Rethinking Seafood Tissue Monitoring for Regional Risk Assessment

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Abstract—Seafood tissue monitoring in Santa Monica Bay, CA has historically been focused around the two large municipal discharges in the Bay: Hyperion (City of Los Angeles) and White's Point (County Sanitation Districts of Los Angeles). While these compliance monitoring programs did provide information about contaminant trends in the vicinity of the outfalls, they were not especially useful in health management for several reasons.

They did not always focus on species caught by sport fishing, the primary contaminant pathway to humans. Neither did they include areas where most sport fishing occurs. The two programs were not coordinated, using distinct sampling patterns to collect different species. Most importantly, the programs were not explicitly designed to feed information into any kind of formal health management process.

The Santa Monica Bay Restoration Project, a part of the U.S. EPA's National Estuary Program, oversaw development of a comprehensive and regionally coordinated environmental monitoring program. One organizing principle was that monitoring should produce information directly useful to California EPA's periodic health risk assessments of seafood consumption rather than routine compliance data for the Regional Water Quality Control Board. As a result, data from the monitoring program will be used to help set and/or modify seafood consumption advisories. This primary principle led to secondary principles, including, for example, that monitoring should focus on species important in the sport catch and areas where sport fishing occurs, even if these are not adjacent to the outfalls.

The revised monitoring program was designed specifically to support health management decision making. Its central feature is that sampling occurs much less frequently (as little as once every five years) for those species and sites where tissue contaminant levels are far from that at which a management action (setting or modifying a consumption advisory) would be taken. Sampling would occur more frequently as tissue levels neared such levels. Another important feature is that the results of California EPA's periodic health risk assessments are used to target monitoring at specific sites, fish species, and contaminants.

I. INTRODUCTION

The crucial role of monitoring data in providing input for and feedback about environmental management decisions has long been recognized [1-8]. However, recent shifts in the overall management context for environmental issues have created three particular kinds of challenges for monitoring programs. First, the use of more analytical approaches such as risk assessment and decision analysis often requires more precisely focused and structured monitoring data than more traditional narrative assessments. Second, the recently increased emphasis on regional and cumulative impacts [9-11, 5] demands a degree of standardization and coordination across separate programs that is not typical of established point source monitoring efforts. Finally, the changed political climate in the U.S. has greatly increased pressures to improve program cost effectiveness and performance. In this climate, there is little enthusiasm or support for new "layers of monitoring" to address regional concerns. Rather program managers and participants stress the importance of first attempting to take advantage of available resources by improving existing monitoring efforts.

This paper describes a successful effort by the Santa Monica Bay Restoration Project (SMBRP), an element of the U.S. EPA's National Estuary Program, to revise existing monitoring programs to meet the three challenges described above. It demonstrates how a detailed understanding of decision makers' information needs can provide a clear target for program redesign. It also illustrates the kinds of adjustments and tradeoffs that are often involved in regionalizing existing site-specific monitoring.

II. THE NEW MONITORING PROGRAM

Following a set of planning activities that defined underlying questions, established goals and objectives, and developed a framework for regional monitoring [13-16], the

SMBRP formed workgroups to develop the technical details of the highest priority components of the overall regional program. The seafood tissue monitoring workgroup included representatives from a range of organizations (Table I).

The workgroup carried out its work from June 1994 through June 1996 and operated under key groundrules that originated from discussion during the planning efforts referenced above. The new monitoring program would:

- address health risk on a Bay-wide basis, irrespective of where permitted activities occur
- replace, not simply add to, existing monitoring
- not necessarily be constrained by existing monitoring, although every effort would be made to continue adding to valuable long-term datasets
- not cost more than existing seafood tissue monitoring programs
- be focused on the needs of specific decision makers and reflect a consistent set of decision-making priorities
- be based on the best available scientific information
- be arrived at by consensus among the members of the workgroup.

