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Research article

Quantifying ocean monitoring effort and cost in the Southern California Bight over the last 25 years

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ABSTRACT

Ocean monitoring to assess the status and trends of the physical, chemical, and biological integrity of the coastal zone is critical for successful environmental decision making. The National Research Council found in 1990 that ocean monitoring in the Southern California Bight (SCB), while extensive, was largely ineffective for decision making and numerous steps have been taken since to improve monitoring. Here, we repeat a study conducted in 1997 to inventory ocean monitoring throughout the SCB to answer three questions: (1) How much ocean monitoring is conducted in the SCB in terms of effort and cost? (2) How does this ocean monitoring effort and cost vary amongst different habitats, indicators, and monitoring agencies? (3) How does ocean monitoring effort and cost compare to ocean monitoring 25 years prior? We found that 64 organizations conducted ocean monitoring in 2022, compared to 115 monitoring organizations in 1997. Despite roughly half the number of monitoring agencies, the number of samples collected more than tripled from 244,917 to 919,858 per year. The cost of ocean monitoring also doubled from 62 million dollars ($62M) in 1997 (inflation adjusted to 2022 dollars) to $138M in 2022. The majority (58 % of samples and 52 % of costs) of the ocean monitoring effort in the SCB is conducted by agencies with National Pollutant Discharge Elimination System (NPDES) permits, a requirement imposed by state and federal regulators. The reduction in number of monitoring agencies is in part attributable to fewer NPDES dischargers between 1997 and 2022. The largest monitoring effort was for beach water quality monitoring, a direct outcome of legislation to protect public health of beach goers. While this ocean monitoring effort may appear large, the effort amounts to <0.5 % of the region's ocean-generated revenue.

1. Introduction

Environmental monitoring is fundamental to assessing the health of the coastal ocean. Without monitoring, decision makers would not have the information to answer basic questions such as "is it safe to swim?", "is it safe to eat the fish?", or "are our ecosystems protected?" enshrined in the Clean Water Act (33 U.S.C. § 1251 *et seq*. 1972). Monitoring-informed management decisions can incorporate if there is an environmental need, how big the need is, if the need is increasing or decreasing over time, and if decisions to remediate the impact have been effective (National Research Council, 2001; US EPA, 1991; Krenkel and Novotny, 1980; Stein and Cadien, 2009).

Ocean monitoring incorporates a wide variety of study designs, measurements, locations, and agencies. This variety makes large-scale assessments of ocean health extremely challenging for decision makers (Beliaeff and Pelletier, 2011, Keil et al., 2021). Much of the variety is a direct result of the monitoring agency's mission, monitoring questions being asked, and actions to be taken once the monitoring questions are answered. The agencies conducting monitoring are equally varied, ranging from Universities to local, state, and federal agencies, and

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include agencies who are mandated to monitor for regulatory compliance. Monitoring indicators vary from physical measurements, such as currents or discharge plumes, to chemistry-focused water or sediment quality, and can include biological assemblages for plankton, kelp beds, invertebrates, fish, marine mammals and seabirds. The combinations of monitoring agencies, study designs, and measurement indicators appear nearly limitless.

Southern California is an example of where there is a large variety of ocean monitoring which challenges coastal management decision making. The southern California Bight (SCB) has a unique and sensitive ecosystem resulting from the convergence of the cold, temperate, southerly flowing California Current with the warm, sub-tropical, northward-flowing California counter-current (Dailey et al., 1993; Schiff et al., 2000; Dong et al., 2009). The SCB is a major stop along the migration routes of whales and seabirds of the eastern North Pacific Ocean, is the home range to >750 fish species and >7000 invertebrate species, and encompasses one of the country's largest underwater National Parks and part of an integrated network of statewide Marine Protected Areas and Areas of Special Biological Significance (Dailey et al., 1993; Claisse et al., 2018; Schiff et al., 2011). However, the SCB also has a population of nearly 29 million people that live within an hour's drive of the coastal ocean. This presents a host of potential ocean stressors including shoreline development and habitat loss, over-fishing, and discharges of treated wastewater or untreated urban runoff (Lyon and Stein, 2009; Schiff et al., 2016a,b; Frieder et al., 2024).

