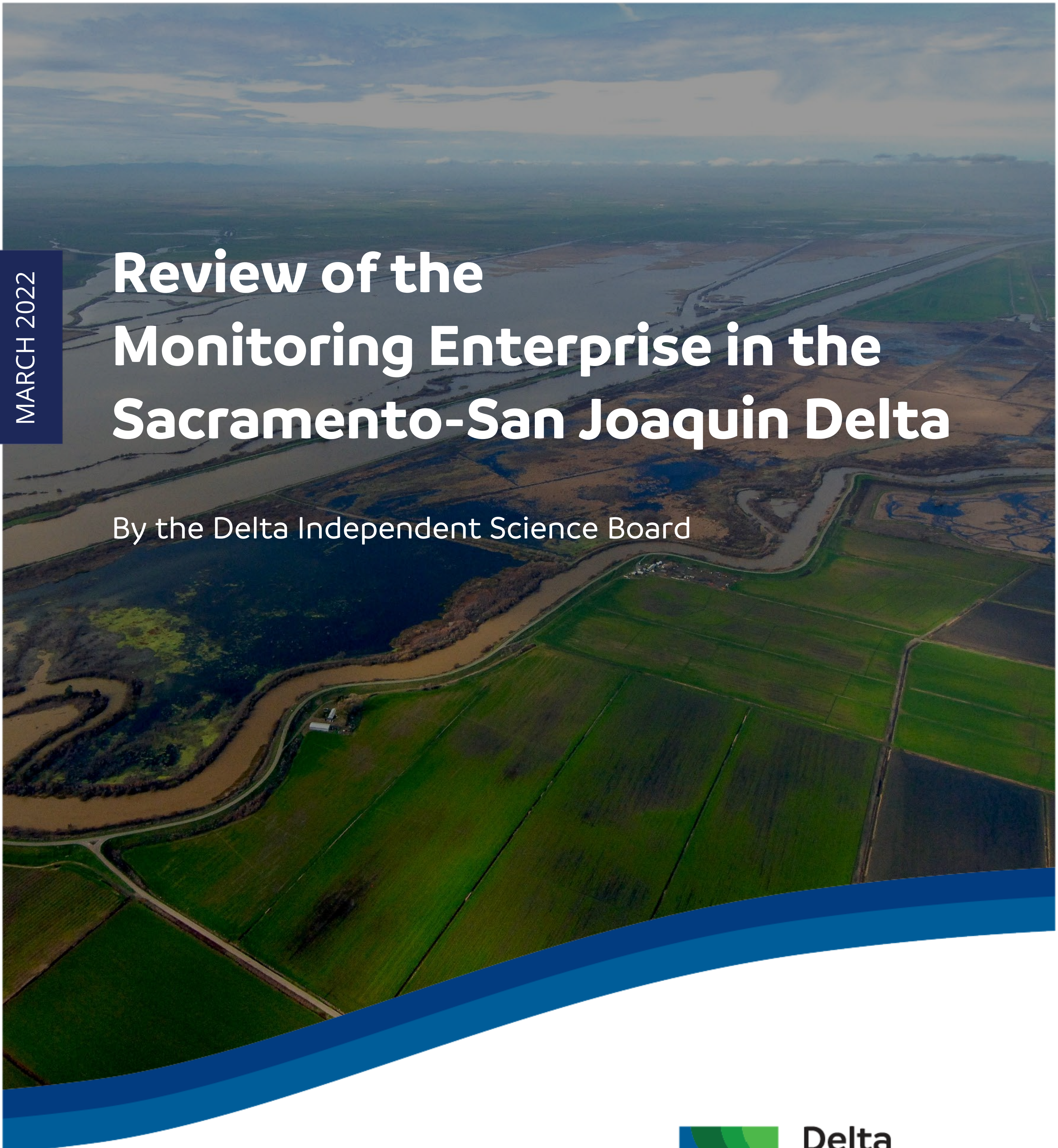
MARCH 2022

Review of the Monitoring Enterprise in the Sacramento-San Joaquin Delta

By the Delta Independent Science Board



Delta Independent Science Board

DELTA STEWARDSHIP COUNCIL

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Created by the Delta Reform Act of 2009 and appointed by the Delta Stewardship Council, the Delta Independent Science Board is a standing board of nationally and internationally prominent scientists that provide oversight of the scientific research, monitoring, and assessment programs that support adaptive management of the Sacramento-San Joaquin Delta through periodic reviews.

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Executive Summary

Monitoring is vital to understanding ecosystem status, functioning, and responses to management actions and changes in environmental drivers. For the Sacramento-San Joaquin Delta and Suisun Marsh (the Delta), monitoring has been imperative for decision-making on water operations, water conveyance, water quality and human health, flood protection, environmental restoration, species protection, regulatory compliance, and habitat alterations. Monitoring is a key step in adaptive management, which is required by the Delta Plan for water management and ecosystem restoration projects in the Delta and is part of the Delta Plan's adaptive management cycle (Delta Stewardship Council 2013). Given the importance of monitoring to achieving the coequal goals of the Delta Plan, the Delta Independent Science Board (Delta ISB) undertook an analysis of the monitoring enterprise, covering a suite of monitoring activities and programs in the Delta. The goals of this review were to assess how well the information collected from monitoring is meeting the needs of management agencies, if coordination and information flow could be improved, and how monitoring data can better support the implementation of adaptive management. The Delta ISB also assessed potential gaps, opportunities to increase efficiencies, data quality and accessibility, and resources being dedicated to monitoring. This review helps implement Delta Science Plan Action 3.3 ("*Routinely evaluate monitoring programs in the Delta to identify gaps, redundancies and management relevance*;" see Delta Stewardship Council - Delta Science Program 2019) and is part of the Delta ISB's legislative mandate in the 2009 Delta Reform Act (California Water Code Section 85280).

Given the complexities and breadth of the monitoring enterprise in the Delta, a logical first step was to conduct a new comprehensive inventory of monitoring. Although existing inventories are highly useful (e.g., Bay-Delta Live and the California Data Exchange Center), they were not sufficiently comprehensive to assess the monitoring enterprise, as they did not span the full suite of physical, chemical, biological, and social science drivers in the Delta required to assess the region's diverse environmental monitoring enterprise. As a result, this review was divided into two components. Component 1 was the development of a comprehensive inventory of monitoring activities in the Delta and three reports summarizing that effort. Component 2 was the Delta ISB's evaluation of monitoring and suggestions for improvements.

The reports from both components constitute the full Monitoring Enterprise Review. Component 1 includes the inventory and the three Component 1 reports, which were prepared by ESSA Technologies Ltd, CBEC eco engineering, and PAX Environmental Inc. in collaboration with and under the direction of the Delta ISB:

1. A lessons and methodology report (Nelitz et al. 2019), which consists of a literature review of lessons learned within the Delta along with five other systems (Chesapeake Bay, Great Lakes, Puget Sound, and Coastal Louisiana in the United States, and Queensland, Australia) for enabling effective monitoring and adaptive management;
2. A summary report of the monitoring activities from the full inventory (Nelitz et al. 2020a); and
3. A comprehensive synthesis report of the inventory results (Nelitz et al. 2020b), which assesses the relevance of monitoring activities in serving the needs of decision makers and supporting adaptive management and identifies opportunities to improve monitoring based on the initial analysis of the inventory.

This current report, developed by the Delta ISB, represents the output of Component 2, which incorporates an analysis of findings from Component 1 and results from additional engagement of scientists and managers within and external to the Delta. Those efforts included a questionnaire survey of members of the Delta science and management community, interviews with representatives of organizations involved with monitoring in the Delta, a series of scientific panels and seminars, a workshop, comprehensive literature reviews, and the professional experiences of Delta ISB members with monitoring in the Delta and elsewhere.

A key finding of the review was that although most monitoring activities in the inventory (97 out of 157 monitoring activities, 62%) are influenced or required by a management driver (laws, regulations, permits or licenses such as a biological opinion or an incidental take permit), there was a general lack of clarity around the problems that monitoring and adaptive management are intended to address. Overall, the desired outcome for the Delta is based on achieving the coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem, which needs to be achieved in a manner that protects and enhances the Delta as an evolving place (CA Water Code Section 85054). Although the Delta Plan provides useful guidance on decision-making needs, there is not a consolidated description of the management context, decision-making needs, or specific questions for adaptive management in the Delta (e.g., Wiens et al. 2017; Nelitz et al. 2019) sufficient to fully evaluate monitoring gaps.

The needs for adaptive management span concerns of water supply, water quality, flood protection, species, habitat, and land use to achieve the coequal goals. The questionnaire and workshop further confirmed that there was a common perception of a monitoring-management disconnect. The disconnect between monitoring needs and data collection is not unique to the Delta and could be improved through better planning, coordination, and communication.

To help improve coordination and adaptive management and to inform monitoring that better meets the needs of management, we provide and advise that an Adaptive Management Framework be used for structuring all monitoring programs and further provide best practices that we recommend be formally adopted into **individual** monitoring programs (Figure ES-1). We conclude with three overarching recommendations ("big moves") that are directed at the monitoring enterprise as a whole, and take into consideration recognized barriers and opportunities.

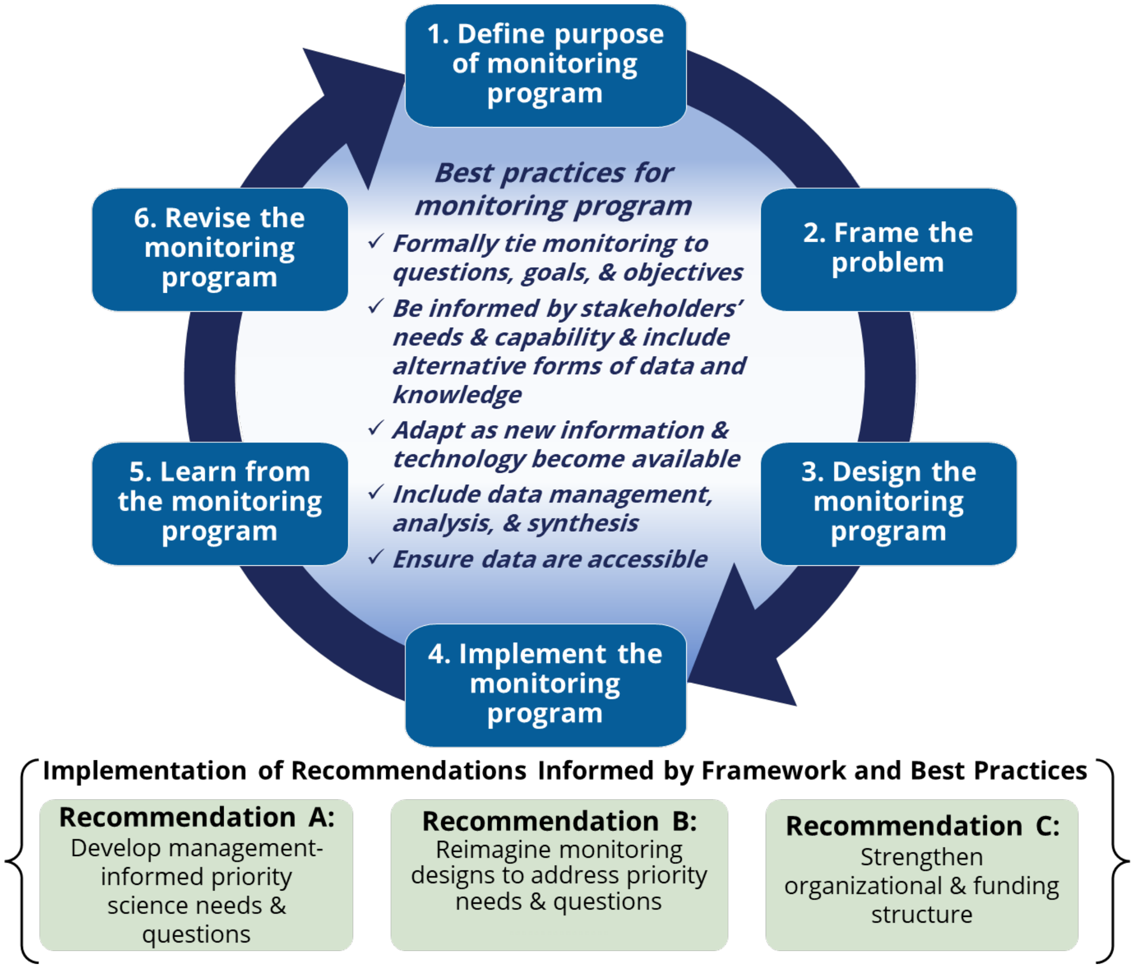


Figure ES-1. Adaptive management monitoring framework, best practices, and key recommendations.

Adaptive Management Framework for Monitoring

Overall, the Delta ISB advises that every monitoring program develop a monitoring plan or road map using the Adaptive Management Framework (Figure ES-1) for a well-designed monitoring program to promote the collection of data and information that effectively addresses management concerns. This framework involves six steps: (1) establishing the purpose of the monitoring program; and then developing (2) a problem statement, (3) monitoring design, and (4) program implementation; and finally articulating (5) how the information collected will be used and assessed to facilitate learning, and (6) how the monitoring program will be revised, if necessary, and improved for existing or new monitoring purposes.

Adaptive management is a structured, iterative application of science-based knowledge to reduce uncertainty and build flexibility into decision-making (Wiens et al. 2017). It is required by the Delta Plan for ongoing ecosystem restoration and water management projects. Adopting an Adaptive Management Framework for monitoring (i.e., Figure ES-1) will provide a more rigorous setting of purpose, expectations, and review, as well as fostering communication at all levels. We contend that this approach will provide a vehicle to address many of the questions raised in this review.

Monitoring plans should be written as publicly assessable planning documents at the beginning of any monitoring program and include times for public and stakeholder comment and input. Most noteworthy is the value of adopting a plan that is flexible and can be changed by design if objectives are not being met or as conditions, policies, and technologies change.

Best Practices for Individual Monitoring Programs

The Delta ISB identified five best practices that should be formally adopted into individual monitoring programs to help address challenges and issues with monitoring identified in the review:

1. Monitoring should be tied to the goals, objectives, and specific questions of interest to managers, decision makers, scientists, and stakeholders.
2. Monitoring should also be informed by stakeholder engagement and participation, and, when appropriate, include alternative forms of data and knowledge such as Traditional Knowledge, experiential information, and qualitative observations.

3. Monitoring plans should have enough flexibility to take advantage of new information and opportunities to adapt to issues, to scientific opportunities such as unusually low or high flows, and as new techniques and technologies become available.
4. Monitoring programs must include adequate data management, quality control, analysis, and synthesis, and should strive to improve statistical validity.
5. Monitoring programs should ensure the data produced are accessible and shared with the public and other agencies.

Recommendations for the Monitoring Enterprise

Adoption of an Adaptive Management Framework for monitoring by individual monitoring programs and the use of best practices would address: disconnects between monitoring and management, communication of results, and data quality and accessibility. However, more transformative changes are needed to fully address the findings of this review. Therefore, **the Delta ISB recommends three “big moves” to better link monitoring to management** and to begin addressing gaps and opportunities to improve efficiencies identified in this report. These recommendations are:

> **Recommendation A:** Develop priority management-informed science needs and questions for the monitoring enterprise and synthesize information around these questions in biennial reports or at a policy-science summit. It is important to identify which organizations and stakeholders should be involved in developing the needs and questions.
>
> **Recommendation B:** Reimagine monitoring designs that are guided by priority questions and needs (identified in recommendation A) and system-wide conceptual or numerical models for relevant Delta processes. Monitoring designs should be reimagined to be more systematic and integrated. This could entail discussing what existing monitoring activities could address the priority questions or re-designing existing monitoring designs to ensure they can address priority questions. As some monitoring activities are considered “compliance” monitoring, there is a need to explore the level of flexibility available to make changes in monitoring designs.
>
> **Recommendation C:** Strengthen the organizational and funding structures to support monitoring integration, analysis, and adaptive management. Implementing recommendations A and B will help address this

recommendation. However, a more formal organizational structure with proper funding is needed to improve integration and coordination of monitoring, to develop more science-based insights from monitoring data, and to enhance communication. A new authority or council with proper funding and resources could be established, or an existing entity could take on these responsibilities, such as the Delta Science Program or the California Water Quality Monitoring Council. In addition, a more formal organizational structure should facilitate routine monitoring evaluation to identify gaps, redundancies, and management relevance. This evaluation should include independent peer review at least once every four years.

The implementation of the three interlinked recommendations should be guided by the six-step Adaptive Management Framework for monitoring developed for this review (Figure 12), which could ultimately lead to a comprehensive monitoring plan for the overall monitoring enterprise. These recommended changes will be difficult to implement, but the complexity, urgency, rapidity of change, and long-standing nature of many challenges facing the Delta dictate the need to do things differently. As no single agency could implement all the recommendations alone, the decision on how to proceed with recommendations lies with the enterprise as a whole. To move forward, the Delta ISB suggests the Delta Stewardship Council via the Delta Plan Interagency Implementation Committee (DPIIC) and Delta Science Program form a workgroup to facilitate monitoring program coordination and integration, as described in Delta Science Plan Action 3.4 (Delta Stewardship Council - Delta Science Program 2019), to discuss the findings and recommendations of this review and how to move these recommendations forward.

The inventory of monitoring activities developed for this review will be useful for implementing these “big move” recommendations by providing information on what is being done in the Delta and helping with integration and coordination of monitoring. The data and information from the inventory will be incorporated and made public with the launch of the Delta Science Tracker in 2022, which will provide a comprehensive tool to track, visualize, and summarize science activities in the Delta region.

Definitions

Mon·i·tor: To watch and check a situation carefully for a period of time to discover something about it.[a] The systematic process of collecting, analyzing, and using information to track a program's progress toward reaching its objectives and to guide management decisions.[b]

Stake·hold·er: Any person or group who is involved in, has responsibilities toward the success of or is affected by a course of action (from Dale et al. 2019)

A·dapt·ive Man·age·ment: A structured, iterative application of science-based knowledge to reduce uncertainty and build flexibility into decision-making (from Wiens et al. 2017)

[a] Taken from the Cambridge Dictionary.

[b] Taken from UN Women.

1. Introduction

1.1. Delta ISB Mandate and Scope of this Review

The Delta ISB reviews the adequacy of the science in support of adaptive management for the Delta (Figure 1). The Delta Reform Act of 2009 states that "*The Delta Independent Science Board shall provide oversight of the scientific research,* ***monitoring****, and assessment programs that support adaptive management of the Delta through periodic reviews of each of those programs*…." (California Water Code Section 85280; boldface added for emphasis). Thus, a review of monitoring in the Delta is a fundamental charge to the Delta ISB. The act also requires the Delta ISB to submit to the Delta Stewardship Council *"a report of the results of each review, including recommendations for any changes in the programs reviewed by the board."* The Delta ISB accomplishes its mission through a variety of means and has produced over 50 products during the last decade (Hastings et al. 2022). Most notably, comprehensive reviews are approached thematically with previous topics on habitat restoration, water quality, fish and flows, Delta as place, levees, adaptive management, non-native species, and the Interagency Ecological Program (IEP).

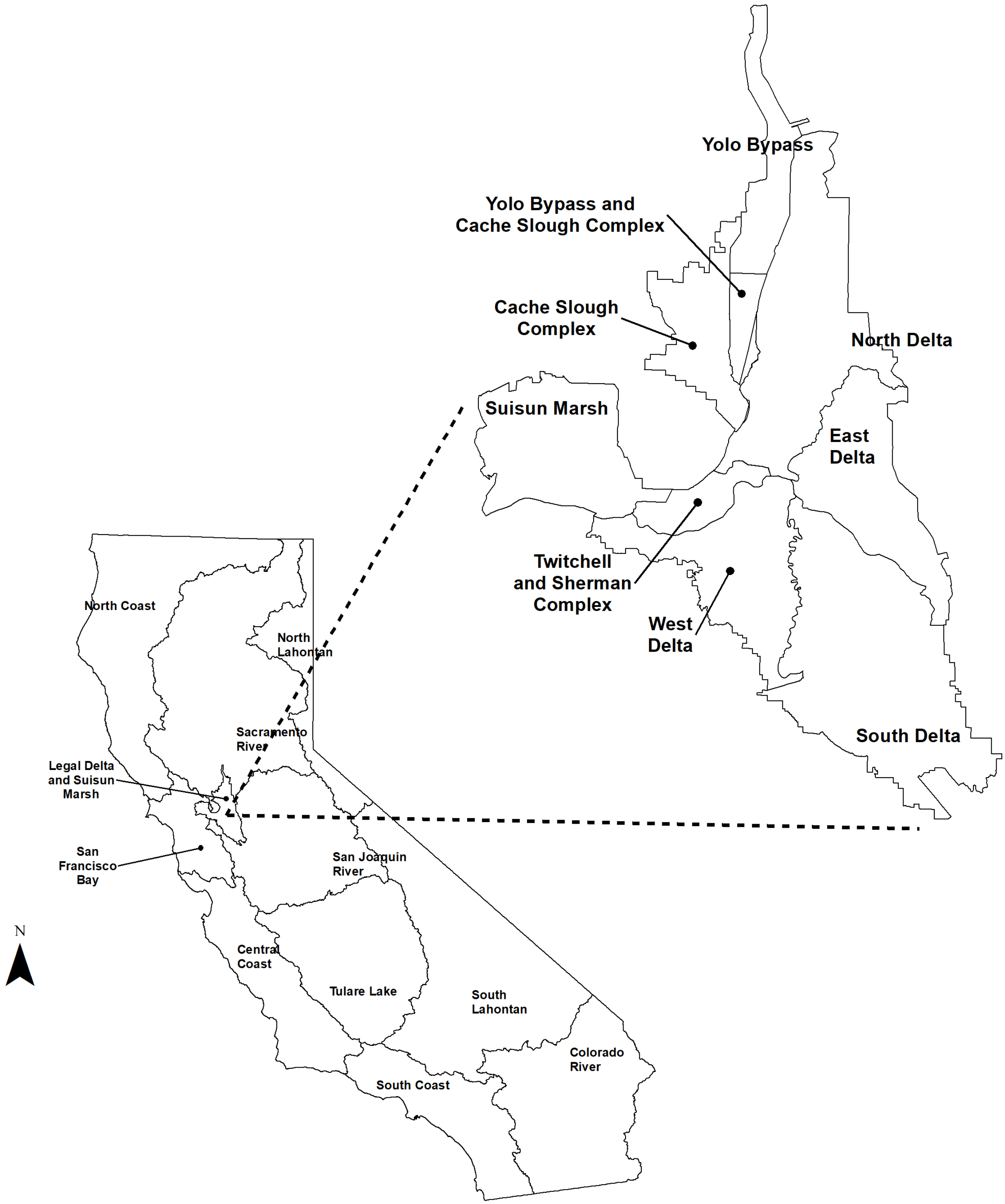


Figure 1. Geographic overview of the Delta regions, along with the California Basins.

Monitoring is central to all topics considered in the previous and current Delta ISB reviews and is a key component of the Delta Plan's adaptive management process (Delta ISB 2016; Wiens et al. 2017; see Figure 2). The Delta Plan requires the use of adaptive management for all major ecosystem and water projects in the Sacramento-San Joaquin Delta and Suisun Marsh (the Delta; see Figure 1; Delta Stewardship Council 2013). Adaptive management is a structured, iterative application of science-based knowledge to reduce uncertainty and build flexibility into decision-making (Wiens et al. 2017). Adaptive management is an opportunity to learn from taking an action (Delta ISB 2016), and monitoring is essential to assess the effects of management actions and triggers for management reassessment. The need to assess long-term monitoring programs in the Delta to ensure they are responsive to management has been identified through various venues and in initiatives endorsed by the DPIIC (see Delta Stewardship Council and United States Geological Survey 2018, Delta Stewardship Council 2019). Moreover, monitoring serves other purposes, including taking the pulse of the Delta by assessing status and trends, understanding baseline conditions and relationships, evaluating responses to environmental drivers, answering scientific questions, and identifying emerging issues.

Consequently, the Delta ISB undertook a review of the monitoring enterprise, which covers the suite of monitoring activities or programs that collect data on the physical, biological, and chemical components of the Delta. The review also included the direct social drivers of ecosystem function and processes (e.g., fishing activities), but did not include demographic or macro-level social drivers (e.g., population size and economics) at this time.

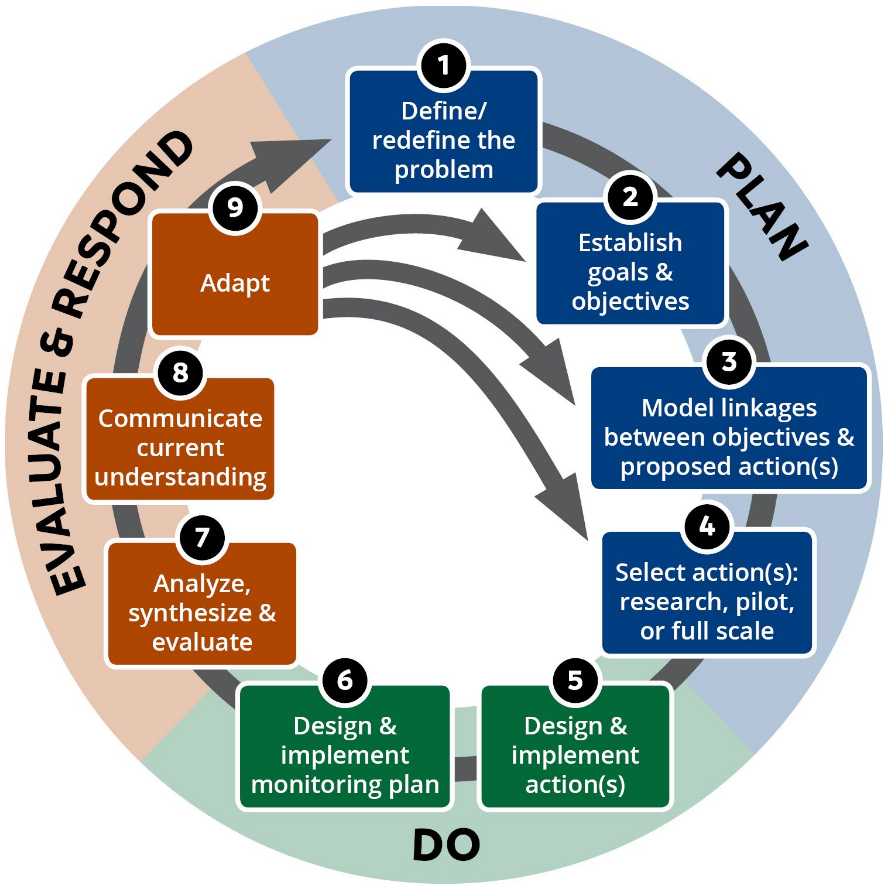


Figure 2. The nine-step Adaptive Management Framework. Taken from the Delta Plan (Delta Stewardship Council 2013) and Wiens et al. (2017), modified for accessibility.

This is the largest review yet undertaken by the Delta ISB. We examined the broad array, networking, and coordination of monitoring programs for the Delta and assessed whether they provide adequate information to rigorously respond to the Delta's many changing challenges and problems. We also examined how monitoring data are used by managers and agencies to provide accurate and current information to policy makers. The overall objectives of the Monitoring Enterprise Review are to summarize and assess the state of monitoring in the Delta and to offer recommendations to improve how (1) current and future monitoring programs serve both the present and expected informational needs of management and policy; (2) individual and larger-scale monitoring programs can be improved through better coordination; and (3) monitoring data can better support implementation of adaptive management and assessments of performance measures that span the biological, geological, physical, chemical, and social aspects of the Delta.

The intended audience for this review spans the DPIIC member agencies, the Delta Stewardship Council, adaptive management practitioners, decision-makers, stakeholders interested in status and trends, those conducting monitoring or using data from monitoring, and the many entities that use monitoring information from the Delta to plan, conduct, and regulate management in the Delta, including policy making. In particular, various collaborative initiatives have expressed interest in the findings and recommendations from this review, including:

- **The Water Resilience Portfolio**, which contains a suite of actions to prepare California from water supply challenges, such as extreme drought and floods, and rising temperatures (see CNRA et al. 2020; Action 23.2: *"Improve Delta monitoring efforts based upon Delta ISB recommendations*").
- The DPIIC-endorsed **Delta Science Funding and Governance Initiative**, which builds on the discussions from the 2016 Science Enterprise Workshop, and is assessing whether the current levels of funding and the governance structure can efficiently meet current and future science needs (see Delta Stewardship Council 2019; Recommendation 2.3: *"Develop protocols and coordinate independent, regular reviews to evaluate the effectiveness of monitoring, following the completion of the Delta ISB reviews*"); and
- The DPIIC-endorsed **2019 Delta Science Plan**, which provides a framework for coordinating and communicating science activities (see Delta Stewardship Council - Delta Science Program 2019; Action 3.3: "*Routinely evaluate monitoring programs in the Delta to identify gaps, redundancies, and management relevance*").

This report complements our completed review of the IEP, which is a major coordinator of monitoring and scientific activities in the Delta. The IEP review took a broader overview of Delta ecological science, while also giving more attention to IEP as a program with its own organizational structure. In contrast, this Monitoring Enterprise Review looks into both monitoring activities coordinated by the IEP and those that are not.

1.2. What is Monitoring?

As described earlier in the definitions, science-based monitoring entails measuring something to grasp what is happening. But science-based monitoring for complex environmental systems is more than that; it is a systematic process conducted with specific objectives and outcomes in mind. Several formal and informal definitions and guidelines exist for monitoring.

Fundamentally, monitoring provides data that serve as a foundation for a 'supply chain' of scientific knowledge that flows from knowledge producers to knowledge consumers (e.g., see Lemos et al. 2012) and can serve a number of purposes. Long-term monitoring provides insight on how the ecosystem changes over time and helps differentiate between short-term and long-term variability (e.g., Wolfe et al. 1987; Bograd et al. 2003; Lindenmayer et al. 2012; Hughes et al. 2017). Information from long-term monitoring can help to anticipate problems before they occur. This process occurs as data are collected, quality controlled, stored, distilled, and synthesized into different knowledge products and data and modeling analyses that add value at different points to serve different audiences (e.g., Wiens et al. 2017).

Many have noted the imperative need for improving monitoring and decision making in the Delta. Policy makers, managers, scientists, and resource users working in the region are faced with a complexity of interrelated and interacting issues that will only become more difficult in the future with intensifying climate change (Hanak et al. 2012; Luoma et al. 2015; Healey et al. 2016; Delta Stewardship Council 2018a; 2018b).

The monitoring enterprise in the Delta spans many disciplines in the physical, chemical, geological, and biological sciences as well as the social sciences. Successful monitoring programs provide critical information, the uses of which are not limited to informing decisions. Arguably the more important uses of scientific and monitoring information are to help ask the right questions and better identify and organize the right frameworks for decisions, and the testing of decisions against empirical outcomes.

In addition, monitoring is essential in the "plan, do, adjust" cycle of adaptive management (Figure 2). For example, monitoring data could inform both the design of an engineering project (e.g., a fish ladder) and be used to test the functionality of the project. "Monitoring" covers a wide range of activities and objectives. Roni et al. (2013) recognized several purposes for monitoring environmental variables: baseline, status and trends, implementation, effectiveness, and validation (see Table 1 for definitions). The various types of monitoring are linked to an adaptive management process in Table 1 but could also be used for scientific purposes (e.g., developing and testing forecasting models), stakeholder or community interests (e.g., tracking the health of the Delta), or for other audiences.

An Adaptive Management Framework for monitoring could also provide better predictive and management understanding of problem-related processes, as well as evaluation of management and policies. At the broadest level, many monitoring activities in the Delta are explicitly or implicitly required by law, regulations, permits, or licenses (referred to as compliance monitoring for this review). Compliance monitoring is designed to deliver inputs, outputs, and sometimes outcomes regarding the consequences of actions that are prescribed. Compliance monitoring has varying degrees of legal flexibility and specificity.

Table 1. Different types of monitoring adapted from Roni et al. 2013 linked specifically to adaptive management.

Types of Monitoring	Description	Uses with Links to Steps of Adaptive Management (AM)
Baseline	Monitoring to characterize biological, physical, chemical, and/or socio-economic conditions for future purposes.	Useful for characterizing conditions in the planning stage before an action is implemented as a reference point for the future in the evaluate stages. AM Steps 1, 2, 3, 4, 6, 7, 8, 9.
Status	Monitoring to characterize conditions across a defined area.	Useful for characterizing conditions across space relative to management goals / objectives in the evaluate stage; helping prioritize management intervention in the planning stage. AM Steps 1, 2, 3, 7, 8, 9
Trend	Monitoring to characterize changes in condition over time.	Useful for characterizing how conditions change over time relative to when actions are being implemented; how conditions change over time relative to management goals / objectives in the evaluate stage. AM Steps 1, 2, 3, 7, 8, 9

Types of Monitoring	Description	Uses with Links to Steps of Adaptive Management (AM)
Implementation (including administrative)	Monitoring to determine or ensure that management actions are being implemented as designed.	Useful for documenting how actions were implemented on the ground in the doing stage, to explore the cause-effect relationships and ensuring actions are consistent with permit requirements in the evaluate stage. AM Steps 4, 5, 6, 7, 8, 9
Effectiveness	Monitoring to determine whether a management action had its desired effect on conditions.	Useful for understanding effectiveness of management / restoration actions and whether they are achieving desired outcomes in the evaluate stage; a more intermediate endpoint than status and trend endpoints. AM Steps 4, 5, 6, 7, 8, 9, 1
Validation (including research)	Monitoring to test whether a hypothesized cause-effect relationship is valid.	Useful for prioritizing hypotheses in the plan stage, ultimately ensuring effectiveness of management / restoration actions in the evaluate stage. AM Steps 1, 2, 3, 4, 5, 6

Attempts to pigeonhole monitoring efforts into one or another category are likely to obscure some of the ways in which monitoring varies. Monitoring should be matched to a specific goal. First, the *level of specificity* of what is needed in a monitoring program is highly variable and depends on the audience (Nelitz et al. 2019) and goal. For example, a recovery plan developed through a broad engagement process may articulate a goal to restore tidal wetland habitats. A modeler may articulate a need to assess the impacts of wetland restoration on Delta flows, water levels, water quality, ecosystems, and fish communities.

A program manager may be interested in monitoring the acreage of existing or restored habitat types as a measure of program success, whereas a scientist may be interested in understanding how tidal wetland restoration leads to sustained changes in vegetation architecture and plant species composition. Each of these cases relates to a common need for decision-making (e.g., tidal wetland restoration), but describes the need in a different way at a different level of specificity. In the Delta, Jones (2014) highlighted such differences in terms of communication needs, as have those involved in reporting data as part of routine natural resource management (Fancy et al. 2009) and water quality monitoring and reporting in the Bay-Delta (CWQMC 2008).

Second, the *questions of relevance differ for decision makers and scientists* (Nelitz et al. 2019). Nichols and Williams (2006) differentiated between “monitoring for active conservation” (i.e., monitoring with a focus on discriminating among competing hypotheses about effective conservation actions) and “monitoring for science” (i.e., monitoring with a focus on studying specific attributes, relationships, or hypotheses to improve predictions and understanding of the system). Questions or hypotheses that reflect uncertainties about the system, and hence serve as a motivation for monitoring, can be distinguished into “scientific uncertainties” and “management uncertainties” (some of which overlap in their relevance). In adaptive management programs elsewhere (e.g., Missouri River, Fischenich et al. 2018), such a distinction enables decision makers to focus on uncertainties most relevant to them and scientists to focus on priority research efforts.

Monitoring data are foundational to adaptive management, which is highlighted by the Delta Reform Act of 2009 as an essential component of management in the Delta. In combination, monitoring and adaptive management strengthen the “line of sight” through critical knowledge gaps, the actions over which decision makers have some control, and the ability of scientists to learn about the system that managers are trying to influence. Adaptive management provides a systematic structure for focusing on critical uncertainties for decision makers, implementing management actions to help resolve those unknowns (ideally using principles of experimental design), and then using rigorous science (including monitoring) to evaluate and learn about the effectiveness of those interventions (Meyer 2013; Waylen and Blackstock 2017; Wiens et al. 2017).

2. Review Methods

As stated, this is the most comprehensive review ever conducted by the Delta ISB. It consisted of an extensive inventory of monitoring programs in the Delta, a review of other monitoring programs in major aquatic ecosystems, a questionnaire survey of members of the Delta science and management community, interviews with representatives of organizations involved with monitoring in the Delta, a series of scientific panels and seminars, a workshop (ESSA et al. 2019), comprehensive literature reviews, participation in other workshops and the professional experiences of past and current Delta ISB members with monitoring in the Delta and elsewhere. Public comments were sought throughout the process (prospectus, involvement in workshop and panel discussions, board meetings that included this review almost monthly, draft reports, and formal request for public comment). Our specific approaches and focus evolved as we gained more information along the way. The process took nearly four years.

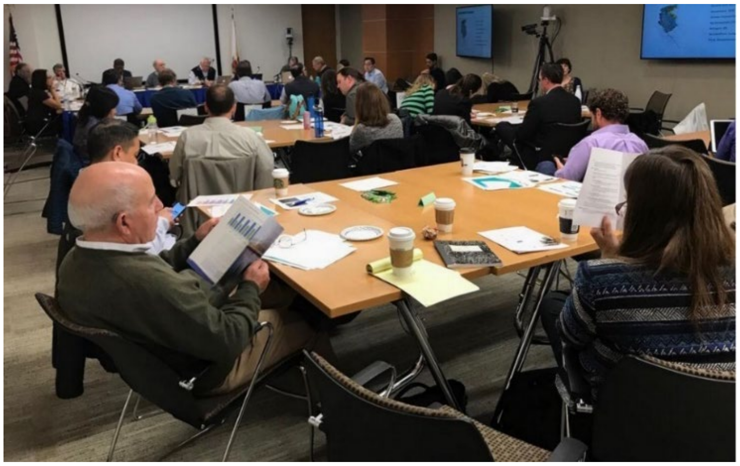
The existing inventories of monitoring activities in the Delta, such as the Bay-Delta Live or the California Data Exchange Center, are not sufficiently comprehensive to span the physical, chemical, biological, and social aspects of the Delta for assessing the monitoring enterprise, and this niche was addressed in this Delta ISB review. It consists of two components:

Component 1 (2018 to 2020) focused on developing a monitoring inventory and developing initial insights surrounding monitoring in the Delta, which was prepared by ESSA Technologies Ltd., CBEC eco engineering, and PAX Environmental Inc. (the Project Consulting Team) under the continual direction, guidance and collaboration with the Delta ISB and with funding from the Delta Stewardship Council, Delta Science Program. The Project Consulting Team was selected after two Requests for Proposals from the Delta Science Program, where Delta ISB members were involved in the final selection process.

