollutant capture within the JWPCP processes. Metals in sediments declined along the same trend as DDTs, although not so precipitously, as demonstrated by trends in the concentration of cadmium and copper in surface sediments off Palos Verdes (Figure 7). Other toxic organic chemicals, such as PCBs and PAHs, also exhibited declines similar to those observed in DDTs, both in effluent and sediments surrounding outfalls (LACSD 2006). Measures of organic enrichment (i.e., organic carbon, biological oxygen demand) responded as did organic nitrogen. Secondary measures resulting from organic oversupply (i.e., depressed dissolved oxygen levels in bottom water and H_2S production in pore waters) have also responded to decreased mass emissions. As effluent contaminant concentrations decreased, dissolved oxy-

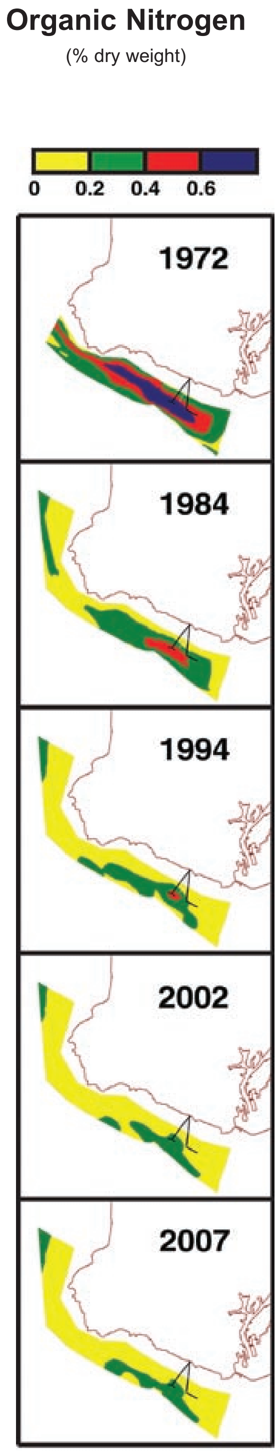

Figure 5. Organic nitrogen (% dry weight) in surface sediments (0 - 2 cm) off Palos Verdes 1972 to 2007. Selected years represent primary treatment (1972), advanced primary treatment (1984), partially secondary treatment (1994), full secondary treatment (2002), and most recent data (2007).

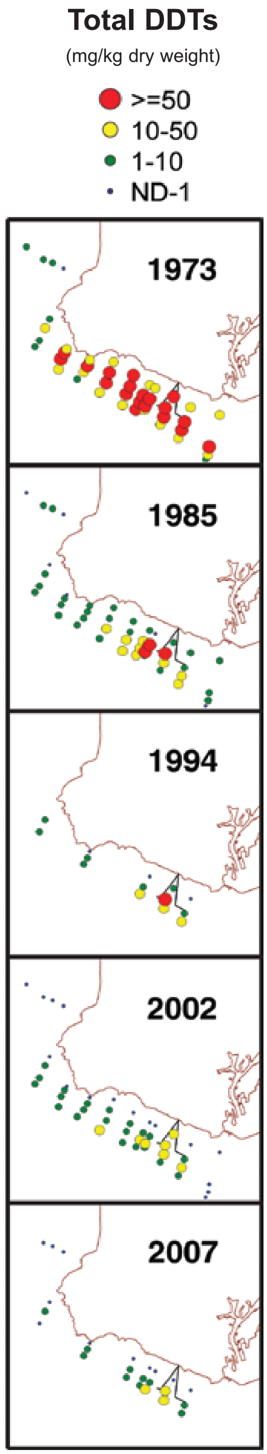

Figure 6. Total DDTs (mg/kg dry weight) in surface sediments off Palos Verdes 1973 to 2007. Selected years represent primary treatment (1973), advanced primary treatment (1985), partially secondary treatment (1994), full secondary treatment (2002), and most recent data (2007).