The National Research Council (NRC) used the SCB as their primary case study when critiquing the state of ocean monitoring in the late 1980s (National Research Council, 1990). Despite 17 million dollars ($17M) spent annually on ocean monitoring, it was largely ineffective for informing decision making because the monitoring did not address specific management questions of interest including basic questions about fishable, swimmable, and ecological resources.

Schiff et al. (2002a) conducted an inventory of monitoring ten years after the NRC study as part of an effort to upgrade monitoring effectiveness in the SCB. They found that monitoring in 1997 had expanded to $31M per year, with nearly three-quarters of the effort expended by National Pollutant Discharge Elimination System (NPDES) permitted water quality regulatory requirements. That finding was an early step in restructuring NPDES permits regionally toward achieving more coordinated and management question-focused ocean assessments.

The issues and questions being asked by ocean managers have evolved over the last quarter century. As a result, there has been a tremendous change in ocean management and monitoring since the late 1990s. Here we repeat the Schiff et al. (2002a) assessment 25 years later to examine how the regional mix of SCB monitoring has evolved. Our goal was to answer three questions: (1) How much ocean monitoring is conducted in the SCB based on effort and cost? (2) How does ocean monitoring vary among habitats, indicators, and monitoring sectors? and (3) How has ocean monitoring effort and cost changed in the past 25 years? Answers to these questions will enable ocean managers to assess the value of monitoring relative to changes in policy and inform if appropriate levels of effort are being directed towards the highest