Component 2 is the Delta ISB's evaluation and recommendations on the monitoring enterprise, informed by results of Component 1 and a questionnaire survey of members of the Delta science and management community, interviews with representatives of organizations involved with monitoring in the Delta, extensive literature reviews, and the professional experiences of Delta ISB members with monitoring in the Delta and elsewhere.

The Delta ISB also organized three seminars and five panel discussions (that included 28 experts) from 2017 to 2018 to learn about the state and scope of monitoring for the Delta and current challenges with monitoring (see Appendix A). The topics included tidal wetlands, water quality, invasive weeds, IEP, and regional programs. These seminars and panel discussions provided useful information and extensive perspectives to identify monitoring activities for the inventory and helped identify needs and best practices that could be considered to improve the effectiveness of monitoring activities. These initial perspectives provided valuable insights at the early stages of the review (see details in Appendix A).

In addition, a monitoring workshop was held on April 30, 2019, in Sacramento, California. The workshop was attended by 60 representatives from various organizations to explore their hopes and concerns for the Monitoring Enterprise Review and to help inform the development of an inventory (see ESSA et al. 2019). Based on feedback received from this workshop and other assessments, the review of the monitoring enterprise in the Delta focused on the following questions to help assess how current monitoring programs meet management needs and how they might be coordinated or modified to improve their value:



1. Are there potential gaps or redundancies in serving the relevant needs of decision makers?
2. What is the level of coordination of data collection across different organizations?
3. Are there other opportunities to increase efficiencies in monitoring?
4. Is the data quality of monitoring appropriate to address purposes and needs for information?
5. Are data accessible to the public, decision makers, other scientists, stakeholders and all interested and affected parties?
6. What resources are being dedicated to monitoring?

2.1. Component 1: Monitoring Inventory and Analyses

Based on the above questions, the Project Consulting Team, with direction and in collaboration with the Delta ISB, completed the first component of this review, which involved undertaking a comprehensive inventory of the monitoring of physical, chemical, biological, and geological conditions, and socio-economic drivers across the Delta and summarizing how these activities are addressing the needs of decision makers. It resulted in reports that are considered part of the overall Monitoring Enterprise Review, along with this report:

1. a lessons and methodology report (Nelitz et al. 2019),
2. the development of the monitoring inventory database and a subsequent summary report of monitoring activities in the inventory (Nelitz et al. 2020a), and
3. a comprehensive synthesis report (Nelitz et al. 2020b), which assesses the relevance of monitoring activities in serving the needs of decision makers and identifies opportunities to improve monitoring based on the initial analysis of the inventory.

There was also a workshop convened among monitoring practitioners, program managers, key decision-makers, and scientists to gather information about monitoring in the Delta and receive guidance on priority drivers, big questions, and needs for monitoring (see ESSA et al. 2019).

We briefly summarize the methodology and results from these reports to provide context for the Delta ISB's findings and recommendations reported here.

2.1.1. Previous Reviews of Monitoring and Literature Reviews

To help inform the review methods and the recommendations, a literature review using a Results Hierarchy (or logic model framework) as the structure for categorizing the information was done to gather insights learned from other systems, as well as the Delta (Gates Foundation, 2010). The selection of case studies was focused on including, to the extent possible, large-scale monitoring programs in complex, highly managed ecosystems primarily within North America that also have applied adaptive management to varying degrees. The final selection of case studies was guided by the Delta ISB. These five case studies included: (1) Chesapeake Bay, (2) Great Lakes, (3) Coastal Louisiana, and (4) Puget Sound in the United States, as well as (5) Queensland, Australia.

Results from this literature review are summarized in Nelitz et al. 2019 and in the recommendations section of this report. Findings from these case studies identified attributes that could contribute to effective monitoring and adaptive management in the Delta across themes of leadership, organizational structure, problem definition, communication, and funding strategies and practices.

2.1.2. Inventory Development

Making an inventory of monitoring enterprise activities required clarifying the scope of monitoring activities, which involved developing a structure for organizing metadata about monitoring activities. Based on the literature review (see Section 2.1.1) and feedback from the Monitoring Enterprise Review Workshop (ESSA et al. 2019), an organizational framework was developed to represent monitoring parameters within the scope of this review (Figure 3). The intent in developing this framework was not to represent the full complexity of cause-effect linkages among all components in the Delta. More tractably, it depicts broad linkages among management actions and environmental drivers/conditions, habitats, and species of interest to decision makers, scientists, and stakeholders in the Delta, as well as direct socio-economic drivers of ecosystem change.

Regarding the temporal horizon of monitoring activities, the intent of this review was focused on inventorying ongoing/active monitoring activities rather than historical, now defunct monitoring. The intent was to focus on monitoring activities for which data had most recently been collected within the previous five years (i.e., at least once since beginning of 2014) and for which it is anticipated to occur again within the next five years (i.e., before the end of 2024).

This research included monitoring activities related to all monitoring themes and parameters in Figure 3, with a focus on monitoring activities within the legal boundaries of the Delta and Suisun Marsh (Figure 1). However, the Delta is strongly subject to upstream and downstream influences. Such upstream and downstream linkages were considered where appropriate for many parameters. In many cases, however, statewide or national monitoring activities included sampling locations within and outside the Delta. To represent the spatial coverage of such activities, the hydrologic unit code (HUC) boundaries for the state were used to assign sub-basins where sampling locations were located for an activity (see Figure 1).

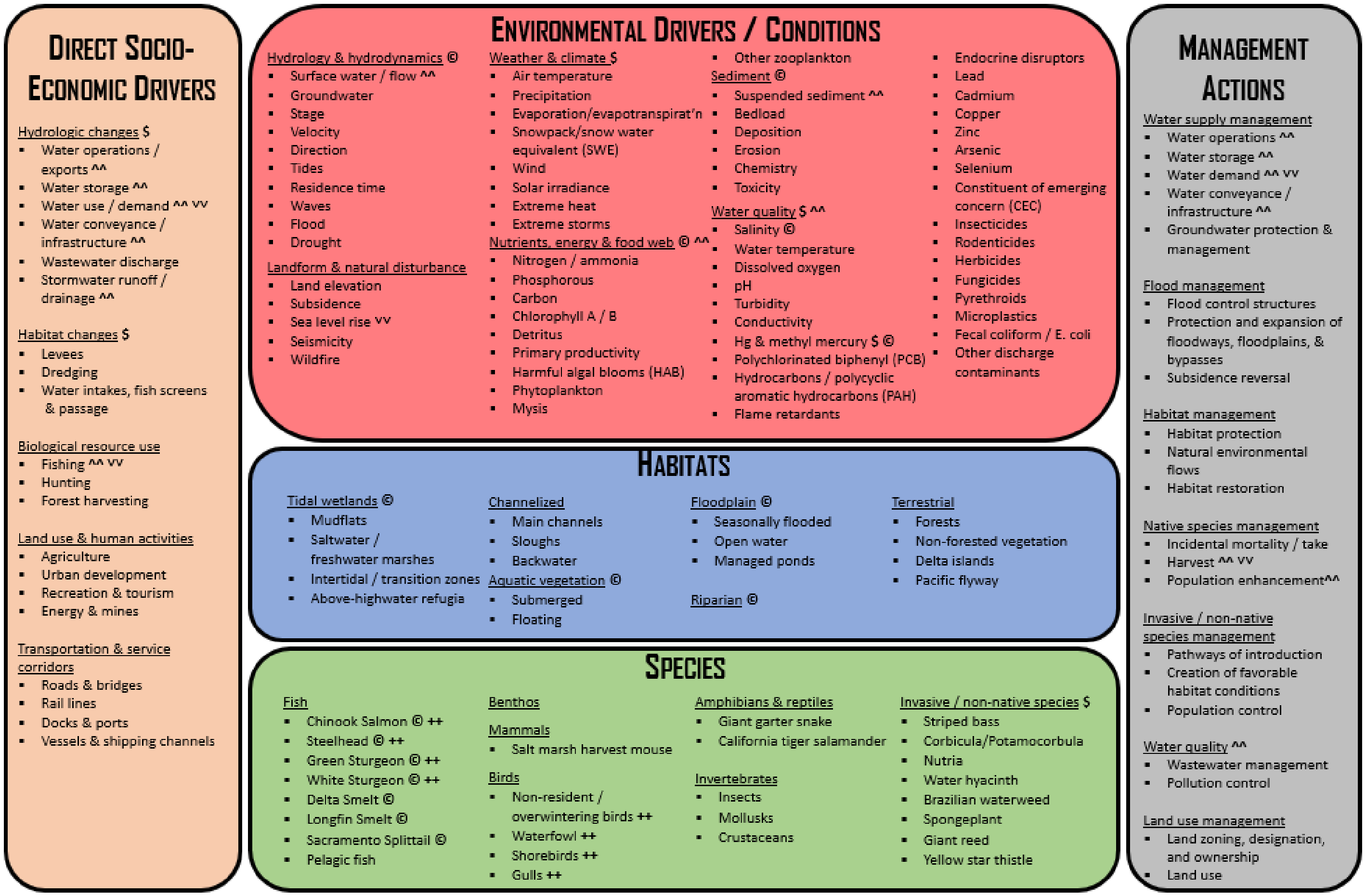


Figure 3. Organizational framework representing the biological, physical, chemical, geological attributes of the Delta and direct socio-economic drivers of environmental change and within scope of this review. Note the use of the following abbreviations: $ denotes primary stressors on the Delta, © denotes components with detailed conceptual models, ^^ (double caret) denote components with upstream drivers/stressors that influence the Delta, vv (double circumflex) denote components with downstream drivers/stressors that influence the Delta, and ++ denote non-resident species that use the Delta for a portion of life cycle. See Appendix B for the organizational framework in list format.

The monitoring inventory also collected metadata on monitoring activities within scope of this review (see Appendix B, Table B-1 for the metadata collected in the inventory). Monitoring activities within scope of the review were identified through the literature reviews, the Monitoring Enterprise Workshop (ESSA et al. 2019), the discussions during the seminars and panels, and additional searches on the internet. Metadata for the inventory was collected through internet searches, and when information was missing, monitoring programs were contacted by email or telephone. Quality assurance and control of the metadata were ongoing throughout the review process, but most information collected was last updated in March 2020.

Quality assurance and control of the inventory's metadata included training of the project team members involved with entering information into the inventory, which was based on a common set of definitions for classifying information (e.g., see Table 1 and Appendix B). Upon completion, each record was reviewed by a different project team member for consistency and accuracy. When issues and questions arose, monitoring program leads were contacted for clarification. The inventory was also released for public feedback, as part of Delta ISB meeting materials, from November 2019 to March 2020, and corrections were made by two programs (the IEP (Steve Culberson) and the Fish Restoration Program (Stacy Sherman) during the review period. It is also important to note that a small number of leads for the monitoring activities in the inventory indicated that they did not have resources to review the metadata generated for their monitoring activity, which highlighted a limitation of Component 1.

Although most of the records were last updated in March 2020, there are plans to incorporate the metadata collected from this review into the pending web-based tracking system of science activities in the Delta, known as the Delta Science Tracker, which will be launched by the Delta Stewardship Council – Delta Science Program in 2022 (see Delta Science Plan Action 5.3 for more information, Delta Stewardship Council - Delta Science Program 2019). As part of the incorporation into the Delta Science Tracker, additional quality assurance and control will be performed on the metadata that was collected for this review. If any major errors are identified from the incorporation of the metadata from the monitoring inventory into the Delta Science Tracker, the Delta ISB may issue an addendum to this report to update its findings and recommendations.

It is noted that analysis of the inventory's metadata found in Nelitz et al. (2020b) should be treated as initiatory but should not, on its own, be used as the basis for any conclusions or recommendations. Additional feedback on the results of the inventory analysis was sought with the release of a questionnaire in May 2020 to understand perceptions of the results by monitoring practitioners (see Section 2.2.1).

2.1.3. Inventory Analysis

An organization framework for evaluating the Delta monitoring enterprise was developed (Figure 3). This framework laid out the key biological, physical, chemical, and geological attributes of the Delta ecosystem, the socio-economic drivers of ecosystem change, and the management actions across seven major management areas. The inventory analyses focused on the six major questions listed above. Methods to answer each of these questions are briefly described below and detailed methodology is more fully described in Nelitz et al. (2019).

1. Are there potential gaps or redundancies in serving the relevant needs of decision makers?

For the purposes of this review, *gaps* are defined as monitoring parameters with insufficient temporal and/or spatial coverage to address specific questions, whereas *redundancies* are areas of overlap in temporal and/or spatial coverage to answer specific questions. Determining gaps and redundancies in monitoring requires understanding the purpose of the monitoring program and the specific science or management questions being addressed, and the specific monitoring parameter, as temporal and spatial coverage varies with the parameter.

Overall, the desired outcome for the Delta is based on achieving the coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem, which needs to be achieved in a manner that protects and enhances the Delta as an evolving place (CA Water Code Section 85054). However, there is not a consolidated description of the management context, decision-making needs, or specific questions for adaptive management in the Delta (e.g., Nelitz et al. 2019) sufficient to fully evaluate monitoring gaps.

Understanding the management context is needed to help assess how well monitoring is serving decision making. This is the core of using an Adaptive Management Framework for monitoring. Without understanding the clear goals of a monitoring program, it is challenging to assess gaps or redundancies. To address gaps in Delta monitoring within the inventory analyses, the Delta Plan (Delta Stewardship Council 2013), Delta Science Plan (Delta Stewardship Council - Delta Science Program 2019), and Science Action Agenda (Delta Stewardship Council - Delta Science Program 2017) were used as the basis for identifying common management themes and actions, since these documents guide science and decision making in the context of the Delta's coequal goals. Through this process, seven management areas were identified to help inform the review (see Nelitz et al. 2019 for details).

Water Supply Management – Decisions that influence how water resources affect the Delta and its users. Such actions include water operations, water storage, water demand, water conveyance/infrastructure, and groundwater protection and management.

Flood Management – Decisions that influence how flood waters are managed affecting ecosystems, people, and property in the Delta. Such actions include construction and operation of flood-control structures; protection and expansion of floodways, floodplains, and bypasses; subsidence reversal; and floodplain and land use management to reduce flood damage vulnerability.

Habitat Management – Decisions that influence how terrestrial, riparian, and aquatic habitats are managed within the Delta. Such actions include restoration, protection, and the use of flows and habitat to improve ecosystem conditions.

Native Species Management – Decisions affecting the abundance of native aquatic or terrestrial animal or plant species relevant to the Delta. Such actions influence incidental take or mortality (e.g., at fish screens and water intakes), harvest (e.g., recreational harvesting of fish and wildlife), and population enhancement (e.g., through hatcheries).

Invasive Species/ Non-native Species Management – Decisions affecting the population abundance and habitats of invasive/non-native species in the Delta. Such management actions include preventing introductions, avoiding creation of favorable habitat conditions, and controlling populations (e.g., harvest, culling, biocontrol).

Water Quality Management – Decisions affecting surface and groundwater quality within the Delta. Such actions include wastewater management (e.g., effluent reuse, recycling, and treatment of wastewater), pollution discharge controls (e.g., pyrethroids, methylmercury, CECs, pesticides, nutrients), and their adverse events on aspects of water quality in the Delta (such as dissolved oxygen, turbidity, salinity, and harmful algal blooms or HABs).

Land Use Management – Decisions affecting terrestrial land designation, use, and cover within the Delta (e.g., urban, agricultural, and natural/protected areas). Such management actions include land zoning, designation, conversion, and ownership, as well as land use.

The management context provides insights on decision-making needs and help determine monitoring gaps and redundancies. However, we did not attempt to develop an agreed upon list of questions that information from monitoring should address.

To help understand the spatial and temporal coverage, "monitoring needs profiles" were developed for each of the seven management themes identified above (Nelitz et al. 2020b). Monitoring parameters within each management theme were identified based on a review of important drivers of management within the Delta, including key plans, strategies, biological opinions, and related legislation (see Appendix B for a list of management drivers). Afterwards, the monitoring inventory was queried to produce summary plots for each monitoring parameter within each management theme, which included the total number of sampling activities, the relative distribution of those activities across Delta regions (e.g., south Delta, north Delta; see Figure 1), sampling frequency classes (e.g., 15-minute intervals, hourly, daily, weekly), and across sampling program durations. These metrics help provide an overview of the general spatial and temporal coverage of monitoring parameters that are important across a range of management contexts and lend themselves to high-level interpretations of possible patterns in gaps and redundancies. However, the coarse resolution of this analysis did not support detailed inferences about whether monitoring is occurring at exactly the right times or places to meet management needs. Instead, the results of this assessment were a starting point to identify potential gaps and redundancies. Additional analysis of gaps and redundancies was assessed in Component 2.

2. What is the level of coordination of data collection across different organizations?

Network analyses provided insights on the level of coordination. Network analysis is a quantitative and visualization approach to identify patterns in relationships across different elements of a system, including individuals, organizations, ecosystem components, and management objectives for conservation and monitoring (see Nelitz et al. 2020b). Organization names, roles, and monitoring themes were extracted from the monitoring inventory and used to develop network diagrams, calculate network and node metrics, and ultimately explore the level of coordination across monitoring activities in the monitoring enterprise. However, these analyses do not provide an indication about what type of network may be most desired or ideal for the monitoring enterprise since that determination is based on a value judgment. Additional engagement, during Component 2, was used to identify specific opportunities for positively influencing coordination among organizations involved in monitoring.

3. Are there other opportunities to increase efficiencies in monitoring?

The inventory was used to calculate the number of monitoring activities collecting data for each monitoring parameter. Metadata information in the inventory was reviewed for monitoring parameters with the most monitoring activities, such as water quality, fish, waterfowl, and habitat, to qualitatively identify potential opportunities to improve efficiency and reduce redundancies, with a focus on considering improvements to data management, sampling methods/approaches, and monitoring design.

4. Is the data quality of monitoring appropriate to address purposes and needs for information?

Based on an extensive literature review, the following data attributes were common for assessing both data quality (question 4) and accessibility (question 5) (US EPA 2006; Kahn et al. 2012; DAMA UK 2013; Pickard et al. 2015):

- Purpose: Do the data and monitoring meet the intended goals and criteria of the study in which they were collected?
- Monitoring guidance: Were the methods used to obtain data well-described and do they represent best practices (e.g., following established sampling protocols or monitoring design)?

- Quality Assurance and Control (QA/QC): Have the data been reviewed to ensure they are correct, reliable, and free of error (e.g., independently reviewed, inter-compared, published, QA/QC'ed)?
- Timeliness: Do the data represent conditions at the required point in time (e.g., real-time, weekly, annually updated)?
- Public accessibility: Are the data readily accessible (e.g., open source)?
- Machine readable: Are the data provided in a machine-readable format ready for analyses?
- Uncertainty: Does the data include quantitative estimates of variability (e.g., 95% confidence intervals)?

To assess the data quality of monitoring activities in the inventory, each monitoring activity was queried on whether it followed monitoring guidance (yes/no/unknown), had QA/QC protocols (yes/no/unknown), reported uncertainty (yes/no/unknown), was accessible to the public (yes/no/unknown) and whether reporting was timely (reported in >1 year, < 1 year, or unknown). This provides information about the quality of data, but not whether it is appropriate to address information needs. The latter was evaluated in Component 2.

5. Are data accessible to the public, decision makers, other scientists, stakeholders, and all interested and affected parties?

To assess data accessibility, each monitoring activity in the inventory was queried on whether it was accessible to the public (yes/no/unknown), machine readable (yes/no/unknown), and whether reporting was timely (reported in >1 year, < 1 year, or unknown).

6. What resources are being dedicated to monitoring?

Insights on the resources dedicated to monitoring arose from summarizing information about cost (i.e., start up and annual costs) and effort (i.e., number of sample sites within the Delta) for each monitoring activity in the inventory.

2.2. Component 2 Analyses

Component 1 provided important insights on potential gaps and redundancies (scope, parameters, spatial and temporal coverage), coordination, and opportunities to improve efficiencies (see Nelitz et al. 2020b). However, additional analyses and deliberations were needed to understand the management and stakeholder context in which to make recommendations, the constraints and challenges for making recommendations, and perceptions of monitoring and how it aligned with the inventory analysis. Analyses for Component 2 were based on information from Component 1, the discussions during the seminars and panels, a questionnaire, interviews, literature reviews, and the Delta ISB members' experiences with monitoring.

2.2.1. Seminars and Panels

From November 2017 to July 2018, the Delta ISB hosted three seminars and five panel discussions (with 28 experts) to help understand the state of monitoring in the Delta, as seen from a wide range of perspectives, to help inform its review on the monitoring enterprise. Information obtained from these seminars both helped inform Component 1 of the review, which was the development of the monitoring inventory, and Component 2, which was the development of Delta ISB recommendations (see details in Appendix A). These seminars and panels discussions helped introduce the various programs/activities that either collect or coordinate monitoring data in the Sacramento-San Joaquin Delta to the Delta ISB, such as the California Water Quality Monitoring Council and Fish Restoration Program Monitoring Team.

The seminar speakers and panelists provided a wealth of information about current monitoring programs, including challenges and needs (detailed in Appendix A). Perspectives from the seminar presenters and panelists led to some key insights surrounding the broad review questions for the Monitoring Enterprise Review, which were further investigated once the inventory was developed. These findings were used to develop initial best practices for improving the monitoring enterprise in the Delta and helped with the development of the recommendations.

2.2.2. Questionnaire Analysis

The Delta ISB released a questionnaire to the Delta community **to seek perceptions of and feedback on Component 1 findings and recommendations,** which were based on an initial analysis of the Delta monitoring inventory.[1] The purpose of the questionnaire was to help refine the findings and recommendations from Component 1 and to help identify areas for further analysis. Respondents were presented with 19 statements based on findings or recommendations from Component 1 (see Nelitz et al. 2020b). Respondents were asked to indicate the extent to which they disagreed or agreed with each statement on a scale ranging from 1 (strongly disagree) to 5 (strongly agree). They were also given the option to select "I do not know." Each statement had a write-in text option where respondents could explain or elaborate upon their numerical response.

The questionnaire, available from May 21, 2020 to June 5, 2020, was distributed to 60 participants from the 2019 Monitoring Enterprise Review Workshop (ESSA et al. 2019), which helped inform the scope of the inventory and analysis. The survey was also distributed to the IEP mailing list (215 recipients) and the Delta Stewardship Council listserv (2,862 recipients). It is difficult to precisely quantify the number of individuals who had an opportunity to take the questionnaire because there was some cross posting among emailing lists, and the survey was also available on other platforms, including the Delta Stewardship Council's website and Maven's Notebook.

A total of 34 individuals responded to the questionnaire. While insights from this sample are interesting and informative, they cannot necessarily be generalized to represent the views of the broader Delta population due to the small sample size and non-random survey distribution methods. Survey results are used to supplement other data sources, as just one part of the larger review methodology. Quotations throughout the review were selected to provide additional context for the questionnaire results we report. Quotations reflect the detail and nuance associated with individual responses, but do not necessarily represent the perceptions of any larger population. Results of our data analysis appear in Appendix C.

[1] A copy of the questionnaire can be found online. Detailed results from the questionnaire can be found in Appendix C.

Here and in Appendix C, we report summary statistics (counts) for each statement. In all cases, responses of agree and strongly agree (4 or 5) were combined into "agree" and responses of strongly disagree or disagree (1 or 2) were grouped into "disagree." A numerical response of 3, the midpoint of the scale, was interpreted as neutral. Write-in responses were analyzed qualitatively to identify and distill key takeaways and major themes.

2.2.3. Interviews and Analyses

The Delta ISB conducted 11 semi-structured interviews between April and May 2021 with scientists and managers who either have knowledge and experience with monitoring in the Delta, and/or whose agency has management responsibilities that could be informed by monitoring. Interviewees included representatives from State (n=5), federal (n=2) and local agencies (n=2), as well as a consulting firm (n=1) and a non-governmental organization (n=1). They were selected to cover interests aligned with the range of management themes that were identified for the review (see Section 2.1.3).

Questions (in Appendix D) were sent to interviewees in advance, with follow-up and clarifying questions incorporated as needed. Questions were designed to elicit detailed discussions of management needs for monitoring, gaps, monitoring design and sampling, data analyses and management, communication, financial needs/constraints, and agency coordination. Interviewees were asked to respond to our ideas for best practices and recommendations and provided an opportunity to make their own suggestions. All interviews were recorded and transcribed for purposes of analysis. In all, there were over 200 pages of transcripts.

Interview data were analyzed using the methods of qualitative content analysis (Cho and Lee 2014). An analytical framework was developed for interview transcript "coding," a process used to identify, organize, and categorize qualitative data based on questions or topics of interest. Interviews were coded for content pertaining to the following thematic areas: current and future management needs; monitoring gaps, including barriers to and suggestions for addressing gaps; ideas about improving monitoring for adaptive management; and monitoring coordination needs, including barriers to and suggestions for addressing these needs (See Appendix D).

Coding results were quantitatively summarized and qualitatively synthesized. These results provided context on barriers, constraints, and challenges related to efforts to improve the monitoring enterprise. They also provided additional management context to help inform the Delta ISB in formulating its recommendations. As with quotes presented from questionnaire write-in responses, quotations from interviews are provided to reflect the detail and nuance provided during interviews, but do not necessarily represent the perceptions of any larger population.

Lastly, interviewees were asked to complete an optional survey to provide feedback on the initial best practices (see Appendix D). Feedback was used to clarify best practices into the final versions presented in this report.

3. Synthesis of Findings

The monitoring inventory (Component 1 of this review) included 157 unique monitoring activities, with 170 sampling activities at over 4,000 sampling locations representing 128 unique monitoring parameters (all of the monitoring activities in the inventory are found in Nelitz et al. 2020a and Appendix B). Of the 157 monitoring activities, 97 (62%) had some management driver. The top five most referenced drivers are the Clean Water Act: Section 303(d), California Fish and Game Code, Water Right Decision 1641/Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, Federal Endangered Species Act, and the biological opinion on the long-term operations of the State Water Project and Central Valley Project from the United States Fish and Wildlife Service.[2]

[2] Note that the development of the inventory was undertaken when the 2008 and 2009 biological opinions were in effect for the long-term operations of the State Water Project and Central Valley Project, along with the 2009 incidental take permit for the State Water Project. Results were generally cross checked with the new biological opinions and incidental take permit.

Many long-term monitoring programs for the Delta have informed management. Long-term monitoring has helped in assessing the status and trends of various species, used to support the listing of a species under the federal or State Endangered Species Act (e.g., longfin smelt; see CDFG 2009) or delisting of a species (e.g., splittail; see USFWS 2003; Sommer et al. 2003), and to track the overall health of the Delta based on Delta Plan Performance Measures. Long-term monitoring can also help detect new non-native or invasive species that enter the Bay-Delta system, such as the overbite clam in 1986 (e.g., see Carlton et al. 1990; also see Delta ISB 2021).

Outside of status and trends, long-term monitoring data can be analyzed by statistical methods to create or inform policy. For example, Jassby et al. (1995) analyzed long-term flow and ecological data to introduce the X2 concept, where salinity in the estuary that measures two parts per thousand has a positive statistical relationship to various estuarine resources (e.g., phytoplankton, larval fish survival). The concept was adopted as a regulatory standard under Water Right Decision 1641, by which flows in the Delta are managed to meet X2 requirements at various times of the year (SWRCB 2000).

Most monitoring activities in the inventory are influenced or required by a management driver (e.g., a biological opinion) and there are many examples of long-term monitoring informing Delta management. Nearly half of the questionnaire respondents (16 of 34) disagreed that "*Overall, current information collected from monitoring serves the needs of decision makers and stakeholders across the Delta*" (whereas 6 agreed, 11 were neutral, and 1 did not know; N=34; see Figure 4).

Additionally, when asked if "*data are analyzed and synthesized in a way that enables management decisions*," many questionnaire respondents (14 of 34) disagreed (whereas 5 agreed, 11 were neutral, and 4 did not know; N=34; see Figure 4). In their write-in responses, several respondents indicated that synthesis is not well-connected to management decisions or communicated in an accessible or timely manner to those who need the information. They expressed that data analysis needs improvement to adequately address management needs.

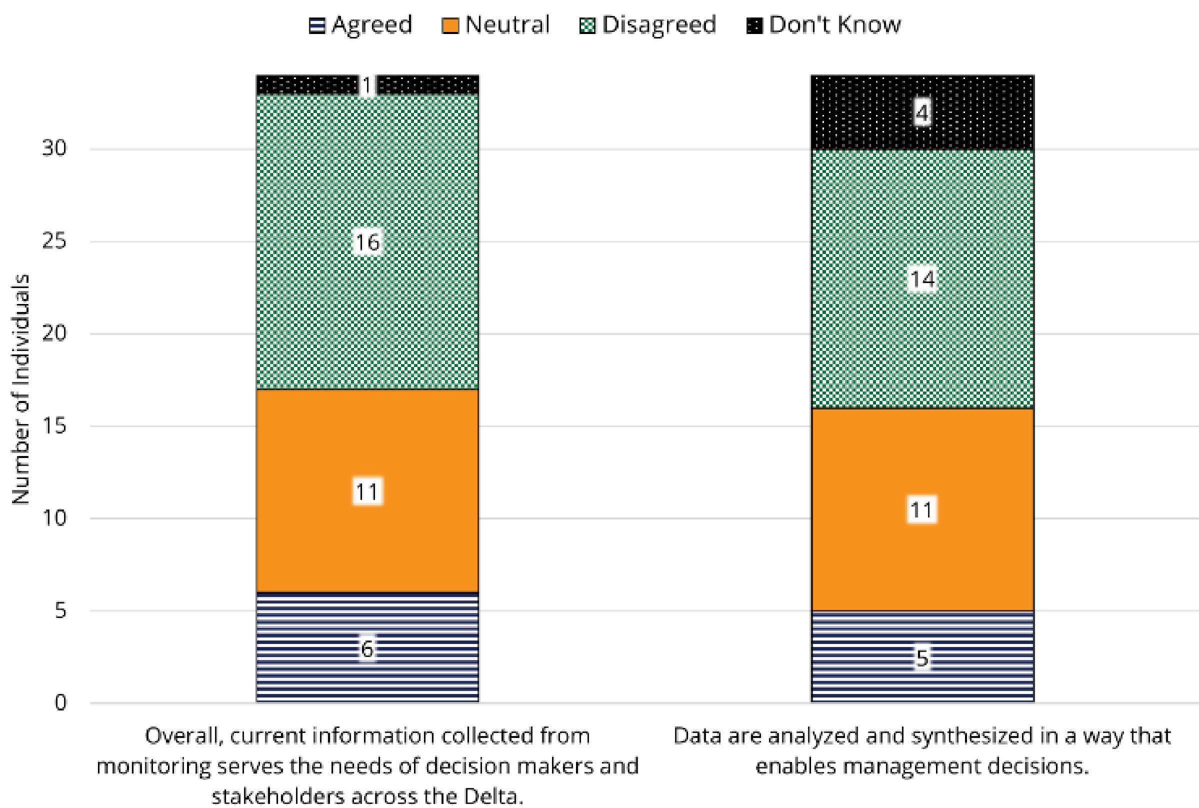


Figure 4. Questionnaire respondents' perceptions about whether information collected, analyzed, and synthesized from monitoring serves the needs of decision-makers. Labels within a bar graph indicate the total number of people who selected each response. See Appendix C for more information.

Several write-in responses from the questionnaire indicated a perceived monitoring-management disconnect in the Delta. The reasons for the perceived disconnect vary by individual. Some expressed concerns over the lack of data on specific species or resources, such as riparian and near-aquatic terrestrial resources. Several commenters also perceived a need for more real-time monitoring to inform decision-making. Some pointed out that, even in cases where substantial resources are dedicated to monitoring species of concern, including Chinook salmon and Delta smelt, monitoring programs are not always designed to sufficiently answer management questions and do not collect essential detailed information such as habitat use and life stage information. The monitoring enterprise was also critiqued for not being nimble enough to respond to rapidly changing management needs, such as HABs, invasive species, and protection of species of concern. Other questionnaire respondents expressed concerns about an emphasis on long-term studies at the expense of more direct special studies.

The following quotes illustrate the diversity of the comments on these topics:

"*I think the needs of decision makers change more quickly than the science does. Existing monitoring programs provide data that are important, but this monitoring isn't nimble enough meet changing needs. Perhaps some existing monitoring should change (e.g., IEP surveys), or perhaps they should have partnered research studies that help us fill in knowledge gaps*."

"*Using longfin smelt again as an example, the coverage of the adult distribution has been greatly hampered in the last 4 years due to incomplete survey effort. The Fleet Resiliency strategy has not changed this yet.*"

"*Need to implement more real-time methods and new technology to make decisions quicker*."

"*Especially for invasive species, more real-time detection should be prioritized. Part of it is educating people already monitoring to keep their eyes open (like for alligator weed), but newer methods like eDNA should be prioritized for this*."

"*Monitoring for HABs, phytoplankton, and some water quality parameters are not collected with enough spatial or temporal resolution to inform decision-makers*."

"*Monitoring of waterbird populations in the Delta are very limited, and thus the frequency is much too little sampling*."

Additionally, 11 participants indicated a neutral stance on this statement. These responses fell into three categories: first, that monitoring has been improving, although it still needs to continue to improve; second, it is difficult to determine whether or not monitoring is sufficiently addressing management needs, either due to a lack of communication or that the linkage to structured decision-making has yet to be formalized; or third, that monitoring is sufficient, but there are other limitations to addressing management needs, namely modeling capabilities and data accessibility.

To help inform recommendations to improve monitoring for management, key findings from the seminars and panels discussions (Appendix A), literature review (Nelitz et al. 2019), the inventory analysis (Nelitz et al. 2020b), questionnaire analysis (Appendix C), and interview analysis (Appendix D) are summarized and synthesized below by each review question.

3.1. Are there potential gaps or redundancies in serving the relevant needs of decision makers?

3.1.1. Identifying Gaps and Redundancies

Identifying gaps requires a clear statement of the monitoring purpose, goals, and scope. In Section 5 (A Way Forward: Adopting Adaptive Management, Best Practices, and Recommendations), we promote a detailed framework for designing, implementing, and adapting an effective monitoring program based off Reynolds et al. (2016). It suggests that the process of identifying gaps begins with a robust problem definition, which can be developed through cross-disciplinary and inclusive workshops, and development of conceptual model or frameworks as critical foundations of an effective monitoring program. The problem statement and conceptual model/framework can also be used to identify attributes that need to be monitored to address specific management needs. Clear articulation of monitoring goals and needs can guide the identification of gaps and redundancies that may be impeding optimization of a monitoring program. A clear and specific foundation not only supports a robust monitoring program, but also allows for efficient analysis of program effectiveness. Reynolds et al. (2016) also underscored the importance of prioritizing data documentation, management, and analysis for an effective monitoring program. Timely analysis and summarization of new information and timely communication of information to decision makers will allow for detection of issues, gaps, and redundancies so that they may be addressed in a timely manner.

Although Delta-specific conceptual models exist for various topical areas, such as the effects of tidal wetland restoration on fish (Sherman et al. 2017), the biology of Delta smelt (Baxter et al. 2015), and the scientific understanding of important aspects of the Delta ecosystem for the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP; e.g., see Durand 2008 for aquatic food web, Werner et al. 2008 for chemical contaminants, etc.), the inventory analyses could not find a comprehensive conceptual model robust enough to link existing conceptual models and/or span significant management areas (e.g., Figure 3). As management questions and needs in support of adaptive management have not been clearly defined for the monitoring enterprise, we did not attempt to create an agreed upon conceptual model but created an organizational framework (Figure 3) for identifying monitoring that is within the scope of the review to help with the assessment of gaps and redundancies.

"Monitoring Needs Profiles" were thus developed for each of the seven management themes relevant to the Delta to better understand potential gaps or redundancies based on the inventory analysis, which can be found in Nelitz et al. (2020b). Although useful, the coarse resolution and breadth of this analysis for 128 parameters across the entire monitoring enterprise did not lend itself to definitive inferences about whether monitoring is occurring at the right times or places for all management needs. As a result, additional information was collected from discussions during the seminars and panels, interviews, and from questionnaire responses.

We did not focus our work on redundancies in monitoring based on feedback received from the Monitoring Enterprise Review Workshop (ESSA et al. 2019), which was not an area where participants felt the Delta ISB should focus our review. Instead, workshop participants were interested in potential gaps. However, we note that identifying and reducing redundancies could save funds and resources to address monitoring gaps. This needs further assessment. Illustrations of gaps identified through our review are below.

3.1.2. Environmental Drivers/Conditions – Contaminants and Harmful Algal Blooms

Based on the inventory analysis, chemical contaminants - with the potential exception of mercury/methylmercury - was identified as a potential gap, and over half of the questionnaire respondents (18 of 34) agreed that this is a gap (whereas 4 disagreed, 7 were neutral, and 5 did not know; N=34; see Figure 5). Respondents who disagreed with the statement in the questionnaire did not necessarily disagree that there may be gaps with the monitoring of chemical contaminants, but rather that there was extensive monitoring of mercury/methylmercury. Gaps for chemical contaminants were also mentioned during the seminars and interviews.

Overall, contaminants have a range of effects on both human and ecosystem health (see water quality review by the Delta ISB (Delta ISB 2018)). High levels of mercury/methylmercury are a long-standing concern for fish health and human consumption of fish (Scheuhammer et al. 2007). However, additional contaminants are a concern for humans when they threaten the quality of drinking water and ecosystem health. Herbicide and pesticide runoff is a serious concern and was mentioned as a likely driver of decreased chlorophyll-a, with larger food-web consequences as phytoplankton and zooplankton are likely affected by such contaminants.