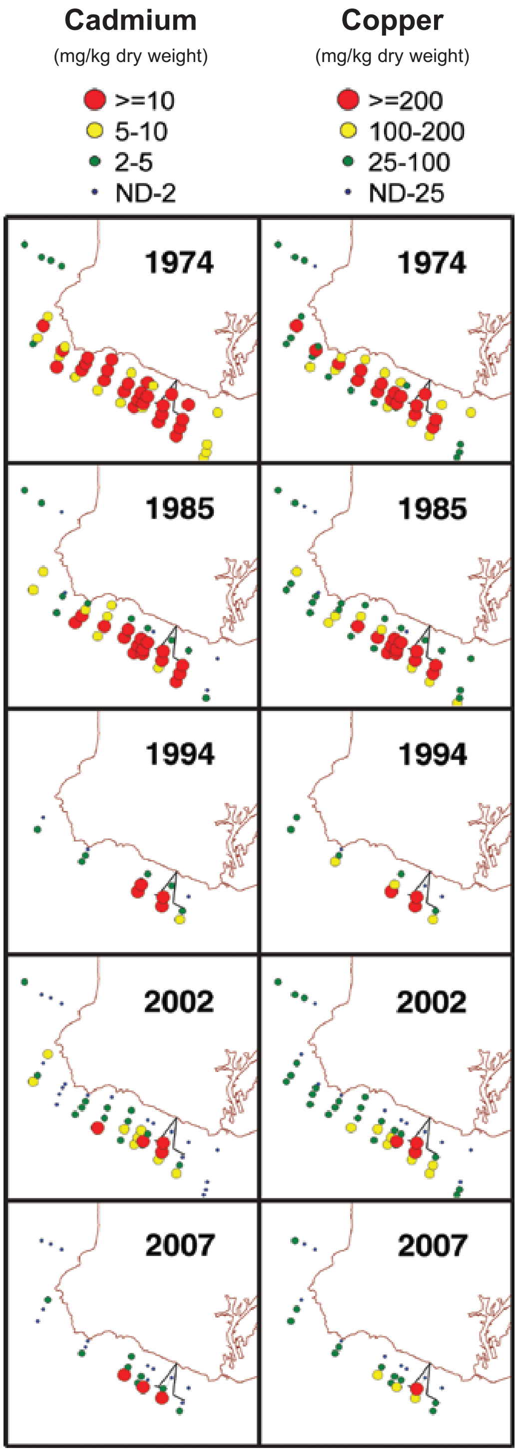

Figure 7. Cadmium (Cd) and copper (Cu) concentrations (mg/kg dry weight) in surface sediments off Palos Verdes 1974 to 2007. Metals data were not gathered in 1972 and 1984; hence data from 1974 and 1985 are presented.

gen levels increased in bottom-water and pore-water sulfides decreased, eventually dropping to undetectable levels over most of the area (LACSD 2008).

The most dramatic reduction in sediment contamination coincided with the transition from primary to secondary treatment in response to CWA requirements. Although contamination continues to decline, improvement since the late 1980s has been less dramatic. As mass emissions decreased, sediment response eventually began to decouple from discharge reductions, and it became more likely that other factors are having greater influence on sediment contamination. Bioturbative re-exposure of buried legacy sediments and other toxicants has begun to equal or exceed the levels of effluent introduction (Niederoda *et al.* 1996, Stull *et al.* 1996). Stormwater discharge has also become a proportionately larger contributor to sediment contamination (Schiff *et al.* 2006). For example, stormwater-runoff turbidity plumes were found to be spatially extensive, covering up to 2,500 km^2 of the SCB nearshore zone (Nezlin *et al.* 2007). In addition, large storms also assist the redistribution of buried legacy contaminants, eroding away deposits and reintroducing toxic materials to surface sediments (Sherwood *et al.* 2002). Reintroduction of previously discharged contaminants can be inferred from the distribution relative to known inputs. Sherwood's observations, for instance, used sediment vertical contamination profiles to document declines in offshore sediment DDT inventory and redeposition in other shelf areas following erosional resuspension.

Temporal patterns in sediment contamination around the JWPCP outfalls are reflected in the results of the periodic Bight regional surveys. Bight-wide surveys indicate little change in the extent of sediment contamination since 1994. In the 2003 regional survey, approximately 94% of the SCB was enriched (by anthropogenic input) in at least one sediment constituent, 88% was enriched by at least one trace metal constituent, and 71% was enriched by at least one organic constituent. Total DDT was the most widespread sediment contaminant enriching 71% of the SCB sediments (Schiff *et al.* 2006). The lack of a detectible trend since 1994 likely reflects that fact that the majority of reductions in POTW mass emissions occurred prior to this time. It also suggests that other sources, such as stormwater discharge, legacy sediment contamination, and regional circulation patterns, have become the primary factors influencing regional patterns of sediment contamination.