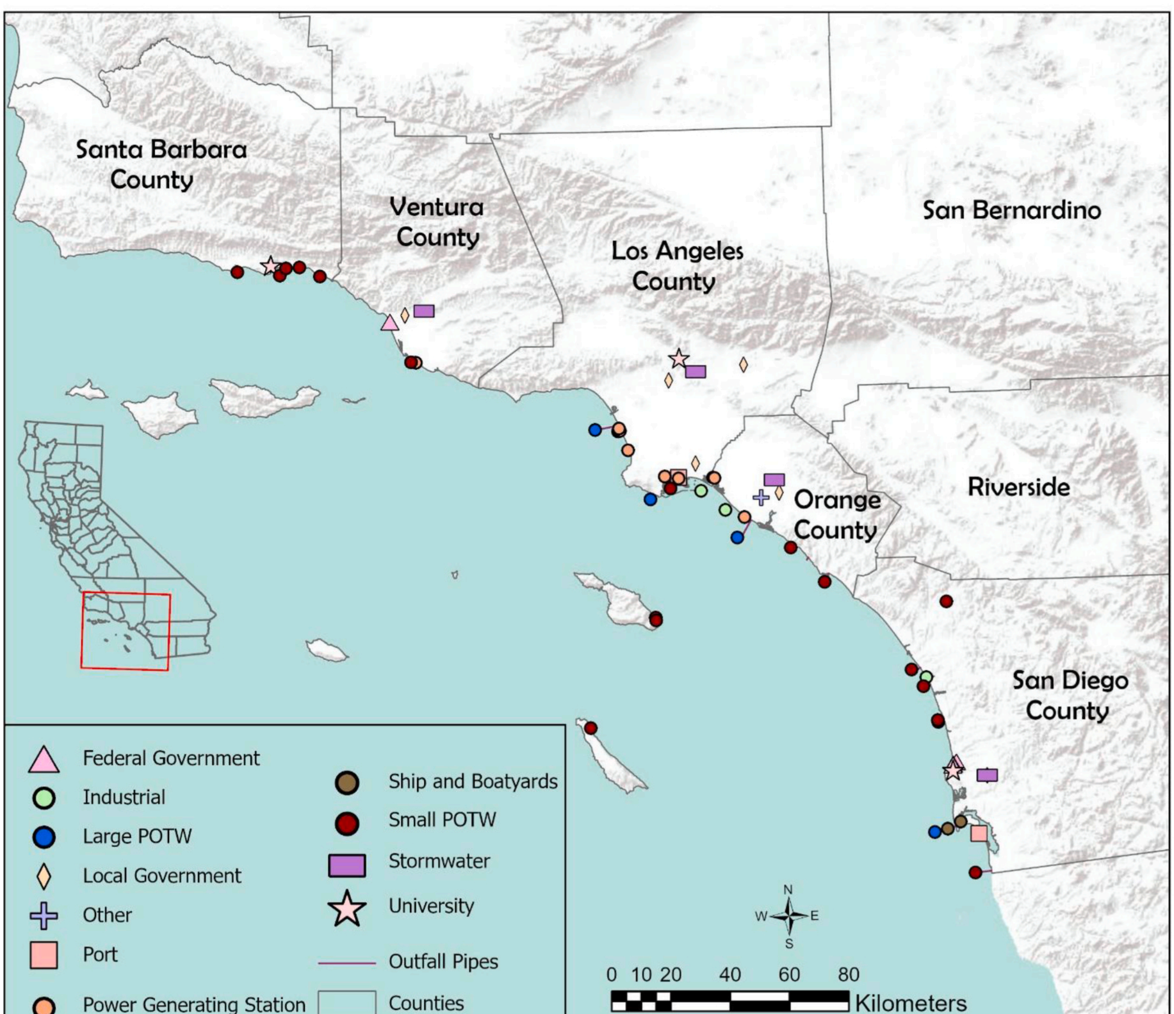

Fig. 1. Map of the Southern California Bight and locations of the 64 agencies in the monitoring inventory.

priority management questions.

2. Methods

The methods used for this study mirrored Schiff et al. (2002a). To be included in the inventory, an ocean monitoring program had to meet all of the following criteria: (1) was in existence (or expected to be in existence) for at least 10 years; (2) collected samples at any time between 2021 and 2023; and (3) data or data reports were publicly accessible. The programs had to sample in the SCB, which is bounded by the following geography: (1) south of Pt. Conception, California, and north of the United States-Mexico international border; and (2) no farther inland than the head of tide and no farther offshore than the outer Channel Islands (Fig. 1).

For each long-term monitoring program, the number of stations sampled, frequency of sampling, number of depths monitored, media, analytical parameters, sample collection methods, and analytical methods were compiled. Information about discharge monitoring programs was obtained from the state or federal regulatory agency that issued the permit, from the permittee directly, and/or the written permit monitoring requirements. Information about other programs, such as university-driven monitoring, was gathered through the examination of data sets and/or project reports and was often augmented with interviews of the project managers. For programs in which the number of sites, number of depths, or frequency of sampling were not evenly distributed over multiple years, the effort expended in the years between 2021 and 2023 was averaged to obtain a representative single-year estimate.

The inventory included both discharges to the ocean (e.g., treated wastewater effluent and stormwater runoff) and receiving water monitoring programs. Discharge monitoring included quantity and quality measures from NPDES-regulated agencies including Publicly Owned Treatment Works (POTWs) for municipal wastewater (23 agencies), industrial facilities (8 agencies), power generating stations (8 agencies), and municipal stormwater (4 agencies). For stormwater agencies, discharge monitoring was typically conducted at the end of the watershed, just upstream from head of tide. Receiving water monitoring included nine different elements: (1) bacteria, (2) conductivity temperature depth (CTD) casts, (3) eutrophication such as nutrient concentrations, chlorophyll, plankton, and harmful algal blooms (HABs), (4) fish and shellfish populations such as community assemblages and bioaccumulation, (5) intake screens from flow-through seawater systems, (6) intertidal physical habitat and biological communities for both rocky and sandy shorelines, (7) rocky subtidal habitats such as kelp beds and related fish and invertebrate communities, (8) sediment quality such as sediment chemistry, sediment toxicity, and benthic infauna, and (9) water quality such as sensor or lab analysis of water samples as well as ocean current measurements. These are the same categories used in Schiff et al. (2002a,b).

Monitoring programs were classified as to whether the monitoring was conducted by a federal, state, or local government agency, an NPDES-regulated agency, a university, or a non-governmental organization (NGO). Classifications were based on which agency conducted the monitoring and had primary access to the monitoring data as opposed to which agency funded the monitoring (e.g., federal funding for a university-led monitoring program was classified as a university program).