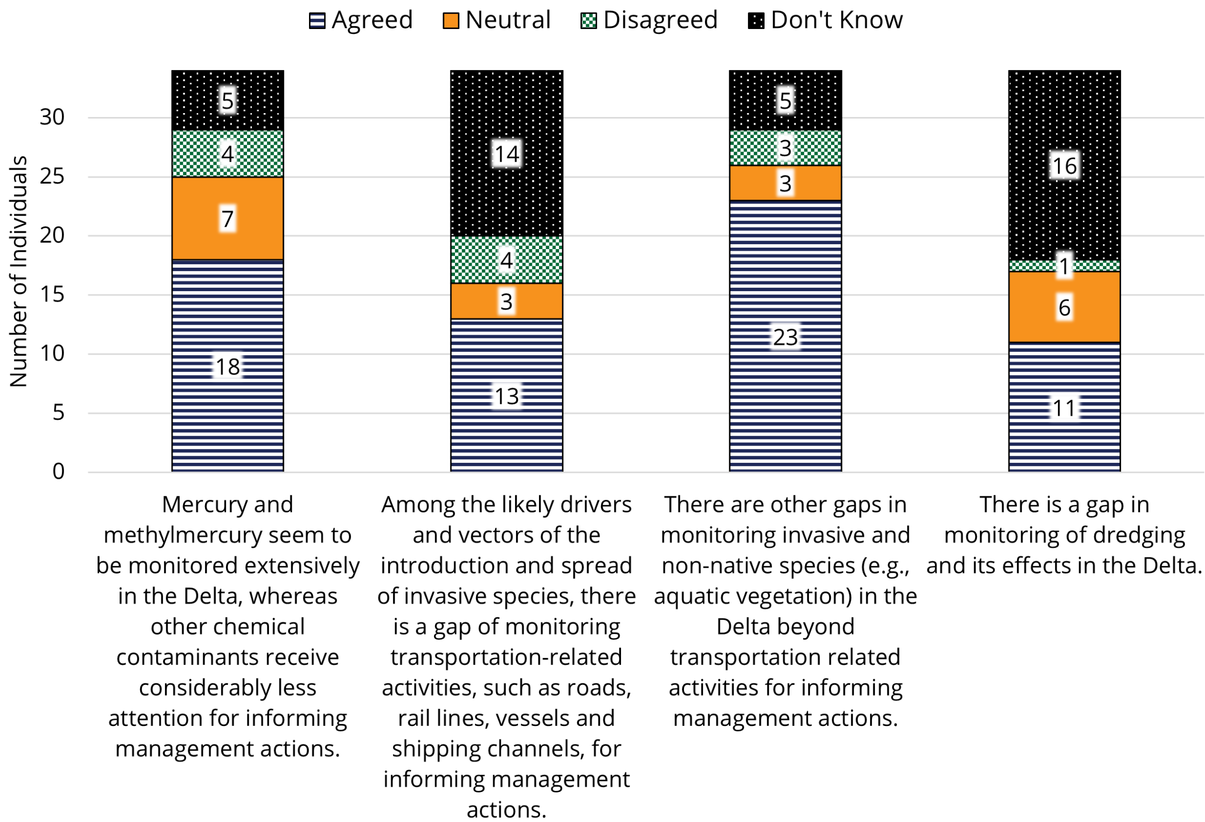


Figure 5. Questionnaire respondents' perceptions of the gaps identified from the inventory analysis. Labels within a bar graph indicate the total number of people who selected each response. See Appendix C for more information.

Several interview and questionnaire respondents expressed concern about the lack of knowledge about contaminants of emerging concern, potential synergistic interactions, sublevel effects, and ecosystem reactions to the range of contaminants that enter the Delta. One interviewee expressed this concern: *"We know contaminants are having an effect on species. We don't know the magnitude, we don't know the spatial extent, we don't even know necessarily what all the contaminants are. So, if folks are doing monitoring of their discharge to be in compliance with their waste discharge requirements, that doesn't tell us what's happening in the ecosystem. And there's mixtures of chemicals and then there's other things that we don't even know that we should be monitoring for."*

That is, there are unknown unknowns. These findings are consistent with the recommendations made in our water quality review, where we recommended that the Delta Regional Monitoring Program expand the contaminants it monitors and increase the temporal and spatial coverage of its measurements (Delta ISB 2018).

Although many questionnaire and interview participants indicated the need to improve and expand monitoring for contaminants, one questionnaire participant indicated: *"Numerous other contaminants are monitored by agricultural, wastewater, and storm water agencies, with management programs established to help reduce the impacts of chemicals exceeding established TMDL concentrations. Selenium, pesticides, nutrients, and heavy metals all receive a fair amount of monitoring in regulated water discharges."*

This indicates that there could be missing monitoring activities in the inventory and that monitoring of regulated discharged is not designed to "*tell us what's happening in the ecosystem*." In addition, another questionnaire participant who disagreed felt there was quite a bit of pesticide and herbicide monitoring, but less so for contaminants of emerging concern. Other questionnaire participants who agreed with the finding acknowledged that, although there is monitoring of contaminants, there is not enough information to identify sources, fates, and effects on the Delta ecosystem.

Although not identified by the inventory analysis as a gap, harmful algal blooms (HABs) were mentioned by interviewees and questionnaire respondents as a potential gap. This is also consistent with the Delta ISB's review on water quality science, in which the need for a more structured and exhaustive monitoring for cyanoHABs and toxins was stressed to effectively forecast bloom inception and mitigate HAB events (Delta ISB 2018).

HAB's have been a concern for drinking water quality for decades, and can cause cyanobacterial toxin poisoning in people, fish, shellfish, mammals, and birds in addition to other potential ecological effects such as hypoxia and over shading of large swaths of habitat (Hallegraeff 1993, Graham 2006, Lewitus et al. 2012). HAB events have been increasing in California, likely driven by drought and higher temperatures, but still remain inadequately understood (Anderson et al. 2021). As one interviewee explained: "*The risk of harmful algal blooms through the system, the occurrence and the conditions that lead to their development and their associated toxins within the watershed and also macrophytes, the type that are growing under the water and floating on top of the water and really what effect they're having on nutrients through the system is greatly unknown*."

Other environmental drivers/conditions mentioned less frequently during the course of the review include:

- Sub-surface Salinity
- Sediment Toxicity
- Nitrogen
- Zooplankton
- Tidal flows on water quality

3.1.3. Non-native species/Invasive Species

Invasive or non-native species can impact every aspect of ecosystem services and sustainability, including food-webs and habitat structure (Delta ISB 2021), and have contributed to an estimated 25% of all plant extinctions and 33% of animal extinctions globally (Pyšek et al. 2020). From the inventory analysis, there is a gap in monitoring of non-native or invasive species. Among the likely drivers and vectors of introduction and spread, there is very little monitoring of transportation-related vectors, such as roads, rail lines, vessels, and shipping channels, though it is unclear whether the comprehensiveness of these monitoring activities is sufficient to address the needs for this information. We sought to clarify this uncertainty through the questionnaire. Overall, a large portion of the respondents did not know if there were gaps in monitoring of transportation-related activities for invasive/non-native species (14 did not know, 13 agreed, 3 were neutral, 4 disagreed; N=34; see Figure 5).

When asked if there are gaps in monitoring in general for invasive or non-native species beyond transportation-related activities, most agreed there are gaps (23/43, whereas 3 disagreed, 3 were neutral, and 5 did not know; N=34; see Figure 5). In write-in responses, some of the respondents who agreed indicated that there is not a specific monitoring network to quickly identify new invasive species early in the invasion or a comprehensive invasive species monitoring program in the Delta for some of the most widespread and established invasive plant and animal species.

There were also comments on the impact of budget cuts in creating these gaps. For example, UC Davis conducted annual measurements of the Delta with hyperspectral imagery to map invasive aquatic weeds from 2004 to 2008 for the then Department of Boating and Waterways. It stopped during the recession and then started again in 2014 for California Department of Fish Wildlife and later the California Department of Water Resources.

As noted during our panel discussion on invasive weeds monitoring, the California Department of Food and Agriculture once had the Noxious Weed Eradication Program, which had dedicated biologists surveying the whole state at regular intervals and taking care of high priority invasive and noxious weeds, and the Weed Management Area Program, which were local stakeholder collaborations focused on control of invasive plants. Each weed management area had their top 10 weeds that they were monitoring and looking out for. Both programs were terminated due to funding issues despite being defined in State code.

3.1.4. Direct Socio-Economic Drivers

Concerning direct socio-economic drivers, there are many monitoring activities for drivers of land use change (agriculture and urban development) based on the inventory analysis. However, there is a possible gap in monitoring of dredging, despite its potential impacts on fish habitat and water quality, and its importance to several management themes (see Nelitz et al. 2020b). Dredging in the Delta is important for flood control, levee stability, and recreation, and can range from marina dredging to major channel deepening (ACOE 2007). When asked if there is a potential monitoring gap with dredging, 11 questionnaire respondents agreed this was a gap, whereas only 1 disagreed. However, 16 respondents did not know and 6 were neutral (N=34; see Figure 5). As with the monitoring of transportation-related activities to manage non-native or invasive species, existing monitoring might be sufficient but is not well integrated with the rest of the monitoring enterprise.

Other socio-economic drivers mentioned less frequently during the review include:

- Water use/demand
- Levees
- Recreation and tourism
- Agriculture
- Socio-economic data gaps generally
- The effectiveness of management actions (including flow, restoration, etc.)
- Perceptions of the Delta as a place (unique Delta values, recreation, cultural and natural resources)
- The need for more detailed information on structure of disadvantaged communities, including access to green space

3.1.5. Fish

Monitoring related focal species of most relevance to decision makers, such as Chinook salmon, steelhead, Delta smelt, and green sturgeon, tend to be relatively well represented in the inventory (see Nelitz et al. 2020b). Status and trends monitoring of fish listed under the State or federal Endangered Species Act are used to inform the water operations of the State Water Project and Central Valley Project (Tempel et al. 2021), and many restoration projects in the Delta are planned to provide habitat for listed fish, like Delta smelt and longfin smelt (DWR and DFG 2012). Despite the wealth of monitoring, some gaps in monitoring were mentioned for listed species with a particular focus on Chinook salmon and Delta smelt during the interviews, seminars/panel discussions, and public comments.

For winter-run Chinook salmon, Johnson et al. (2017) assessed the current monitoring network with existing conceptual models and found that there is limited information on condition, genetic identity, life stage, and abundance once Chinook salmon leave the upper Sacramento River. Some of the gaps associated with Chinook salmon monitoring mentioned in questionnaire responses were consistent with the findings from this article.

Although Delta smelt was noted as having too much focus during the interviews and in questionnaire responses, others also mentioned specific Delta smelt gaps, primarily related to how Delta smelt are sampled. Some of the long-term monitoring programs that are used to monitor Delta smelt were noted as being ineffective, such as the Fall Mid-Water Trawl, which was described as follows during the IEP seminar: *"[It] does not sample well in the shallows (where Delta smelt are) and many critics say it is not a useful sampling device*." However, the Enhanced Delta Smelt Monitoring Program was recognized by several questionnaire respondents as a great improvement (USFWS 2019). During the tidal wetland restoration seminar and panel discussion, presenters spoke to the difficulty of monitoring a critically endangered species that spends a lot of its life in shallow habitats that are difficult to sample. These constraints have led to incomplete ecological and life cycle data, which can make their preservation and restoration particularly difficult (Polansky et al. 2018). In addition, some panel participants raised concerns that it is difficult to receive an incidental take permit to start up new studies or monitoring activities to understand the impact that management actions have on Delta smelt. Food resources are often monitored to assess the value of tidal restoration on this species.

3.1.6. Birds

Monitoring of birds was mentioned multiple times in questionnaire responses as a potential gap. The Delta region provides important habitat for a diversity of birds and may serve as a promising opportunity for bird conservation. Waterfowl, shorebirds, ducks, and birds of prey, including many listed and at-risk species, use and rely on Delta habitats, including managed wetlands, shallow-flooded habitats, grasslands, oak savannahs, and riparian forests, and rely on the Delta as an essential migration and overwintering location (Dybala et al. 2020). However, multiple questionnaire respondents noted a serious lack of bird monitoring in the Delta; for example: "*There are few if any long-term datasets to inform management on birds in the Delta.*" One respondent stated that, "*Monitoring of avian species in the Delta has never been well done, coordinated, or a priority*." Dybala et al. (2020) write that large amount of habitat restoration will be required to maintain healthy bird populations, and without adequate monitoring, bird populations will remain inadequately understood and protected.

3.1.7. Invertebrates

Invertebrates, particularly benthic invertebrates, were also noted by questionnaire respondents and interviewees as being poorly understood due to a lack of spatial and temporal coverage, although they likely play numerous influential roles in the ecosystem. One questionnaire participant stated, "*There are very few programs monitoring life in the benthos, which can be important in understanding nutrient cycling, phytoplankton biomass, food web interactions, and alternate sources for Delta fish. Current monitoring programs lack the spatial and temporal coverage necessary to understand the role and impact of this factor on the Delta ecosystem*." As explained by one interviewee, benthic invertebrates can play an important role in food-web support, but also include non-native species of concern, including the Asian clam and overbite clam. One interviewee commented that, "*There's the DWR program through IEP [the Environmental Monitoring Program] looking at [the benthics], but otherwise we don't have many monitoring programs to understand what the role of benthic organisms are…We need to understand the community composition before effective regulations can start being enacted*."

3.1.8. Habitats

Monitoring of aquatic and terrestrial habitats tend to be relatively well represented in the inventory (see Nelitz et al. 2020b). However, a lack of monitoring in the shallows, which was not tracked in the inventory, was frequently mentioned during the seminars and the interviews. Shallow habitat accounts for a large portion of the habitat in the Delta, and likely plays an important role in providing habitat for fish (including Delta smelt, as mentioned by questionnaire respondents and seminar participants), invertebrates, and phytoplankton. Slow moving, shallow habitats historically supported native fish populations including Sacramento perch, Sacramento splittail, hitch, and others (SFEI-ASC 2014). As good habitat for phytoplankton and invertebrates, these productive areas are likely a significant source of food for fish and essential support for the food web (Odum 1980; Lucas et al. 2002). Although they are difficult to sample, they must be sampled to understand their significance in the ecosystem and to adequately restore them.

Three interviewees commented on the importance of shallow habitats, with one mentioning potential species interactions that may be affecting their ecological role: "*It's in the shallows where people want to have phytoplankton growing, which is also where they can really get going is the shallows, but not if the clams are there, they'll graze them right down*." Not all shallow habitat is the same, however. The high residence time of shallow habitats can support beneficial phytoplankton populations but can also facilitate invasion of non-native submerged aquatic vegetation, including *Egeria* (SFEI-ASC 2014), underscoring the importance of monitoring and understanding shallow habitats across the Delta.

3.2. What is the level of coordination of data collection across different organizations?

Monitoring activities across the monitoring enterprise are implemented, funded, and/or supported by 132 organizations. The nine most common and influential were the organizations that have historically coordinated under the IEP:

1. California Department of Fish and Wildlife
2. California Department of Water Resources
3. California State Water Resources Control Board
4. National Oceanic and Atmospheric Administration
5. U.S. Army Corps of Engineers
6. U.S. Bureau of Reclamation
7. U.S. Environmental Protection Agency
8. U.S. Fish and Wildlife Service
9. U.S. Geological Survey

Our examination of the network analyses, found in Nelitz et al. (2020b), was extensive. It highlighted differences in the number of organizations involved in monitoring networks for various topical areas (e.g., fish monitoring) and also revealed that the density of these networks depends on the issue or topic. For instance, water quality monitoring appears to have a denser monitoring network than bird monitoring (for example, see Figure 6). This suggests that the structures for coordinating and sharing monitoring information should be assessed not just across the entire monitoring enterprise, but within specific issue areas. Although the information from the network analysis cannot be used to prescribe improvements to monitoring networks, it does provide useful diagnostic information for understanding the structure of monitoring networks and exploring ways of strengthening support and coordination among organizations with common information needs.

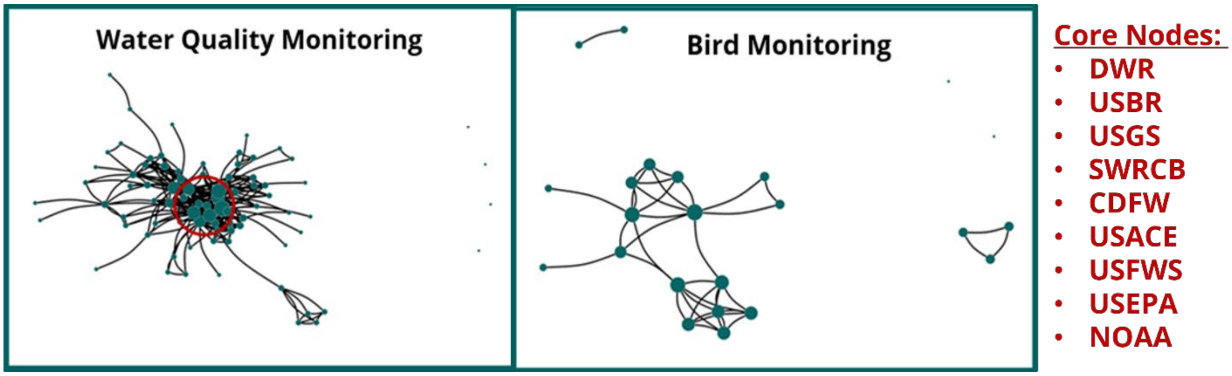


Figure 6. Example of monitoring networks found in Nelitz et al. 2020b.The diagram represents the number of organizations (i.e., nodes or dots) and ties (i.e., lines between nodes) among organizations involved in networks related to monitoring activities associated with different monitoring themes. The size of the node reflects an increasing degree of influence in the network across all possible roles (e.g., implementing, funding, or supporting). The coordinates of dots in the network are not meaningful. Each tie or line between nodes represents a joint interaction between entities around a common monitoring activity, and each tie in the illustration can represent more than one interaction between organizations.

Component 2 analyses further explored aspects of the Delta monitoring enterprise for which coordination can be improved. Currently, the California Department of Water Resources is working to establish the Rio Vista Estuarine Research Station, which will convene State and federal agencies and scientists conducting field programs and monitoring under the IEP into a single location. Moreover, coordination is occurring at some level through project work teams of workgroups for some topical areas, such as the California Water Quality Monitoring Council workgroups, the Delta Interagency Invasive Species Coordination Team, IEP's Tidal Wetland Restoration Monitoring Project Work Team, and IEP's Juvenile Monitoring Project Work Team.

Even so, interviewees pointed to specific issues, such as nutrients, species, flows, food webs, and chemicals/contaminants, which would benefit from greater monitoring coordination. More generally, interviewees highlighted the need for coordinating monitoring across ecosystem components, such as between water quality and agricultural land use; habitat restoration and land use; human health and environmental conditions; and flood control and water quality. As described by one interviewee, "*the floodplain people aren't talking to water quality people downstream…the notion of flood control is traditionally divorced from the notion of water quality. When in fact it should be considered to be a component of water quality, right*?" Questionnaire respondents also generally agreed that changes are needed to support better coordination in monitoring and adaptive management. For example, one questionnaire respondent noted, "*It is not clear there is any integration of monitoring in adaptive management. No biological models being used for adaptive management are being informed by the survey data*."

Several interviewees indicated that the organizations they represented, as well as other key organizations, should be involved in coordinating monitoring. These roles may vary - whether by providing the scientific expertise, the regulatory structure, the organizational venue, or the resources for coordination (e.g., tools, data, communication). Additionally, some interviewees recommended that monitoring plans should take local interests and local knowledge into consideration, so they produce information local people can use.

Monitoring that is better coordinated, and potentially more integrated, across topical areas, as well as spatial and temporal scales, can foster a more holistic understanding of monitoring needs and uncover new ways to solve problems. As one interviewee suggested, "*The more we work together, I think the better it gets for everybody*." These benefits are widely supported by literature on ecosystem management and monitoring. In any ecosystem, coordination of monitoring data is critical for diagnosing and understanding the drivers of complex ecosystem problems, for assessing how policy solutions or management actions affect the system as a whole, and for creating capacity to respond to ecosystem-wide changes (Burton et al. 2014; Schultz et al. 2015; Kupschus et al. 2016; Sparrow et al. 2020). Despite transaction costs and communication costs that occur with greater coordination, there are also opportunities to improve efficiencies in the monitoring enterprise and foster creative problem solving.

There is often a keen interest in the economics of monitoring, but not a lot of detailed data on costs specific to monitoring. For example, there is an interest via the Delta Science Funding and Governance Initiative to conduct an assessment of science funding and the efficiency in use of those funds (Delta Stewardship Council 2019). Coordinating across programs and examining where there are synergies, versus where efforts do not align, can improve the economics of monitoring.

3.3. Are there other opportunities to increase efficiencies in monitoring?

Concurrent with the Delta ISB's review, there have been efforts to review monitoring or make improvements to monitoring, including efforts to develop a steelhead monitoring plan for the Sacramento-San Joaquin basin (see Delta Stewardship Council and USBR 2021); a completed review by IEP on the effectiveness of three IEP monitoring surveys (Fall Midwater Trawl, Bay-Study, and Suisun Marsh Study); and a six-agency effort to review IEP monitoring surveys to meet the evolving needs for management of Delta smelt and longfin smelt (Summer Townet Survey, Fall Midwater Trawl, Spring Kodiak Trawl, Smelt Larval Survey, and 20mm Survey). These efforts and this review of the monitoring enterprise provide collaborative opportunities for more efficient, coordinated, and useful monitoring by the various monitoring agencies.

3.3.1. Opportunities Identified

Through the inventory analysis, the following opportunities for efficiencies were identified:

- Related to monitoring of environmental drivers/conditions, most emphasis of monitoring is on water quality, specifically water temperature, turbidity, salinity, conductivity, and dissolved oxygen. For these parameters, there may be opportunities for increasing comparability of data by standardizing use and calibration of equipment, employing consistent sampling protocols, and centralizing data management. From the questionnaire results, most respondents (21 of 34) agreed with this finding (whereas 3 disagreed, 4 were neutral, and 6 did not know; N=34; see Figure 7). Respondents indicated that the California Department of Water Resources and the United States Geological Survey are working on standardizing their protocols for their individual organizations, so there may be opportunities to build on these efforts.

- Related to habitat monitoring, channelized and tidal wetland habitats are commonly represented across the monitoring enterprise. There may be opportunities for greater coordination of monitoring of habitat and species components since habitat monitoring tends to be driven by species needs. This coordination could be further improved if guided by standardized habitat classification schemes. In the questionnaire, 20 respondents agreed with this finding (whereas 4 disagreed, 6 were neutral, and 4 did not know; N=34; see Figure 7). The State Water Resources Control Board is currently using a standard classification system developed by the science consortium of Southern California Coastal Water Research Project, Moss Landing Marine Lab, and San Francisco Estuary Institute; however, it is not commonly used in the Delta. A valuable first step would involve getting the full monitoring enterprise to agree to a classification scheme.
- Related to species monitoring, the most recurrent species in the monitoring inventory are Chinook salmon, steelhead, and green sturgeon. Based on the network analysis of monitoring activities, fish monitoring appears to be relatively well coordinated, though efficiencies may exist for improving telemetry data collection. In the questionnaire, about one-third of the respondents (11 of 34) agreed that fish monitoring is well coordinated (whereas 7 disagreed, 7 were neutral, and 9 did not know; N=34; see Figure 7). During the course of this review, the Interagency Telemetry Advisory Team was formed, which has helped improve the data collection of telemetry.

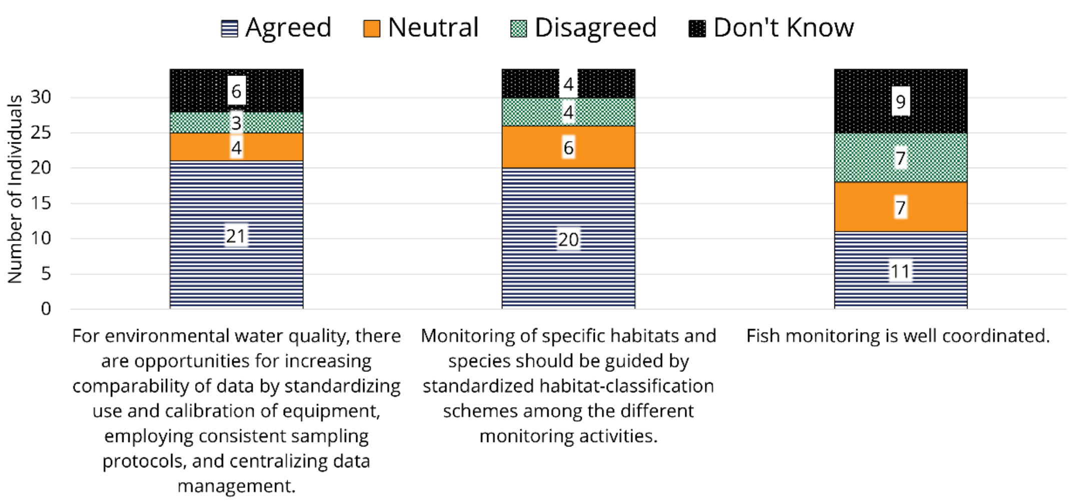


Figure 7. Questionnaire respondents' perceptions of opportunities to improve efficiencies identified from the inventory analysis. Labels within a bar graph indicate the total number of people who selected each response. See Appendix C for more information.

3.3.2. National Wetland Condition Assessment and National Rivers and Streams Assessment

Based on the panel discussion with regional and national monitoring programs, national monitoring programs should include sites in the Delta and coordinate with Delta programs. There is an opportunity to join the United States Environmental Protection Agency's monitoring activity, the National Wetland Condition Assessment (see Appendix A), which surveys the nation's wetlands and assesses the extent to which they support healthy ecological conditions. Field sampling includes assessment of non-native species, which we identified as a potential gap, and a suite of indicators of disturbance to aquatic ecosystems. This effort occurs at five-year intervals and already includes sampling in the Delta. Sampling can be expanded to allow comparisons of wetland conditions between the northern and southern Delta, as well as with the broader nation-wide array of monitoring sites. If the State of California were to agree to develop a proposal with the United States Environmental Protection Agency's Office of Water to add sites in the Delta, there would be no financial costs to the Delta region outside of staff time to develop the proposal. Furthermore, there is an opportunity to participate in the National Rivers and Streams Assessment, scheduled for 2023 to 2024, which assesses the ecological conditions of rivers and streams and the key stressors that affect them throughout the United States. Macroinvertebrates and fish are used to indicate condition, as part of the National Rivers and Streams Assessment.

3.3.3. New Techniques, Technologies, and Analyses

The Delta monitoring enterprise needs to consider incorporating new techniques, technologies, analyses, and database management procedures, which, when integrated, are also commonly known as 'smart monitoring' solutions. We consider this as a key component of our monitoring framework outlined in Section 5. Rapid innovations in sensory material and the advent of new fabrication paradigms of electronic, computer, and bio-molecular technologies have resulted in advanced sensors with vast functionalities at micro, nano- and molecular scales. Modern sensors are miniature, more accurate, fast, rugged, stable, and low power, and at times possess self-calibrating and multifunctional capabilities. Their data rates are extremely high, and because of this, a variety of data storage systems (or 'key-value stores') have emerged with focus on scalability. These sensors typically transmit monitoring data wirelessly, allowing the streamlining of data acquisition and data processing using Artificial-Intelligence (AI) and machine learning techniques encapsulated in Internet of Things (IoT).

Integration of disparate sensors with extremely large volumes of data (i.e., Big Data Paradigm) via wireless networks into a single database, for example on a cloud-based system, is enabled by IoT. AI may perform QA/QC and analyses, data fusion, and identification of causalities, thus transforming Big Data into actionable insights with minimum human intervention. This, in turn, results in lower latency and timely information for management and policy decisions. For example, the NSF-funded Array of Things (AoT) and its successor Software-Defined Sensor Networks (SAGE) for the City of Chicago is of this ilk and may provide useful pointers for development of IoT networks (Licaurte 2021).

A new technique that is rapidly becoming a standard tool is the environmental DNA (or eDNA), where DNA is extracted from an environmental sample (e.g., soil, sediment, water, or snow that contain excretions from live and dead organisms). The rapid space-time diffusion of DNA from its source(s) causes its presence somewhere in the waterbody to be known during sampling. The method involves the collection of water samples, eDNA extraction, and a rapid PCR step to amplify the DNA of the target species. eDNA sequencing can be used to detect rare, transient, and domain obscure species, including non-native/invasive species and their biomass distributions, or to map high-resolution space-time variation of ecosystem change and biodiversity patterns (Darling and Mahon 2011; Chave 2013; Shade et al. 2018). Modern sequencing methods allow identification of entire faunas and rapid ecosystem assessments. eDNA techniques are environmentally benign, multi-species, non-invasive, efficient, easy to standardize, and more accurate than other field sampling methods, although workflow involving eDNA remains specialized (Rees et al. 2014). With ever advancing DNA sequencing technology, the adaptation of eDNA is rapidly growing. As eDNA is a non-invasive technique, it could provide a useful way to sample for Delta smelt to understand the impact of restoration on this fish, given concerns we have heard about the inability to sample for Delta smelt due to the difficulty of acquiring incidental take permits.

Another technique with growing environmental monitoring applications is the Unmanned Autonomous Systems carrying a myriad of sensor systems for spatial/temporal monitoring and analysis, a review of which can be found in Manfreda et al. (2020). Implementation of such systems for Delta monitoring enterprise is afoot (Bloch 2020), and appears to offer great potential, especially for detecting non-native/invasive species, which was identified as a potential gap in our review.

We recognize the challenges of allocating resources to new technologies, but this can be done if adopting new technologies or modifying a monitoring program is considered to be part of the program from the start. New technologies may even produce cost savings through automation (e.g., electronic *in situ* sensors replacing costly boat time).

3.4. Is the data quality of monitoring appropriate to address purposes and needs for information?

There are a variety of desired data attributes that serve as a useful guide for ensuring data (and related monitoring) are of high quality and provide credible information for decision makers (e.g., US EPA 2006). Based on the inventory analysis, a substantial number of monitoring activities (44% or 69 of 157 monitoring activities) meet several fundamental attributes that represent high data quality to address the purposes and needs of that data, such as publicly accessible data, data collection guided by a monitoring design or sampling protocol, and reliable QA/QC procedures (see Nelitz et al. 2020b; Figure 8). From the inventory analysis, roughly 60% of the monitoring activities had QA/QC procedures in place. However, 12 questionnaire respondents disagreed that "*The procedures for quality assurance and control for the sampling methods …are adequate*" (whereas 10 agreed, 3 were neutral, and 9 did not know; N=34; see Figure 9). Several comments from questionnaire respondents noted that a general lack of data (particularly for bird, plant, and invertebrate monitoring) inherently reduces data quality assurance. In a write-in comment on this question, one respondent who disagreed noted: "*The methods are suitable for the program's goals but are not well-documented (especially metadata), tracked, and updated…The Delta science community has placed a disproportionate amount of value on peer-reviewed science publications, rather [than] on documentation and QA/QC, and QA/QC related studies.*"

The scope and breadth of this review did not allow a detailed evaluation of the scientific rigor of all monitoring activities in the monitoring inventory since that would require knowledge of the detailed design and purpose of each monitoring activity. Understanding data quality can provide some insights on scientific rigor. To help provide additional insights, we sought feedback from the Delta community in Component 2. Based on the discussions during the seminars and panels on tidal wetland restoration, monitoring in the Delta needs to pay attention to the statistical criticisms that can be raised against it. One problem of monitoring in an aquatic system arises from the linear array of boat-based sampling. The samples are not randomized and there is a potential for spatial autocorrelation among those samples. It is, however, possible to test for spatial autocorrelation to determine the degree to which the samples are in fact independent of one another or the degree to which they are compromised by autocorrelation.

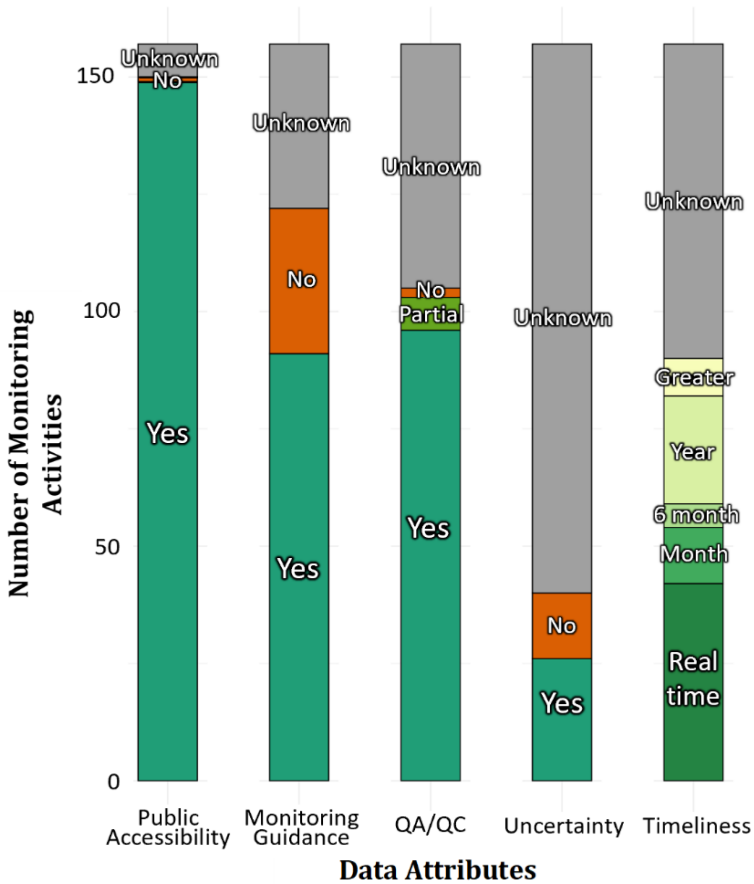


Figure 8. Stacked bar graph representing groupings and counts of monitoring activities from the inventory analysis according to five attributes of data quality (public accessibility, monitoring guidance, QA/QC, timeliness, and uncertainty estimate).

Questionnaire respondents were asked to identify the top two major monitoring parameters they believed the Delta ISB should consider in greater detail and were then asked if the monitoring and QA/QC procedures for these parameters are sufficiently rigorous. A large number of respondents (24 of 34) disagreed that there was enough scientific rigor for the two monitoring parameters they selected (whereas 3 agreed, 4 were neutral, 3 did not know; N=34; see Figure 9). Broadly speaking, several respondents suggested in written comments that the scientific rigor of monitoring in the Delta is inadequate since programs are infrequently, if ever, reviewed for their scientific rigor or how well they address management needs. Others mentioned sampling design flaws and constraints (small sample sizes, fish size bias, inappropriate or inadequate sampling techniques, inadequate and/or inconsistent spatial and temporal monitoring) and topical, temporal, and geographical gaps (birds, plants, invertebrates, shallow habitats, tidal wetlands, night sampling) that result in inadequate scientific rigor.

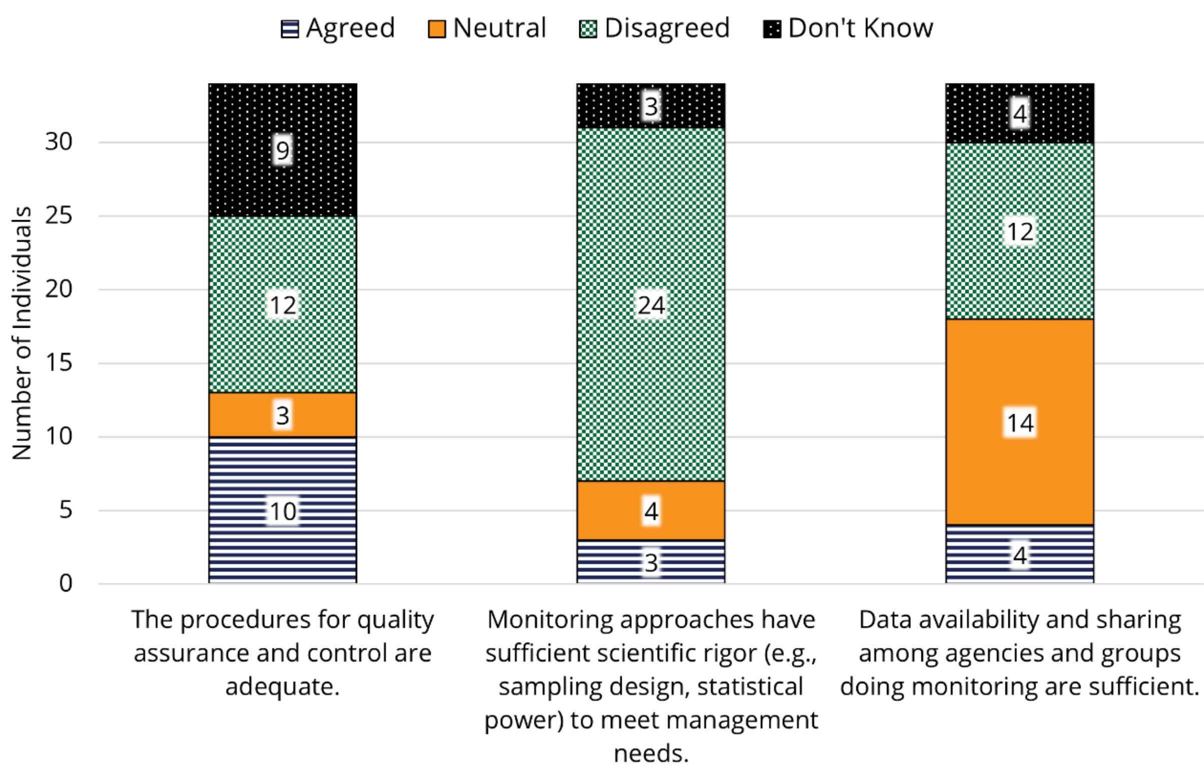


Figure 9. Questionnaire respondents' perceptions of statements related to data quality and availability. Labels within a bar graph indicate the total number of people who selected each response. See Appendix C for more information.

3.5. Are data accessible to the public, decision makers, other scientists, stakeholders, and all interested and affected parties?

From the inventory analysis, 95% of the monitoring activities are publicly accessible (149 of 157 monitoring activities), 63% are machine readable (99 of 157), and 52% are available within a one year or less timeframe (82 of 157). Overall, 34% of all monitoring activities (53 of 157) meet all of these conditions: are publicly accessible, machine readable, and available within a one year or less timeframe (see Figure 10). Although data appears to be accessible, 12 questionnaire respondents disagreed with the statement, "*Data availability and sharing among agencies and groups doing monitoring are sufficient"* (whereas 4 agreed, 14 were neutral, and 4 did not know; N=34; see Figure 9). Regardless of whether a questionnaire respondent agreed or disagreed, there was general acknowledgement in written responses that improvements have been made in recent years. The passage and current implementation of The Open Data and Transparent Water Act (Assembly Bill 1755) has helped, which requires the California Department of Water Resources in consultation with other State agencies to develop and operate an integrated platform for sharing data and for developing protocols for data documentation, data sharing, public access, and quality assurance/control.