Trends in the Health of Benthic Infaunal Communities

Benthic infauna form the base of many marine food chains. Because they live and feed in surficial sediments, benthic infauna are an excellent proximal indicator of ecosystem condition and often used to help relate pollutant discharge to ecological stress (Pearson and Rosenberg 1978, Smith *et al.* 2001). Their responses also integrate environmental conditions over time because they have limited mobility and cannot avoid adverse conditions (Smith *et al.* 2001, Borja *et al.* 2003). Benthic infauna have been monitored by LACSD along transects across the southern California coastal shelf since the early 1970s. Historically the areas around POTW discharges have been characterized by low benthic species diversity and abundance (Warwick and Clarke 1994). Between 1970 and 1995, infaunal species richness and diversity increased to a level where adverse effects were limited to an area immediately surrounding the POTW outfalls (Stull 1995, Bergen *et al.* 2000). By 1984, isobath banding near discharge locations began to resemble typical species richness patterns throughout the SCB (Figure 8). By 1994 species richness had increased several-fold throughout the monitored area, including sites near the outfalls; these increases continued, although at a slower pace, between 1994 and 2007 (Figure 8).

Species richness and diversity alone do not tell a fully interpretable tale of benthic community condition. Because infaunal species respond to organic enrichment in a non-linear fashion, many may reach peak numbers at intermediate disturbance levels (Pearson and Rosenberg 1978). Multivariate indices often provide a better measure of relative community status. The Benthic Response Index (BRI) provides an abundance-weighted pollution tolerance score for benthic communities, which varies along a gradient extending from unaffected background to heavily polluted (Smith *et al.* 2001). The BRI represents the aggregate pollution tolerance score of each included genus, weighted by its abundance at a given site. Tolerances are defined for each species as the midpoint of its population along a known gradient of disturbance. All collected species meeting minimum abundance and frequency-of-occurrence requirements are used, ensuring that the index represents a broad spectrum of species level responses. This index was applied to data from the area around the JWPCP discharge to evaluate recovery of benthic communities over time. As the index is a continuous numeric vari-

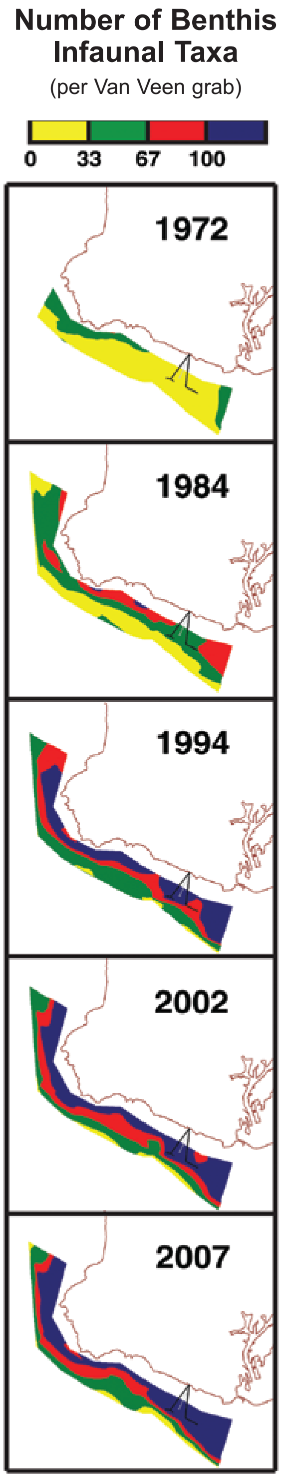

Figure 8. Number of benthic infaunal taxa per Van Veen grab sample off Palos Verdes 1972 to 2007. Minimum acceptable grab penetration 10 cm. Grab surface area 0.1 m^2, with fauna retained on a 1.0-mm screen.