Effort was translated into annual cost by multiplying the number of samples of each type by their unit cost for sample collection (field, Eq (1)) and analysis (laboratory, Eq (2)). Unit costs were obtained as the median value of up to six price quotes for each parameter obtained from local contractors. The field plus laboratory costs were then doubled to account for program planning, database activities, data analysis, and report preparation, equivalent to what was done by Schiff et al. (2002a) (Eq (3)). The standardized unit-cost approach for estimating total costs was used because there are discrepancies in ways that different organizations, particularly public organizations, account for their costs. However, we validated our cost estimates by comparing to a subset of monitoring agencies that track their programmatic costs and found that our average cost estimate to be accurate within ±51 %.

$$FC = \sum_{f=1}^{F} \left(X_f * C_f\right) \quad \text{Eq 1}$$

Where: FC = Field Costs per monitoring program.
F = number of field monitoring elements.
X_f = number of field collected samples for element F.
C_f = cost of field collection per sample for element F

$$LC = \sum_{p=1}^{P} \left(X_p * C_p\right) \quad \text{Eq 2}$$

Where: LC = Lab Costs per monitoring program.
P = number of lab parameters for each monitoring element.
X_p = number of samples for parameter p per monitoring element.
C_p = cost of lab analysis for parameter p per sample

$$TC = \left(\sum_{m=1}^{M} \left(FC_m + LC_m\right)\right) * k \quad \text{Eq 3}$$

Where: TC = Total cost per monitoring program.
m = number of monitoring programs
k = 2, the multiplier for cost of planning, data management and analysis, and reporting (see text).

To compare costs from 1997 to 2022, an inflation rate of 1.89 % per year was used to adjust the 1997 costs estimates. This rate was obtained as the average All-Urban Consumer Price Index (CPI) for the four coastal counties in the SCB; Los Angeles, Orange, San Diego and Ventura Counties (US Bureau of Labor Statistics 2025). This CPI is the standard used by the United States federal government and includes price changes for food, energy, housing, apparel, transportation, medical care, recreation, education, and other items. Unless noted, all costs in this manuscript are standardized to 2022 dollars.

Access to the raw data in comma-delimited files can be found at https://cost-of-monitoring-2025-sccwrp.hub.arcgis.com/.

3. Results

3.1. Inventory of monitoring programs

There were 64 monitoring programs conducting ocean monitoring in the SCB during 2022. Of these, 47 of the programs were designed to comply with NPDES monitoring requirements of treated wastewater facilities, stormwater discharges, power and non-power generating industrial facilities, ports and shipyards. The remaining 17 monitoring programs included local municipalities, universities, or state and federal programs.

The number of monitoring programs declined from 115 to 64 between 1997 and 2022. The biggest decline in programs was for shipyards/boatyards and oil platforms. Likewise, the number of monitoring programs for power generating stations, industrial facilities, and state-led programs also declined between 1997 and 2022. The number of large POTW and stormwater monitoring programs stayed the same. Small POTW monitoring programs increased from 15 to 19 programs not due to new POTWs, but due to the inclusion of new monitoring requirements and the inclusion of inland small POTWs with combined ocean outfalls.

Between 1997 and 2022, the population in the four coastal counties spanning southern California increased from 15.2 to 17.1 million people (California DOF 2007; 2025). The amount of urban land use also increased by 2.1 % according to the National Land Cover Data set (MRLC, 2024).

3.2. Inventory of monitoring effort

There were 919,858 samples collected for ocean monitoring in 2022 (Table 1). Of these, 58 % were collected as part of NPDES required monitoring (Table 1). NPDES monitoring required nearly four-fold more samples in receiving waters than in their effluent discharges (409,360vs 120,740, respectively).

The largest monitoring focus in the SCB was for beach bacteria, in which 278,538 samples per year were collected along swimming beaches to address public health associated with body contact recreation. The next largest type of monitoring was CTD and water column monitoring to track discharge plumes. The least monitoring effort was expended on intake screens, commensurate with a large reduction in the number of once-through cooling water intakes for power generating facilities.