Nevertheless, improvements should continue to be made, as datasets are hard to find, lack sufficient documentation, or are not available in a timely manner to conduct analysis, as mentioned by some questionnaire respondents. This is consistent with the inventory analysis, where nearly 95% of the data from monitoring activities are publicly accessible, but this percentage drops to 34% when considering whether the data are accessible in a timely manner and also machine readable (Figure 10). Although there were many comments that improvements in data accessibility have been made in recent years, there was a comment from one interviewee that it appeared there has been a reduction in transparency and data sharing: "*We've noticed a significant reduction in transparency from both the State and federal agencies in recent years, and that is really counterproductive to informing and engaging the public and some of these needs*." However, this depends on the datasets. As part of our review, we found that United States Bureau of Reclamation has improved its efforts in recent years by providing an integrated platform of sharing its monitoring data that it funds related to the in-season management of Chinook salmon via the SacPAS website (Central Valley Prediction and Assessment of Salmon).

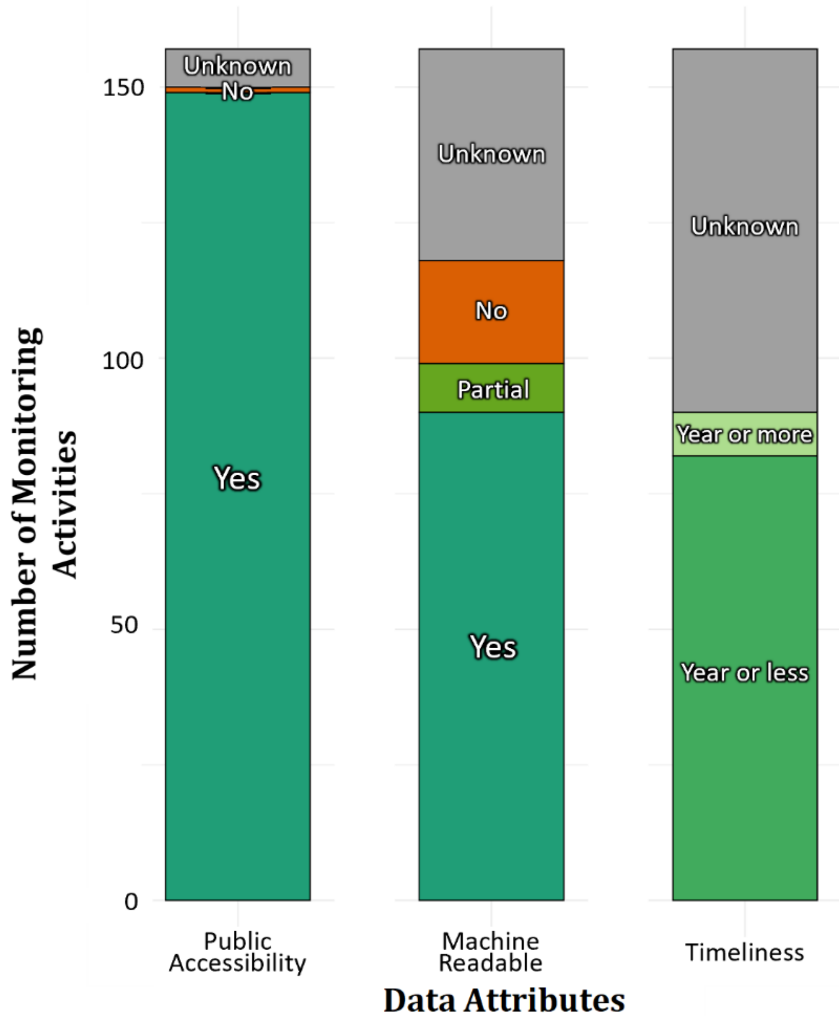


Figure 10. Stacked bar graph representing groupings of monitoring activities according to three attributes of data accessibility (public accessibility, machine readable, and timeliness). Queried from monitoring inventory analysis.

3.6. What resources are being dedicated to monitoring?

Although not the case for every organization that works within the Delta, obtaining funding for long-term monitoring has been a bane because of ever changing funding priorities and mechanisms or because funding carries restrictions. For example, bond funding may provide money for monitoring, but may not follow up and determine the outcomes (i.e., lacks accountability). Dedicated and sustainable sources of long-term funding and greater flexibility in how that funding may be spent are needed to support effective and cost-efficient monitoring programs (State of California 2015; Delta ISB 2016; EcoRestore 2017). As a start, there is a need to quantify the amount of funding spent on monitoring in the Delta.

However, monitoring costs could not be generated for most monitoring activities in the inventory, as the information was not available or could not be disaggregated between monitoring activities (e.g., funding is aggregated by an agency for multiple monitoring activities in the inventory) or within a monitoring activity for different regions (e.g., a monitoring activity has stations in the Bay and Delta). There was annual cost information available for 25% of monitoring activities (39 of 157 monitoring activities).

Although costs of monitoring cannot be determined for all 157 monitoring activities, the DPIIC is now releasing an annual Delta crosscut budget of science and monitoring expenditures that spans State, federal, and local agencies and is working to address the issues identified from the inventory analysis with estimating cost. The first report was released in July 2020 for science related expenditures from July 1, 2018, to June 30, 2019 (Delta Stewardship Council 2020) and a second report was released in July 2021 for science related expenditures from July 1, 2019 to June 30, 2020 (see Delta Stewardship Council 2021).

Information across both years cannot be compared, as more organizations reported in year 1 than in year 2, and there were additional inconsistencies with reporting between years (see Delta Stewardship Council 2021). Even so, the crosscut budget provides information on the level of funding available for the Delta. From July 1, 2018 to June 30, 2019, a total of $47.1M was expended on monitoring, comprising 53% of all science expenditures, including research and synthesis, for that fiscal year. Many of the issues identified from this review are present in these calculations from DPIIC (e.g., it does not disaggregate funding between the Bay-Delta for a single monitoring activity), but the effort is a great start to help improve the understanding on the financial resources devoted to monitoring.

4. Barriers and Opportunities

From our findings, there is a need for more integration and collaboration, and ultimately coordination, across monitoring activities focused on different thematic areas and geographic regions to help identify and fill gaps, and improve efficiencies, data quality, and accessibility. This will help foster a more holistic understanding of Bay-Delta status, trends, and responses to management.

Despite recognition of the need for, and benefits of, greater coordination and addressing monitoring gaps, the in-depth interviews conducted as part of this review highlighted a number of barriers that can impede coordination and the ability to address monitoring gaps (Figure 11). These include what is perceived as the restrictive nature of organizational structures, perceived risks associated with changing monitoring programs, the time and effort required when monitoring staff have other priorities, regulatory and legal constraints, funding, lack of leadership, a perceived disconnect between monitoring and management needs, and poor communication, among others. Funding and organizations working in silos were most frequently identified as barriers for improving coordination or filling gaps.

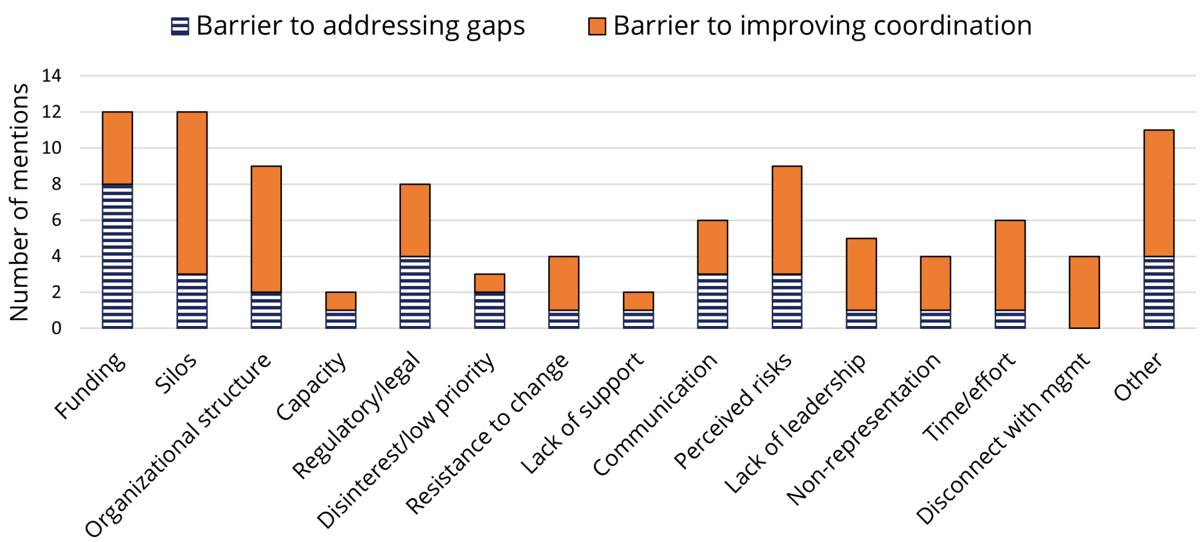


Figure 11. Barriers to addressing monitoring gaps and achieving greater coordination in monitoring. Counts refer to the number of interviewees who mentioned each barrier to addressing gaps and/or barrier to improved coordination in the Delta. Multiple mentions within interviews were counted as a single mention.

Component 2 analyses showed diverse opportunities and mechanisms for overcoming barriers to coordination and filling monitoring gaps in the Delta monitoring enterprise. When interviewees were asked how to address monitoring gaps, their recommendations often related to coordination or reorganization, since these were also seen as strategies for addressing gaps. Opportunities that were identified for overcoming barriers to achieve greater coordination and to fill monitoring gaps can be categorized into four overarching types of change or investments: (1) financial; (2) organizational /structural; (3) regulatory and legal; and (4) cultural/social.

1. **From a financial perspective**, one interviewee noted: "*the strongest tool that's available to make people work/coordinate with each other is the money*". Others mentioned that funds are currently allocated primarily by the California Department of Water Resources and the United States Bureau of Reclamation – and thus there is a need for funding sources that are not tied to the water projects (e.g., the State general fund). Other options that were discussed include the potential for co-funding by multiple organizations, such as through a joint-powers authority, or through end-users of Delta water resources.
2. **From an organizational/structural perspective**, a number of interviewees, as well as questionnaire respondents, indicated a need for adapting existing or creating new organizational mechanisms that allow different monitoring authorities and agencies to work together on monitoring. While some recommended a new entity, or a new a federal-state partnership, others identified existing organizations, such as the Delta Science Program, which could take the lead in coordinating monitoring. Others focused on improving coordination between regulators and regulated entities. As one questionnaire respondent stated: "*If we want better coordination, it should broaden leadership between regulatory and regulated entities so power is shared*." Another interviewee suggested that voluntary agreements between agencies (e.g., similar to the National Estuary Program) can also create the organizational infrastructure needed to establish effective coordination.
3. **From a regulatory/legal perspective**, interviews highlighted the importance of regulatory tools linked to funding streams (e.g., Clean Water Act Section 401 Water Quality Certifications and 404 permits). Relatedly, permits with more specific guidance on goals, use of adaptive management, and coordination could incentivize coordination; or agencies with regulatory requirements, such as the State Water Resources Control Board, California Department of Fish and Wildlife, and National Marine Fisheries Service, could potentially mandate coordination of efforts. Other suggestions related to regulation included outcome-based regulatory options to encourage trying new tools, ideas, and approaches to monitoring; updating the Bay-Delta Water Quality Control Plan; a new set of biological opinions; and a new incidental take permit. One interviewee emphasized the need to understand how various tools complement one another, and how they can be used to coordinate monitoring without imposing excessive burden on regulatory or regulated communities. In addition to these regulatory mechanisms, one interviewee emphasized the potential for either legislation or an executive order to mandate monitoring coordination and provide funding support.

4. **From a cultural/social perspective**, several options for overcoming barriers related to miscommunication, distrust, and risk hesitancy were identified in the interviews. These include spending time building shared vocabularies to avoid miscommunication, as well as building more shared understanding of the state of the system, and convening multi-stakeholder groups and interested parties with diverse interests to ask management questions, form research programs, and discuss findings. Collaborative groups can also conduct more economical experiments (e.g., multiple agencies comparing and calibrating chlorophyll-a measurements) and bring partners closer to collecting comparable data. These efforts can help address hesitancy to reorganize monitoring programs for fear of losing long-term datasets, which was a recurring theme in interviews. To alleviate these concerns, several interviewees emphasized the importance of retaining long-term datasets. One interviewee further noted the importance of having initial champions get the momentum going on these types of effort.

5. A Way Forward: Adopting Adaptive Management, Best Practices, and Recommendations

Monitoring is fundamental to understanding and managing the Delta ecosystem and it is clearly important to optimize the monitoring effort to gain the most information possible. This review has raised a number of questions regarding the monitoring enterprise in the Delta. What can be done to fill gaps and improve the level of coordination, efficiencies, data quality, data accessibility, and communication across this complex organizational structure? To help improve coordination and monitoring that better meets the needs of management, we provide an Adaptive Management Framework for structuring all monitoring programs and also a set of best practices that we recommend to be formally adopted into **individual** monitoring programs. We conclude with three overarching recommendations that are directed at the monitoring enterprise as a whole, which take into consideration the barriers and opportunities described above.

5.1. Adaptive Management Framework for Monitoring

Overall, we advise that every monitoring program or activity develop a monitoring plan or road map using the six-step Adaptive Management Framework (Figure 12) which involves describing (1) the purpose of the monitoring program, (2) how to frame the problem, (3) the monitoring design, (4) program implementation, (5) how information collected will be used and assessed to facilitate learning, and (6) how the monitoring program will be revised, including considerations of periodic independent peer review.

Adaptive management is a science-based, structured approach for decision-making and is required by the Delta Plan for ongoing ecosystem restoration and water management projects. Adopting an Adaptive Management Framework for monitoring (i.e., Figure 12), will provide a more rigorous system for establishing purpose, setting expectations, and conducting review of monitoring programs, as well as fostering communication at all levels. We contend that this approach will provide a vehicle to address many of the questions raised in this review. The Adaptive Management Framework for any given monitoring program should be written as a publicly assessable planning document at the beginning of the program and should include times for stakeholder and public comment/input.

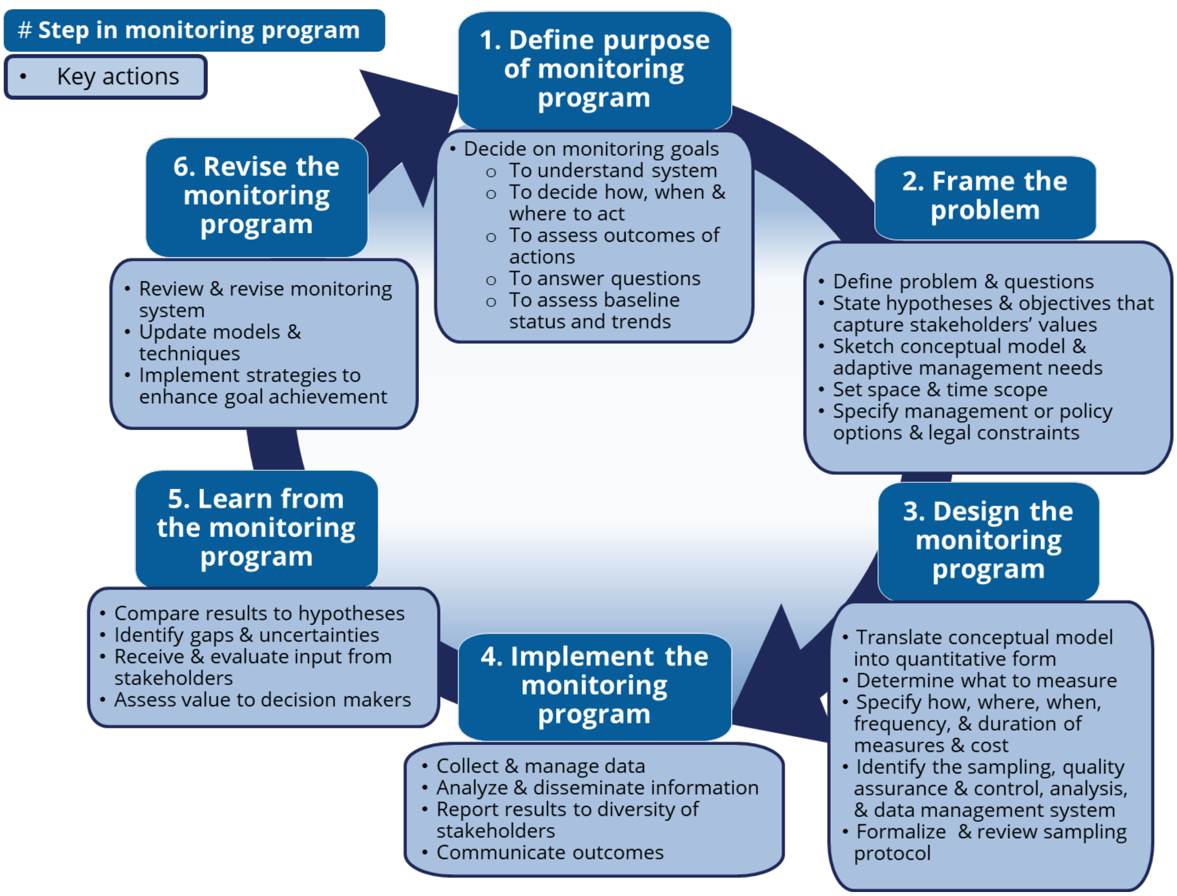


Figure 12. Adaptive Management Framework for a well-designed monitoring program. Based on the road map in Reynolds et al. (2016).

Most noteworthy is the value of adopting a plan that is flexible and can be changed by design if objectives are not being met or conditions and technologies change. Flexibility and change are often not recognized (or funded) as part of a monitoring program when these programs begin.

Each of the six steps for a monitoring program requires actions and decisions as shown in Figure 12 and detailed below. Because objectives, sampling technology, ecosystem processes and drivers, and scientific understanding can change as the monitoring proceeds and new information becomes available, the program is depicted as a cycle. While some steps can be initiated simultaneously, finalization of later steps depends on completion of the prior steps. Iterations within and among the steps can occur as a step is influenced by new information. The entire circuit may be reinitiated if monitoring objectives are adjusted in view of changing conditions, priorities, or available information.

Step 1: Define Purpose of Monitoring Program. The first and perhaps most critical step is to clearly define the purpose of the monitoring program. The goal(s) of a monitoring program could be to better understand the system; to decide how, when, and where to take actions; to assess the outcomes of actions; to answer specific management or scientific questions; and/or to assess baseline status and trends. A clear statement of the purpose will help better define the scope of the monitoring itself and clarify understanding for monitoring practitioners, stakeholders and other interested parties. This step is critical when assessing potential gaps. While monitoring programs can and do serve multiple purposes, the framing, design, implementation, and learning from the program should be able to be traced back to individual goals. Lumping all of the goals into one grand and general goal (e.g., we want to learn about fish in the Delta) has the real danger of not being specific enough to test the monitoring capability and validity.

Step 2: Frame the Problem. Once the purpose has been established, the monitoring scope can be further tuned or framed. Framing the problem includes several components. First, key questions or hypotheses that are being assessed should be explicitly set forth. For example, as part of the adaptive management process, "Will 'X' change as a result of this management action?", the management action might be designed to produce a desired change in "X" (e.g., if "X" refers to an at-risk fish species, the action may aim to improve fish survival); or managers may be concerned that "X" could be negatively affected by the management action (e.g., result in reduced fish survival). Sketching a model of the key components that includes interactions within the system will better set expectations and thresholds for the adaptive management process. Models can be conceptual or numerical. In some cases, numerical models of hydrodynamics, water quality, and lower trophic levels, or parsimonious system models, can make conceptual models more precise (and perhaps more accurate) and provide a means of integrating results of monitoring to improve our predictive and conceptual understanding, as well as management, of problems (Hollings 1978). Models that predict responses to changes in drivers are particularly useful. Assumptions should be clearly stated. Framing the problem also requires setting the space and time scales of the monitoring program. For example, is sampling required across the entire Delta or only in a localized area? The extent and duration as well as the frequency and density of monitoring should be specified. Identifying boundaries can be challenging, particularly if products or wastes are exported outside the system.

The final part is to identify management or policy options as well as any legal constraints.

Step 3: Design the Monitoring Program. Designing a monitoring program must be based on science and the purpose of the monitoring program (step 1) and how the problem is specified (step 2). The design step requires that the conceptual model be translated into a quantitative form. The monitoring design includes the metrics (what will be measured), the methods (how will the measurements be taken), and the sampling design (where, when, and the frequency & duration of measures). The cost of the monitoring program should be part of this process, recognizing that often the cost of monitoring restricts what can be implemented. The design also includes the sampling regime, quality assurance and control, analysis, and the system for data management. A final component is formalization of the sampling protocol. When possible, the design will benefit from a scientific and statistical review before implementation.

Step 4: Implement. Implementation of the monitoring program is straightforward if the prior steps have been followed. Implementation includes the collection and management of data according to the established protocol as well as analysis and sharing of information. Results should be reported to stakeholders in a way that suits their experience, knowledge, and modes of communication. Communication of outcomes from the monitoring program should highlight effects and potential consequences of current activities in the system and anticipated changes.

Step 5: Learn. Learning from the monitoring program is a key part of making monitoring an adaptive management process. An assessment of the monitoring program should be established on a regular basis and initiated by the program managers/funders as part of the monitoring program itself. It should not be an afterthought. This assessment asks the basic question: Is the monitoring program effectively addressing the goals as originally stated? This assessment can be done in a number of ways and at various levels of rigor. It could include quantitative assessment of uncertainty or levels of confidence, stakeholder engagement, or independent review. Are there changes in technology which could improve the monitoring program? Are there gaps in the data or redundancies? Has the ecosystem changed sufficiently to warrant a new conceptual model or new expectations? Are current assumptions or theories still valid or should they be rejected, or (as is frequently the case) modified based on the new information? Sometimes the information from the monitoring program can be used to refine and improve quantitative models of the problem. The information learned can then be conveyed to stakeholders for their evaluation. The learning should be communicated to decision makers with a request to assess its value.

Step 6: Revise Monitoring Program. Revising and updating the monitoring program is the final step. Information about the knowledge gained, gaps, uncertainties, and value of the monitoring program should guide the revision. Furthermore, models and techniques may need to be updated based on the learnings from the monitoring program, new information, new pressures to the system, anticipated changes, or advances in sampling procedures. These revisions may improve strategies to enhance goal achievement.

5.2. Best Practices for Individual Monitoring Programs

Individual monitoring programs should be underlain by five best practices to help address some of the challenges and issues with monitoring identified in the review (Figure 13): (1) formally tie monitoring to goals, objectives, and questions; (2) be informed by stakeholders needs and capability and include alternative forms of data and knowledge; (3) adapt as new information and technology become available; (4) include data management, analysis, and synthesis; and (5) ensure data are accessible. Each practice should be a part of each step in the monitoring program. We recognize that some monitoring programs are already incorporating best practices and incorporate elements of the monitoring framework to varying extents, but not in an Adaptive Management Framework like we propose. A useful first-step exercise would be for each monitoring program to evaluate adoption of these practices in their own program.

The five best practices identified for this review are meant to be actions that most monitoring programs could implement immediately in efforts to improve monitoring. Although they are strongly recommended, we recognize that each best practice may not be appropriate or applicable for all monitoring programs or in all situations. For example, there could be some potential limitations with what can be changed or be informed by stakeholder input, as some compliance monitoring is set by the regulatory agency. However, having compliance monitoring activities follow this framework will bring more value to monitoring and is something that regulators should consider.

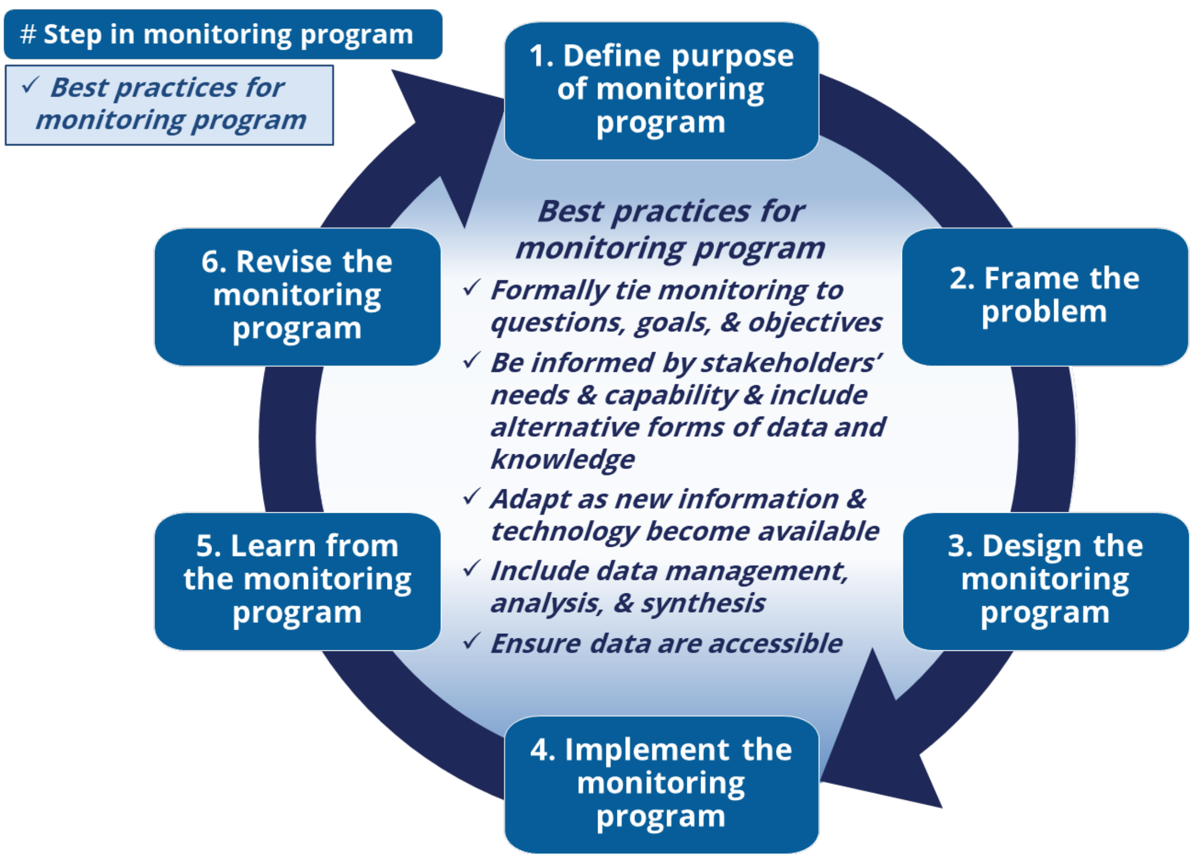


Figure 13. Best practices for individual monitoring programs. Best practices should be a part of each step in the monitoring program.

1. **Monitoring should be closely tied to the goals, objectives, and specific questions of interest to managers, decision makers, scientists, and stakeholders.**

Specific management and/or scientific goals, objectives, and questions must be defined to focus monitoring system design on the collection of data that will be most relevant to decision-making, especially when resources are limited. Linking monitoring with the design of management actions will also help to ensure that the monitoring is targeted towards key parameters and appropriate time and space scales, informative, and cost-effective rather than broad-based and unfocused (IEP-SAG 1999; CAMT 2017; see Reynolds et al. 2016).

As stated above, a clear monitoring goal is critical for improving the linkage of monitoring to management and identifying gaps. Several commenters from the seminars and interviews identified a disconnect between management needs and monitoring as a barrier to improving coordination and addressing monitoring gaps. As indicated in the questionnaire results, nearly half (16 of 34) disagreed that overall monitoring was serving the needs of decision makers across the Delta (see Figure 4). Although there are cases where data have been successfully coopted to serve purposes that it was not explicitly designed for, the use of monitoring data to address management needs that the data was not explicitly designed to address was noted during our panel discussion on tidal wetland restoration monitoring as a common practice that can result in ineffective management. More relevant and directed monitoring, designed through communication between managers and scientists, would help "*to bridge the gulf between articulated need and usability*," as described during one of our interviews. However, many interviewees warned that this improvement should not come at a cost to current long-term monitoring programs that serve an essential role of monitoring long-term trends and ecosystem drivers, emphasizing that both types of monitoring must be prioritized in the monitoring enterprise. Additionally, this best practice can be difficult to implement in cases where questions and priorities change rapidly and cannot always be addressed.

Monitoring goals, objectives, and specific questions need to be made clear at the beginning of a monitoring program so that all interested and affected parties, decision-makers, and those designing and implementing monitoring programs can recognize the value of the monitoring programs and understand the proper use of the data. Communication at all levels is essential for a successful monitoring enterprise. A need for additional efforts of "coordinating the coordination" through improved communication between scientists and managers was discussed as a way to improve the efficacy of the monitoring enterprise during our seminar and panel discussion on tidal wetland restoration monitoring. Staff should be aware of program goals to ensure data quality and proper decision making.

2. **Monitoring should be informed by the needs, capabilities, and participation of all stakeholders and other affected parties and, when appropriate, include use of alternative forms of data and knowledge such as Traditional Ecological Knowledge, experiential information, and qualitative observations.**

Stakeholders are broadly defined as "*any person or group who is involved in, has responsibilities toward the success of, or is affected by a curse of action*" (from Dale et al. 2019). For monitoring we include those individuals that use monitoring information which includes the general public, elected officials, and governmental and non-governmental organizations. In addition, monitoring programs may affect parties such as sovereign Tribal governments which, having unique legal and cultural status, and hold more than just a "stake" in issues that may be addressed by monitoring. Stakeholders are recognized as a key component to the monitoring enterprise, but they are often neglected. Multiple interviewees identified the issue of some entities not having a seat at the table as a major barrier to coordination and reorganization of the monitoring enterprise. The definition of a successful monitoring program can differ among stakeholder groups, therefore early involvement can be important for context framing and identification of constraints. Without stakeholder support, programs will likely face difficulties launching and integrating into the monitoring enterprise. Although engagement with stakeholders and other affected parties can be overall beneficial for monitoring programs, several commenters noted that relying on these parties to guide the direction of the monitoring enterprise is "*not likely to result in a robust program that is representative of broad interests*," and should be used when appropriate, but not overly relied upon. However, stakeholder engagement and co-generation improves monitoring programs by providing alternative forms of information, such as qualitative or experiential observations, and Traditional Ecological Knowledge. The unification of Traditional Ecological Knowledge with Western Ecological Knowledge not only improves natural resource management, but also enhances the protection of the Delta's unique cultural values (Zedler and Stevens 2018).

Best practices for engagement with stakeholders and other affected parties include situational awareness of the place and problem, creation of a suitable culture for engagement, focus on power-sharing in the engagement process, co-ownership, co-generation of knowledge and outcomes, the technical process of integration, the processes of reflective and reflexive experiences, and regular and transparent communication (Kliskey et al. 2021). Situational awareness requires knowledge of the diverse worldviews and cultural experiences of the stakeholders and communities being engaged. Appropriate cultures for successful engagement are based on empowerment, trust, and equity (Reed 2008). Power sharing requires initiating engagement early, creating repeated engagement opportunities, and sustaining the engagement process. Co-ownership requires attention to the power dynamics among those being engaged so as to allow all contributions to be valued, for different actors often have unique insights into the dynamics of the system. Co-generated knowledge involves stakeholders and/or other affected parties at all stages in the monitoring program. The technical process of stakeholder engagement requires explicit integration of stakeholder knowledge and science using a wide range of approaches. Reflective and reflexive approaches to stakeholder engagement include the sharing of experiences and discussion of uncertainties, risks, and shortcomings that arise in the engagement process (Khodyakov, et al. 2018; Thizy et al. 2019). Regular and transparent communication among stakeholders and scientists fosters successful stakeholder engagement and co-generation of knowledge.

Capacity limitations can be a significant barrier to cross-agency and cross-jurisdictional collaboration on monitoring and management at broader ecological scales, particularly in a system driven by the frequent emergence of crises that divert attention from long-term efforts. Only when individual agencies and programs are capable of fulfilling their basic mandates will they be able to consider and support broader, overarching, and cross-jurisdictional issues (Hoenicke and Hoshovsky 2002; Delta ISB 2016; Delta Stewardship Council - Delta Science Program

2017). During our interviews, funding, capacity, and staff time were identified as key barriers to improving coordination of monitoring or addressing key gaps (Figure 11). When internal capacity is limited, citizen-science monitoring programs carry great potential to expand regional monitoring capacity, provided that sufficient training, support, and oversight can be provided (USEPA-SFEP 1994; Grossinger et al. 1996; SFEP 2007, Skinder and Hoover 2009; Kraus-Polk and Milligan 2019).

Citizen science can be most effective when there is an objective approach, such as photography or identifying a distinct event (e.g., a levee break, or presence of an easily identifiable invasive species, which were gaps identified during this review). One commenter during our panel discussion on national and regional monitoring programs noted that there is clearly a role for community involvement in monitoring, noting that The National Oceanic and Atmospheric Administration's (NOAA) cooperative data collection program has been using climate data collected by people with gauges in their backyard for decades. This panelist further acknowledged that although citizen science can provide some useful data, a fair amount of effort is needed to make these program rigorous enough so that the monitoring information can be interpreted and put to good use. Citizen science information can be useful as an addition to professionally collected data, but can be unreliable, so incorporation must be carefully designed and evaluated.

3. **Monitoring plans should have enough flexibility to take advantage of new information and opportunities to adapt to issues as new techniques and technologies become available.**

Several commenters from the seminars/panels and interviews noted inflexibility, either in funding or in permits, as a barrier to rapid responses to management needs. It was noted that a large share of IEP monitoring is compliance monitoring or a result of a regulatory mandate, resulting in programs that are difficult to adjust. Flexibility, where possible and appropriate, could help to address monitoring and management gaps more quickly. A monitoring plan in the adaptive management context should be seen as a living document, where changes could be made to meet evolving needs. Essential long-term information should always be collected, but additional monitoring information may be subject to modification as needed based upon critical evaluation. However, one interviewee warned that "*flexibility and adaptation within a regulatory framework can deprive the regulated communities of their rights,*" and therefore should be very cautiously used in regulatory requirements.

Investment of time and resources into exploring the potential of new monitoring techniques and technologies (e.g., remote sensing, real-time monitoring systems) can increase program capacity to collect data more efficiently across broader spatial and temporal scales or answer new monitoring and management questions than previously possible using traditional methods (Cloern et al. 2002; Hestir et al. 2008; IEP-SAG 2013; Fichot et al. 2015; Healey et al. 2016; Schiff et al. 2016; Bergamaschi et al. 2017). Some of the modern techniques highlighted during the questionnaires and interviews include remote sensing, eDNA, and large sample statistical techniques ("Big Data"). When considering new technologies or techniques, especially for long-term monitoring programs, there must be mechanisms in place that guide how to and whether to incorporate new technologies or techniques.

Using modern techniques for data collection and analysis will improve programs by reducing incidental take, increasing accuracy and precision, and improving data synthesis and communication. Some of these techniques can come at a high cost and are not appropriate for all programs but can greatly improve others and should be considered, where feasible. Although it has notable limitations, eDNA was suggested as a promising strategy during our seminar and panel discussion with national and regional monitoring programs for detection of rare species and could be used to limit mortality of sampling for listed species, especially Delta smelt. Big Data approaches are useful for discovering the "*hidden needle in a haystack of data*." This is especially valuable for any kind of high frequency monitoring especially one that generates volumes of data.

Monitoring programs should set up a formal independent scientific review conducted at regular time intervals to reassess the effectiveness of the program at achieving its goal(s) with recommendations for improvement, and whether information is collected at the appropriate time and space scales. There should be mechanisms in place on how to transition a monitoring design to different temporal or spatial scales or sample density when warranted. There is often resistance to changing a monitoring scheme and having a mechanism in place for establishing a culture amenable to change and adaptation for scientifically valid changes of a program would be important.

4. Monitoring programs must include adequate data management, quality control, analysis, and synthesis, and should strive to improve statistical validity.

Data in specific subject areas have often been collected faster than they can be analyzed using sophisticated statistical procedures or simple numerical models (Hoenicke and Hoshovsky 2002). Data analysis, interpretation, and reporting out to policy makers, managers, and the public should have equal priority with data collection and be resourced accordingly to support evidence-based decision-making (Luoma et al. 2011; CAMT 2017). As we learned during the water quality seminar and panel discussions, lack of data analysis and communication causes data siloes, which have resulted in separate and compartmentalized science that has impeded the ability to make informed management decisions.

Many questionnaire write-in responses noted that, although data analysis, synthesis, and communication have been improving over time, they are still inadequate and must continue to be improved and prioritized alongside data collection. Multiple write-in responses suggested that adequate data analysis and synthesis are important for addressing gaps in the monitoring enterprise, and that programs will not be effectively updated without it. Several questionnaire respondents and panelists noted that this is not an easy task enterprise-wide, can be costly, and may require additional training, support, and guidance to be done properly. Expressing views similar to the seminar and panelist participants, many questionnaire respondents did not feel that data are analyzed or synthesized in a way that enables management decisions. They perceived that synthesis is not well-connected to management decisions or communicated in an accessible or timely manner to those who need the information.

To improve statistical validity, monitoring designs should be developed with the assistance of an environmental statistician to produce sampling designs that are: representative of variability in conditions, account for confounding factors and shifting baselines, and make efficient use of limited resources to produce robust results that can be used to draw predictive inferences about unmonitored sites to answer specific monitoring questions (CAMT 2017; Raimondi et al. 2016).

Several comments during the seminars were on the issue of statistical reliability in many monitoring programs and suggested integrating hypothesis testing and quantitative approaches whenever appropriate to improve statistical validity.

However, interviewee comments additionally acknowledged that it is not always feasible to collect statistically rigorous data in the field, due to the scale of the monitoring enterprise, limited resources, and the unpredictability of collecting biological data.