TABLE I
PARTICIPANTS IN THE SANTA MONICA BAY RESTORATION PROJECT'S
TECHNICAL WORKGROUP ON SEAFOOD TISSUE MONITORING

Organization	Responsibility / Area of Expertise
SMBRP	Regional planning, coordination
Los Angeles Regional Water Quality Control Board	Regulatory compliance, permitting
California EPA: Office of Environmental Health Hazard Assessment (OEHHA)	Health risk assessment (chemicals), seafood consumption advisories
City of Los Angeles Hyperion Treatment Plant	Wastewater treatment, compliance monitoring
County Sanitation Districts of Los Angeles	Wastewater treatment, compliance monitoring
Southern California Coastal Water Research Project (SCCWRP)	Fish biology and ecology, sport fishing and consumption
Heal the Bay	Public interest advocacy
California Department of Health Services	Health risk assessment (biotoxins), seafood consumption advisories
EcoAnalysis, Inc.	Facilitation

A. Setting Objectives and Priorities

The previous planning activities had developed a consensus that the motivating question underlying seafood tissue monitoring was: "How safe is it to eat the locally caught seafood?" and that an appropriate objective outlining how this question should be addressed was:

Ensure that human health risks are reduced to acceptably low levels. Use risk assessment and other appropriate methods to define acceptable contaminant levels in seafood species. Monitor these periodically in both contaminated and relatively uncontaminated areas. Collect additional data on other contributors to health risk, such as human consumption of seafood and contaminant levels in the environment [14].

Monitoring is intended to contribute information to three distinct activities related to this objective:

- primarily, to furnish regulators and managers with an effective tool for implementing, reviewing, and updating seafood consumption advisories to protect public health
- secondly, to perform and update regional assessments of exposure and health risk and how these might be changing over time
- thirdly, to evaluate the effectiveness of Restoration Plan actions taken to reduce seafood contamination and/or attendant human health risks.

The workgroup agreed that the monitoring program would be designed principally to focus on the first of these purposes. This was an important decision, since the clear statement of purpose provided an unambiguous "litmus test" for evaluating the relevance of proposed monitoring approaches throughout the workgroup's effort.

Further prioritization was required, however, since different processes contribute to seafood contamination, with its resulting health risks to humans:

- biotoxins and microbial contaminants
- chemical contamination of shellfish (e.g., clams, mussels, urchins, crabs, lobsters)
- chemical contamination of finfish.

After building a conceptual model for each process and reviewing environmental and health monitoring data as well as available risk assessments, the workgroup decided to focus on chemical contamination of finfish.

Risks from biotoxins and microbial contaminants appear to be small. There have been no reported instances of domoic acid, paralytic shellfish, or diarrhetic shellfish poisoning from sport caught fish or invertebrates in southern California. In addition, toxin levels (as measured by the California Department of Health Services' statewide monitoring program) are only very rarely above alert levels established by the Department. Similarly, risks from chemical contamination of shellfish also appear to be small. There are only a few areas in Santa Monica Bay where shellfish can legally be harvested and consumption is correspondingly limited.

B. Monitoring in the Risk Assessment Framework

As described above, the principal goal of the seafood tissue monitoring program is to support the establishment and man-

agement of consumption advisories. The monitoring program must therefore be designed to produce information appropriate to the process by which advisories are developed. Both the U. S. EPA and California EPA's OEHHA have decided to use quantitative risk assessment as the basis for regulation and management [17]. This is because it is usually difficult if not impossible to directly monitor the actual incidence of illnesses (e.g.. cancers) that might result from consuming finfish contaminated with anthropogenic chemicals. Management actions such as therefore typically focus on reducing the estimated risk of illness on the assumption that this will ultimately result in lower numbers of actual illnesses. The following discussion illustrates how specific features of the risk assessment framework were used to structure key aspects of the monitoring design.

The risk assessment analysis at OEHHA results in ATCs (advisory tissue concentrations), which are the contaminant levels in seafood above which risk exceeds a pre-defined acceptable level (e.g., one in one million chance of excess cancer). The ATC for a particular contaminant is compared to actual levels monitored in seafood tissue as a basis for deciding whether a consumption advisory is warranted. Changes in tissue concentrations from place to place and from time to time would be one important basis for deciding to modify the advisories. (Another would be new information about the toxicity of specific chemical contaminants.) Therefore, the monitoring program should focus primarily on providing information on tissue concentrations where advisories are in place or might need to be updated.

In general, risk is a function of contaminant levels in seafood, how much seafood people consume, and their body weight. Risk increases as contaminant levels and consumption increase, and decreases with higher body weight. Past monitoring and research data [18] show that, at any one time, levels of chemical contaminants in seafood tissue can vary by two or three orders of magnitude among locations. In contrast, human consumption rates of seafood and human body weight vary by much less [19-20]. Variations in levels of contaminants in seafood tissue are therefore the largest contributor to differences in risk levels. This implies that measurement of tissue concentrations should be the central part of the monitoring design.