The cumulative level of ocean monitoring effort increased between 1997 and 2022 (Fig. 2). The total number of ocean monitoring samples collected in 1997 was 27 % of the total number of samples collected in 2022 (244,917 vs 919,858, respectively). The largest increase in effort was for bacteria affiliated with beach water quality monitoring (191,467 samples per year difference). Ocean water quality and CTD monitoring also increased, with greater than 100,000 more samples per year between the two time periods. The smallest increases in monitoring effort were for intertidal habitats and fish and shellfish. The number of intertidal and fish/shellfish samples marginally increased (<10 %) while the number of samples for intake screen decreased between 1997 and 2022.

3.3. Estimates of monitoring costs

An estimated $138,917,000 annually was spent on ocean monitoring in the SCB (Table 2). The greatest expenditure (38 %) was for bacteria, with those costs paid by County Health Departments and NPDES permitted agencies. The second largest expenditure (24 %) was for water quality monitoring, largely focused on offshore physical water quality and associated issues such as ocean acidification, hypoxia, and fish larval communities. Universities and, to a lesser extent, NPDES permittees paid the costs for water quality monitoring. CTD water column monitoring was the third largest expenditure (12 %), investigating how physical and chemical water properties influence the distribution of marine life and how changes in water temperature and salinity are affected by climate change. This cost was borne by Universities, NPDES regulated agencies and federal agencies.

Cumulatively, all of the sectors spent substantially more in 2022 than 1997 (Fig. 3). In 1997, the total estimated cost of ocean monitoring per year was 45 % of the total cost in 2022, even after accounting for inflation. Local government had the largest relative increase in cost between 1997 and 2022 (189-fold). NPDES regulated agencies had the largest magnitude of cost increase ($30.4M). The cost of monitoring decreased at state and federal agencies between 1997 and 2022.

The NPDES sector spent 92 % more on receiving water monitoring than effluent monitoring in 2022 ($72.8M vs $5.8M, respectively). Large and Small POTWs spent more than any other NPDES segment and were similar in costs (~$25M) (Table 3), for effluent and receiving water monitoring combined. Each of the four Large POTWs averaged roughly $6.4M annually. The 19 Small POTWs in the SCB averaged closer to $1.4M per agency annually, consistent with the small POTWs having an order of magnitude smaller discharge on average than the large POTWs.

The increased costs between 1997 and 2022 can be attributed not just to more samples, but also to increased unit costs. Median laboratory costs increased roughly 25 % per parameter between 1997 and 2022. In contrast, median field collection costs increased over 600 % per field activity. Unlike laboratory analysis where there were few parameters that were not measured in both 2022 and 1997, there were a number of field collection activities that are new and some of these are quite costly including real-time current meter moorings, High-Frequency Radar networks, Autonomous Underwater Vehicles (AUVs), and satellite imagery.

4. Discussion

There were at least 64 long-term monitoring programs in the SCB collecting in excess of 919,800 samples per year at a cost of more than $138M annually. This large effort reflects the highly prized economic value of the SCB's oceans. The National Ocean Economic Program (Kildow et al., 2016) estimated that ocean related activities generated $31 billion in gross domestic product and supported more than 275,000 jobs across the four SCB coastal counties during 2007 (http://www.oceaneconomics.org/). So, while the ocean monitoring effort may appear large, the monitoring effort amounts to less than 0.5 % of the region's ocean generated economy based on tourism, fisheries, offshore oil and gas, and ports and cargo data, amongst others.

The largest change in monitoring over the last 25 years was an increase in beach water quality monitoring answering a key management question: "Is it safe to swim?" Beach recreation is a prized resource in the SCB where an estimated 129 million beach visits occur annually (Dwight et al., 2007). So, even small increases in health risk could result in 100, 000's of illnesses (Given et al., 2006). The increased monitoring effort resulted from public policy and state legislation (California Assembly Bill 411, Cal. Civ. Code § 3344., 1998) requiring routine monitoring at beaches with more than 50,000 annual visitors, which we found resulted in more than 2,000 monitoring sites sampled between daily and weekly. Large portions of this increased monitoring cost was initially paid by County Health Agencies (i.e., local government), the agencies responsible for posting warnings and closures of beaches for public health risk. Subsequently, NPDES-permitted agencies increased their beach monitoring efforts to enhance public health monitoring protection, especially when identified locations exceeding bacteria thresholds (Schiff et al., 2001). This combination of legislation and regulatory impetus now illustrates one of the great successes in SCB ocean management. Over 98 % of SCB beaches comply with bacteria thresholds during the summer months when the largest density of swimmers are present (Noble et al.,

Table 1
Number of ocean monitoring samples collected in the southern California Bight per year in 2022.