5. **Monitoring programs should ensure data are accessible and shared with the public and other agencies.**

Data accessibility, usability, versatility, and interoperability across databases and models are critical to serve a wide variety of different user needs and to promote the use of monitoring data in decision-making across multiple thematic, spatial, and temporal scales (NSF 2016). Although our inventory analysis indicated most data from monitoring activities in the inventory were accessible, several interviewees noted data inaccessibility, both intentional and unintentional, as a major barrier to addressing monitoring gaps and reorganizing the monitoring enterprise. Similar to the effort of improving the statistical robustness of monitoring programs, proper data accessibility takes time and resources and may require training, support, and guidance. Although the seminars and panels and interviews made it clear that data accessibility and communication have improved in recent years, a more intentional and concerted effort by monitoring programs to improve data accessibility would greatly benefit the monitoring enterprise and encourage trust building between decision makers, scientists, and the public. These efforts should be done in coordination with and build upon the efforts of the California Department of Water Resources to implement The Open and Transparent Water Data Act (Assembly Bill 1755).

5.3. Recommendations

Consideration of the best practices for developing a monitoring plan by an individual monitoring activity or program would help address some of our findings related to the disconnect between monitoring and management, communication, and data quality and accessibility. However, more transformative changes may be needed to help ensure monitoring is responsive to needs of management at the enterprise level, as there are not agreed-upon adaptive management questions that monitoring should inform spanning the management areas of water supply, water quality, flood, species, habitat, and land use to achieve the coequal goals. Without such management questions, we cannot fully assess how monitoring is addressing the informational needs of management agencies.

Therefore, we make three recommendations (or "big moves" as adopted from the inventory synthesis) that could better link monitoring to management and begin to address the gaps and opportunities to improve efficiencies described in the previous section of the report (Figure 14).

The implementation of the three recommendations is interlinked and should be guided by the monitoring framework in Figures 12 and 13, which could ultimately lead to a monitoring plan for the entire Delta monitoring enterprise. These recommended changes will be difficult to implement, but the complexity, urgency, and long-standing nature of many challenges facing the Delta dictate the need to do things differently.

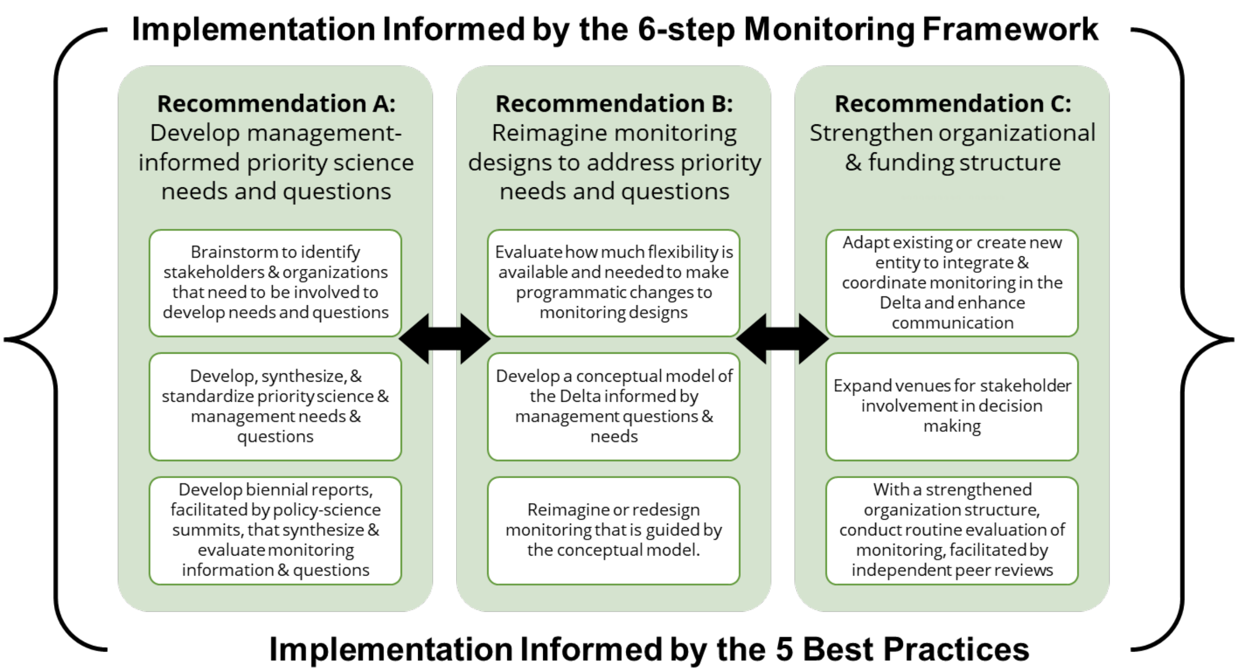


Figure 14. Road map for implementing the three recommendations of the review guided by the monitoring framework and best practices.

Recommendation (Big Move) A:

Develop priority management-informed science needs and questions for the monitoring enterprise and synthesize information around these questions in biennial reports or at a policy-science summit.

Most monitoring guidance emphasizes the need for a clear purpose at an early stage of monitoring design (e.g., US EPA 2006; McDonald-Madden et al. 2010; Roni et al. 2013; Reynolds et al. 2016), which is reflected in in step 1 of our monitoring framework (see Figure 12 and 13). Having a clear and appropriate purpose is important since not all problems are well suited for adaptive management (Murray et al. 2015; Wiens et al. 2017; Delta ISB 2016). Adaptive management represents one clear and often required learning strategy available to scientists and decision makers in the Delta Plan. This review of the monitoring enterprise revealed that there are a multitude of management themes around which adaptive decision making could focus and many monitoring activities collecting data, each with their own dedicated purpose. However, few long-term monitoring activities focused on resolving fundamental management uncertainties that underpin the reason for applying adaptive management. This recommendation promotes a shift toward providing a clearer synthesis of the state of knowledge, including fundamental management uncertainties of relevance to the Delta, more standardization in the way the Delta and its management uncertainties are described and referenced, as well as more focus around the priority science and management needs for monitoring and adaptive management.

More work is also needed to increase specificity on management-informed science questions to guide monitoring and adaptive management. For instance, workshop participants revealed a long list of over 150 questions of relevance to monitoring and adaptive management yet had little agreement around the fundamental questions (or hypotheses) of most importance (ESSA et al. 2019). Moreover, 23 of 34 questionnaire respondents disagreed that "*there is a common understanding of the priorities required to meet science and management needs*" (whereas 3 agreed, 5 were neutral, and 3 did not know; N=34; Figure 15).

Written responses from the questionnaire indicated that it was not necessarily a disadvantage or surprising that organizations would have their own priorities and needs. For example, one write-in response stated, "*Science and management is not one monolith – there are many needs, and it doesn't seem useful to force 'science' into one box*." Science needs are hypothesis-driven, while management needs are driven by day-to-day operations. However, according to interviewees, some of the greatest barriers to filling gaps or to improving coordination are related to organizations working in silos (Figure 11). In other words, organizations contributing to monitoring have their own interests and priorities – with monitoring programs designed, accordingly, to collect data differently.

Synthesizing, standardizing, and developing priority science and management needs and questions would be an important first step toward beginning to address this barrier. The development of priority management-informed science questions should be guided by step 1 (Define the purpose of monitoring) and step 2 (Framing the problem) of the monitoring framework (Figures 12 and 13). People and stakeholders representing diverse disciplinary and organizational affiliations may need to be engaged to identify different types of monitoring needs that span the physical, biological, chemical, geological, and social sciences and the previously described management areas to achieve the coequal goals. In the review of Delta as an Evolving Place (Delta ISB 2017), the Delta ISB found that there was a need to better integrate the natural and social sciences. The Delta Science Program or DPIIC could take a lead here.

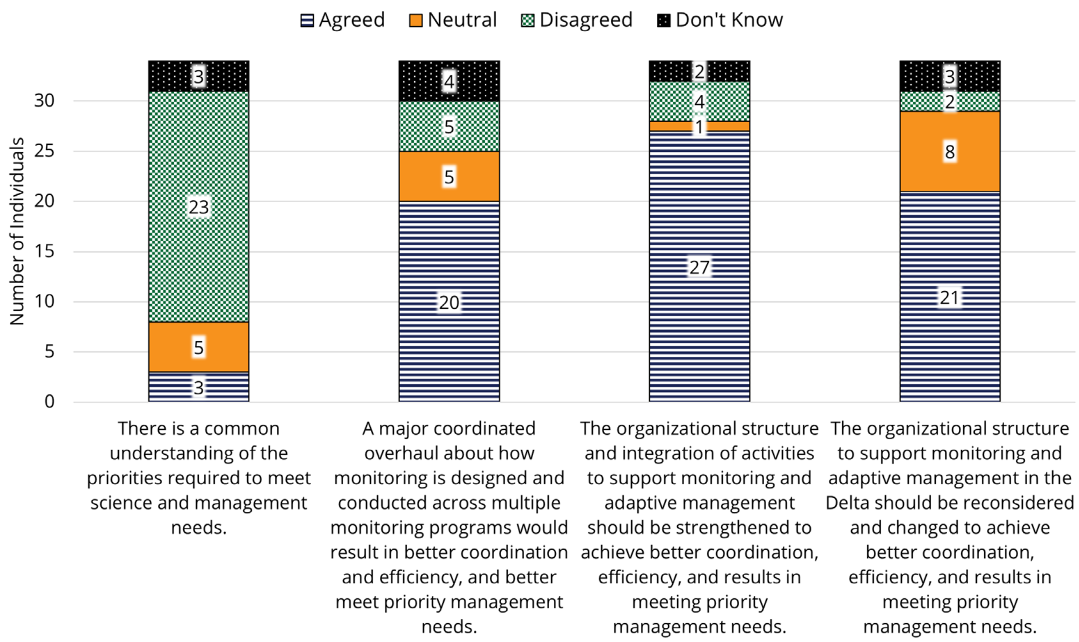


Figure 15. Questionnaire respondents' perceptions of changes needed in the Delta monitoring enterprise. Labels within a bar graph indicate the total number of people who selected each response. See Appendix C for more information.

As part of this review, some interviewees and questionnaire respondents identified gaps related to the socio-economic drivers of monitoring, but no major themes arose. However, it is important to note that there was less representation of perspectives from those working in land use or flood management, compared to those working in water supply or habitat management (see Appendix C and D).

When developing management-informed science needs and questions, it will be essential to solicit perspectives from these management areas and the social sciences. A variety of existing resources are available to provide guidance on how to implement this recommendation (e.g., US EPA 2006; Reynolds et al. 2016). Furthermore, the 2022-2026 Science Action Agenda update is identifying and prioritizing management questions and science actions to address research gaps and could be used as a framework for developing management-informed questions and needs for monitoring.

With the development of priority management-informed science needs and questions, the Delta Science Program could facilitate the development of biennial reports that synthesize monitoring information to answer these questions, assess whether there are any gaps in answering these questions, and evaluate if any changes need to be made. Regular evaluation is increasingly important to ensure needs and questions have not changed as new issues arise from climate change, for example, or when unexpected consequences of management actions become known as part of the adaptive management cycle. The biennial reports could provide opportunities to integrate siloed monitoring by answering broader questions that are identified by the enterprise. These monitoring reports could be facilitated by policy-science summits to help synthesize information. The development of these reports should be guided by steps 4 to 6 of the monitoring framework.

Recommendation (Big Move) B:

Reimagine monitoring designs that are guided by priority questions and needs and a system-wide conceptual model.

Many monitoring activities across the monitoring enterprise have not been designed and/or implemented to explicitly support adaptive management in the Delta. For instance, there is limited effectiveness monitoring, which represents only 3% of monitoring activities in the inventory, and some potential gaps in the availability of monitoring to provide data on parameters of relevance to all management issues. As a result, it is unrealistic to expect that the broad collection of monitoring activities will adequately meet the diversity of adaptive management needs. In addition, deficiencies in monitoring can be difficult to address after a monitoring design has been implemented (e.g., Downes et al. 2002).

For these reasons, achieving improvements in coordination of monitoring among different organizations, ensuring sufficiency of coverage, and identifying other opportunities for efficiency gains may best be served by reimagining the monitoring designs for priority monitoring needs, as opposed to finding piecemeal ways to adjust existing monitoring activities that were never designed to work together. Hence, the intent with this recommendation is to encourage investments in a reimagined monitoring design that is more systematic, integrated and targeted toward priority needs that are of fundamental importance to decision-makers and adaptive management across the Delta. Such investments may become increasingly essential for understanding and responding to the rapid changes facing the region (Norgaard et al. 2021).

Reimagining monitoring designs could entail deciding which data from current monitoring activities could be used to answer the priority questions, and where changes to the design are needed to address priority questions. To advance implementation of this recommendation, it is important to consider how monitoring stations for different parameters like fish and water quality can be co-located in space and time, as recommended in our water quality review (Delta ISB 2018) and the Delta Science Plan (Delta Stewardship Council - Delta Science Program 2019). Furthermore, when reimagining a monitoring design, we suggest employing principles of monitoring design – randomization, stratification, and replication (Cochran 1977; Green 1979; Sit and Taylor 1998; McDonald 2003 US EPA 2006; Montgomery 2012).

In our questionnaire, 20 respondents agreed that "*a major coordinated overhaul about how monitoring is designed and conducted across multiple monitoring programs would result in better coordination and efficiency, and better meet priority management needs*" (whereas 5 disagreed; 5 were neutral, and 4 did not know; N=34; Figure 15). Among interviewees there was an interest to make monitoring more programmatic rather than driven by compliance or specific management drivers (e.g., Water Right Decision 1641), and also in better integrating modeling and monitoring with key management needs. However, we understand that many of the monitoring activities are part of "compliance monitoring," particularly when key decisions are based off a particular monitoring station (e.g., water quality compliance under Water Right Decision 1641). As a result, there are some limitations in what can be changed without revising permits. Even so, permits often do not specify how monitoring should be designed.

To implement this recommendation, we suggest as an initial step exploring where there is flexibility to make changes to the monitoring design, as many of the programs are considered part of compliance monitoring. Understanding the level of flexibility in monitoring design is especially important as new issues increasingly arise from climate change, droughts, invasion of new non-native species, and continued decline of some species listed under State and federal Endangered Species Acts, which require rapid programmatic response (Delta ISB 2019b).

A major concern of practitioners with an improved monitoring design is the risk of losing long-term datasets or losing the quality of a dataset if changes are made. However, there are methods described in the literature for cross-calibrating data between different methodologies. For example, different gear types and trawling methods are used across monitoring activities to sample zooplankton in the Delta (Kayfetz et al. 2020). Methods exist for comparing zooplankton data collected using different methods; although, there are limitations (Ohman and Smith 1995; Clark et al. 2001; John et al. 2001).

Also, many long-term monitoring programs have undergone changes to sampling, including the Delta Juvenile Fish Monitoring Program (USFWS 2019) and fish salvage at the John E. Skinner Delta Fish Protective Facility (Morinaka 2013). Many individual monitoring programs or activities, such as the California Department of Water Resources' Environmental Monitoring Program, have undergone periodic peer review and incorporated programmatic changes from their peer reviews (see Mueller-Solger and Hymanson 2003 on how the Environmental Monitoring Program addressed recommendations from a technical review by the IEP Science Advisory Group that involved stakeholder engagement).

The clarity provided by an improved understanding of priority needs from **Recommendation A** will ensure that a monitoring design is guided by a clear purpose. Implementation of **Recommendation B** should be guided by step 3 of our monitoring framework (Design the monitoring program; see Figure 12 and 13). To help improve a monitoring design, it may be useful to develop a comprehensive conceptual model that looks at the system holistically. Such a comprehensive conceptual model currently does not exist for the Delta at the level needed for system-wide evaluations of major driving forces and responses (e.g., Figure 3). Developing this model will be possible once the management questions or needs are known. A comprehensive conceptual model could be used to identify major uncertainties and gaps related to addressing the management questions. A conceptual model depicting how the system works provides a mechanism for an entity to justify sampling some parameters and not others. Many conceptual models for various topical areas currently exist and could help with developing a comprehensive conceptual model to guide and coordinate monitoring efforts.[3]

Recommendation (Big Move) C:

Strengthen the organizational and funding structures to support monitoring integration, analysis, and adaptive management.

Studies and reviews of monitoring programs have found that coordination and integration are among the important functions being provided by an effective organizational structure (Green et al. 2015) and several others have noted that these functions could be strengthened for the Delta (e.g., Herrgesell et al. 1993; Bernstein et al. 1997; Cloern et al. 2002; CWQMC 2008; 2010; Noon et al. 2017). Many components of an organizational structure already exist in the Delta for monitoring or coordinating data, such as the California Water Quality Monitoring Council workgroups, the Collaborative Science and Adaptive Management Program, and the IEP. However, this structure may not lend itself to implement the recommendations described above using the monitoring framework laid out for this review.

The Delta monitoring enterprise lacks an overall organizational framework linking the range of management drivers in the Delta (e.g., Water Right Decision 1641 and

[3] The Interagency Adaptive Management Integration Team (IAMIT) has compiled a list of conceptual models, which is available on the IAMIT website.

State Water Project Incidental Take Permit) across monitoring programs and implementing adaptive management at a system-wide scale, despite many management drivers calling for an adaptive management approach. This has resulted in some fragmentation in monitoring and implementation of adaptive management, despite the Delta Plan providing broad guidance and authority for aligning adaptive management around a common need.

As noted in the case studies from this review (Nelitz et al. 2019), and in a review of adaptive management programs by others (Greig et al. 2013), such fragmentation could be addressed by a more integrated organizational structure. For this reason, we recommend strengthening the organizational structure, integration, and coordination to better support management efforts to address important scientific data gaps. Implementing the above two recommendations would improve the organization of monitoring. However, a more formal organizational structure, with proper funding and a clear statement of purpose and scope, may eventually be needed to improve integration, coordination, and communication; and to facilitate the routine evaluation of monitoring to identify gaps, redundancies, and management relevance, as facilitated by an independent peer review at least once every four years. A more formal organizational structure could come in the form of a new authority or council to integrate, coordinate, and enhance communication on monitoring in the Delta region, or an existing entity could take on these responsibilities. Candidates for such an existing entity include the Delta Science Program or the California Water Quality Monitoring Council, which was previously found to require additional resources and authority to be more effective (Delta ISB 2018).

The lack of this kind of authority was evident during the panel discussion in 2018 with regional and national monitoring programs. At this discussion we learned of an opportunity for the Delta monitoring enterprise to expand the monitoring sites of the Environmental Protection Agency's monitoring activity, the National Wetland Condition Assessment (see Section 3, Synthesis Findings), which is a collaborative survey of the nation's wetlands to assess the extent to which they support healthy ecological conditions. Field sampling includes an assessment of non-native species, which we identified as a potential gap in this review, and a suite of indicators of disturbance to aquatic ecosystems. Costs associated with sampling would have been covered by the Environmental Protection Agency, but the State of California would need to work with Environmental Protection Agency's Office of Water to suggest the level/density of sampling desired to compare randomly chosen wetland sampling points. This opportunity was presented to senior scientists and managers in the Delta region, but there was not an apparent decision-making body charged to determine how to proceed with this opportunity or how expanded monitoring sites would be used in the region.

The review of five case studies from other systems (Chesapeake Bay, Great Lakes, Puget Sound, Coastal Louisiana in the United States, and Queensland, Australia) identified several attributes that could contribute to successful monitoring and adaptive management in the Delta (see Nelitz et al. 2019). These attributes could be considered when discussing how to strengthen the organizational structure: [4]

- **Leadership and executive direction:** Effective communication with and a strong commitment from leadership facilitate success, backed up by the decision authority and legislative driver(s) to support adaptive management.
- **Organizational structure:** A structure to make and implement decisions, involve others, and respond to unexpected events or the availability of new information over time. An organizational structure needs to include at least five components to effectively support complex adaptive management programs: (1) scientists, (2) implementation staff, (3) leadership and managers, (4) independent science reviewers, and (5) stakeholders.
- **Problem definition and practice of adaptive management:** Agreement and focus on the correct problem to address in a way that is durable and captures the larger context. A rigorous science process that adopts a mindset focused on learning about uncertainties affecting decisions should also help to address the problem.
- **Communication:** Clear, accurate, multi-directional communication to engage audiences within and outside the organizational structure governing adaptive management.
- **Funding:** Sufficient financial resources to implement monitoring and adaptive management, which can be an indicator of either the presence or lack of leadership support.

[4] It should be emphasized that similar needs were identified in the Delta ISB's review of the IEP's ability to provide science and support adaptive management (Delta ISB 2019). In that report, recommendations 6 to 8 dealt with the above issues.

Although no case study was without its drawbacks and no case study except for Coastal Louisiana met all five attributes, they provided useful insight for the Delta monitoring enterprise. A detailed summary of key insights from each case study is found in Nelitz et al. (2019). Lessons can also be learned from other programs that we did not review, such as the Rhode Island Environmental Monitoring Collaborative, Everglades, and the Platte River Project. In addition, there is value in looking at other programs within California, including the San Francisco Bay Regional Monitoring Program, the San Francisco Estuary Project, the Southern California Coastal Water Research Project, and Southern California Wetland Regional Monitoring Program.

One feature of the case studies from other systems that is particularly critical for the Delta monitoring enterprise is enhanced communication. Several interviewees noted the importance of more sustained communication between scientists, managers, and policy makers to support adaptive management. This may require expanding or creating new venues for those involved in the monitoring enterprise to interact regularly across different scales of decision-making and across issue or topical areas. Such regularized and structured communication is necessary for building shared understanding and overcoming organizational and regulatory path dependencies, differences in organizational cultures, and perceived risks to modifying monitoring systems, which several of our interviewees highlighted. In our questionnaire, we asked respondents two separate questions related to organization. We first asked if the organizational structure and integration of activities to support monitoring and adaptive management should be **strengthened** to achieve better coordination, efficiency, and results in meeting priority management needs. Subsequently, we asked if it should be **reconsidered**. Both questions generated similar results (see Figure 15). Over three-quarters of the respondents (27) agreed the organizational structure should be **strengthened**, whereas only 4 disagreed, 1 was neutral, and 2 did not know (N=34). In comparison, 21 agreed that the organizational structure should be **reconsidered**, whereas 2 disagreed, 8 were neutral, and 3 did not know (N= 34).

Organizational changes could help address some of the barriers identified above, such as groups working solely within one agency, lack of leadership, and funding, to fill gaps or improve coordination to better meet the needs of management. Some of the interviewees noted that a strengthened or different organization structure could:

- Reduce the amount of work done in silos and any work that appears redundant if an umbrella organization or State-Federal program with an overarching mandate relating monitoring and the coequal goals overall was formed.
- Broaden the set of partners that could provide a broader set of funding to fill gaps. Current funding structures also contribute to "silos" – i.e., when decisions are made by directors according to their own objectives/requirements.
- Increase efficiencies in addressing gaps by providing a venue for collaboration.

5.4. Next Steps

As no single agency could implement all these recommendations alone, decisions about how to proceed with recommendations lie with the enterprise as a whole, in which efforts are coordinated through collaborative venues like the DPIIC, the IEP, or the Collaborative Science and Adaptive Management Program. Although there was strong support for these recommendations from those who completed the questionnaire and those we interviewed, the Delta ISB has made similar recommendations about re-organization or improving the integration of science and monitoring to address certain management needs. For example, the Delta ISB made calls to IEP to re-consider its organization to ensure it continues to meet the needs of its partners and stakeholders (Delta ISB 2019a), and the science enterprise as a whole, to prepare for rapid environmental changes that will occur (Delta ISB 2019b). These recommendations have been considered for implementation, but substantial changes have not been made, although a proposal is being developed for re-organizing the science enterprise as part of the Science Needs Assessment. We understand that the major recommendations in this report are not easy to implement and require substantial collaboration and resources.

To help move forward, we provide a few suggestions. As this review helps address Action 3.3 in the 2019 Delta Science Plan ("*Routinely evaluate monitoring programs in the Delta to identify gaps, redundancies, and management relevance*"), we suggest that the Delta Stewardship Council form the workgroup via the Delta Science Program and DPIIC described in Delta Science Plan Action 3.4 ("*Develop a working group to facilitate monitoring program coordination and integration*"; Delta Stewardship Council - Delta Science Program 2019), to discuss the findings and recommendations of this review, and how to move forward with recommendations.

In addition, this workgroup could work to advance implementation of recommendations from other venues such as the Delta Science Funding and Governance Initiative (see Delta Stewardship Council 2019) and The Water Resilience Portfolio (see CNRA et al. 2020), which have also expressed interest in making improvements to monitoring, based off the findings and recommendations from this report. Over the course of this review, we have also learned of many other activities to review monitoring (e.g., 6-Agency Monitoring Re-design of IEP fish surveys) and have received invitations to present findings and recommendations of this review from the Delta Regional Monitoring Program and the Collaborative Science and Adaptive Management Program. Although there is overlap of individuals and agencies in these venues, it will be useful to discuss the findings and recommendations of this review collectively along with other efforts to improve monitoring to avoid creating silos of discussion.

As part of implementation, the workgroup should consider the geographic context for implementing the recommendations. Although this review is focused on the Delta, the workgroup should consider the entire Bay-Delta or Central Valley Watershed, depending on who will lead the effort. According to the monitoring activity inventory compiled for Component 1 of this review, most monitoring activities relevant to the Delta occur at the state scale (31%), followed by the Delta regional (29%), local (19%), and national scales (18%).

One potential barrier to implementing the three recommendations is that practitioners perceived risks from change that include (1) fear that good programs currently in place could be scrapped, or could lose quality/consistency, (2) fear of losing authority/influence, and (3) concern about increased cost. However, as climate change continues to cause environmental change and shift baselines, it is necessary to adapt monitoring programs to these changes. One potential way to overcome this barrier is openly discussing the risks of change as an enterprise. By examining the likelihood that various risks will actualize, and exploring opportunities to address or minimize risk, it may be possible to reduce general aversion to change and increase willingness to try new approaches. The workgroup suggested above could provide a venue for these discussions. Furthermore, workgroup discussions could help facilitate discussions on the level of flexibility needed to make changes to compliance monitoring.

According to the Delta Science Plan, efforts to implement Action 3.4 should be led by the IEP, the California Water Quality Monitoring Council and its workgroups, and the Delta Regional Monitoring Program (Delta Stewardship Council - Delta Science Program 2019). Interestingly, these organizations were not named when interviewees involved in this review were asked who should lead efforts to improve the coordination and organization of monitoring. Potential leaders that were mentioned by our interviewees include:

- Delta Stewardship Council- Delta Science Program in collaboration with United States Environmental Protection Agency if covering the Bay as well as the Delta
- Delta Independent Science Board
- California Natural Resources Agency
- California Department of Water Resources
- California Department of Fish and Wildlife
- Waters users and contractors

However, collaborative leadership was mentioned by several interviewees. One individual described collaboration among regulatory and regulated agencies and other community members, while another described a State/federal partnership. As an initial start, the Delta Science Program could help facilitate the formation of the workgroup and discuss leadership structure with workgroup participants. Regardless of who leads the workgroup or how the workgroup is formed, there must be opportunities for public participation and engagement of stakeholders, or partnerships which could help to address concerns about some organizations being excluded or, as expressed by one interviewee, not "*having a seat at the table*." Indeed, monitoring that incorporates public participation and stakeholder engagement is a best practice identified in this review.

6. Conclusion

The California Delta is a large, complex, and interconnected ecosystem spanning multiple jurisdictions. Applying adaptive management to large, complex ecosystems is difficult, and many scientific uncertainties remain despite the large investment to science and monitoring in the region. These difficulties are not surprising given the geographic extent over which the Delta is influenced, from the upstream headwaters of the Sacramento and San Joaquin basins to the downstream coastal communities that rely on the Delta's water supplies. Such difficulties are shared by other large ecosystems (e.g., Nelitz et al. 2019) as illustrated by the following quote from a recent review of information coordination and flow in the Great Lakes basin: *"Results from the analyses conducted on the program inventory and at the workshop showed that we [scientists] dedicate most time and resources to the collection, management, and analysis of data and much less attention to delivery of information to decision makers. In fact, we were unable to find a single example of a regional or basin wide decision maker who had access to the necessary information for assessing programs and progress to accomplish GLWQA objectives and making well-informed allocation decisions"* (Great Lakes Science Advisory Board 2018).

Monitoring is vital to understanding ecosystem status, functioning, and responses to management actions and changes in environmental drivers. Monitoring is essential to assessing our progress on achieving the coequal goals, and how well we are protecting ecosystem services, human health, and individual species. A review of the monitoring enterprise in the Delta was long overdue.

Given the complexities and breadth of the monitoring enterprise in the Delta, a fundamental first step was to conduct a comprehensive inventory of monitoring. Therefore, as part of this review, we developed an inventory of monitoring activities, which will be a useful tool for implementing the three recommendations by providing information on what is being done in the Delta and helping with integration and coordination of monitoring. The data and information from the inventory will be incorporated and made public with the launch of the Delta Science Tracker in 2022, which will be a comprehensive toolkit to track, visualize, and summarize science activities in the Delta region. Metadata within the inventory (and consequently the Delta Science Tracker) can quickly become outdated, so we encourage the community to maintain the tool to keep it up to date and explore how the Delta Science Tracker could be fully utilized.

The Delta ISB carefully deliberated and discussed all the various input and evaluations from the inventory analyses as well as panels, seminars, questionnaires, interviews, public input, a workshop, the literature, and Board member expertise to derive an Adaptive Management Framework for monitoring programs, best practices, and recommendations. The Delta ISB contends that adopting these practices throughout the Delta will enhance abilities to achieve and measure progress toward the coequal goals by increasing collaboration, communication, coordination, and integration of both science and monitoring activities to help inform management decisions in the region, especially in light of rapid environmental change.

Appendix A. Seminars and Panel Discussions Summaries

From November 2017 to July 2018, the Delta ISB hosted three seminars and five panel discussions to increase understanding of the state of monitoring in the Delta, as seen from a wide range of perspectives, and to help inform its review on the monitoring enterprise. Information obtained from these seminars helped inform both Component 1 of the review, which was the development of the monitoring inventory, and Component 2, which was the development of Delta ISB recommendations. These seminars and panel discussions helped introduce the Delta ISB to the following programs/activities that either collect or coordinate monitoring data in the Sacramento-San Joaquin Delta.

- **California Water Quality Monitoring Council** was created to coordinate water quality monitoring efforts across the state and has 13 workgroups, networks, and web portals to integrate and coordinate water quality and related ecosystem monitoring, assessment, and reporting. These workgroups cover topics including bioaccumulation, harmful algal blooms, environmental flows, estuary monitoring, wetland monitoring, molecular methods, trash monitoring, water quality monitoring, data innovation and utilization, and safe drinking water.
- **California-Nevada River Forecast Center (CNRFC)**: The CNRFC aggregates flow data into a local database to provide two types of forecasts: deterministic river guidance and ensemble streamflow. They coordinate with federal, State, and local agencies to collect critical data and make these data available in an interactive site.
- **Interagency Ecological Program (IEP)**: The IEP is a consortium of State and federal agencies that conduct broad ecological monitoring, research, modeling, and data syntheses to provide and integrate information for the management of the San Francisco Bay-Delta ecosystem. The IEP performs both long-term and focused monitoring of a wide variety of organisms and habitats, including fish, invertebrates, and vegetation, as well as water quality. Some of the key programs conducted by IEP include:
    - ***The San Francisco Bay Study***, focused on monitoring listed species under the Endangered Species Act and detecting new invasive species;

  - *The Fall Midwater Trawl (FMWT),* focused on monitoring the abundance and distribution of striped bass and used to determine the incidental take limit at the pumping facilities for Delta smelt; and
  - ***Enhanced Delta Smelt Monitoring (EDSM*)**, which increases the frequency of the sampling collection to support life-cycle model data needs and acts to supplement long-term IEP monitoring programs.
- **Fish Restoration Program:** The Fish Restoration Program (FRP) is a joint effort between the Department of Water Resources and the California Department of Fish and Wildlife that, in coordination with IEP, monitors how sensitive fish populations respond to tidal habitat restoration projects in Suisun Marsh and the Sacramento-San Joaquin Delta ecosystems. The main goals of the program are to restore 8,000 acres of intertidal habitat to enhance food web production and transport for native fishes and to increase the amount and quality of salmonid rearing habitat and increase salmonid survival in the Delta. The FRP monitoring team monitors fish and zooplankton abundances before, during, and after restoration projects and provides guidance to promote consistency in monitoring methods across the Delta.
- **Delta Regional Monitoring Program:** The Delta Regional Monitoring Program, initiated by the Central Valley Regional Water Quality Control Board, conducts, coordinates, and synthesizes water quality monitoring in the Delta focusing on mercury, nutrients, pesticides and toxicity, and pathogens. This program aims to provide baseline information of Delta water quality and provide data to assess potential linkages between water contaminants and ecosystem response to inform water usage decisions in the Delta.
- **Monitoring Avian Productivity and Survival (MAPS):** MAPS is an international monitoring program of the Institute for Bird Populations (IBP) that consists of over 1,200 stations in the United States and Canada and aims to provide demographic information of bird populations through banding, which is done by members of public agencies, non-governmental groups, and individuals. MAPS provides information to assist with avian management, such as tracking and estimating vital rates (productivity, survivorship, recruitment), key habitat locations, and population response to acute and large-scale habitat and climate changes.
- **Monitoring Neotropical Migrants in Winter (MoSi):** MoSi, the sister program of MAPS, also uses banding efforts by public agencies, non-governmental groups, and individuals across 22 countries to monitor and provide vital rates of birds, focusing on Neotropical migrant land birds that breed in the United States and Canada, to address similar management questions as MAPS.

- **National Water Quality Assessment (NAWQA):** NAWQA monitors the status and trends in water quality of important watersheds throughout the United States, including some sites in the Delta, to examine the effectiveness of the nation's environmental laws on water and to support science-based policies and management strategies to improve and protect water resources used for drinking water, recreation, irrigation, energy development, and ecosystem needs. NAWQA has long term monitoring programs of surface water and groundwater.
- **San Francisco Bay National Estuarine Research Reserve (NERR):** The San Francisco Bay NERR is one of 29 National Estuarine Research Reserves established across the United States that monitor estuary ecosystems to track environmental change and address the needs of decision makers and support science-based management. NERR programs also prioritize education and outreach, stewardship, and training to promote communication and collaboration within and between agencies, stakeholders, and the broader community. The San Francisco Bay NERR has two sites in the San Francisco Bay-Delta Ecosystem: China Camp State Park in San Pablo Bay and Rush Ranch in Suisun Marsh, where they monitor aquatic and terrestrial plant and animal populations, including birds, mammals, fish, reptiles, and amphibians.
- **National Wetland Condition Assessment (NWCA):** The NWCA is a national monitoring program that is part of the larger National Aquatic Resources Surveys (NARS) program of the US Environmental Protection Agency (EPA). The NWCA surveys, conducted every five years, use standardized sampling practices of all wetlands, tidal and nontidal, in the conterminous United States to characterize biological, chemical, and physical features of each site, including vegetation, soil, hydrology, water chemistry, algae, and buffer characteristics. These data are used to answer basic questions about the extent to which the nation's wetlands support healthy ecological conditions and the prevalence of key stressors at the national and regional scales.

This appendix describes how the information obtained from the seminar was used to inform the Delta ISB's review. Panelists/speakers, topics, and questions are summarized in the table below.

Table A-1. Summary of panelists/speakers, topics, and questions from the three seminars and five panel discussions.

Topic (with video recording)	Date	Seminar Speaker/Panelists	Seminar/Panelist Questions
Tidal wetland restoration monitoring	11/17/17 Part 1	**Seminar Speaker:** Stacy Sherman (California Department of Fish and Wildlife) Seminar Presentation: Fish Restoration Program: Monitoring the Effectiveness of Tidal Wetland Restoration for the Benefit of Native Fish Species **Panelists:** • Rosemary Hartman (California Department of Fish and Wildlife) • Erik Loboschefsky (California Department of Water Resources) • Ramona Swenson (ESA Associates) • Heather Swinney (United States Fish and Wildlife Service)	• What are some of the key issues with monitoring in the Delta? • How can the Delta ISB's review help inform your work? • Are current monitoring programs meeting informational needs of management agencies? • Can individual and larger-scale monitoring programs be better coordinated? • Does monitoring data support implementation of adaptive management and assessments of performance measures? • Can you identify gaps in monitoring? • In your opinion, is an appropriate level of scientific rigor being used in current programs to meet the needs of management and policy decisions? • Can you recommend how/if the monitoring enterprise can be improved, consolidated, coordinated, and streamlined?

Topic (with video recording)	Date	Seminar Speaker/Panelists	Seminar/Panelist Questions
Water quality monitoring	1/5/18 Part 3	Seminar Speaker: Karen Larsen (State Water Resources Control Board) Seminar Presentation: California Water Quality Monitoring Council – Increasing Efficiency and Effectiveness Through Collaboration Panelists: • Greg Gearheart (State Water Resources Control Board) • Kris Jones (California Department of Water Resources) • Lori Webber (State Water Resources Control Board) • Adam Laputz (Central Valley Regional Water Quality Control Board) • Laura Valoppi (State and Federal Water Contractors Agency) • Val Connor (Retired)	Same as above

Topic (with video recording)	Date	Seminar Speaker/Panelists	Seminar/Panelist Questions
"Invasive" weed monitoring	5/3/18 Part 4	**Seminar Speaker:** None **Panelists:** • Gina Darin (California Department of Water Resources) • Eddie Hard (California Department of Parks and Recreation) • Shruti Khanna (California Department of Fish and Wildlife) • Susan Ustin (University of California, Davis) • Jeff Wingfield (Port of Stockton)	Same as above

Topic (with video recording)	Date	Seminar Speaker/Panelists	Seminar/Panelist Questions
Monitoring conducted by the Interagency Ecological Program (IEP)	1/4/18 Part 2	**Seminar Speaker:** Steve Culberson (IEP) Seminar Presentation: IEP Management Science: Theory, Practice, Future **Panelists:** • Kaylee Allen (United State Fish and Wildlife Service) • Larry Brown (United States Geological Survey) • Gregg Erickson (California Department of Fish and Wildlife) • Wim Kimmerer (San Francisco State University) • Ted Sommer (California Department of Fish and Wildlife)	• How effective is coordination among IEP agencies and between IEP and other agencies/programs with producing and using science? • How effective is the IEP science-governance structure in providing credible and relevant scientific information in support of managing the water-export facilities in a way that can minimize harm to key ecosystem components, while also providing a reliable water supply? • How effective are the current institutional arrangements that support the interagency investment in IEP for producing and using science? Are these current institutional arrangements applicable in the future? • Does IEP have the ability to use ecosystem forecasting mechanisms to anticipate environmental changes? What is IEP's ability to communicate this information to other agencies? • What is the role of IEP as a synthesizer of information about the Delta and its environment and as the nexus for the creation of "science narratives" about the needs of the Delta that go beyond what is in technical reports? • How well are the various components of IEP working to produce and use science? Are there organizational suggestions that could improve IEP efficiencies

Topic (with video recording)	Date	Seminar Speaker/Panelists	Seminar/Panelist Questions
Regional and national monitoring that includes the Bay-Delta	7/12/18 Part 5	**Panelists:** • Steve Albert (Institute for Bird Populations) • Joseph Domagalski (United States Geological Survey) • Matt Ferner (San Francisco State University) • Robert Hartman (National Weather Service, Retired) • Mary Kentula (United States Environmental Protection Agency)	• Please briefly describe the monitoring program: ○ What are the purposes and goals of your program? ○ What is the geographic scale? ○ What is the temporal scale? • What are some of the products of the monitoring data (decisions, publications, syntheses)? • Who are the major users of your data? • How are the data from your program being used in the Delta region (if applicable)? • How does your program coordinate its monitoring, both internally within the program, and externally with other entities? Is this effective?