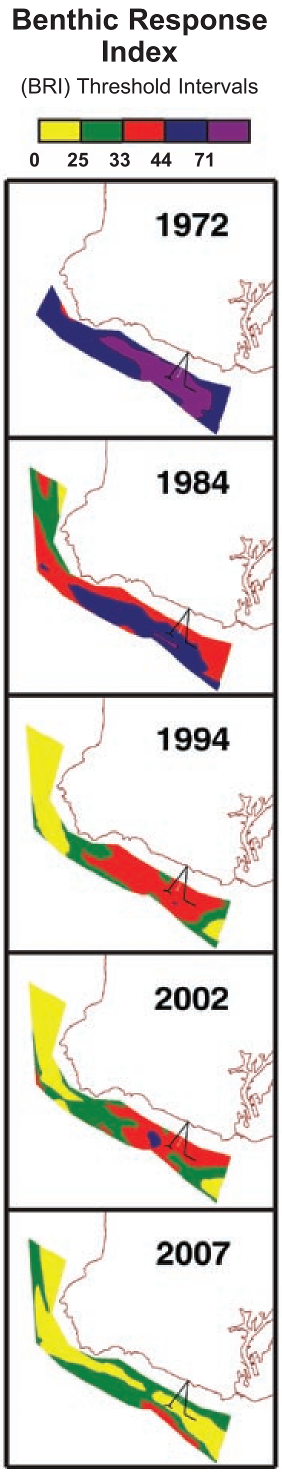

Figure 9. Benthic Response Index (BRI) classification of infaunal community samples off Palos Verdes 1972 to 2007. >= 72 = Defaunation; 44-71 = Loss of Community Function; 34-43 = Loss in Biodiversity; 26-33 = Marginal Deviation from Reference Condition; and <= 25 = Reference Condition.

able, it allows establishment of thresholds dividing the response continuum into impact classes (Figure 9). The data in Figure 9 are based on single grab samples, except for 1972 data which are a composite of three smaller grabs of equivalent surface area.

Application of the BRI to historical monitoring data indicated that during the 1970s benthic communities near the JWPCP outfall were severely impacted and classified by the BRI as "defaunated"; more distant sites were classified as having a "loss of community function" (LACSD 2006). Recovery of benthic communities lagged several years behind reductions in mass emissions and associated sediment contamination. By 1984, two sites near the discharge outfall remained in "defaunation" status, while other sites improved to resemble reference sites located far from outfalls in 1972. By 1994 none of the 44 monitored sites were classified as either "defaunated" or "loss of community function". Areas around the outfall still exhibited "loss of biodiversity", and areas removed from outfalls were in reference condition or deviated marginally from that condition. By 2007, when species numbers suggested that areas near the outfall were similar to those more removed from it, the BRI still showed that the upper slope and outer continental shelf sites adjacent to the outfall suffered from a "loss in biodiversity" (i.e., diversity of species across multiple portions of the ecosystem), indicating that full recovery of the benthic communities had not yet occurred (LACSD 2008).

As was observed for sediment contamination, regional surveys dating back to 1994 do not indicate strong differences over the past ten years in the bight-wide condition of benthic communities (Ranasinghe *et al.* 2007). Overall, estimates used in these surveys indicate that benthic macrofauna in 98.4% of the SCB were in reference condition or deviated only marginally from reference. Areas near large POTWs did not differ substantially from other areas at similar depths on the coastal mainland shelf. On the other hand, macrofaunal communities in bays and estuaries were more frequently disturbed. Nearly 13% of the area in these embayments contained clearly disturbed benthos, with the greatest frequency occurring in estuaries and marinas (Ranasinghe *et al.* 2007). This is consistent with other studies that have reported that most areas in the SCB with reduced benthic community abundance are located near river discharges (Schiff *et al.* 2000). Similar to patterns of sediment contamination, improved wastewater treatment has resulted in improved benthic community structure near POTW outfalls and shifted management priorities toward other pollutant sources.

Trends in Fish and Macroinvertebrate Communities

Demersal fishes and megabenthic invertebrates are found in soft-bottom habitat and widely distributed on the southern California shelf and slope. These sedentary fishes and invertebrates provide a good indicator of higher food-chain effects of pollutant discharges, and thus have been monitored extensively during the past three decades to assess impacts of wastewater discharge.