	Total Number of Samples										
	Bacteria	CTD	Effluent	Eutrophication	Fish and Shellfish	Intake Screen	Intertidal	Kelp Beds/ Rocky Subtidal	Sediments	Water Quality	Grand Total
Federal Government		24		2436			2130	99		2019	**6708**
Local Government	134,028										**134,028**
NPDES	144,510	71,513	120,740	25,644	13,817	93		5043	71,219	77,521	**530,100**
State Government					175						**175**
University		93,600		83,844				1761		69,642	**248,847**
Grand Total	**278,538**	**165,137**	**120,740**	**111,924**	**13,992**	**93**	**2130**	**6903**	**71,219**	**149,182**	**919,858**

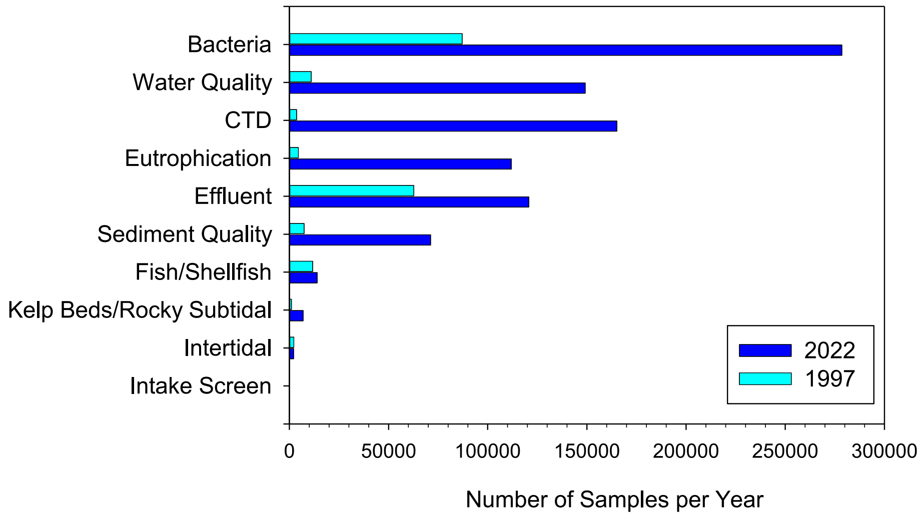

Fig. 2. Comparison of the number of monitoring samples per year in 1997 versus 2022 for different ocean monitoring foci in the Southern California Bight.

Table 2
Estimated costs for ocean monitoring in the southern California Bight per year in 2022.

	Cost (in US$ 1,000s)										
	Bacteria	CTD	Effluent	Eutrophication	Fish and Shellfish	Intake Screen	Intertidal	Kelp Beds/ Rocky Subtidal	Sediments	Water Quality	Grand Total
Federal Government		16		827			224	446		100	**1613**
Local Government	24,100										**24,100**
NPDES	29,042	7377	5835	8427	4244	372		1407	9624	6511	**72,839**
State Government					36						**36**
University		9880		1937				1786		26,726	**40,329**
Grand Total	**53,142**	**17,273**	**5835**	**11,190**	**4280**	**372**	**224**	**3638**	**9624**	**33,338**	**138,917**