Management actions can. over the longer-term. reduce chemical contaminant levels in seafood tissue. However, past monitoring data show that the rate of decrease in average levels of key contaminants such as PCBs and DDT is slow [18. 21]. In addition, the calculated risks in the risk assessment in most cases represent lifetime rather than instantaneous probabilities of developing cancer and other illnesses. Such risk by definition reflects exposure over relatively long periods of time. Short-term changes in key parameters such as seafood contamination or human exposure will therefore not greatly affect overall levels of risk. Only very large changes

or changes that persist for several years are likely to affect these. Monitoring should therefore focus on detecting longer-term trends rather than shorter-term fluctuations in these parameters.

Consumption advisories issued by OEHHA are typically framed in terms of the maximum number of seafood meals of particular species from certain areas or locations that should be consumed in a given period of time (e.g. no more than two meals a month of species X from the Palos Verdes Shelf). These represent the amounts of consumption consistent with a predetermined level of acceptable risk (e.g., 1 in 1 million chance of excess cancers). Data from seafood consumption studies enter into such an analysis only by focusing the risk assessment on the most commonly caught and consumed species. Therefore, seafood consumption monitoring need not strive for quantitative estimates of the actual amounts of seafood eaten by different segments of the population. (However. such information is useful in targeting risk communication.)

C. Guiding Principles for Monitoring Redesign

Based on these considerations, and on the seven basic groundrules described above, the workgroup articulated a set of guiding principles (Table II) for the monitoring design. These reflect the program's emphasis on providing information to set and update consumption advisories. However, they also recognize that the design must maximize the information gained from monitoring by carefully and efficiently using available monitoring resources. This of necessity involves making some tradeoffs since it is not possible to measure every contaminant in every fish species at all sites throughout the Bay on a yearly basis. The principles thus reflect a fundamental decision to allocate monitoring effort where it will have the highest information return for decision making.

TABLE II
GUIDING PRINCIPLES FOR THE MONITORING DESIGN

Management Needs	Monitoring Design Principles
Primary: Manage consumption advisories	• sample most frequently where tissue concentrations approach ATCs • establish broad sampling zones rather than specific sites • focus on target species identified by advisories • focus on chemicals that contribute most to risk • focus on longer-term trends • build flexibility into the monitoring design
Secondary: Assess relative regional health risk	• periodically sample a wider range of sites and species • obtain additional needed information from other components of the regional program • focus on longer-term trends
Tertiary: Evaluate restoration actions	• track long-term trends in inputs, environmental contamination. and tissue concentrations

D. Revised Monitoring Design

In applying these principles, the workgroup developed a design that differed in four important ways from the programs it replaced:

- sampling frequencies are not fixed but change with the level of contamination
- sampling occurs in broad zones rather than at specific fixed sites
- target species are those caught by sport fishermen
- only those chemicals known to contribute to health risk are measured.

These four features are discussed in greater detail in the following paragraphs.

D.1 Sampling Frequencies

The existing seafood tissue compliance monitoring programs in the Bay specified that sampling occur at fixed time intervals. While this is typical of long-term monitoring programs, it is not efficient in this case since management decisions to set or modify consumption advisories will be made only when tissue contaminant levels cross or approach the ATC. Fewer data points are needed to reliably distinguish between relatively high and relatively low values (i.e., the ATC and a value far above it) while more data points are needed to distinguish between more similar values (i.e., the ATC and a value near it). In addition, more data points are required to track a rapidly changing trend relative to the ATC than a more slowly changing one. The sampling design therefore prescribes only infrequent sampling where tissue concentrations are far above the ATC and/or appear to be declining very slowly (Fig. 1). At the other extreme, instances where tissue concentrations are close to the ATC and/or appear to be declining rapidly should be sampled most frequently. Over the long term, the trend lines of tissue contaminant levels can also be projected into the future to predict when levels will approach ATCs. This information can then be used to adjust sampling frequencies to improve overall efficiency. Instances where tissue concentrations are far below the ATC need be sampled only infrequently (once every five years or more). Because of their foraging habits, fish species in the Bay in this category (mostly pelagic species) are unlikely to approach the levels that would require consumption advisories [20-21].