These seminars and panel discussions helped identify the following key resources that were used **to help inform the development of the monitoring inventory.**

- IEP Tidal Wetland Restoration Monitoring Framework: This document assessed system-wide tidal wetland sampling efforts to identify potential needs and opportunities for improvement and developed a framework founded on hypothesis-based monitoring to assess the effectiveness of tidal wetland restoration projects in the Delta and Suisun Marsh. The document provides suggestions for cost-effective monitoring strategies and recommendations for data management, analysis, quality assurance, and reporting protocols. This report documents much of the existing monitoring in the Delta that could inform monitoring of the effectiveness of tidal wetland restoration monitoring, and recommends methods, considerations, and constraints for many monitoring topics also discussed in the Monitoring Enterprise Review.

- IEP Framework for Aquatic Vegetation Monitoring in the Delta: This document described potential frameworks for monitoring the aquatic vegetation community and distribution in the Delta and Suisun Marsh to inform resource management needs. It defined three objectives of monitoring programs focused on aquatic vegetation and presented three possible scenarios ("best case scenario", the "moderate-funding scenario", and the "bare bones scenario") and how such programs could best address these three objectives. The report also evaluated various kinds of remote sensing tools available to monitor in the Delta and Suisun Marsh, summarized existing data and data presently being collected over parts of the Delta-Suisun region, and examined aquatic vegetation monitoring methods in other regions similar to the Delta.
- Independent Review of the Delta Regional Monitoring Program (RMP): This review identified features of an effective monitoring program, provided an assessment of the ability for the Monitoring Design of the Regional Monitoring Program to address management needs and answer assessment questions, and provided recommendations of scientific criteria for distributing limited resources toward monitoring. The review provided general recommendations for statistical analyses involved in sampling design and consideration of tidal and other temporal factors when determining sample schedules, while also providing specific suggestions for each of the detailed monitoring designs addressing the four priority constituents (pesticides and toxicity, mercury, pathogens, and nutrients). Many of the recommendations and topic areas also apply to the Delta monitoring enterprise.
- Past External Reviews of IEP: The IEP Science Advisory Group (SAG) is a standing panel of independent external experts that was established in the 1990s. IEP regularly calls on the SAG to review IEP elements and provide advice on scientific issues. IEP programs undergo review, and these reports were used for ESSA's literature review (Nelitz et al. 2019).

The seminar speakers and panelists provided a wealth of information about current monitoring programs, including challenges and needs. Perspectives from the seminar presenters and panelists led to some key insights surrounding the broad review questions for the Monitoring Enterprise Review, which were further investigated once the inventory was developed. A summary of these preliminary perspectives, organized below by question and management topic, were used to develop initial versions of the best practices for improving the monitoring enterprise in the Delta and helped with the development of the recommendations.

Perspectives that Emerged from the Seminars and Panels on the Monitoring Enterprise

- An overall organizational framework needs to be considered for the Monitoring Enterprise Review. An overall monitoring framework is lacking for the Delta, but it is being considered in some quarters. For example, the State Water Resources Control Board uses the monitoring framework proposed by the EPA. In any event, there is a need to define questions better, need for a technically defensible design, development of core indicators, and continuation of quality assurance, data management assessment, external peer review, and infrastructure planning (see Delta RMP review report for details).
- Many of the monitoring programs in the Bay and Delta have similar goals and are affected by similar stressors. Rather than having separate programs, they should be combined when appropriate. Tidal wetlands offer the best opportunity for this change in monitoring. Both the Bay and Delta are being affected by climate change at increasing rates. Both have well developed scientific capabilities for monitoring, and the regions have similar structures for program governance and administration. These programs could be linked. The Wetlands Regional Monitoring Program being developed for the San Francisco Bay can readily be adapted to the Delta.
- National monitoring programs should include sites in the Delta and coordination with Delta programs. The Delta Science Program, with the assistance and cooperation of the IEP, could serve as a clearinghouse to coordinate with national monitoring programs.
- Monitoring should be closely tied to the goals, objectives, and specific questions of interest to managers and decision makers. Several participants from the panel discussion on tidal wetland restoration monitoring seminar and interviews identified a disconnect between management needs and monitoring as a barrier to improving coordination and addressing monitoring gaps. Participants noted the common practice of using monitoring to address management needs that it was not explicitly designed to address, which can result in ineffective management.

- Stakeholders need to be more involved when monitoring programs in the Delta are started, stopped, or changed. Stakeholders are a key component to the monitoring enterprise but are often neglected. It is important to involve stakeholders early on to discuss how to integrate new and changing programs. These relationships and discussions are key for launching subsequent phases of monitoring programs. Some organizations have consistent stakeholder involvement, such as the California Water Quality Monitoring Council; however, more outreach to stakeholders, such as non-governmental organizations and environmental justice advocates, is needed.
- Management needs and questions must be made clear to staff designing and conducting monitoring. However, the conversations must be two-way, with the monitoring staff also understanding the important questions that confront management. A need for "coordinating the coordination" through improved communication between scientists and managers was discussed as a way to improve the efficacy of the monitoring enterprise during our seminar and panel discussion on the Fish Restoration Program.
- New ways need to be established for setting Delta smelt take. Agencies should consider ways of monitoring Delta smelt that minimize take (e.g., eDNA, cameras). Incidental take from pulling a net through water for collecting zooplankton for food-web monitoring is inevitable; permitting incidental take in these situations should continue.
- Monitoring in the Delta is not flexible enough to be proactive as new issues arise. This needs to be corrected through actions such as routine assessment of permitting requirements to look for opportunities to streamline or eliminate them. A very large share of IEP monitoring is compliance monitoring or the result of a regulatory mandate, which is often perceived as not being very flexible. Flexibility currently may lie somewhere between the "shalls" and the "shoulds." However, monitoring requirements in a biological opinion or a water rights decision are often not very explicit and some adjustments to the "should" can be made. These adjustments require more coordination and often lie outside the IEP jurisdiction. Because the agencies that require the monitoring must agree to changes, this can make things challenging.

- The use of remote sensing in monitoring could be expanded. Satellite imagery is collected every few weeks and has many uses but is subject to cloud-free atmosphere and is coarse in spatial resolution, for example, limiting the capability to detect cover of plant species on waterways. Hyperspectral imagery from piloted aircraft is expensive and not easily processed in a timely manner. It also is less expensive in flying costs and far quicker to process. This may include real-time imaging by remotely piloted small drones, in which case, the cost could come down to even more affordable levels. Boat-mount extension-arm digital mega-pixel RGB photos sent back in real-time may be the most practical, lowest-cost solution for monitoring and management of Delta aquatic vegetation.
- More data analysis and synthesis are needed; "Big Data" techniques and approaches can help. When everyone thinks about monitoring, the focus is mostly on data collection, data-management issues, and synthesis and analysis. Studies have demonstrated that data management, syntheses, and analyses require more time than the field effort. One estimate is that 25 to 30% of the overall budget is spent on the quality assurance part alone. Monitoring programs often generate huge quantities of data. Huge quantities of data are the subject of current Big Data approaches being developed in California institutes and universities. Big Data approaches are useful for discovering the "hidden needle in a haystack of data". The difficulty, however, is in knowing what characterizes the "needle" that is valuable in the "haystack" of data collected. NERR's perspective that is emerging is focused around an analysis package in R (swampr) that is set up to analyze data, look at different stations and years, and plot it in different ways to look for different relationships and patterns and allow people who are good at data manipulation to adjust and play with the scripts. This is especially valuable for any kind of high frequency monitoring especially one that generates volumes of data.
- Qualitative or anecdotal observations gathered along with quantitative monitoring data can be of critical importance and must be reported and archived in a fashion that can preserved, analyzed, and used. Photographic records are often used by the United States Geological Survey and stored with field observations in a database. They are then used in training for citizen science and teaching programs for school children. There are various approaches to make this information accessible. For example, when it is directly related to data that are being archived, the information can be included as a metadata note in the associated file. This information should be accessible beyond the agency gathering the information.

- While monitoring, personnel are often observing novel events and changes. Ways of tagging unique observations must be maintained. Probability sampling may result in more of these types of encounters because just a map is used and there is no judgment about whether a site is easy to sample or convenient. This approach forces monitoring crews to go into places they have never been before rather than traditionally taking the water sample where, for example, the road crosses the bridge. Reportedly, a group of academic researchers rethought their wetland classification they developed for an area because they were seeing types of wetlands they had never seen before with probability sampling.
- Community and citizen science could be more involved in Delta monitoring programs, both to offer opportunities for expanded monitoring activities as well as to increase public awareness of environmental issues. The Delta Stewardship Council and the Delta Science Program have made public participation a priority in their various activities. NERR has tried many different citizen science initiatives around the NERRs, and there are a variety of perspectives and opinions about their success. Approaches to make sure the data are collected consistently, that people are recording what they are supposed to record, and not omitting records are questionable in some cases. However, an approach that has worked well is photo monitoring. Any time that there is an objective component of citizen monitoring, those types of approaches have been shown to be highly effective. Another approach that works to some extent is with educational units, such as high school science classes and clubs. Likewise, community and citizen monitoring have a role in emergency services with spotter networks that are able to observe when negative events are happening. A levee break, water getting into someplace unexpected, a potential dam break, monitoring for the presence of invasive species such as nutria are all possible examples. There is clearly a role for people to observe events and to be able to get that information to the appropriate agencies. For example, the cooperative data collection program that NOAA supports is the backbone of their climate network, and these data are all collected for free by people with gauges in their backyards, and they have been doing that for over 100 years. It has to be acknowledged though that for some advantages that community and citizen monitoring provide, a fair amount of effort is needed to make the program rigorous enough so that the monitoring information can be interpreted and put it to good use.

Summary of Preliminary Findings by Key Questions and Management Topic

A summary of the comments and perspectives provided during the panels and panel discussions are organized below by question and management topic.

Question 1. Are there potential gaps and redundancies in serving the relevant needs of decision makers?

During the seminar and panel discussions on tidal wetland restoration monitoring, we heard the following:

- Most of the effectiveness monitoring that occurs under the Fish Restoration Program at restored tidal wetlands focuses on food resources for listed fish species, as restoration was undertaken to address requirements from biological opinions or the incidental take permit on the long-term operations of the Central Valley Project and State Water Project. There is not a dedicated source of funding to monitor non-listed fish species, including mammals, birds, and microbes, which could be a potential gap.
- Although the Fish Restoration Program is evaluating the effectiveness of restored sites for listed fish under the Endangered Species Act, perhaps the biggest issue for monitoring is listed species take (especially for Delta smelt). Due to concerns with sampling an endangered species, it is difficult to receive take for Delta smelt for monitoring. If you cannot sample your targeted species, you hamper the ability to learn.
- There is an emphasis on surface open-water habitat monitoring, but semi-shallow water habitats as well as deep open-water habitats are underrepresented.

During the seminar and panel discussions on water quality monitoring, we heard the following:

- The Delta RMP review recommended that tidal phase and variation in flow need to be taken into account in sampling plans. If the tidal phase/flow is not taken into consideration, then one might conclude the source is upstream when in reality it is downstream, or vice versa, depending on whether the sample was taken on a flood, ebb, or slack tide. This is especially important in water-quality monitoring, but the principle is applicable to chemical, physical, or biological components being sampled in the water column of a tidal system.

- For pesticide monitoring, the review panel emphasized using aquatic and sediment toxicity testing more widely to identify where and when toxicity is occurring in the Delta, then use further testing and chemical analysis (especially broad or non-target chemical analysis) to further identify sources of the toxicity.
- The Delta RMP review also identified the need for thresholds, trigger points, and estimates of reliability.
- One easy gap to identify is contaminants of emerging concern, which the Delta RMP is working to address.

During the seminar and panel discussions on invasive weeds, we heard the following:

- There are both gaps in monitoring, as well as overlap. Monitoring needs to occur at the correct timing and the correct quality. The IEP Aquatic Vegetation Project Work Team is trying to bring together a dataset of existing monitoring of the Delta that has been conducted over the past several decades, what has been done with it, and what key findings those studies provided.
- The California Department of Food and Agriculture once had the Noxious Weed Eradication Program, which had dedicated biologists surveying the whole state at regular intervals and taking care of high priority invasive and noxious weeds, and the Weed Management Area Program, which were local stakeholder collaborations focused on control on invasive plants. Each weed management area had their top 10 weeds that they're monitoring for and are on the lookout for. Both programs were cut due to funding issues despite being defined in State code.

Question 2. What is the level of coordination of data collection across different organizations?

During the seminar and panel discussions on tidal wetland restoration monitoring, we heard the following:

- There is a need for improved communication between scientists and managers (i.e., coordinating the coordination).

During the seminar and panel discussions on regional and national monitoring, we heard the following:

- There is a lot of coordination, but it isn't complete. In many cases, collaboration is the means for any level of success. Some programs don't collect any data but are dependent on observations from thousands of sites. Relationships with other agencies that you're dependent on for those data are critical. A structure and framework that helps people work together is needed, like the California Data Exchange Center that facilitates sharing of water quality data.

During the seminar and panel discussions on IEP monitoring, we heard the following:

- Monitoring that falls under IEP appears to be very well coordinated through the Science Management Team, the work plan process, project work teams, the annual meeting, etc. Participants generally know what each other are doing and are helping each other out. IEP staff do not always do a good job at reporting back within their own agency. When a program is up and running, there is less need for oversight.
- The number of potential forces that can blow everything apart in IEP in any given year is astounding. The fact that IEP has been able to get things going for over 40+ years speaks to IEP's ability. There are a lot of different parts in how IEP does coordination. IEP Coordinators and IEP Science Management Team Members are very active in going to different non-IEP management forums, such as the Collaborative Adaptive Management Team and the Collaborative Science and Adaptive Management Program. The coordination at times actually is excessive. With respect to funding and doing other projects, IEP works as much as possible with other funding entities to discuss shared priorities and coordinate shared needs. All of this comes with a price, since the number of issues that IEP is responsible for is staggering. It is way more complicated and at times not feasible to cover everything that people want IEP to do. A solution to coordination is resources. IEP has high turnover and is burning though staff pretty quickly since expectations are high, especially at the management level. There is a constant re-training within individual agencies.
- However, programs not within IEP (e.g., Delta RMP) sometimes get forgotten and are not talking to one another. There are similar issues with special studies from university researchers. This is especially true of special studies where there is not a good understanding of what everyone is doing and why. This is especially unfortunate because all are working in a system with limited resources, including limited take of Delta smelt.

During the seminar and panel discussions on water quality monitoring, we heard the following:

- The California Water Quality Monitoring Council coordinates data management initiatives. There is a strong need for agency scientists to have guidance and support on how to effectively manage their data in a coordinated way. This recently came up in the review of the sustainability of water and environmental management in the Bay-Delta by the National Research Council. In their review, they noted how silos of data have resulted in separate and compartmentalized science that has impeded the ability to make informed management decisions.
- Better integration of water quality with the other monitoring types is needed, as is a unified discussion and communication on coordination and collaboration.
- There could be better integration across programs, such that water quality and toxicity testing is an integrated part of monitoring that is being conducted for biological components. The current Directed Outflow Program integrates toxicity testing and chemical analysis into a fish and food-web monitoring program to evaluate outflow augmentation. Such an integrated approach of evaluating fish presence, food-web components, and toxicity testing is an important addition to the traditional approach of monitoring just fish and food-webs.

Question 3. Are there other opportunities to increase efficiencies in monitoring?

During the seminar and panel discussions on water quality monitoring, we heard the following:

- Barriers to improve monitoring really are institutional/organizational and human nature. They have a lot to do with training. The State Water Resources Control Board has an incredible training academy that was developed by Office of Information Management Analysis . Training helps with infrastructure and deals with the “people” part of monitoring. It’s the social part that needs to be addressed, and this requires expertise in organizational behavior and management and people skills. In terms of that expertise in organizational behavior and management, biological scientists don’t have a lot of expertise in that.

- Most agency scientists are not data-management professionals, although they may try to do due diligence to effectively manage their data. There are inherent challenges with bringing data together from siloed programs, such as different QA/QC procedures, data standards, and protocols. These are challenges that a lot of agency scientists do not really have the training to deal with.
- There really is a need for support and guidance to help scientists on how to effectively manage data. Data management is often an afterthought. Data management should be discussed at the onset of projects, and agency scientists should have the support and guidance that they need to be able to effectively manage data in a coordinated way.

During the seminar and panel discussions on tidal wetland restoration monitoring, we heard the following:

- There are times when there are opportunities to sample due to the hydrological conditions, but you cannot go out and sample because it is not in your study plan, and you do not have the necessary incidental-take permits
- There is a need for flexible work plans to address issues of take for targeted species.

During the seminar and panel discussions on national and regional monitoring programs, we heard the following:

- The NERRs have debated about the intention of a monitoring program and whether or not you have a hypothesis you are testing, or a specific question you are trying to address with your monitoring program, which is often the case. The NERRs have had a lot of internal debate about this because that program was not set up that way, other than the general question of trying to understand short-term variability and long-term trends in environmental drivers, which was the primary motivation for setting up the monitoring programs. Whether you have a research question-driven monitoring program or a more general “let’s monitor things to see how they change” kind of program, you can extract general and specific information from each of those, which may need to be supplemented or augmented over time as new factors come into play. For example, a lot of bench chemistry that was done in the lab or the sensors used were the earliest versions of automated data loggers. As new sensors have come out, maintaining the same parameter types and same basic frequencies of monitoring should be the aim. Coming to a consensus about upgrading and pulling everyone up to the next level is important, but the old methods and data collected should still be compatible. That is at least the intention.

- In the case of the NARS Assessments, techniques become obsolete and new questions arise. Core indicators stand the test of time and are the ones used to assess the basic condition of aquatic resources. At the same time, we always have a number of indicators that are being tested to anticipate the future or that might be a better way to do something that is core.

During the seminar and panel discussions on invasive weeds monitoring, we heard the following:

- Remote sensing could be more widely used, acknowledging its strengths and limitations.
- Having more systematic monitoring is important. Often a monitoring program is structured with reference to particular needs, questions, and hypotheses and is tuned to those kinds of purposes. This is an advantage because it's a tailor fit, but there are also disadvantages because then the data are constrained by the questions that are being asked. This becomes particularly important in two respects: one is how can you tailor a data-collection system and the data themselves to address future questions that have not even been thought of? New questions related to climate change and to a variety of other changing conditions may be outside the framework of what has been previously experienced. Agencies want to be able to use long-term datasets to address some of the potential consequences of these changes, but the long-term datasets may have been designed with reference to different kinds of questions, so part of the question is how do you make that transition? Is the data collection, the very basis of the monitoring program, something that constrains future options in terms of dealing with it and using it? That relates also to the parallel question of, if you start these things using state of the art methodology at that time that's no longer state of the art at a later time, that's forgotten art. New methods of data collection come along: how do you design a monitoring program that can absorb the new methodologies without creating incompatibilities in the dataset, or do you stick with the old methods even though you can no longer get the results published because they're no longer state of the art methodologies?

Question 4. Is the data quality of monitoring appropriate to address purposes and needs for information?

During the seminar and panel discussions on tidal wetland restoration monitoring, we heard the following:

- Some of the key issues with monitoring in tidal marshes and for restoration are data-management challenges, limited resources, and just the scale over which we need to monitor. Moreover, tidal-marsh monitoring is not often done at a level for doing really rigorous hypothesis testing, which is where we would really like to be to test the designs of these projects.
- Sooner or later scientists will question the adequacy and statistical reliability of the monitoring data on which decisions are being made. Monitoring in general and in the Delta in particular needs to pay attention to the statistical criticisms that can be raised against it. One of the problems of monitoring in an aquatic system arises from the linear array of boat-based sampling. The samples are not randomized and there is a potential for spatial autocorrelation among those samples. You can test for spatial autocorrelation to determine the degree to which the samples are in fact independent of one another or the degree to which they are compromised by autocorrelation.
- However, it is difficult to begin with a robust statistical design and expect to follow it, so often one must start with the realities of the field situation and one's objectives and then adjust the sampling accordingly. Furthermore, agency staff may not have the time to actually analyze their data or the resources to learn how to analyze their data properly. However, some agencies reportedly have some new programs to help increase scientific training, including statistical training.

During the seminar and panel discussions on water quality monitoring, we heard the following:

- The usual approach in the Delta of collecting data, then figuring out what statistical and data analysis will be performed on the data after the fact, is inefficient and should be greatly improved by applying key monitoring principles and designing monitoring using a quantitative approach.

Question 5. Are data accessible to the public, decision makers, other scientists, stakeholders and all interested and affected parties?

During the seminar and panel discussions on tidal wetland restoration monitoring, we heard the following:

There is a lot of monitoring that goes on, but academic researchers, monitoring groups and other interested and affected parties have a lack of understanding on how to access other program's data, a lack of data standards, and a lack of knowledge of how data should be stored and managed. The IEP's Data Utilization Work Group is working toward improving this and there is a movement to comply with Assembly Bill 1755, which requires water-related data to be made publicly available. Data accessibility is improving quickly but could still be better.

Appendix B. Monitoring Inventory (Component 1)

The monitoring inventory developed for this review provides a useful database structure for bringing together disparate information sources into a common platform, and an online portal for making this information accessible to others. The reports from both components make up the full Monitoring Enterprise Review. In addition to a database, the three Component 1 reports, which were prepared by ESSA Technologies Ltd, CBEC eco engineering, and PAX Environmental Inc. in collaboration with and under the direction of the Delta ISB, were:

1. A lessons and methodology report (Nelitz et al. 2019), which consists of a literature review of lessons learned within the Delta along with five other systems (Chesapeake Bay, Great Lakes, Puget Sound, and Coastal Louisiana in the United States, and Queensland, Australia) for enabling effective monitoring and adaptive management;
2. A summary report of the monitoring activities from the full inventory (Nelitz et al. 2020a); and
3. A comprehensive synthesis report of the inventory results (Nelitz et al. 2020b), which assesses the relevance of monitoring activities in serving the needs of decision makers and identifies initial opportunities to improve monitoring based on the initial analysis of the inventory.

The metadata attributes found in the inventory can be found in Table B-1 and the 157 monitoring activities in the inventory can be found Table B-2. A full overview of the inventory can be found in Netliz et al. 2020b.

The inventory is currently available upon request and the metadata collected will be launched through the Delta Science Tracker web portal, which is currently being developed by the Delta Stewardship Council - Delta Science Program that will cover both monitoring and research in the Delta.

Table B-1. Metadata attributes and descriptions in the monitoring inventory.

Metadata Category	Metadata Attributes
Overview	• Name • Monitoring program • Description • Purpose • Information sources • Name & role of organization (Implementing, Funding, Supporting) • Known challenges • Cost and year of start-up • Annual cost • Cost comment • Management themes / actions • Management drivers • Management comment
Data Quality	• Data QA/QC • Data management • Data reporting • Timeliness • Uncertainty • Machine readable
Sampling Activity	• Monitoring themes / parameters (Direct socio-economic drivers, Environmental drivers / conditions, Habitats, Species) • Monitoring metrics • Type of monitoring • Sampling years • Sampling frequency • Sampling timing • Sampling location(s) (California sub-basins, Delta regions, Delta islands, Delta channels) • Spatial scale • Spatial extent • Number of locations (Entire geographic extent, Within California, Within Delta) • Sampling comment • Sampling equipment • Monitoring design • Sampling protocol

Table B- 2. Summary of management drivers and their alignment with management themes of relevance.

Note the use of the following abbreviations to denote management themes to which these drivers apply: WSM = Water Supply Management, FLD = Flood Management, WQL = Water Quality, HAB = Habitat Management, SPP = Native Species Management, ISM = Invasive / Non-Native Species Management, and LUM = Land Use Management. Y=Yes or N=No.

Name of management driver	Start Year	WSM	FLD	WQL	HAB	SPP	ISM	LUM
A Central Valley Project Improvement Act Implementation Plan for Fish Programs / Fish Restoration Plan	2015	Y	Y	N	Y	Y	N	N
California WaterFix	2016	Y	N	Y	Y	Y	N	N
California Code of Regulations: Title 23: Waters	1941	N	N	N	N	N	N	N
California EcoRestore	2015	N	Y	N	Y	N	N	N
California Environmental Quality Act (CEQA) Compliance – Mitigation Monitoring and Reporting Program (MMRP)	1969	N	N	N	N	N	N	N
California Guidelines for Cyanobacteria in Recreational Inland Waters	2008	N	N	Y	N	N	N	N
California Hatchery Review Project	2012	N	N	N	N	Y	N	N
California State Endangered Species Act (SESA or CESA) – Incidental Take Permit (ITP) – 2081(b)	1997	N	N	N	N	N	N	N
California State Lands Commission (CLSC) – Article 5: Marine Terminals Inspection and Monitoring	1938	N	N	N	N	N	N	N
Central Valley Flood Protection Plan (CVFPP)	2012	Y	Y	N	N	N	N	N
Central Valley Flood Protection Plan (CVFPP) – Conservation Strategy	2016	N	Y	N	Y	N	N	N
Central Valley Joint Venture (CVJV) Implementation Plan	1990	Y	N	N	Y	N	N	Y
CDFW SWP Incidental Take Permit	2009	N	N	N	N	N	N	N
CEQA: AB 52, Consultation with Native American Tribes	2015	N	N	N	N	N	N	N
Clean Water Act: Sections 401, 402, 404(b)(1)	1970	N	N	N	N	N	N	N
Cosumnes Preserve's North Delta Program	2018	N	Y	N	Y	N	Y	N
Delta Conservation Framework 2018-2050	2018	N	Y	Y	Y	Y	Y	Y

Name of management driver	Start Year	WSM	FLD	WQL	HAB	SPP	ISM	LUM
Delta Levees Maintenance Subventions Program	1973	Y	Y	N	Y	N	N	N
Delta Levees Special Flood Control Projects	1988	Y	Y	N	Y	N	N	N
Delta Levees Investment Strategy	2013	Y	Y	N	Y	N	N	N
Delta Plan / Delta Reform Act of 2009	2013	Y	Y	Y	Y	Y	Y	Y
Delta Smelt Resiliency Strategy	2016	N	N	Y	Y	Y	Y	N
Dutch Slough Tidal Restoration Project	2016	N	N	N	Y	N	N	N
East Contra Costa County Habitat Conservation Plan and Natural Community Conservation Plan	2007	N	N	N	Y	Y	N	Y
Endangered Species Act: Section 4 "Post-Delisting Monitoring"	1973	N	N	N	N	N	N	N
Endangered Species Act: Section 7 "Interagency Consultation"	1973	N	N	N	N	N	N	N
Fish Restoration Program Agreement (FRPA)	2010	N	N	N	Y	N	N	N
National Historic Preservation Act (NHPA) – Section 106 (State Historic Preservation Officer)	1966	N	N	N	N	N	N	N
Porter Cologne Water Quality Control Act (California Water Code)	1969	N	N	N	N	N	N	N
Proposition 1 Restoration Grant Program	2014	Y	N	Y	Y	N	N	N
Recovery Plan for Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead	2014	Y	N	N	Y	Y	N	N
Recovery Plan for the Central California Distinct Population Segment of the California Tiger Salamander (*Ambystoma californiense*)	2017	N	N	N	Y	Y	Y	N
Recovery Plan for the Giant Garter Snake	2017	N	N	N	Y	N	N	N
Recovery Plan for the Southern Distinct Population Segment of N. Am. Green Sturgeon	2018	Y	N	Y	Y	Y	N	N
Recovery Plan for Three Endangered Species Endemic to Antioch Dunes, California	1984	N	N	N	Y	N	Y	N

Name of management driver	Start Year	WSM	FLD	WQL	HAB	SPP	ISM	LUM
Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California	2013	N	N	N	Y	N	N	N
Recovery Plan for Vernal Pool Ecosystems of California and Southern Oregon	2005	N	N	N	Y	N	N	N
Sacramento San Joaquin Delta Diazinon and Chlorpyrifos TMDL	2007	N	N	Y	N	N	N	N
Sacramento Valley Salmon Resiliency Strategy	2017	N	Y	N	Y	Y	N	N
Sacramento-San Joaquin Delta Methylmercury TMDL	2010	N	N	Y	N	N	N	N
San Joaquin County Multi-Species Habitat Conservation and Open Space Plan	2000	N	N	N	Y	Y	N	Y
Solano Multispecies Habitat Conservation Plan	2012	N	N	N	Y	Y	N	Y
South Sacramento Habitat Conservation Plan	2018	N	N	N	Y	Y	N	Y
Suisun Marsh Habitat Management, Preservation, and Restoration Plan	2013	N	Y	Y	Y	Y	Y	Y
SWP-CVP NMFS Operations Biological Opinion (BiOp) / Re-initiation	2009	Y	Y	Y	Y	Y	Y	Y
SWP-CVP USFWS Operations Biological Opinion (BiOp) / Re-initiation	2008	Y	Y	Y	Y	Y	Y	Y
Water Right Decision 1641 / Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary-Update	2018	Y	N	Y	N	N	N	Y
Water Quality Control Plan Voluntary Agreements	No Data	Y	N	N	Y	N	N	N
The Water Infrastructure Improvements for the Nation (WIIN) Act	2016	Y	N	Y	N	N	N	N
Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan	2012	N	N	N	Y	Y	N	N
Yolo Habitat Conservation Plan / Natural Community Conservation Plan	2018	N	N	N	Y	Y	N	Y

Table B-3. Summary of monitoring activities in the inventory. If unknown start and end year, noted as "UNK" in table.

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
7	Statewide Crop Mapping	California Department of Water Resources (DWR), Land IQ	2014	2019
8	National Wetlands Inventory	US Geological Survey (USGS), US Fish and Wildlife Service (USFWS)	1975	2019
10	Continuous Water Quality Monitoring Stations	California Department of Water Resources (DWR)	1968	2019
12	20-mm Survey (Delta Smelt distribution monitoring)	California Department of Fish and Wildlife (CDFW)	1995	2019
13	Benthic Organism Study	California Department of Water Resources (DWR), US Bureau of Reclamation (USBR)	1975	2019
14	Fall Midwater Trawl Survey (FMWT)	California Department of Fish and Wildlife (CDFW)	1967	2019
15	San Francisco Estuary Invasive Spartina Project	California State Coastal Conservancy	2000	2019
16	Bioaccumulation Monitoring Program	Moss Landing Marine Laboratories, California Department of Fish and Wildlife (CDFW), San Francisco Estuary Institute (SFEI)	2011	2019
17	Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG)	US Department of Agriculture (USDA) – Forest Service Region 5	1978	2018
19	Bioassessment Program	California Department of Fish and Wildlife (CDFW)	2000	2019
21	Juvenile Salmonid Monitoring – Red Bluff Diversion Dam	US Fish and Wildlife Service (USFWS)	1994	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
22	Central Valley Chinook Adult Escapement Monitoring Project	Western Ecosystems Technology Inc., Pacific States Marine Fisheries Commission, California Department of Fish and Wildlife (CDFW)	2007	2018
23	San Francisco Bay Study	California Department of Fish and Wildlife (CDFW)	1980	2019
24	Soil Survey Geographic Database (SSURGO)	US National Park Service (NPS), US Department of Defense (DoD), US Bureau of Land Management (BLM), US Bureau of Indian Affairs (BIA), US Department of Agriculture (USDA) – National Cooperative Soil Survey	UNK	2019
25	Groundwater Ambient Monitoring and Assessment Program (GAMA)	California Department of Pesticide Regulation (DPR), California Department of Water Resources (DWR), California State Water Resources Control Board (SWRCB), US Geological Survey (USGS)	2000	UNK
26	Fisheries Branch Anadromous Assessment	Yuba River Management Team, US Fish and Wildlife Service (USFWS), The Fishery Foundation of California, US Bureau of Reclamation (USBR), East Bay Municipal Utilities District, California Department of Fish and Wildlife (CDFW), California Department of Water Resources (DWR)	1952	2019
27	Anadromous Fish Abundance and Trends	California Department of Fish and Wildlife (CDFW), Pacific States Marine Fisheries Commission	1998	2019
28	Anadromous Fish Distribution	National Oceanic and Atmospheric Administration (NOAA), Pacific States Marine Fisheries Commission, California Department of Fish and Wildlife (CDFW)	2002	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
29	Freshwater CyanoHABs Program (Blue-Green Algae Harmful Algal Blooms)	US Environmental Protection Agency (US EPA), California State Water Resources Control Board (SWRCB)	2005	2019
30	Stream Pollution Trends Monitoring Program (SPOT)	California State Water Resources Control Board (SWRCB)	2008	2019
31	Environmental Monitoring Program (EMP): Discrete Water Quality Monitoring	California Department of Water Resources (DWR)	1975	2019
32	Smelt Larva Survey	California Department of Fish and Wildlife (CDFW), California Department of Water Resources (DWR), California State Water Resources Control Board (SWRCB)	2009	2019
33	Spring Kodiak Trawl Survey	California Department of Fish and Wildlife (CDFW)	2002	2019
34	Striped Bass Study	California Department of Fish and Wildlife (CDFW)	1969	2019
35	Sturgeon Study	California Department of Water Resources (DWR)	UNK	2019
36	Summer Townet Survey	California Department of Fish and Wildlife (CDFW)	1959	2019
37	Zooplankton Study	California Department of Water Resources (DWR)	1972	2019
38	Delta Juvenile Fish Monitoring Program (DJFMP)	University of California – Davis (UC Davis), US Fish and Wildlife Service (USFWS)	1976	2019
39	Suisun Marsh Fish Study	University of California – Davis (UC Davis)	1979	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
40	Fire and Resource Assessment Program (FRAP) Fire Perimeters	US National Park Service (NPS), US Bureau of Land Management (BLM), US Department of Agriculture (USDA) – Forest Service Region 5, California Department of Forestry and Fire Protection (CALFIRE)	1996	2019
41	California Aquatic Resource Inventory (CARI)	California Wetlands Monitoring Workgroup (CWMW), San Francisco Estuary Institute (SFEI)	2008	2016
44	Breeding Waterfowl Surveys	California Waterfowl Association (CWA), California Department of Fish and Wildlife (CDFW), Pacific Flyway Council	1948	2019
45	Multibeam Delta Bathymetry Surveys	California Department of Water Resources (DWR)	2011	2019
46	Fish Salvage and Genetic Analysis	California Department of Fish and Wildlife (CDFW), California Department of Water Resources (DWR), US Bureau of Reclamation (USBR)	1957	2019
47	Feather River Hatchery/ Oroville Facility Fishery Studies	California Department of Fish and Wildlife (CDFW), California Department of Water Resources (DWR)	1961	2019
48	Recreational Freshwater Fishing Licenses	California Department of Fish and Wildlife (CDFW)	UNK	2019
49	Hunting Licenses (waterfowl)	California Department of Fish and Wildlife (CDFW)	UNK	2019
50	State Park System Statistics Monitoring	California Department of Parks and Recreation	1961	2019
51	Yolo Bypass Fish Monitoring	California Department of Water Resources (DWR)	1998	2019
52	California Boat Registration	California Department of Parks and Recreation	1960	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
53	Periodic Groundwater Level Measurements	California Department of Water Resources (DWR)	2009	2019
54	Municipal Water Quality Investigation Program (MWQI)	California Department of Water Resources (DWR)	1982	2019
55	Enhanced Delta Smelt Monitoring (EDSM) Program	US Fish and Wildlife Service (USFWS)	2016	2019
56	Quality Assurance & Quality Control (QA/QC) Program	California Department of Water Resources (DWR)	1992	2019
57	Vegetation Classification and Mapping Program (VegCAMP)	California Department of Fish and Wildlife (CDFW)	2007	2019
58	Sacramento District Water Control Data System (WCDS)	US Army Corps of Engineers (USACE)	1990	2019
59	California Irrigation Management Information System (CIMIS)	University of California – Davis (UC Davis), California Department of Water Resources (DWR)	1982	2019
60	Delta Region Areawide Aquatic Weed Project (DRAAWP)	California Department of Water Resources (DWR), National Aeronautics and Space Administration (NASA) – Ames Research Center, Sacramento-San Joaquin Delta Conservancy, California Department of Food and Agriculture (CDFA), US Department of Agriculture (USDA) – Agricultural Research Service, University of California – Davis (UC Davis), California Department of Parks and Recreation	UNK	UNK
61	Invasive Species Program	California Department of Fish and Wildlife (CDFW)	UNK	UNK

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
62	Water Tracker	Point Blue Conservation Science	UNK	UNK
63	Continuous Monitoring of Water Quality & Suspended-Sediment Transport (Bay-Delta)	US Geological Survey (USGS)	1988	2019
64	Water Quality of San Francisco Bay	US Geological Survey (USGS)	1968	2019
65	Suisun Marsh Monitoring Program	California Department of Water Resources (DWR)	1998	2019
66	Western Regional Climate Center (WRCC) – Weather Monitoring	Desert Research Institute (DRI), National Oceanic and Atmospheric Administration (NOAA)	1986	2019
67	Surface Water Protection Program	US Environmental Protection Agency (US EPA), California State Water Resources Control Board (SWRCB), US Geological Survey (USGS), California Department of Pesticide Regulation (DPR)	1925	2018
68	Plate Boundary Observatory (PBO)	UNAVCO	2003	2019
69	Farmland Mapping & Monitoring Program (FMMP)	California Department of Conservation (DOC), US Department of Agriculture (USDA)	1982	2019
70	National Pipeline Mapping System	US Department of Transportation (DoT)	2002	2019
73	Well Completion Monitoring	California Department of Water Resources (DWR)	1969	2019
74	Water Conservation and Production Reports	California State Water Resources Control Board (SWRCB)	2014	2019
75	National Water Use Science Project (NWUSP)	US Geological Survey (USGS)	1950	2015