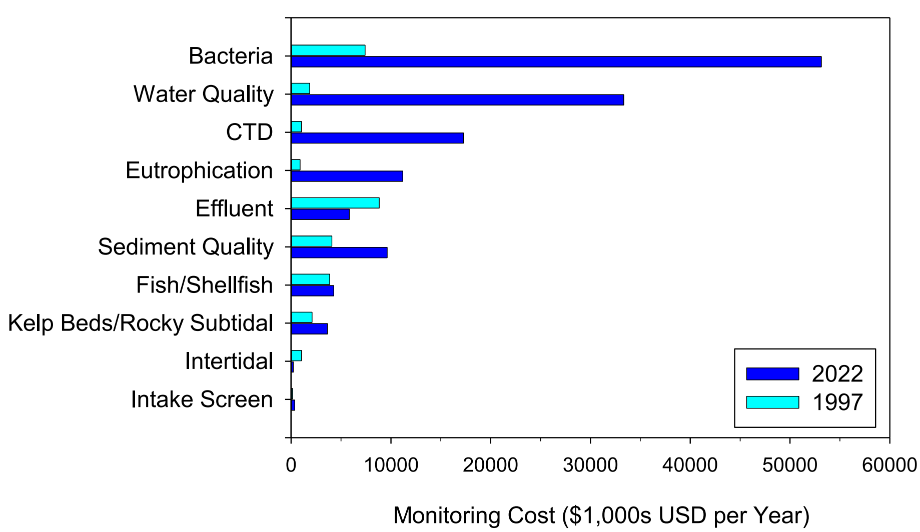

Fig. 3. Comparison of estimated monitoring costs per year ($1,000s) in 1997 versus 2022 across the different ocean monitoring sectors in the Southern California Bight. 1997 costs were inflation-adjusted to better compare with 2022 dollars.

2003).

A second example of where ocean policy and legislation increased monitoring effort is for water quality. The federal authorization of ocean observing systems in 2009 led to the creation of the Southern California Coastal Ocean Observing System and the Harmful Algal Bloom and Hypoxia Research and Control Act in 1998 helped enhance monitoring of harmful algae. These programs, run largely by university researchers, are tackling some of the most challenging issues facing environmental managers today; ocean acidification, hypoxia, and algal toxins. Recent monitoring indicates that ocean acidification is now impacting portions of the SCB (McLaughlin et al., 2018; Hauri et al., 2009) with aragonite saturation states at levels potentially leading to habitat compression in

Table 3
Comparison of number of agencies, samples per year, and cost of monitoring (in $US), amongst NPDES-regulated sectors in the southern California Bight in 1997 versus 2022.

	Number of Monitoring Agencies		Number of Samples		Cost ($1000)	
	1997	2022	1997	2022	1997[a]	2022
Power Gen Stations	15	8	9656	10,169	6431	2074
Industrial	9	2	9078	5794	1473	694
Large POTW	4	4	60,321	176,195	20,266	24,986
Platforms	19	2	8539	3774	551	366
Ports	–	3	–	6595	–	2144
Regional Monitoring	NA[b]	NA	222	10,542	–	5271
Small POTWs	15	19	43,787	246,428	13,683	25,852
Stormwater	4	4	8799	62,740	3081	10,373
Ship/Boatyards	16	4	10,023	7863	2160	1078
Non-NPDES	33	17	76,728	389,758	14,364	66,078
Total	**115**	**64**	**244,917**	**919,858**	**62,009**	**138,917**

[a] Indicates 1997 costs are inflation adjusted.
[b] Not applicable.

marine calcifies (Sato et al., 2017). Algal toxins have resulted in the beach strandings of hundreds of marine mammals (Smith et al., 2023). While management solutions are still elusive, this water quality monitoring is affording the opportunity for more rapid reaction time to help protect ecosystems and inform marine spatial planning efforts (Murray and Hee, 2019).

Policy and legislation also resulted in decreased monitoring effort between 1997 and 2022. For example, there were prohibitions of once-through cooling water to prevent entrainment of larval fish and invertebrate species, which ended ocean monitoring for many power generating stations (Ehrler et al., 2002; Barnthouse, 2013; SWRCB, 2023) in accordance with Clean Water Act §316a and b. Shipyards/boatyards had prohibitions of both wastewater and stormwater discharges, which had impacted water and sediment quality in harbors, thereby negating their requirements for ocean monitoring (SD RWQCB, 2019a,b). In both these cases, it was ocean monitoring that documented their ocean impacts (Schiff et al., 2007; Fairey et al., 1998) and helped justify the prohibitions. Economic factors also reduced the number of monitoring programs. For example, as economic drivers shifted, industrial facilities such as oil refineries or salt works moved their operations out of the SCB, taking their monitoring effort with them (Lyon and Stein, 2009). Monitoring by oil platforms was reduced due to a combination of platform decommissioning and combining platform discharges into fewer treatment facilities. Only a limited number of agencies have initiated new ocean monitoring programs in the last 25 years. One example is NPDES-required monitoring to track the possible impacts from coastal desalination facilities (Lykkbo et al., 2019, SD RWQCB, 2019a,b) who were conducting ocean monitoring in 2022, but were not present in 1997. A second example are the new investments in monitoring Marine Life Protected Areas to quantify the benefit of their limited fishing status.