D.2 Sampling Zones

Past consumption advisories established by OEHHA [20] have targeted particular species at very specific locations such as individual piers and jetties. These advisories were based on risk assessment calculations that estimated excess lifetime cancer risk. While this reflected a study design for the risk assessment that sampled a range of such specific locations throughout Santa Monica Bay, it was not realistic, given that

sport fishermen do not spend their entire lives fishing at a single location. Instead many sport fishermen often move to a series of locations throughout the Bay over a period of weeks and months, sometimes fishing from one pier or another and at other times from private or charter boats. Because they were based on lifetime cancer risk at each specific location, these advisories do not provide useful guidance to fishermen who, by moving their fishing sites, are in fact integrating risk levels over multiple locations.
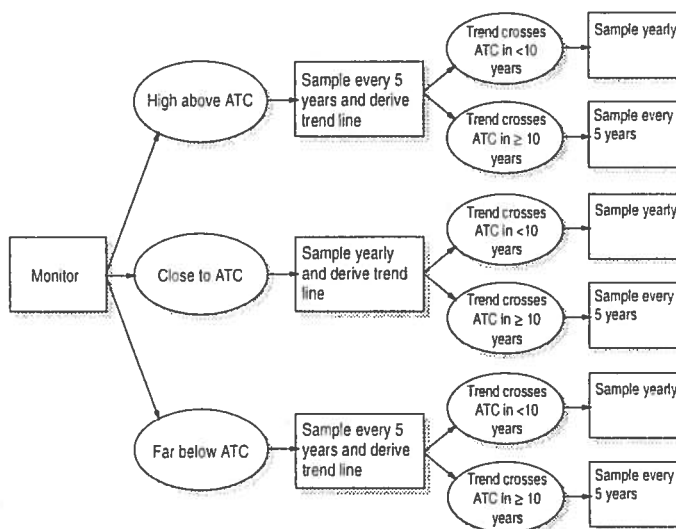

Fig. 1. Scheme for adjusting sampling frequencies to relative contaminant levels. Actions are shown as rectangles; information resulting from these actions as ovals. Over the long term, this will furnish information needed to derive trend lines needed to track tissue contaminant levels.

In addition, existing seafood tissue compliance monitoring programs in the Bay focused on fixed sites near the two major municipal wastewater outfalls. While this tracks contaminant levels around these outfalls, it has not provided useful information for risk assessment, since sport fishing does not occur exclusively around outfalls. In fact, sport fishermen often avoid fishing around the County Sanitation Districts' outfall at White Point because of the well-known DDT contamination in the vicinity.

The workgroup therefore defined a number of sampling zones (Fig. 2) that encompass larger subsets of Santa Monica Bay, that include popular sport fishing areas, and that the workgroup assumed were relatively homogeneous in terms of long-term risk levels. These were based on knowledge of:

- submarine topography and its effect on fish distribution and movement
- benthic contaminant levels
- results of OEHHA's 1991 risk assessment [20]
- patterns of contaminant levels in commonly caught sport fish and
- popular fishing locations

gained from compliance monitoring programs, research studies, and environmental impact and assessment studies. Sampling locations within zones (Table III) differ depending on where particular target species are most likely to be found.

As a result of the shift to sampling zones, OEHHA will be able to frame future consumption advisories more usefully in terms of broad regions of the Bay.

D.3 Target Species

The effort required to monitor all possible species-site combinations would far exceeded available resources. The workgroup therefore identified a set of target species (Table III). This is a common practice in such monitoring and management programs [22], based on the assumption that these represent a wider group of species because of similarities in their morphology, physiology, feeding behavior, and habitat requirements or preferences. In selecting the target species for Santa Monica Bay, the workgroup evaluated data from compliance monitoring programs, research studies, environmental impact and assessment studies, and past risk assessments to identify which species:

TABLE III

TARGET SPECIES FOR EACH OF THE SAMPLING ZONES ILLUSTRATED IN FIG. 1. "KELPBASS" REFERS TO *PARALABRAX CLATHRATUS*. "SANDBASS" TO *PARALABRAX NEBULIFER* OR *MACULATOFASIATUS*, AND "CROAKERS" TO *GENYONEMUS LINEATUS*. SEE TEXT FOR DISCUSSION OF THE "ROCKFISH" AND "SURFPERCHES" SPECIES GROUPS.