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
76	Berkeley Seismology Lab Geophysical Networks	University of California – Berkeley, US Geological Survey (USGS)	1993	2019
78	Stormwater Multiple Application and Report Tracking System (SMARTS)	California State Water Resources Control Board (SWRCB)	UNK	2018
79	California Strong Motion Instrumentation Program (CSMIP)	California Department of Conservation (DOC)	1972	2019
80	Regional Monitoring Program for Water Quality in San Francisco Bay	San Francisco Estuary Institute (SFEI) – Regional Monitoring Program (RMP), US Geological Survey (USGS)	1993	2019
81	Fish Restoration Program Monitoring	California Department of Fish and Wildlife (CDFW)	2015	2019
82	Regional Geologic Mapping Program (RGMP)	California Geologic Survey (CGS), California Department of Conservation (DOC)	1981	2019
83	Seismic Hazards Program	California Department of Conservation (DOC)	1992	2019
84	Energy Almanac	California Energy Commission (CEC)	1981	2019
85	Mineral Resources Program	California Department of Conservation (DOC)	1978	2019
86	National Strong Motion Project (NSMP)	US Geological Survey (USGS)	1932	2019
88	Atmospheric River Reconnaissance	National Oceanic and Atmospheric Administration (NOAA), National Center for Atmospheric Research (NCAR), University of California – San Diego – Scripps Institute of Oceanography	2014	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
89	Advanced Hydrologic Prediction Service – Precipitation Monitoring	National Oceanic and Atmospheric Administration (NOAA)	1961	2019
90	Local Climatological Data	National Oceanic and Atmospheric Administration (NOAA)	1931	2019
92	Streamflow Monitoring	US Geological Survey (USGS)	1850	2019
93	National Geospatial Agriculture Monitoring	US Department of Agriculture (USDA), National Agricultural Statistics Service (NASS)	1997	2019
95	California Cooperative Snow Surveys (CCSS) program	California Department of Water Resources (DWR)	1929	2019
96	Precipitation Monitoring	California Department of Water Resources (DWR)	1956	2019
97	Physical Oceanographic Real-Time System (PORTS)	National Oceanic and Atmospheric Administration (NOAA)	1991	2019
98	Mid-Winter Waterfowl Survey (MWS)	US Fish and Wildlife Service (USFWS)	1935	2019
99	Central Valley Joint Venture (CVJV)	US Fish and Wildlife Service (USFWS)	1988	2019
100	San Francisco Bay Joint Venture	US Fish and Wildlife Service (USFWS)	1988	2019
101	Delta Regional Monitoring Program	University of California – Davis (UC Davis) – Aquatic Health Program Laboratory, Moss Landing Marine Laboratories, California Department of Water Resources (DWR), US Geological Survey (USGS), San Francisco Estuary Institute (SFEI) – Aquatic Science Center	2015	2019
102	Pacific Flyway Shorebird Survey	Point Blue Conservation Science	UNK	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
103	The Heron and Egret Project	San Francisco Bay Bird Observatory, Audubon Canyon Ranch	2011	2019
105	Audubon Christmas Bird Count (CBC)	National Audubon Society	1900	2019
106	California Partners In Flight (CalPIF)	Point Blue Conservation Science	1992	
107	Central Valley Enhanced Acoustic Tagging Project	University of California – Santa Cruz, National Oceanic and Atmospheric Administration (NOAA)	2017	2019
110	North American Breeding Bird Survey (BBS)	Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO), Environment and Climate Change Canada (ECCC), US Geological Survey (USGS)	1966	2019
111	Marine Invasive Species Program (MISP)	Smithsonian Institute – Smithsonian Environmental Research Center, California Department of Fish and Wildlife (CDFW)	2000	2019
112	Monitoring Avian Productivity and Survivorship	The Institute for Bird Populations	1989	2019
113	Central Valley Project – Reservoir Monitoring	US Bureau of Reclamation (USBR)	1938	2019
114	State Water Project – Reservoir Monitoring	California Department of Water Resources (DWR)	1960	2019
115	Water Quality Data for California	US Geological Survey (USGS)	1915	2019
116	eBird	Cornell Lab of Ornithology	UNK	UNK
117	Discrete dissolved oxygen monitoring in the Stockton Deep Water Ship Channel	California Department of Fish and Wildlife (CDFW), US Geological Survey (USGS), California Department of Water Resources (DWR)	1968	2019
119	Surface Water Quality Monitoring	California State Water Resources Control Board (SWRCB)	1999	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
120	Drinking Water Well Monitoring	California State Water Resources Control Board (SWRCB)	2019	2019
121	Surface Water Monitoring	California Department of Water Resources (DWR)	UNK	UNK
122	Phytoplankton and Chlorophyll-a Monitoring	California Department of Water Resources (DWR)	1975	2019
123	Delta-Mendota Canal Water Quality Monitoring	US Bureau of Reclamation (USBR)	2002	2019
124	Aquatic Invasive Species Programs	California Department of State Parks, Division of Boating and Waterways	1983	2019
125	National Pollution Discharge Elimination System (NPDES) Self-Monitoring Program	US Environmental Protection Agency (US EPA)	1972	2019
126	Contra Costa Water District Source Water Monitoring	Contra Costa Water District (CCWD)	1940	2019
128	Grasslands Bypass Project Monitoring	US Bureau of Reclamation (USBR)	1998	2019
129	Central Valley Project	US Army Corps of Engineers (USACE), US Bureau of Reclamation (USBR)	1933	2019
130	State Water Project	California Department of Water Resources (DWR)	1960	2019
131	Endangered Species Project	California Department of Pesticide Regulation (DPR)	1988	2019
132	Pesticide Use Reporting	California Department of Pesticide Regulation (DPR)	1989	2019
133	San Francisco Bay Bathymetry	National Oceanic and Atmospheric Administration (NOAA) – National Ocean Service (NOS), National Oceanic and Atmospheric Administration (NOAA), US Geological Survey (USGS)	1867	UNK

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
134	Freeport Regional Water Project	East Bay Municipal Utilities District	2007	2019
135	Highway Performance Monitoring System (HPMS)	California Department of Transportation (Caltrans)	1978	2019
136	AIS Marine Vessel Traffic Monitoring	Marine Traffic	2013	2019
137	California Recreational Fisheries Survey (CRFS)	California Department of Fish and Wildlife (CDFW)	2004	2019
138	National Water Level Observation Network (NWLON)	National Oceanic and Atmospheric Administration (NOAA) – National Ocean Service (NOS)	UNK	UNK
139	DOGGR Oil and Gas Well Monitoring	California Department of Conservation (DOC)	1900	UNK
140	Waterborne Commerce of the United States (WCUS) Monitoring	US Army Corps of Engineers (USACE)	1922	2018
141	Port of Stockton Monitoring	Port of Stockton Board of Commissioners	2000	2019
142	Lower Sacramento River Green Sturgeon Telemetry Monitoring	California Department of Fish and Wildlife (CDFW)	2015	2019
143	California Fish Passage Assessment Database (PAD)	Pacific States Marine Fisheries Commission	2002	2019
144	Local Maintaining Agency Annual Reporting	California Department of Water Resources (DWR)	2007	2018
145	Levee Inspections	California Department of Water Resources (DWR)	2003	2018
146	Levee Waterside Erosion Surveys	California Department of Water Resources (DWR), US Army Corps of Engineers (USACE)	1998	2018

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
147	Water Quality Exchange (WQX)	US Environmental Protection Agency (US EPA)	1963	2019
148	California Natural Diversity Database (CNDDB)	Department of Fish and Game (DFG), NatureServe, California Department of Fish and Wildlife (CDFW)	1979	2019
149	Drought Stressor Monitoring	California Department of Fish and Wildlife (CDFW)	2014	2017
150	San Francisco Bay National Estuarine Research Reserve	National Oceanic and Atmospheric Administration (NOAA) – National Ocean Service (NOS)	1995	2019
151	Middle Sacramento River Salmon and Steelhead Rotary Screw Trap Monitoring	California Department of Fish and Wildlife (CDFW)	1966	2016
152	Coleman and Livingston Stone Hatchery Releases	US Fish and Wildlife Service (USFWS)	1942	2016
153	Electronic Water Rights Information Management System (eWRIMS)	California State Water Resources Control Board (SWRCB)	2007	2019
154	AmeriFlux Network	US Department of Energy – Office of Biological and Environmental Research (DOE-BER)	1996	2019
155	Telemetered Stream Gauge Stations (Surface Water Monitoring)	California Department of Water Resources (DWR), Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS) (NOAA-Fisheries), US Fish and Wildlife Service (USFWS), US Bureau of Reclamation (USBR)	UNK	UNK

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
156	Groundwater Monitoring	California Department of Water Resources (DWR), Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS) (NOAA-Fisheries), US Fish and Wildlife Service (USFWS), US Bureau of Reclamation (USBR)	UNK	UNK
157	Water Quality Monitoring	California Department of Water Resources (DWR), Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS) (NOAA-Fisheries), US Fish and Wildlife Service (USFWS), US Bureau of Reclamation (USBR)	UNK	UNK
158	Nutria Eradication Program	California Department of Fish and Wildlife (CDFW)	2018	2019
159	Perennial Streams Survey	US Forestry Service (USFS), US Environmental Protection Agency (US EPA), California State Water Resources Control Board (SWRCB), Southern California Stormwater Monitoring Coalition (SMC)	2000	2019
160	Aquatic Invasive Species (AIS) Program	US Fish and Wildlife Service (USFWS)	1991	2019
161	Central Valley Angler Survey	California Department of Fish and Wildlife (CDFW)	1995	2019
162	Mokelumne River Fish Hatchery	East Bay Municipal Utilities District	1964	2019
163	Mokelumne River Rotary Screw Trap Monitoring	East Bay Municipal Utilities District	1992	2019
164	Beneficial Use Assessment	California Water Board, Central Valley Region	2007	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
165	Aquatic Invasive Species Program (CDFW)	California Department of Food and Agriculture (CDFA), California Department of State Parks, Division of Boating and Waterways, California Department of Parks and Recreation, California Department of Fish and Wildlife (CDFW), California Department of Pesticide Regulation (DPR), California Department of Water Resources (DWR)	UNK	2019
166	Water Quality in the Nation's Stream and Rivers	US Geological Survey (USGS)	1991	2017
167	Groundwater Quality Trends Monitoring	US Geological Survey (USGS)	1988	2012
168	SJCDWQC Surface Water Monitoring	San Joaquin County Resource Conservation District, San Joaquin County & Delta Water Quality Coalition (SJCDWQC)	2003	2019
169	SJCDWQC Groundwater Quality Trend Monitoring	San Joaquin County Resource Conservation District, San Joaquin County & Delta Water Quality Coalition (SJCDWQC)	2003	2019
170	Nitrogen Monitoring (Self-Reporting)	Westside San Joaquin River Watershed Coalition	2014	2019
171	National Wetland Condition Assessment (NWCA)	US Environmental Protection Agency (US EPA)	2011	2016
172	Sacramento Watershed Coordinated Monitoring Program (SWCMP)	California Department of Water Resources (DWR), California State Water Resources Control Board (SWRCB), Central Valley Regional Water Quality Control Board (Central Valley RWQCB)	2008	2019

Activ ID	Monitoring Activity Name	Implementing Organization(s)	Start Year	Latest Year
173	California Rice Commission (CRC) Surface Water Monitoring	California Rice Commission	2004	2019
174	California Rice Commission (CA Rice) Groundwater Monitoring	California Rice Commission	1997	2019
175	Moderate resolution imaging spectro radiometer MODIS	National Aeronautics and Space Administration (NASA)	UNK	2019
176	Ecosystem Spaceborne Thermal Radiometer Experiment on International Space Station (ECOSTRESS)	National Aeronautics and Space Administration (NASA)	UNK	2019
177	Landsat Science Program	Goddard Space Flight Center	UNK	2019
178	Sentinel Satellite	European Space Agency	UNK	2019
179	Sacramento River Water Quality Monitoring	Woodland-Davis Clean Water Agency	2009	2019
180	WorldView-3	DigitalGlobe	2014	2019

Appendix C. Questionnaire Analysis

Overview

As one part of its larger review methodology, the Delta ISB administered a questionnaire to seek feedback on the initial findings and recommendations from the initial analysis of the Delta monitoring inventory and to help identify areas for further analysis. Thirty-four people responded to the survey. Detailed methods are described in Section 2.2.1 of the report. This appendix provides a general summary of responses.

At the beginning of the questionnaire, participants were asked to provide background information about their role in the monitoring enterprise (e.g., program manager, data collector, etc.), their years of experience working in the Delta, and the management context in which they were providing their response based on the themes identified for the review (e.g., water supply, land use, etc.).

The majority of respondents had 10 or more years working in the Delta monitoring enterprise, and most respondents self-identified their role in the Delta monitoring enterprise as a data user/analyst/synthesizer of monitoring data. Data collectors and program managers were the second and third most common roles with which respondents self-identified (Figure C-1). Most respondents selected habitat management as the context in which they would respond on the survey. Very few respondents selected flood and land use management (Figure C-1).

Respondents were next asked to indicate the extent to which they disagreed or agreed with the 19 statements that were based on the initial findings and recommendations from the initial analysis. They were asked to rate each statement on a numerical scale with response options ranging from 1 (strongly disagree) to 5 (strongly agree). A response of 3 was interpreted as neutral. Respondents were also given a separate option to select "I do not know." Results can be found in Table C-1 and Figure C-2 below. After providing a numerical rating for each statement, respondents had the opportunity to provide write-in comments elaborating on their rating. These written responses are summarized for each question below, with select quotations provided as examples of comments associated with numerical ratings.

Note we use "*quotations*" throughout to demonstrate the perceptions of some of the participants and provide some context.

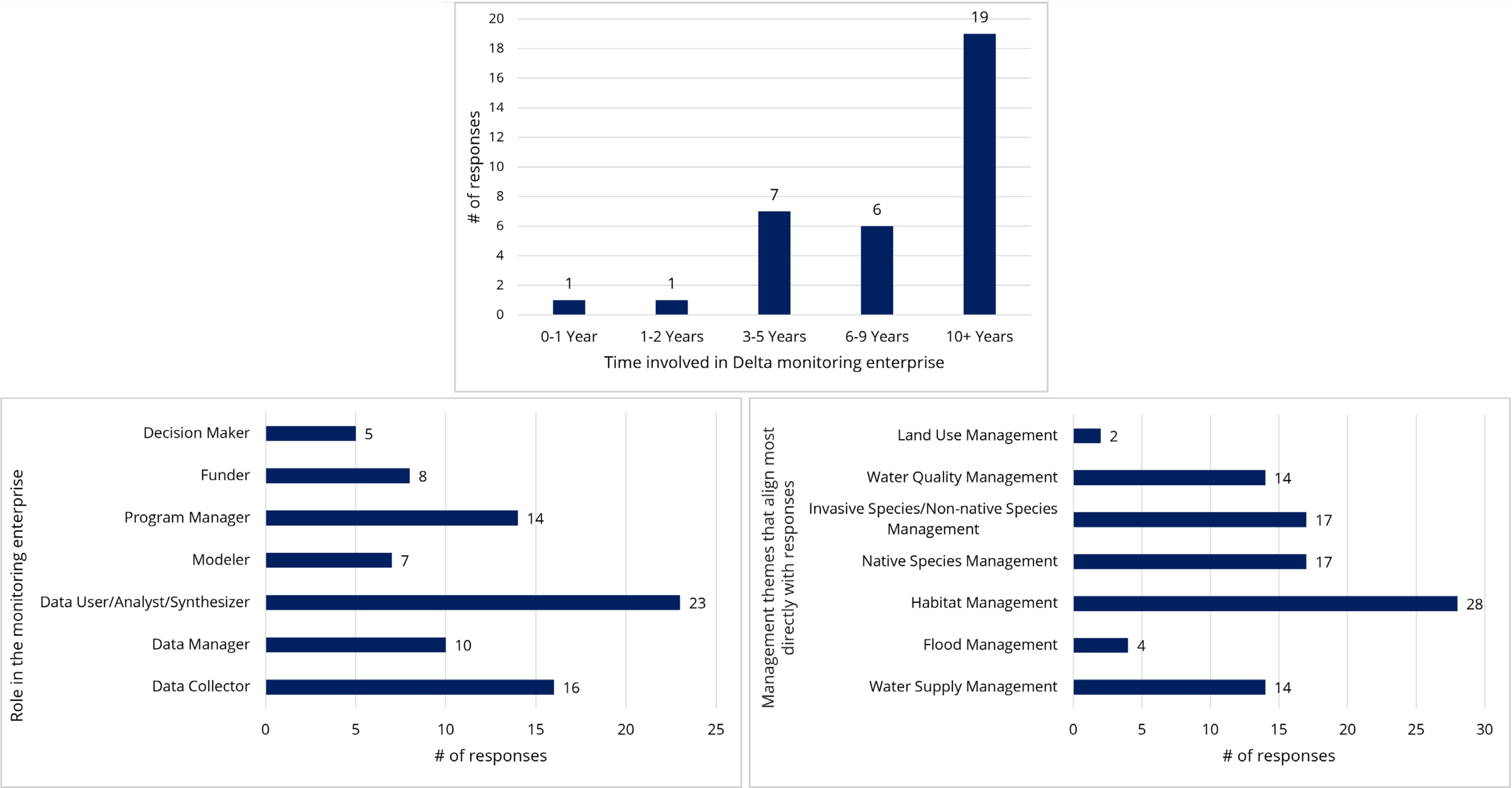


Figure C-1. Self-identified background information about questionnaire respondents. Top graph: Respondents' length of involvement with the Delta monitoring enterprise. Bottom left graph: Respondents' role in the Delta monitoring enterprise. Respondents had the option of choosing multiple categories if they serve multiple roles. Bottom right graph: Management areas upon which respondents based their questionnaire responses. Respondents had the option of choosing multiple management areas. (N=34).

Table C-1. Counts of respondents who agreed, were neutral, disagreed, or answered "I do not know" for each questionnaire statement. For purposes of reporting, responses of "agree" and "strongly agree" were grouped into "agree" and responses of "disagree" and "strongly disagree" were grouped into "disagree." Questions 1 to 4 asked respondents for background information (see Figure C-1); therefore, the questions below begin with Statement 5.

Statement	Agree	Neutral	Disagree	Don't Know
5. Overall, current information collected from monitoring serves the needs of decision makers and stakeholders across the Delta.	6	11	16	1
6. The frequency and timing at which the monitoring of the top two parameters you identified in question 4 are conducted is sufficient for informing management decisions.	7	3	23	1
7. The spatial coverage of monitoring of the top two parameters you identified in question 4 is sufficient for informing management decisions.	5	4	23	2
8. Monitoring approaches have sufficient scientific rigor (e.g., sampling design, statistical power) to meet management needs.	3	4	24	3
9. The procedures for quality assurance and control are adequate.	10	3	12	9
10. Mercury and methylmercury seem to be monitored extensively in the Delta, whereas other chemical contaminants receive considerably less attention for informing management actions.	18	7	4	5
11. Among the likely drivers and vectors of the introduction and spread of invasive species, there is a gap of monitoring transportation-related activities, such as roads, rail lines, vessels, and shipping channels, for informing management actions.	13	3	4	14

Statement	Agree	Neutral	Disagree	Don't Know
12. There are other gaps in monitoring invasive and non-native species (e.g., aquatic vegetation) in the Delta and beyond transportation related activities for informing management actions.	23	3	3	5
13. There is a gap in monitoring of dredging and its effects in the Delta.	11	6	1	16
14. The quality, quantity, and capabilities of sampling equipment (e.g., boats, sensors and sensor networks, nets) are sufficient for conducting effective monitoring in the Delta.	4	6	16	8
15. For environmental water quality, there are opportunities for increasing comparability of data by standardizing use and calibration of equipment, employing consistent sampling protocols, and centralizing data management.	21	4	3	6
16. Monitoring of specific habitats and species should be guided by standardized habitat-classification schemes among the different monitoring activities.	20	6	4	4
17. Fish monitoring is well coordinated.	11	7	7	9
18. Data availability and sharing among agencies and groups doing monitoring are sufficient.	4	14	12	4
19. Data are analyzed and synthesized in a way that enables management decisions.	5	11	14	4
20. There is a common understanding of the priorities required to meet science and management needs.	3	5	23	3
21. The organizational structure and integration of activities to support monitoring and adaptive management should be strengthened to achieve better coordination, efficiency, and results in meeting priority management needs.	27	1	4	2

Statement	Agree	Neutral	Disagree	Don't Know
22. The organizational structure to support monitoring and adaptive management in the Delta should be reconsidered and changed to achieve better coordination, efficiency, and results in meeting priority management needs.	21	8	2	3
23. A major coordinated overhaul about how monitoring is designed and conducted across multiple monitoring programs would result in better coordination and efficiency, and better meet priority management needs.	20	5	5	4

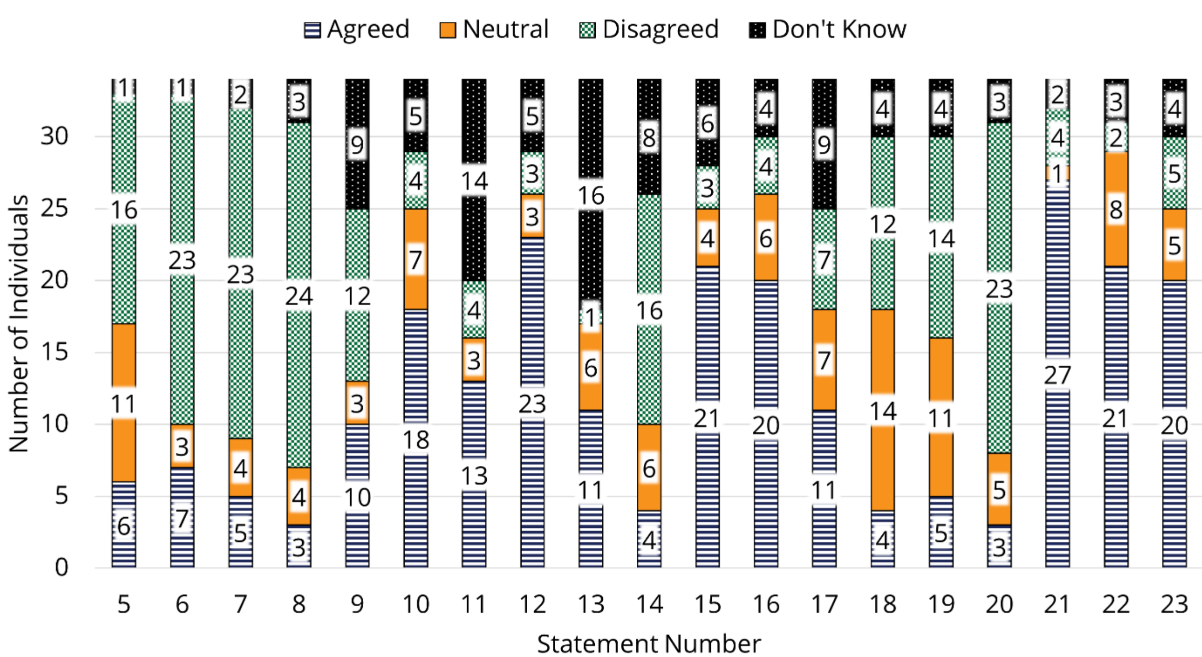


Figure C-2. The number of individuals who responded with agree, neutral, disagree, or "I do not know" for each questionnaire statement. Corresponding statements can be found in Table C-1.

General Perceptions

Prior to completing the inventory analysis, ESSA, on behalf of the Delta ISB, hosted a workshop in April 2019 to gather input from Delta scientists, practitioners, program managers, and decision makers for the review (ESSA et al. 2019). They asked the participants "How well does monitoring currently serve the needs of decision makers and stakeholders across the Delta." A majority (31 of 52) of respondents indicated "Moderately", 9 indicated "Very", 7 indicated "Slightly", and 5 indicated that they did not know (N=52).

The Delta ISB asked a similar question in its questionnaire to get a sense of opinions about the overall effectiveness of the monitoring enterprise. Using the response options described above, respondents were asked to rate their level of disagreement or agreement with the following statement:

> Question 5: Overall, current information collected from monitoring serves the needs of decision makers and stakeholders across the Delta.

Six participants agreed that current monitoring serves the needs of decision makers and stakeholders across the Delta, while 16 disagreed, 11 chose the neutral response, and one answered "I do not know." As an example of a write-in response elaborating on a rating that indicated agreement with the statement, one respondent praised the Delta monitoring enterprise: "*Fisheries and ecosystem monitoring in the Delta are also some of the most long running and robust in our Nation. An extensive amount of monitoring is currently conducted in the Delta to inform management and operations of water conveyance programs, plan habitat restorations, protect sensitive species, regulate pesticide use, advance scientific knowledge, and protect the multiple beneficial uses of water*."

However, many respondents disagreed (16 of 34), with many of them noting both general and specific gaps and disconnects between monitoring and management needs. Specific insufficiencies named in written responses included harmful algal bloom monitoring, terrestrial species (especially birds) and habitat (riparian and near aquatic habitat) monitoring, and the need for more specific information on species that are currently extensively monitored, including salmon and longfin smelt. These participants noted that, although many resources are dedicated to monitoring these species, there are still major knowledge gaps when it comes to specifics such as habitat use and life stage information, largely larval stages. When discussing salmonid monitoring in the Delta, one respondent explained that monitoring efforts are not designed to answer management questions, commenting, "*If we started with questions that need to be addressed, we'd likely end up with juvenile salmonid monitoring in the Delta that is quite different from what we've been doing."*

Respondents who disagreed with the statement commonly commented that there is a monitoring-management disconnect, noting that in some cases monitoring is designed well to answer management questions, but in other case it is not (e.g., "*Trawls such as the Fall midwater, spring kodiak, summer tow net, and 20mm larval, and bay studies*"). One perceived barrier to addressing this issue was that monitoring is not nimble enough to respond to rapidly changing management needs. As stated in one write-in comment, "*the needs of decision makers change more quickly than the science does*." Other respondents noted that there is an emphasis on long-term studies in the Delta, but not enough special studies to address imminent management needs. General gaps mentioned include a need for greater "*spatial and temporal resolution"* in many monitoring efforts, and a need for improved synthesis, analysis, and communication for monitoring to be useful to decision makers.

Additionally, 11 participants indicated a neutral stance on this statement. Written comments associated with these responses can be grouped into three general categories: first, that monitoring has been improving, although it needs to continue improving to be adequate; second, it is difficult to determine whether or not monitoring is sufficiently addressing management needs, either due to a lack of communication or because the linkage to structured decision-making has yet to be formalized; or third, that monitoring is sufficient, but there are other limitations to addressing management needs, namely modeling capabilities and data accessibility.

Monitoring and Sampling Design

Temporal and Spatial Gaps

In their initial review, ESSA was able to identify topical gaps, but could not adequately describe temporal and spatial gaps due to the course resolution of the analysis. Two questions in the questionnaire were designed to help clarify this. Participants were first asked to select the top two major monitoring parameters that they believed the Delta ISB should consider in greater detail (Figure C-3).

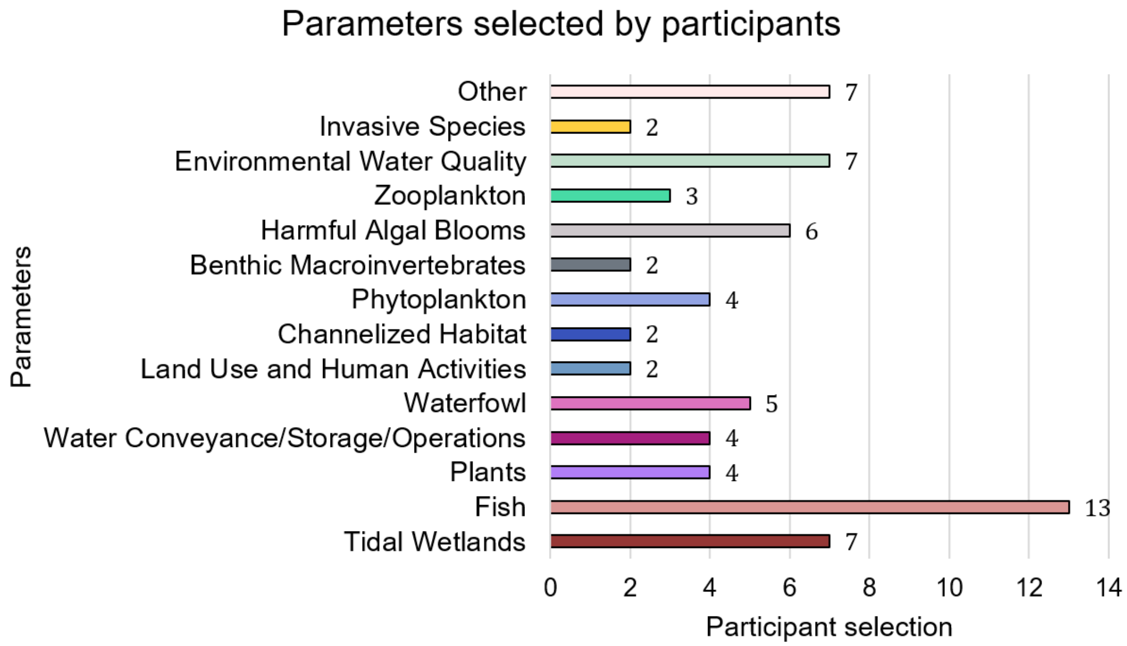


Figure C-3. Parameters selected by respondents as the basis for their responses to Questions 6 through 9.

Using the same response options described above, respondents were then asked to indicate their level of disagreement or agreement with the following follow-up questions about the two monitoring parameters that they selected:

> Question 6: The frequency and timing at which the monitoring of the top two parameters you identified in question 4 are conducted is sufficient for informing management decisions.
>
> Question 7: The spatial coverage of monitoring of the top two parameters you identified in question 4 is sufficient for informing management decisions.

The majority of respondents disagreed that the frequency and timing (23 of 34) and spatial coverage (23 of 34) of monitoring was sufficient to inform management decisions, while 7 and 5 respondents, respectively, agreed that it was sufficient. Three respondents indicated a neutral response, and one responded that they did not know about frequency and timing; and 4 indicated a neutral response and 2 responded that they did not know about spatial coverage. In written comments, respondents who disagreed mentioned a need for greater temporal and spatial resolution broadly as well as deficiencies for specific species and habitats. A common issue mentioned for both questions was that the monitoring being done is not strategic enough to properly sample species or habitats of interest.

One respondent who agreed that the frequency and timing of monitoring is sufficient suggested that fish monitoring may be excessive to the point that is detrimental for fish populations and "*may be having a larger impact on the species than the value of the information and some of the stressors it is purported to inform decisions about*." This person felt fish take should be more strategic. However, other respondents who disagreed with the statement noted specific deficiencies in fish monitoring. Multiple respondents mentioned a need for more frequent and/or more targeted sampling of salmon to clarify how they use the Delta and their response to changes in habitat, including restoration, channelization, and other anthropogenic habitat modification. A need for improved monitoring of restoration projects in general was mentioned, including how fish and wildlife respond to restoration. Additional topical deficiencies mentioned by respondents who disagreed included harmful algal blooms (HAB's), terrestrial animals (particularly birds) and plants, and sediment and benthic invertebrates. While discussing benthic macroinvertebrates, one respondent stated, "*Current monitoring programs lack the spatial and temporal coverage necessary to understand the role and impact of this factor on the Delta ecosystem*."

Other respondents more broadly felt that the frequency of monitoring is insufficient, and that more real-time and year-round monitoring is necessary for effective management. For example, one respondent commented, "*Fine time-scale monitoring is required for ecological understanding,*" going on to write that the monitoring enterprise needs to "*implement more real-time methods and new technology to make decisions quicker."* More specific temporal deficiencies that were named in written comments included a need for higher resolution of data about invasive species and HAB's. One respondent who disagreed with the statement about frequency and timing highlighted the difficulty of effectively monitoring for HAB's: "*HAB's can develop or decline on a daily basis and therefore require very frequent sampling to identify conditions regulating their size and occurrence."*

Respondents who disagreed with the statement that spatial resolution is sufficient mentioned a need for greater monitoring in habitats including wetlands, shallow and benthic habitats, upland habitats, and more specific targeting of fish habitat in general.

Scientific Rigor and Quality Assurance and Control (QA/QC)

As part of the inventory analysis, ESSA attempted to characterize the data quality of the monitoring enterprise by asking the question "**What is the data quality of monitoring to address purposes and needs for data?**" Five attributes of data quality were used to analyze monitoring activities: public accessibility, monitoring guidance, QA/QC, timeliness (lag between collection and reporting), and uncertainty estimate. They grouped various monitoring activities into groups that met varying aspects of data quality and found that a substantial number of monitoring activities (44%) met several fundamental attributes that represent high data quality, including 17% of monitoring activities that provide uncertainty estimates and 52% of monitoring activities that collect data that are reported within a one-year or less timeframe. Although this analysis provided insight into aspects of data quality of the monitoring enterprise overall, it was impossible to conduct detailed evaluations of the scientific rigor of all monitoring activities in the Delta given the scope and breadth of the review. Therefore, in an effort to understand perceptions of scientific rigor, the Delta ISB asked respondents to indicate their level of disagreement or agreement with the following two statements (using the same response options described above) about the top two monitoring parameters that they had previously selected:

> Question 8: Monitoring approaches for the top two parameters you identified in question 4 have sufficient scientific rigor (e.g., sampling design, statistical power) to meet management needs.
>
> Question 9: The procedures for quality assurance and control for the sampling methods of the top two parameters you identified in question 4 are adequate.

A majority of respondents (24 of 34) disagreed that the monitoring approaches for their top two parameters have sufficient scientific rigor to meet management needs. Only 3 agreed that there was sufficient scientific rigor, 4 indicated a neutral stance, and 3 indicated that they did not know. In written comments, several respondents suggested that the scientific rigor of monitoring in the Delta is not adequate because programs are infrequently, if ever, reviewed for their scientific rigor or how well they address management needs. As explained by one respondent, "*There is inadequate survey and method review to determine if much of the fish monitoring actually meets management needs. Phytoplankton* *monitoring is even less well understood than fish*." Other comments provided similar observations about specific efforts including the Environmental Monitoring Program (EMP) phytoplankton monitoring, Delta juvenile salmonid monitoring (include SAIL/ Salmon and Sturgeon Assessment of Indicators by Life Stage; although another commenter suggested SAIL as an example of a well-designed program), and IEP monitoring broadly. Another respondent commented that although "*there is enough scientific rigor to meet the EMP program's goals…there is not enough sampling/rigor to meet the broader science communities needs of more invert/ sediment sampling,*" suggesting a mismatch between monitoring and management needs.

Several comments also mentioned inadequate scientific rigor as an outcome of topical and geographical gaps. Separate comments identified monitoring gaps that result in inadequate scientific rigor including plant and bird monitoring, fish and zooplankton use of restored areas, HABs, shallow habitats and tidal wetlands (particularly as they pertain to zooplankton production for food web support), sampling at night, and insufficient coverage of habitat ranges of species of concern (longfin smelt). Respondents also wrote about other sampling design flaws that result in inadequate scientific rigor. Some commented broadly that sample sizes are too small and therefore result in a lack of power for scientific testing. Additional sample design concerns that were mentioned in written comments included issues with temporal consistency, adequate spatial coverage, detection probability (given presence), fish size bias, and inappropriate or inadequate sampling techniques, including optical tools that do not sufficiently sample microcystis. One respondent suggested that it would not be unfeasible to update programs to improve their scientific rigor, but that many programs are inadequate "*because most existing sampling programs were instituted before development and wide accessibility (to computing power) of Bayesian modeling techniques, and of novel sampling methods (such as eDNA and isotope/otolith analyses). Now it seems many of these programs are not updated because of the notion of required continuity.*" This comment highlights a barrier to improvement that was brought up through multiple aspects of this review.

There was less consensus as to whether there is sufficient quality assurance and control of sampling methods, with 10 respondents agreeing, 12 respondents disagreeing, 3 neutral responses, and 9 indicating that they did not know. In written comments, respondents expressed that QA/QC procedures have improved considerably and are well developed, noting that this aspect of sampling has become a higher priority in recent years. However, others disagreed, with one respondent for example stating, "*The methods are suitable for the program's goals but are not well-documented (especially meta-data), tracked and updated…The Delta science community has placed a disproportionate amount of value on peer-reviewed science publications, rather on documentation and QA/QC, and QA/QC related studies.*" Again, several respondents' comments emphasize the lack of data on topical areas such as birds, plants, and invertebrates in the Delta, and therefore a lack of quality assurance due to that lack of data. One participant also commented on discrepancies between lab-based sampling and noisier, less accurate field sampling. In addition, the 9 respondents who indicated that they did not know the answer to this question may suggest a lack of clarity on the level of quality assurance across programs. However, it is important not to draw generalized conclusions from this observation, as our sample size is small and not representative of any larger population.

Potential Gaps from Inventory Analysis

In the initial inventory analysis, chemical contaminants (with the potential exception of mercury/methylmercury), invasive/non-native species, and dredging had the fewest monitoring activities in relation to other parameters that are of key interest to various management drivers (e.g., Clean Water Act, Delta Plan, etc.), which represents a potential gap. However, there is a possibility that these monitoring parameters can be effectively monitored by fewer monitoring activities. Whether this is an actual gap must be determined by the user community. To investigate this, respondents were asked to indicate their level of disagreement or agreement with the following statements about potential gaps identified by the inventory analysis, using the same response options described above.

> Question 10: Mercury and methylmercury seem to be monitored extensively in the Delta, whereas other chemical contaminants receive considerably less attention for informing management actions.
>
> Question 11: Among the likely drivers and vectors of the introduction and spread of invasive species, there is a gap of monitoring transportation-related activities, such as roads, rail lines, vessels and shipping channels, for informing management actions.

> Question 12: There are other gaps in monitoring invasive and non-native species in the Delta beyond transportation related activities for informing management actions.
>
> Question 13: There is a gap in monitoring of dredging and its effects in the Delta.

The breakdowns of responses to each statement are provided below along with summaries of written comments and example quotations. A recurring comment of one respondent expressed that, although there may be gaps associated with some of these monitoring activities, it is not clear how these gaps would inform management actions. Additionally, another respondent wrote that they were not sure if they would necessarily prioritize these monitoring gaps, even if they agreed that there are existing gaps in these areas.