In the 1970s, fin erosion and epidermal tumors affected 33 of the 151 species examined near POTW outfalls; Dover sole (*Microstomus pacificus*) was affected most severely (Mearns and Sherwood 1974, 1977). Although the etiology of fin erosion was never fully explained, occurrence of the disease in areas of organic accumulation far from POTW outfalls suggests that the disease mechanism is not driven primarily by toxic exposure, but by environmental modifications related to organic oversupply (Moring 1982). By the mid-1980s, fin erosion had largely disappeared from the most affected species and was essentially absent by 1994 (Stull 1995, Allen *et al.* 1998). Similarly, incidences of epidermal tumors have decreased since the 1970s and occurred at background levels as of the late 1990s (Allen *et al.* 1998). Incidence of fin erosion in juvenile Dover sole near the JWPCP outfall declined rapidly in response to effluent improvements (Figure 10). No cases of fin erosion have been observed in the area since 1986 in this, or any other, previously affected species.

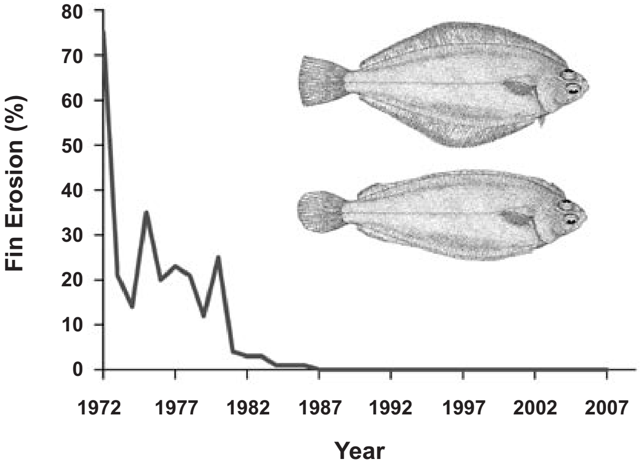

Figure 10. Fin erosion incidence in juvenile Dover sole (*Microstomus pacificus*) as percent population off Palos Verdes 1972 to 2007. All values for 1987 to 2007 are zero.

Fish community structure is also subject to modification by discharge (Stephens *et al.* 1988) and has been examined using a multivariate index similar to the previously discussed BRI. The Fish Response Index (FRI) uses the same approach as the BRI and provides a similar measure of aggregate pollutant impact. Application of the FRI to historical monitoring data shows that in the years immediately following passage of the CWA, the fish community off Palos Verdes was clearly impacted, with all records above the reference threshold. By 1978 at least one of the quarterly trawl samplings scored within the reference range and by 1982 all quarterly samples scored within the reference range (Figure 11). A similar recovery timeline was followed by megabenthic invertebrates captured in trawls. Thompson *et al.* (1993) found that by 1980 (within 10 years of initiation of improved wastewater treatment) the macrobenthic invertebrate communities collected near the JWPCP outfalls were indistinguishable from those in reference areas.

As was found with sediments and benthic infauna, demersal fish and invertebrate populations and assemblages on the southern California shelf were

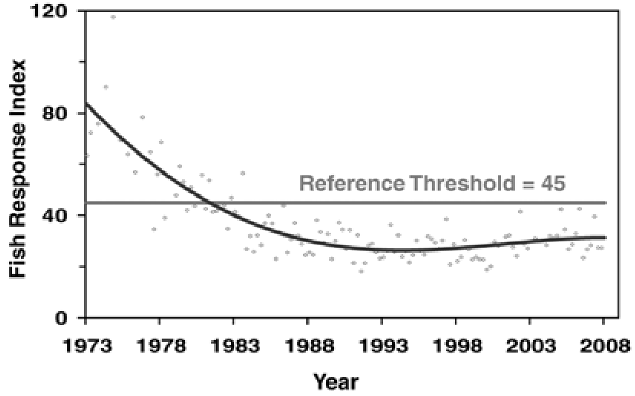

Figure 11. Fish Response Index (FRI) in trawls adjacent to point of effluent discharge 1973 to 2007. Individual points represent quarterly trawls; line represents annual average FRI value. Horizontal line represents threshold of reference condition. Points above the line show a modified fish community, those below the line an unmodified or reference community.

healthy in 2003 compared to conditions in the 1970s. Biointegrity indices identified 96% of the southern California shelf as reference for fish, 92% for fish and invertebrates combined, and 84% for invertebrates. Nonreference (disrupted) assemblages occurred primarily on the inner shelf or bay/harbor areas, suggesting nearshore influences. Fish populations also had background levels of anomalies, while parasites and fin erosion were absent (Allen *et al.* 2007).