| Zone	Rockfish	Kelpbass	Sandbass	Surfperches	Croakers
H	n/a	n/a	n/a	Cabrillo Pier	Cabrillo Pier
1	n/a	along coast	in nearshore	along coast	on the shelf
2	n/a	along coast	in nearshore	along coast	on the shelf
3	edge of canyon	along coast	in nearshore	along coast	on the shelf
4	Short Bank	n/a	near Redondo Pier	Redondo Pier	Redondo Pier
5	Malibu kelpbeds	Malibu kelpbeds	near Marina del Rey	Marina del Rey	Marina del Rey
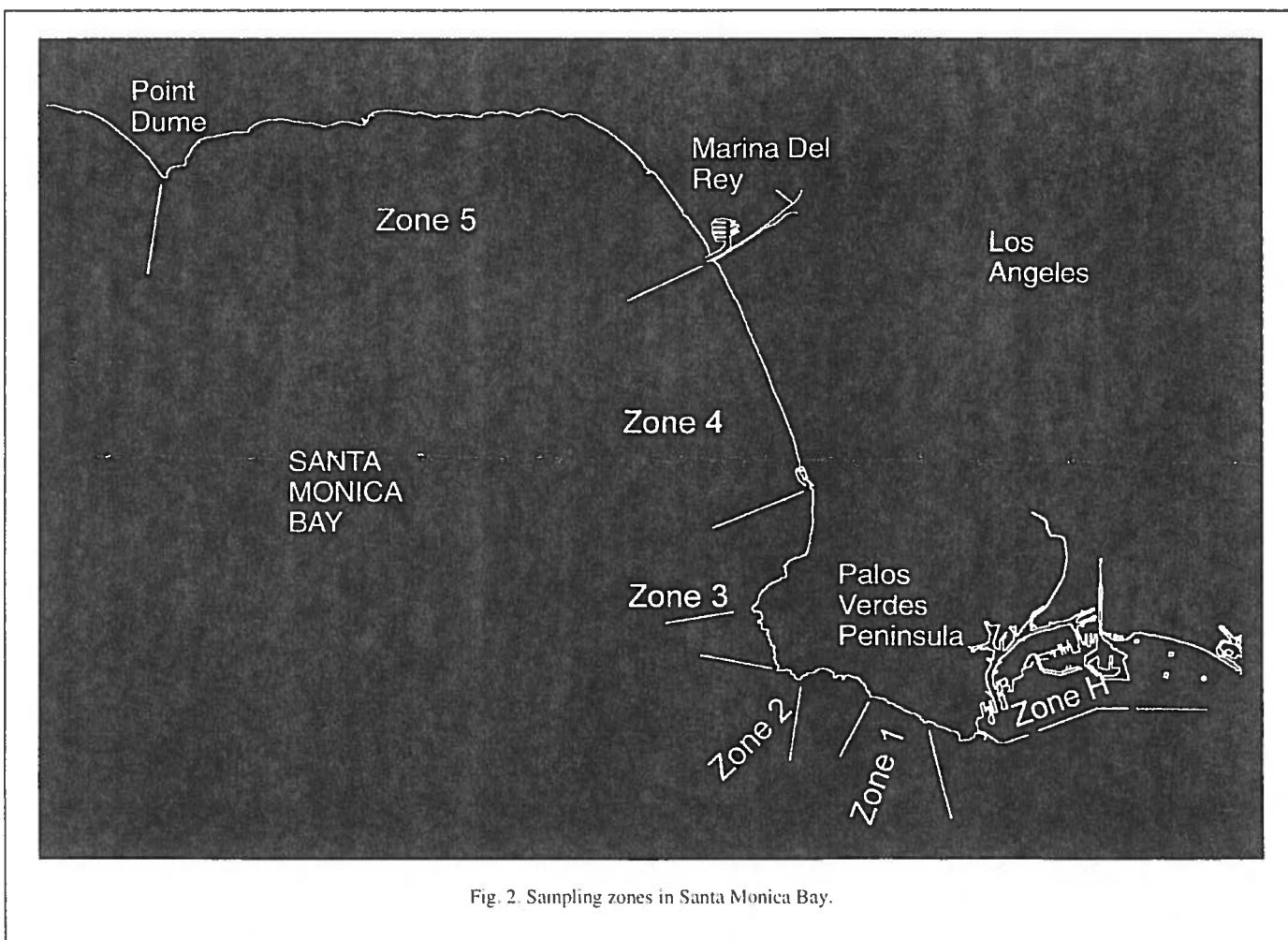
Fig. 2. Sampling zones in Santa Monica Bay.