Monitoring technology – and the associated effort and costs - has also changed between 1997 and 2022. For example, CTDs were present in 1997, but the level of CTD effort has dramatically increased over the last 25 years with more sites, improved sensor technology, and the addition of new sensors for synoptic measurements including transmissivity, colored dissolved organic matter (CDOM), and chlorophyll a. In addition, the technology for real-time oceanographic moorings has improved the robustness for measuring subsurface currents, all of which address an improved ability to track discharge plumes, a critical management decision making challenge.

Monitoring in the SCB appears well-linked to ocean management, particularly as nearly two-thirds of the monitoring is associated with NPDES-required ocean discharge permitting. However, there are exceptions. Beach water quality monitoring for public health is the largest investment, but other public health monitoring, such as "is it safe to eat fish?", are afforded considerably less effort and have grown at a much reduced rate between 1997 and 2022 despite the SCB having large areas with angler warnings for fish consumption (McLaughlin et al., 2021; OEHHA, 2025).

There were three limitations of this inventory project. The first limitation is the granular level of detail needed for deeper data analysis or implement monitoring program changes. One example is the need for improving monitoring efficiency (see Schiff et al. (2002b) as an example). A geospatial analysis of where monitoring occurs – including latitude and longitude of every monitoring location – was not compiled. However, managers are keen to see where overlapping efforts can be reduced and perhaps then redistributed to monitor spatial data gaps. A second example is optimizing sampling frequency. Some monitoring questions have been asked and answered many times. Especially for NPDES compliance, unchanging answers may be considered useful. In other cases, however, monitoring effort re-answering the same question with unchanging results may make less sense than asking and answering new questions. An example of where these challenges have been successfully addressed in the SCB; dozens of ocean monitoring programs – regulated, regulatory, academic and NGO – have initiated an integrated, coordinated region wide ocean monitoring program (Schiff et al. 2016a, b). This Southern California Bight Regional Marine Monitoring Program enables regulated monitoring programs to trade off portions of their ineffective or inefficient monitoring effort to help collect new monitoring information for under-sampled habitats, new ocean stressors, and new indicators of response.

The second limitation of this inventory project is the potential under- or over-estimation of costs. The project's philosophical approach to cost estimation was estimating what it might cost to hire an individual contractor to collect and/or analyze all of the samples in the inventory. We used median contractor cost estimates so, by definition, estimated costs could be more or less than actual costs. Cost overestimates could have occurred because some monitoring agencies have been sampling for 10 or more years and likely have found opportunities for cost savings by increasing efficiencies in field, lab, data management, or reporting. However, cost underestimates could have occurred because capital costs for equipment purchase and maintenance (i.e., monitoring vessels) were not included in this inventory, which would have underestimated true costs.

The third limitation of this project is the potential for cost-benefit analysis based on the cost estimates published herein versus the resulting data. Data compilation, analysis and interpretation of $\geq$10 years of monitoring from all 64 monitoring programs for all 919,858 samples was beyond the scope of this manuscript. However, once compiled, a cost-benefit analysis could be used to assess whether the monitoring expenditures inventoried in this study were well spent.

CRediT authorship contribution statement

Ken Schiff: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Liesl Tiefenthaler:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Joshua Westfall:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Michael Mori:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Kathleen Kelly:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Ryan Kempster:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Ami Latker:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Eugene Moon:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Neil Searing:** Writing – review & editing, Methodology, Data curation, Conceptualization.

Danny Tang: Writing – review & editing, Methodology, Data curation, Conceptualization. **Jarma Bennett:** Writing – review & editing, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kenneth Schiff reports a relationship with Southern California Coastal Water Research Project that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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