Trends in Fish Tissue Contamination

Toxicants released from point and non-point sources can sometimes bioaccumulate in tissues of exposed organisms, that in turn can pose a health risk to fish, birds, marine mammals and humans. This is true of the methylated forms of metals (and to a lesser extent non-methylated forms) and particularly true for organic toxicants such as pesticides and combustion by-products, all of which are associated with POTW effluent. Potential effects of bioaccumulation have been monitored since the 1970s through evaluation of DDT tissue concentrations in several fish species that reside in the SCB (OEHHA 1991, LACSD 2008). Large volumes of DDTs were discharged through the JWPCP outfalls prior to their ban in 1972. Because of their persistence in the environment, DDT tissue concentrations have been of continuing interest. Concentrations in white croaker (*Genyonymus lineatus*) tissue have remained sufficiently high that fisheries closures on Palos Verdes prohibit both commercial and recreational catch of this species. There is a longer, more consistent data series for kelp bass (*Paralabrax clathratus*), which lives further removed from the point source in more shallow waters than does white croaker, and is a much less fatty fish. Since DDTs are lipid soluble, tissue levels of the leaner kelp bass typically do not reach the high levels that triggered fisheries' restrictions related to the white croaker. Nevertheless, the kelp bass is caught and consumed by birds, marine mammals, and humans, and has been used as a sentinel organism in the area.

Fish live for several years, and body burdens of toxicants may persist long after exposure and uptake of the materials. This is reflected in the lag time between the cessation of DDT discharge and the subsequent drop in kelp bass tissue concentration (Figure 12). The downward trend in muscle tissue concentrations has continued, but the persistence of DDTs in legacy sediment deposits around outfalls, and reintroduction to water-column food webs by bioturbation and sediment erosion continue to make them available at low levels in the environment. This is seen in the persistent, albeit increasingly low, levels of DDTs in fish tissues.

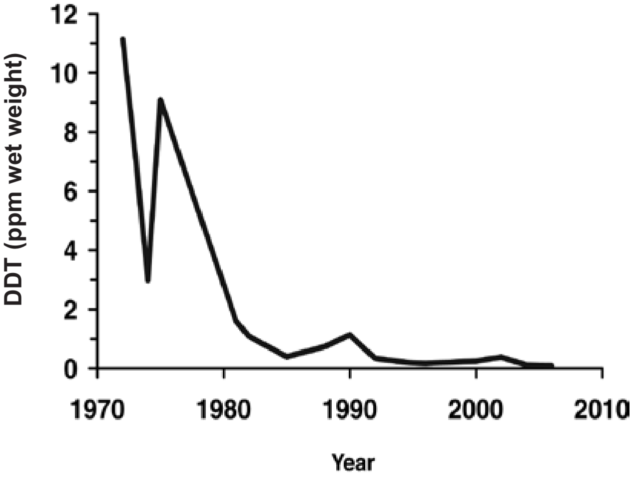

Figure 12. Kelp Bass (*Paralabrax clathratus*) muscle tissue concentration of total DDTs off Palos Verdes 1972 to 2006. No data are available for 1998, 1999, 2005, and 2007. Detectable levels remain in samples from 2006, but all are below 1 ppm wet weight. Analyzed tissues are all from fish 29 - 32 cm in total length.

DISCUSSION: LESSONS LEARNED ON THE UTILITY OF LONG-TERM MONITORING

Effective long-term monitoring should provide useful information to environmental managers, offering temporal cause/effect linkages not typically available in static retrospective analysis (e.g., sediment cores). Like many monitoring programs, long-term monitoring in southern California was originally motivated by permit compliance. Although documenting success or failure at reaching regulatory benchmarks will always remain a goal, successful monitoring programs must evolve beyond this single objective.