- are typically present in the region and thus available to be sampled, especially over the long term
- have exhibited elevated levels of contamination in the past
- are preferred by sport fishermen.

"Rockfishes" and "surfperches" refer to groups of species, not all of which are always present at the same time and place. The workgroup therefore established a set of preferences to guide sampling. These were based on abundance and consistency of occurrence, feeding type, contaminant levels, and presence in the sport catch. For rockfishes, scorpionfish (*Scorpaena guttata*) is the preferred species, followed by bocaccio (*Sebastes paucispinis*), and then by any other abundant and preferably benthic rockfish species. For surfperches, black surfperch (*Embiotoca jacksoni*) is the preferred species, followed by white surfperch (*Phanerodon furcatus*), and then by walleye surfperch (*Hyperprosopon argenteum*).

Ten individuals of each target species will be collected at each location and combined to form one composite sample. Since the key management question is whether or not the trend line over time has crossed the advisory tissue concentration (ATC) (see Fig. 1), there is no need to obtain measurements for individual fish at each sampling time. The replicate variability at each time is contained in the average composite value and the variability of the trend line can be derived from the variability of the series of average composite values over time. This is another example of how an explicit understanding of how monitoring data will be used in decision making can improve the program's cost effectiveness.

D.4 Contaminants

Existing seafood tissue compliance monitoring programs monitor a suite of contaminants that reflect not only known risks to human health but also the character of municipal wastewater effluent. For example, heavy metals have typically been monitored even though there is little evidence that they pose any substantial risk to human health [20]. The workgroup therefore decided that monitoring in this particular program should focus only on those chemicals in finfish muscle tissue that contribute the most to health risk.

The 1991 OEHHA risk assessment [20] determined that DDTs and PCBs, because of their potency and their concentration in finfish in the Bay, outweighed risk due to other chemical contaminants. In addition, there is increased concern about potential health risks from mercury. The seafood tissue monitoring program will therefore focus initially on these three classes of contaminants. Additional contaminants may be added if and when evidence warrants.

D.5 Additional Information and Periodic Review

The core monitoring program defined above will furnish the information needed to manage consumption advisories on an ongoing basis. However, additional kinds of information

will be needed to keep the risk assessments up to date. In particular, these include:

- chemical-specific toxicity information, needed to update the list of contaminants being monitored
- sport fishing patterns, needed to update sampling locations
- seafood consumption patterns, needed to update the list of target species
- more intensive sampling of a wider range of sites and species, needed to reevaluate the sampling zones and the list of target species.

Other aspects of the monitoring program thus include ongoing evaluation of chemical toxicity information by OEHHA staff and more thorough studies of sport fishing, seafood consumption, and finfish contamination patterns every ten years.

In addition, the workgroup will reconvene every year to evaluate the monitoring program in the light of these and other available data and to make any adjustments in focus and/or methodology that may be required to continue meeting the overall objective of the program: to furnish regulators and managers with an effective tool for implementing, reviewing, and updating seafood consumption advisories to protect public health.

III. DISCUSSION

The revised monitoring program that developed from the workgroup's efforts departs in significant ways from past seafood tissue compliance monitoring programs. In particular, it:
- is targeted at specific decision makers' needs
- is designed to produce information for a well-defined decision-making process (i.e., risk assessment)
- takes account, through the use of broad sampling zones, of how scientific information will eventually be communicated to the public
- uses flexible sampling frequencies to increase efficiency.

As a result of these changes, the revised program will produce information that is readily usable by decision makers.

While these and other adjustments seem obvious in hindsight, in fact it is typically difficult to achieve such fundamental changes in well-established compliance programs. In this case, there was a set of enabling factors that contributed to the workgroup's ability to identify and implement such changes. These included:
- consistent, long-term support from the Santa Monica Bay Restoration Project, which recognized that negotiating fundamental program changes takes time
- the active participation of OEHHA, the end user of the monitoring data.
- pre-existing, long-term relationships among the principal stakeholders, which contributed to a collaborative atmosphere

- the willingness of the Regional Water Quality Control Board, the lead permitting agency, to play a facilitative role that allowed for collaborative decision making
- a recognition on the part of all participants that existing monitoring was not as effective as it could be
- the availability of adequate scientific information.

The absence of any of these factors would have prevented the redesign effort from succeeding. As a result, we emphasize the importance of accounting for such institutional and personal factors when attempting to foster change in existing compliance programs.

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