The JWPCP case study illustrates several attributes of more mature monitoring programs. First, monitoring programs should be designed to answer key management questions that will inform future decisions. For example, POTW managers in the 1970s needed to know if the pollutants associated with dischargers were causing or contributing to disease in fish. Addressing this question required information on the condition of fish collected near outfalls, information on the condition of fish throughout the Bight as a basis of comparison, and some investigation of the potential causes of tumors and fin erosion. Results of the question-driven monitoring provided insight into the condition of fish communities relative to long-term spatial and temporal patterns and showed that epidermal tumors proved to be produced by the fish as a response to surface attack by sediment dwelling amoebae, and not to cancerous neoplastic growth (Dawe *et al.* 1979).

Second, monitoring must be adaptable and incorporate both retrospective and prospective approaches. Development of the BRI and subsequent retrospective analysis helped to better elucidate changes in the overall health of benthic communities and relate these changes to past or potential future changes in treatment practices. Understanding the relationship between ecosystem stressors and biological response can aid in modeling or other analyses that attempt to predict how potential future management actions may affect environmental conditions.

Third, monitoring programs should include multiple indicators that evaluate both ecosystem stressors and response. Inclusion of sediment contamination measures, benthic community analysis, and fish health evaluation allows for more direct relationship of changes in effluent quality with associated biological effects at multiple trophic levels. The overall analysis indicates that different trophic levels respond at different time scales, and that there are time lags between reduction in mass emission and recovery of biological communities. Higher trophic levels are subject to internal factors (such as slower growth rates) and external influences (such as additional environmental stressors) that complicate interpretation of monitoring data. Together all elements of the monitoring program can provide a weight of evidence that indicates whether management actions are likely resulting in improvement of environmental conditions.

Finally, targeted compliance monitoring programs should be coupled to regional analysis of ambient condition, such as the Bight Regional Monitoring Program. Regional programs provide context for interpreting targeted/compliance data, place the studied system into a broader definition of regional reference, and help account for the influence of broad scale environmental changes as modifiers of local community status (Bernstein *et al.* 1997). Furthermore, the combination of ambient and targeted monitoring can help identify emerging management needs. In the case of the SCB, integrated monitoring has been able to identify new important sources of contamination that may require future management attention, such as stormwater discharge and bioturbative resuspension of legacy contaminants.

Long-term monitoring also provides data for analysis that can increase overall understanding of the ecosystem receiving the discharge. In the SCB, community dynamics are influenced by both human actions and several long-term cyclical oceanographic influences. In the 1970s, the communities around the JWPCP outfalls were affected mostly by effluent discharge with patterns of community distribution reflecting the proximity to discharge rather than other broader scale environmental gradients. The replacement of this impact-driven pattern with one reflecting other forcing variables is evident in the long-term monitoring data. As the impact of discharge has declined, gradients related to depth (evident in benthic community bathymetric banding), or to temperature (evident in fish populations; Horn and Stephens 2006) have become of greater relative importance and will require greater management attention.

Long-term monitoring can also reveal unexpected beneficial events in areas receiving POTW effluent. Such an event was documented in the early 1980s in the benthic community off Palos Verdes (Stull *et al.* 1986). The build-up of high levels of nutrients in sediments near the JWPCP outfalls attracted a swarm settlement of the Echiuran worm *Listriolobus pelodes*. These animals fed on the organics, grew and reproduced, then largely died out. The result was a significant reduction in the excess of available nutrients and a subsequent improvement in the status of the benthic community. Since these animals are soft-bodied, they left no permanent record of their presence in sediment cores. Without monitoring before, during, and after this event, the rapid improvement in benthic condition would have not been interpretable.

Over time, the demands for environmental remediation or protection have changed due to reduction of the largest historical pollution sources, improved analytical and treatment technologies, interest in new and emerging contaminants of concern, and recognition of the significance of numerous additional sources of pollution. Demand for environmental management typically outpaces available resources to address that demand. Consequently, expenditures are more closely scrutinized and decisions require more complete and resolved data sets. Well-designed monitoring programs can aid in resource allocation decisions by providing feedback for managers on the efficacy of their programs and helping to evaluate potential benefits of actions being contemplated.

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