Contaminants

A majority of respondents (18 of 34) agreed that there are gaps associated with the monitoring of chemical contaminants, while 7 were neutral, 4 disagreed, and 5 did not know. However, in a written comment one respondent stated, "*Numerous other contaminants are monitored by agricultural, wastewater, and stormwater agencies, with management programs established to help reduce the impacts of chemicals exceeding established TMDL concentrations. Selenium, pesticides, nutrients, and heavy metals all receive a fair amount of monitoring in regulated water discharges*." This suggests that there could be missing monitoring activities in the inventory related to the monitoring of regulated discharge. In addition, another respondent who disagreed with the statement elaborated in a comment that they feel there is sufficient pesticide monitoring, but less so for contaminants of emerging concern. Other respondents who agreed with the statement commented that, although there is monitoring of contaminants, there is not enough information to identify sources, fates, and effects on the Delta ecosystem.

Some of the respondents who disagreed with the statement explained in written comments that they do not necessarily disagree there are gaps with monitoring of contaminants but do disagree that mercury and methylmercury seem to be monitored extensively, or that there should be less focus on mercury and methylmercury monitoring (which was not the Delta ISB's intended meaning). Comments also indicate that there could be a potential gap in monitoring mercury/methylmercury concentrations on levees (as most monitoring occurs in channels) and animals, such as fish and birds. According to one respondent, "*Sampling mercury in water is not an appropriate surrogate for directly sampling methylmercury in animals, such as fish and birds. Water and sediment mercury concentrations are not correlated with fish and wildlife methylmercury concentrations*."

Invasive Species

Of the 34 respondents, 14 did not know if there are gaps in monitoring of transportation-related activities for invasive/non-native species (13 agreed, 3 were neutral, 4 disagreed). Written comments indicate that many respondents were aware of the entities that are responsible for managing invasive or non-native species, but did not know the extent of their monitoring activities. As one respondent noted, "*California Department of Fish and Wildlife, State Lands Commission, Food and Agriculture, Parks and Recreation, and Coastal Conservancy all have funded programs to manage invasive species. The U.S. Coast Guard, U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (FWS), U.S. Army Corps of Engineers, and National Oceanic and Atmospheric Administration (NOAA) also play a role in regulating ballast water spread of invasive species. We do not know what the current level of engagement for these organizations is in monitoring transportation-related activities for potential invasive species introductions in the Delta region*." Another respondent acknowledged that they are aware of data being collected but have never seen any data published: "*I know that the State Lands Commission and CDFW collect data on invasive species associated with shipping and recreational vessels, but I have never seen anything published about it. Data that sit in someone's computer or on a website in raw form are as good as useless for decision-makers.*"

Although many respondents did not know if monitoring invasive/non-native species associated with transportation-related activities is a gap, more respondents agreed than disagreed that this is a gap. One comment conveys the perception that existing monitoring in this area is sufficient, but not well integrated with the rest of the monitoring enterprise: "*There are multiagency staff and programs (CDFW's Marine Invasive Species Program and United States Fish and Wildlife Service's Aquatic Invasive Species) that monitor and work on invasive species. These staff and program are not effectively part of the Bay-Delta monitoring enterprise, because of the institutional barriers enterprise leaders reinforce to emphasize the management themes they desire it to focus on.*"

When prompted for their perceptions of gaps in monitoring of invasive/non-native species beyond transportation-related activities, 23 respondents agreed there are gaps in these areas, 3 were neutral, 3 disagreed, and 5 did not know. Comments on this question conveyed the view that there is not a specific monitoring network to quickly identify new invasive species early in the invasion or a comprehensive invasive species monitoring program in the Delta for some of the most widespread and established invasive plant and animal species. For example, one respondent wrote, "*Absolutely a gap in invasive species monitoring. Good examples are Aquatic Vegetation and Nutria. Existing staff and programs are expected to monitor/ track and communicate these invasions without any additional resources (and at times reduced resources). The expansion of Aquatic Vegetation in the Delta is well known anecdotally, but there is no comprehensive monitoring program for it and its potential massive impacts on the ecosystem*." Written comments from other respondents focused on the need to improve communication and public awareness about the spread and prevention of invasive/non-native species.

Many of the comments about gaps related to invasive/non-native species expressed that monitoring of aquatic vegetation is limited and not adequate to understand the extent of the problem or the effectiveness of management actions. A few respondents also made comments about remote sensing. One respondent highlighted this as a gap since remote sensing efforts were cut from 2009 to 2012, due to the budget crisis in the State of California; while another respondent commented that remote sensing programs are not time-intensive enough to provide adequate monitoring for understanding or controlling non-native/invasive species.

Dredging

Of 34 respondents, 16 answered "I do not know" in response to the statement about gaps in monitoring of dredging activities, while 11 agreed with the statement, 6 were neutral, and 1 disagreed. In written comments, two participants indicated that the United States Army Corps of Engineers (ACOE) does quite a bit of monitoring of dredging in the Bay-Delta, which was not reflected in the inventory. As one respondent wrote, "*The ACOE does quite a bit of monitoring on its dredging activities. The ACOE management themes of flood management, habitat management, land use management, etc. are not effectively part of the Bay-Delta monitoring enterprise. Independently, they have developed a parallel enterprise related to this activity because leaders in the monitoring enterprise are not focused* *on this*." Thus, similar to monitoring of transportation-related activities to manage non-native or invasive species, this comment suggests existing monitoring of dredging may be sufficient, but not well integrated with the rest of the monitoring enterprise. Other comments conveyed the view that, while certain aspect of dredging (e.g., chemical composition) are monitored sufficiently, there is a lack of research and understanding about the effects of dredging on aquatic ecosystems in the Delta.

Opportunities for Increasing Efficiency

In their review, ESSA identified new opportunities for increased efficiency for the most common monitoring parameters within four broad monitoring categories (direct socio-economic drivers, environmental drivers/conditions, habitats, and species). In its questionnaire, the Delta ISB included two questions (Questions 15 and 16 below) to get a sense of the level of support for some of ESSA's suggestions for increased efficiency. The Delta ISB also included questions about two additional opportunities for improved efficiency (Questions 14 and 17 below) to evaluate perceptions of the role of limited equipment on improving efficiency and perceptions of the level of coordination of fish monitoring as a whole. Although ESSA found fish monitoring well-coordinated, the Delta ISB included Question 17 to assess perceptions of that finding and to identify potential opportunities for improvement. These statements were rated using the same response options described above.

> Question 14: The quality, quantity and capabilities of sampling equipment (e.g., boats, sensors and sensor networks, nets) are sufficient for conducting effective monitoring in the Delta.
>
> Question 15: For environmental water quality (temperature, dissolved oxygen, conductivity, turbidity), there are opportunities for increasing comparability of data by standardizing use and calibration of equipment, employing consistent sampling protocols, and centralizing data management.
>
> Question 16: Monitoring of specific habitats and species should be guided by standardized habitat-classification schemes among the different monitoring activities.
>
> Question 17: Fish monitoring is well coordinated.

Sampling equipment

Few participants (4 of 34) agreed that the quality, quantity, and capabilities of sampling equipment are sufficient. Write-in comments from the respondents who agreed generally noted that although there is always room for improvement, sampling methods are in good shape overall and continue to improve. However, the majority of respondents (16 of 34) disagreed, while 6 were neutral and 8 indicated that they did not know. In written comments, the most commonly reported issue was an aging boat fleet. For example, one respondent expressed serious concern about the severity of the issue, stating, "*it takes a tremendous amount of time, resources, and technical expertise for agencies to procure a new boat. This is a looming crisis for the Delta monitoring community*." Multiple respondents identified a general lack of funding and resources as the cause of inefficiencies, as insufficient funds are associated with limited and/or underpaid field crews and a lack of equipment redundancy, which in turn results in lost data when equipment malfunctions.

Additionally, multiple respondents explained that the gear used for sampling is not ideal for their sampling targets, whether due to funding limitations or poor sampling design. For example: "*Current trawling gear targets mainly large older juvenile salmon (mainly hatchery release sizes), and not the pre-smolt age classes we are providing habitat for. Beach seines don't work very well in the muddy Bay-Delta*" and "*People also need to recognize the limitations of boat type and not expect one boat (or other piece of equipment) to be able to do everything*." Other respondents mentioned issues of efficiency in juvenile salmon monitoring and littoral habitats generally, and a need for greater standardization across sampling techniques. Several respondents also mentioned data collection networks, including water quality and telemetry networks, as strategies for improving efficiency of monitoring.

As an example of a comment elaborating on a neutral response, one respondent expressed that sampling gear is not the key limitation, but rather how the monitoring enterprise was designed. *"The quality, quantity, and capabilities have led to a world-class network monitoring the Delta. However…most of the monitoring has been focused on a small sector of management themes by its leaders, which have reduced its ability to be nimble and capable to detect changes and effects of the broader set of management themes occurring in the Bay-Delta*."

Environmental water quality, habitat, and species monitoring

Majorities of respondents agreed with ESSA's suggestions about standardization to improve efficiency for environmental water quality monitoring (21 of 34) and species and habitat monitoring (20 of 34). However, many who agreed qualified their responses in written comments. For both environmental water quality and habitat and species monitoring, respondents' comments emphasized that, although standardization would be beneficial in many cases, maintaining flexibility is also essential for addressing management questions. For example: "*Some studies might require full depth profiles conducted from a boat, while others may only need a quick grab sample from the shoreline. Different instruments may be preferred for long-term and continuous deployment vs. a quick field sample. Differing levels of precision and accuracy are required based on the research and management question being addressed.*" Whether agreeing or disagreeing with the statement, many written comments emphasized the importance of prioritizing management needs over standardization.

Fewer respondents reported disagreement, neutral opinions, or answered "I do not know" in response to ESSA's suggestions about standardization to improve efficiency for environmental water quality monitoring (3 disagreed, 4 were neutral, 6 did not know) and its suggestions about standardized habitat-classification for species and habitat monitoring (4 disagreed, 6 were neutral, 4 did not know). One respondent who disagreed suggested that standardization can even be prohibitive in a program's ability to address management needs: "*Monitoring programs need to be adaptive and change their techniques over time as new knowledge of the system is gained and the management questions change. Providing guidelines and recommendations for sampling and analysis techniques can be useful but forcing researchers to use one standardized habitat-classification scheme would greatly impair the ability of researchers to refine their monitoring programs to address their specific study objectives and limit the discovery of new scientific insight.*"

Several comments spoke to the difficult task of standardization, and the necessity of collaboration to achieve appropriate levels of standardization and improved efficiencies in monitoring. For example: "*Centralizing data management is helpful, but this might be a challenge due to the large diversity of water quality monitoring equipment and the large number of research monitoring activities that collect this data over short periods of time to inform other scientific analysis. It can be helpful if one or more entities take the lead in field and laboratory inter-calibration* *studies*." In addition to collaboration, another respondent suggested expanded data networks, such as through community science, can improve efficiencies in monitoring.

Fish monitoring

Perceptions of the coordination of fish monitoring were more evenly distributed, with 11 respondents agreeing fish monitoring is well coordinated, 7 disagreeing, 7 indicating neutral opinions, and 9 who did not know. In written comments, several respondents who reported agreement recognized the role of the IEP in improving coordination of fish monitoring in the Delta. For example: "*To keep these surveys running takes a small army and the different programs should be commended for being able to conduct these surveys under varying levels of adversity*." Other respondents qualified their agreement; for example, in comments that fish monitoring is generally well coordinated but some efforts could still be better integrated, such as the telemetry efforts among agency and academic institutions, and standardized. One respondent agreed that fish monitoring is well coordinated with regular meetings and communication but felt there is still a mismatch between monitoring efforts and management needs: "*Increasingly, decision makers are emphasizing they would like monitoring information to inform them about population-level characteristics from the surveys not just presence/absence or relative indices*."

Among respondents who disagreed that fish monitoring is well coordinated, written comments point to siloed programs with varying specific goals and/or sampling methods that are not coordinated with each other or with other aspects of monitoring, such as environmental drivers or conceptual and quantitative models. One respondent noted some overlap in fish monitoring efforts that may reduce efficiency, but also recognized the benefit of a level of redundancy in monitoring.

Data Availability, Sharing, Analysis, and Synthesis

The inventory analysis identified that 95% of the monitoring activities are publicly accessible (149 of 157 monitoring activities), 63% are machine readable (99 of 157), and 52% are available within a one year or less timeframe (82 of 157). Overall, 34% of all monitoring activities (53 of 157) meet all of these conditions. To help understand perceptions of data accessibility and analysis, respondents were asked to indicate their level of disagreement or agreement with the following statements, using the same response options described above.

Question 18: Data availability and sharing among agencies and groups doing monitoring are sufficient.

Question 19: Data are analyzed and synthesized in a way that enables management decisions.

In terms of data availability and sharing, many respondents (12 of 34) disagreed that it was sufficient, while 4 agreed, 14 were neutral, and 4 did not know. As noted in a written comment from one respondent, *"It is not always easy to determine what data is available, and how to request data from organizations or databases. However, most organizations in the Delta are happy to share their data, and will assist interested individuals in acquiring it, once you know the data exists. There have been many recent efforts by different organizations to make monitoring data more available to the public."* Regardless of whether a questionnaire respondent agreed, disagreed, or was neutral, there was general acknowledgement in the written comments that improvements have been made in recent years. However, respondents indicated that additional improvements can still be made, as some datasets are hard to find, lack sufficient documentation, or are not available in a timely manner to conduct analysis.

Results were similar when respondents were asked if data are analyzed and synthesized in a way that enables management decisions. Many respondents (14 of 34) disagreed, while 5 agreed, 11 were neutral, and 4 did not know. In the written comments, a few respondents indicated the need for more synthesis, while others indicated that more synthesis is occurring than in the past and improvements have been made. However, many written comments indicated that data analysis and synthesis are not well-connected to management decisions or communicated in an accessible or timely manner to those who need the information. As one respondent wrote, *"data analysis and synthesis seems to shy away from addressing management issues,"* while another respondent expressed uncertainty about "*what managers are wanting to be synthesized and how that informs their decisions. Most synthesis activities appear to be a bottom-up approach, rather than a top down*."

Emerging Needs

Based on the inventory analysis, ESSA identified the following needs for improving the long-term effectiveness and efficiency of monitoring to support science and adaptive management (referred to as "big moves"). The final questions were used to help understand the level of disagreement or agreement with the three "big moves," which were presented along with corresponding questions as shown below. Respondents answered the questions using the same response options described above.

- **Big Move #1:** Synthesize, standardize and focus on priority science and management needs.
    a. Question 20: There is a common understanding of the priorities required to meet science and management needs.
- **Big Move #2:** Reimagine monitoring designs for priority monitoring needs.
    a. Question 23: A major coordinated overhaul about how monitoring is designed and conducted across multiple monitoring programs would result in better coordination and efficiency, and better meet priority management needs.
- **Big Move #3:** Strengthen organizational structure and integration to support monitoring and adaptive management.
    a. Question 21: The organizational structure and integration of activities to support monitoring and adaptive management should be **strengthened** to achieve better coordination, efficiency, and results in meeting priority management needs.
    b. Question 22: The organizational structure to support monitoring and adaptive management in the Delta should be **reconsidered and changed** to achieve better coordination, efficiency, and results in meeting priority management needs.

Big Move #1: Synthesize, standardize and focus on priority science and management needs

Of the 34 respondents, 23 disagreed that "*there is a common understanding of the priorities required to meet science and management needs*," while 3 agreed, 5 were neutral, and 3 did not know. Although a majority of respondents disagreed with the statement, written comments demonstrate that respondents who felt there is not currently a common understanding of priorities for meeting science and management needs do not necessarily feel there should be a common understanding of these priorities. Some respondents indicated that it is not necessarily a disadvantage or surprising that organizations would have their own priorities and needs. For example, one respondent stated, "*Science and management is not one monolith – there are many needs, and it doesn't seem useful to force 'science' into one box*." Another respondent wrote, *"Science and management needs will differ for each stakeholder in the Delta, therefore each organization has its own prioritization for monitoring needs."* However, there were also written comments indicating some respondents do feel there is a need for a common set of management questions to guide priorities. As described by one respondent, *"The coequal goals mean something different to different stakeholders. This basic understanding is not commonly understood therefore it is difficult to prioritize science when we do not agree on what that means."* A respondent who agreed with the questionnaire statement indicated that the Science Action Agenda has helped with identifying priorities.

Big Move #2: Reimagine monitoring designs for priority monitoring needs.

Of the 34 respondents, 20 respondents agreed that *"a major coordinated overhaul about how monitoring is designed and conducted across multiple monitoring programs would result in better coordination and efficiency, and better meet priority management needs,*" while 5 disagreed, 5 were neutral, and 4 did not know. Written comments from many respondents who agreed that an overhaul in how monitoring is designed nonetheless pointed out that an overhaul is complicated. As described by one respondent, *"This is a very desirable goal but how to go about it is very complicated. How to get buy in from the various groups so that they would trust that a "major coordinated overhaul" would not lead to a loss of existing data/insight and/or positions will be a challenge."*

Some respondents who disagreed commented that an overhaul would not necessarily lead to better coordination and efficiency. Other respondents who answered "I do not know" expressed that they do not have enough information about what would be overhauled to formulate an opinion. As described by one respondent, "*We do not have enough information on the proposed changes to predict if they could result in better coordination or efficiency…organizations like the IEP are currently undertaking a detailed statistical review of their fish monitoring program and long term datasets (Long-Term Monitoring Review Pilot Effort) to look for redundancies and possible efficiencies."*

Big Move #3: Strengthen organizational structure and integration to support monitoring and adaptive management

In the questionnaire, there were two separate questions related to organization. We first asked if the organizational structure and integration of activities to support monitoring and adaptive management should be **strengthened** to achieve better coordination, efficiency, and results in meeting priority management needs. Subsequently, we asked if the organizational structure should be **reconsidered and changed.** Of the 34 respondents, 27 agreed the organizational structure should be **strengthened**, while 4 disagreed, 1 was neutral, and 2 did not know. In comparison, 21 agreed that the organizational structure should be **reconsidered**, while 2 disagreed, 8 were neutral, and 3 did not know.

Several respondents who agreed indicated that monitoring is not organized to support adaptive management. Written comments from those who disagreed with results expressed that other factors beyond organization are needed to support adaptive management, including more synthesis of existing data, more monitoring programs, and more technical staff to lead projects.

Appendix D. Interview Questions and Coding Framework

This appendix includes the interview questions along with the prompt that was provided to each interviewee before the start of the interview. In addition, interviewees were asked to provide feedback on the draft best practices (see Appendix A) via a survey.[5] Interviewees were provided a copy of interview questions, the prospectus, and the summary of work completed to date prior to the interview. After interviews were completed, responses were analyzed using a coding framework, which is included near the end of this appendix (see Section 2.2.2 of report for methods).

Interviewees from various organizations were invited and represented the wide range of management themes identified from this review. However, when asked in the interview how monitoring could help address current or future management needs, no interviewees mentioned needs related to flood or non-native species management (see Figure D-1).

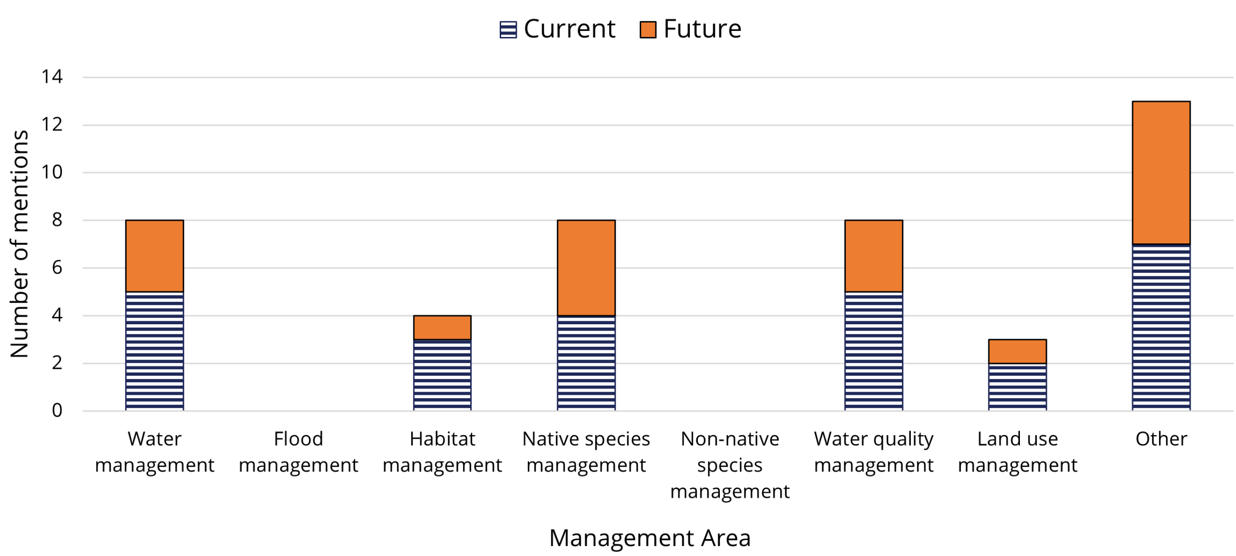


Figure D-1. Current and future management needs addressed by monitoring. Note: multiple mentions within interviews were counted as a single mention. See Table D-1 for "other" management needs.

Management needs mentioned in interviews most frequently related to water supply management, native species management, and water quality management,

[5] A copy of the best practices survey is available online.

along with a host of “other” management needs that were not defined in our analytical framework (see Table D-1). Interviewees representing regulatory agencies indicated that they have monitoring needs centered around determining regulatory protections for beneficial uses. Other interviewees expressed that their organizations do not have management needs per se, as they work to fulfill monitoring requirements for compliance.

Table D-1. “Other” current management and future management needs identified by participants that could be addressed by monitoring.

Current Management Needs	Future Management Needs
• Need to understand the Delta socio-economic system, including recreation, agriculture, and natural resources • Need for performance measures to assess issues governed under the Delta Plan and the achievement of the coequal goals • Needs for legacy monitoring • Need to understand the biological and physical drivers of the ecosystem (especially in order to inform water operations) • Need to understand biological species/wildlife generally (did not specify native or non-native)	• Needs related to understanding the Delta as an evolving place and environmental justice • Management for long-term environmental and climatic change, including drought • Monitoring to inform multi-benefit projects • The need to integrate management of the upper and lower estuaries • Monitoring at high frequencies in order to remove tidal influences

Prompt Read at the Start of Interview

Thank you for agreeing to participate in this interview. I'm ________ and I work as staff for the Delta ISB. For this interview, we are joined by ___________ of the Delta ISB and ________ who also works as staff for Delta ISB. Today, we'll be asking you questions to help inform the Monitoring Enterprise Review, which is assessing how current monitoring programs meet management needs and how they might be coordinated or modified to improve their responsiveness to management. Information collected from these interviews will be aggregated and analyzed using qualitative methods.

The goal of this interview is to learn about your organization's perspective on monitoring. You are also welcome to share your individual perspective at any time, but we would appreciate if you would clearly state when you do so. Otherwise, we will assume you are representing the organizational perspective. Do you have any questions about that?

Participating in this interview is completely voluntary, and if you prefer not to participate you are free to decline. You are also free to skip any questions or discontinue the interview at any time once it is in progress. To help with analysis, we would like to record this interview, which will be transcribed for purposes of analysis. Personally identifiable information will not be included in any publicly available reports, but please be aware that the interview recording, and transcript (including our staff notes) are subject to retrieval under the Public Records Act. Are you okay if we record this interview?

By proceeding with the interview, you indicate your consent to participate and to be recorded.

Questions

1. The monitoring enterprise refers to the full suite of monitoring programs and activities that collectively provide data about the physical, chemical, biological, and socio-economic (i.e., social-ecological) components of the Delta system. For this review, monitoring covers sampling design and sampling, data management, analysis and synthesis, and communication. Please briefly describe your role and experience in relation to the monitoring enterprise in the Delta.
2. What current management needs does your organization have that are addressed or could be addressed by monitoring? Please be as specific as possible.

    a. Do you anticipate future management needs, either in or outside your organization, which are or could be addressed by monitoring? If so, please describe them.
3. Would you say there are major gaps in monitoring in topical, temporal and geographical areas? By gaps, I mean monitoring that is important to address current or future management needs but is not currently done or planned. If so, please describe these gaps that are relevant to your organization's management needs. And for this question, you are again welcome to reflect on gaps that affect the broader enterprise as well, including those of other organizations.
    a. What would you say are the barriers to addressing these gaps?
    b. Do you have any ideas about how to begin addressing these gaps? Please be as specific as possible.
4. From our initial analysis, most of the long-term monitoring has not been designed and/or implemented with the intent of explicitly supporting adaptive management; although, many datasets are used in decision-making. Do you have ideas for improving how monitoring informs or is used in adaptive management, or how monitoring can be designed to support adaptive management?
5. From our initial review, there has not been an overall organizational framework for monitoring in the Delta that cuts across the management areas of water supply, flood, water quality, land use, habitat, and species to achieve the coequal goals. In a questionnaire completed by 34 stakeholders, most agreed there is a need to achieve better efficiency and coordination in monitoring to meet management needs, which could result in major changes with how monitoring is designed and organized. We'd like to hear your ideas about how this could be achieved. I have a set of questions on this topic, which I will ask one by one.
    a. What management areas need better coordination? What are the barriers to improve coordination? If the current organization and level of coordination meets your needs, feel free to state so.
    b. Do you have any ideas on how monitoring should be coordinated that cuts across all areas of management to achieve the coequal goals?
    c. What role do you see for your organization in efforts to re-organize and strengthen the coordination of monitoring?
        i. What other organizations would need to be a part of efforts to re-organize monitoring, and what role do you see them playing?
        ii. Who should take the lead in these efforts?

   d. What financial or regulatory mechanisms could be used to drive changes in the organization of monitoring?
      i. Can you think of other mechanisms or processes that could facilitate change in the organization of monitoring? If so, please describe them.
   e. What challenges are associated with efforts to re-organize monitoring in the Delta?
   f. As part of our review, we have looked into the organization of monitoring of Chesapeake Bay, Great Lakes, Coastal Louisiana, and Puget Sound in the US, and Queensland, Australia to help gain insights that could be applied to the Delta. Are you aware of any other watershed/systems where monitoring is done effectively that we should consider?
   g. Do you have anything else to add about how Delta monitoring could be re-organized to improve efficiency and coordination?
6. Is there anything else we should consider in our review of the Delta Monitoring-Enterprise?
7. Do you have any questions for us about this review, or any of our initial findings that we provided in a summary prior to the interview?

Approach to Analysis

Below is the coding framework used to analyze interview data. For several thematic areas being investigated through the analysis, a deductive coding approach was used in which interview text was sorted into a discrete set of potential ideas or responses – coding categories - which were pre-defined and assigned alphanumeric labels in the analytical framework (Cho and Lee 2014; see Appendix D). Coding categories were derived from findings in Component 1. Recognizing that interviewees were not restricted to comment only on material covered in Component 1, for each thematic area, "other" categories were also created to capture responses or ideas not explicitly identified in the analytical framework. For each interview, text that fit into any given coding category was tagged (i.e., in the margin) with the corresponding alpha-numeric label. After each transcript was coded, results were tabulated in an Excel spreadsheet by assigning 1 to each coding category that was present (i.e., mentioned at least once in the interview), and assigning 0 to all other categories. If a coding category could not confidently be labelled present in or absent from an interview, a numeric value of 97 was assigned as a flag for more detailed analysis (see below).

For the “other” thematic areas there was no reasonable way to anticipate potential responses and pre-define discrete coding categories. Therefore, text relevant to these areas was highlighted and moved to a separate document. Subsequently, an inductive coding approach was used to identify themes and patterns that emerged directly from the interview data (Cho and Lee 2014).

Given limitations in time and capacity, coding responsibilities were shared by two analysts. Each analyst was assigned a subset of thematic areas and coded interview transcripts independently. After all interviews were coded, the analysts held a series of meetings to review and resolve coding categories assigned 97 for each interview. Final coding decisions reflect consensus among both analysts.

Analytical Framework

Section A. Current and future management needs

A1. Current management needs of organization

NOTE: management needs are issues we need monitoring data for. They are not particular monitoring metrics, parameters, or activities. Gaps are particular monitoring metrics, parameters, or activities that are not being measured/done.

Start by coding child-codes (e.g., A1.1a) as follows: 0 absent, 1 present, 97 unclear. Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details. After child codes are complete, assign a code to parent code (e.g., A1.1) as follows: 0 absent, 1 at least one child code present.

- A1.1 Water management
  - A1.1a Water management general
  - A1.1b Water operations
  - A1.1c Water storage
  - A1.1d Water demand
  - A1.1e Water conveyance or infrastructure
  - A1.1f Groundwater protection and management
  - A1.1g Water management other (specify)
- A1.2 Flood management
  - A1.2a Flood management general
  - A1.2b Flood control structures
  - A1.2c Protection and expansion of floodways, floodplains, and bypasses

  - A1.2d Subsidence reversal
  - A1.2e Flood management other (specify)
- A1.3 Habitat management
  - A1.3a Habitat management general
  - A1.3b Habitat protection
  - A1.3c Natural environmental flows
  - A1.3d Habitat restoration
  - A1.3e Habitat management other (specify)
- A1.4 Native species management
  - A1.4a Native species management general
  - A1.4b Incidental mortality/take
  - A1.4c Harvest
  - A1.4d Population enhancement
  - A1.4e Management of specific native species (specify)
  - A1.4f Native species other (specify)
- A1.5 Introduced species
  - A1.5a Introduced species general
  - A1.5b Pathways of introduction
  - A1.5c Creation of favorable habitat conditions
  - A1.5d Population control
  - A1.5e Management of specific introduced species (specify)
  - A1.5f Introduced species other (specify)
- A1.6 Water quality
  - A1.6a Water quality general (including chemicals/contaminants)
  - A1.6b Wastewater management
  - A1.6c Pollution control (emphasis on control/reduction of contaminants)
  - A1.6d Water quality other (specify)
- A1.7 Land use management
  - A1.7a Land use management general
  - A1.7b Land zoning, designation, and ownership
  - A1.7c Specific land use (specify which land use)
  - A1.7d Land use management other (specify)
- A1.8 Other current management need (NOTE: include references to wildlife or general ecosystem goals in this category)
  - 0 Absent
  - 1 Present (specify)
  - 97 Unclear

A2 Future management needs of organization

- A2.1 Water management
    - A2.1a Water management general
    - A2.1b Water operations
    - A2.1c Water storage
    - A2.1d Water demand
    - A2.1e Water conveyance or infrastructure
    - A2.1f Groundwater protection and management
    - A2.1g Water management other
- A2.2 Flood management
    - A2.2a Flood management general
    - A2.2b Flood control structures
    - A2.2c Protection and expansion of floodways, floodplains, and bypasses
    - A2.2d Subsidence reversal
    - A2.2e Flood management other
- A2.3 Habitat management
    - A2.3a Habitat management general
    - A2.3b Habitat protection
    - A2.3c Natural environmental flows
    - A2.3d Habitat restoration
    - A2.3e Habitat management other
- A2.4 Native species management
    - A2.4a Native species management general
    - A2.4b Incidental mortality/take
    - A2.4c Harvest
    - A2.4d Population enhancement
    - A2.4e Management of specific native species (specify)
    - A2.4f Native species other
- A2.5 Introduced species
    - A2.5a Introduced species general
    - A2.5b Pathways of introduction
    - A2.5c Creation of favorable habitat conditions
    - A2.5d Population control
    - A2.5e Management of specific introduced species (specify)
    - A2.5f Introduction species other
- A2.6 Water quality
    - A2.6a Water quality general (includes contaminants/chemicals)

- A2.6b Wastewater management
- A2.6c Pollution control (emphasis on control/reduction of contaminants)
- A2.6d Water quality other

- A2.7 Land use management
  - A2.7a Land use management general
  - A2.7b Land zoning, designation, and ownership
  - A2.7c Specific land use (specify which land use)
  - A2.7d Land use management other
- A2.8 Other future management need (NOTE: include references to wildlife or general ecosystem goals in this category)
  - 0 Absent
  - 1 Present (specify)
  - 97 unclear

Section B. Monitoring gaps

B1. Topical gaps

Start by coding child-codes (e.g., B1.1a) as follows: 0 absent, 1 present, 97 unclear. Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details. After child codes are complete, assign a code to parent code (e.g., B1.1) as follows: 0 absent, 1 at least one child code present.

- B1.1 Direct socio-economic drivers
  - B1.1a Water operations/exports
  - B1.1b Water storage
  - B1.1c Water use/demand
  - B1.1d Water conveyance/infrastructure
  - B1.1e Stormwater runoff/drainage
  - B1.1f Levees
  - B1.1g Dredging
  - B1.1h Recreation and tourism
  - B1.1i Water intakes, fish screens, and passage
  - B1.1j Agriculture
  - B1.1k Urban development
  - B1.1l Roads or bridges
  - B1.1m Rail lines
  - B1.1n Docks or ports
  - B1.1o Vessels or shipping channels

  - B1.1p Wastewater discharge
  - B1.1q Energy or mines
  - B1.1r Forest harvesting
  - B1.1s Socio-economic general
  - B1.1t Socio-economic other
- B1.2 Environmental drivers/conditions
  - B1.2a Surface water/flow
  - B1.2b Water temperature
  - B1.2c Salinity
  - B1.2d Conductivity
  - B1.2e Turbidity
  - B1.2f Water quality general
  - B1.2g Groundwater
  - B1.2h Subsidence
  - B1.2i Stage
  - B1.2j Sea level rise
  - B1.2k Snowpack
  - B1.2l Velocity
  - B1.2m Nutrients, energy, or food web (include zooplankton)
  - B1.2n Sediment- toxicity
  - B1.2o Nitrogen/ammonia
  - B1.2p Phosphorous
  - B1.2q Carbon
  - B1.2r HABs
  - B1.2s Suspended sediment
  - B1.2t Dissolved oxygen
  - B1.2u pH
  - B1.2v Contaminants
  - B1.2w Sediment – erosion
  - B1.2x Environmental general
  - B1.2y Environmental other
- B1.3 Habitats
  - B1.3a Floodplain
  - B1.3b Mudflats
  - B1.3c Saltwater/freshwater marshes
  - B1.3d Intertidal/transition zones
  - B1.3e Above high-water refugia
  - B1.3f Channelized habitat
  - B1.3g Riparian habitat

    - B1.3h Non-forested vegetation
    - B1.3i Tidal wetlands
    - B1.3j Terrestrial
    - B1.3k Shallows general
    - B1.3l Habitat general
    - B1.3m Habitat other
- B1.4 Species
    - B1.4a Communities or ecosystem perspective (general)
    - B1.4b Fish general
    - B1.4c Chinook salmon and steelhead
    - B1.4d Delta smelt
    - B1.4e Longfin smelt
    - B1.4f Green sturgeon
    - B1.4g Birds
    - B1.4h Invasive/non-native species
    - B1.4i Invasive fish
    - B1.4j Invasive plants
    - B1.4j Benthic invertebrates (include shrimp, unless clearly talking about zooplankton)
    - B1.4k Species general
    - B1.4l Species other
- B1.5 Other

<u>B2. Temporal gaps</u>

- 0 Absent
- 1 Present (characterize in notes)
- 97 Unclear

<u>B3. Geographical gaps</u>

- 0 Absent
- 1 Present (characterize in notes)
- 97 Unclear

<u>B4. Technical gaps</u>

This includes sampling design, analysis methods, and instrumentation, etc.

- 0 Absent
- 1 Present (characterize in notes)
- 97 Unclear

Section C. Barriers to addressing gaps

Code each category (e.g., C1) as follows: 0 absent, 1 present, 97 unclear. Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details.

- C1 Funding (includes financial limitations, funding structure)
- C2 Siloed perspectives (e.g., individuals or organizations representing single or specific interests; specific motivations for monitoring)
- C3 Organizational structure/coordination
- C4 Staff capacity/expertise
- C5 Regulatory/legal (permits, monitoring to fulfill regulatory requirements)
- C6 Disinterest/low priority (individual or organizational)
- C7 Cultural resistance to change
- C8 Lack of political will (e.g., support from public, internal leadership, elected officials)
- C9 Communication
- C10 Perceived risks (e.g., of higher regulations; of losing current programs)
- C11 Lack of leadership
- C12 Certain entities not having a seat at the table
- C13 Time/effort required
- C14 Disconnect between monitoring and management needs (monitoring driven by scientific interest, rather than management needs; or generally not monitoring what we need for management)
- C15 Other (make note)

Section D. Suggestions to address gaps

Annotate relevant text with code D and compile in separate document. After compiling all relevant text, cluster as appropriate. Create additional spreadsheet if necessary.

Section E. Suggestions on monitoring for adaptive management

Annotate relevant text with code E and compile in separate document. After compiling all relevant text categorize into these bins. Create additional spreadsheet if necessary.

Section F. Monitoring coordination and reorganization

F1. Management areas needing more coordination

Code each category (e.g., F1.1) as follows: 0 absent, 1 present, 97 unclear. Code all management areas discussed, even if they are mentioned in the same instance (e.g., if person discusses need to coordinate habitat management with native species management, assign 1 to F1.4 and F1.5). Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to characterize the coordination needs.

- F1.1 General need for coordination
- F1.2 Water supply management
- F1.3 Flood management
- F1.4 Habitat management
- F1.5 Native species management
- F1.6 Introduced species management
- F1.7 Water quality management
- F1.8 Land use management
- F1.9 Other coordination needs

F2. Barriers to coordination and/or challenges of re-organization

Code each category (e.g., F2.1) as follows: 0 absent, 1 present, 97 unclear. Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details.

- F2.1 Funding (includes financial limitations, funding structure)
- F2.2 Silos (e.g., individuals or organizations representing single or specific interests; specific motivations for monitoring)
- F2.3 Organizational structure/coordination
- F2.4 Staff capacity/expertise
- F2.5 Regulatory/legal (permits, monitoring to fulfill regulatory requirements)
- F2.6 Disinterest/low priority (individual or organizational)
- F2.7 Cultural resistance to change
- F2.8 Lack of political will (e.g., support from public, internal leadership, elected officials)
- F2.9 Communication
- F2.10 Perceived risks (e.g., of higher regulations; of losing current programs)

- F2.11 Lack of leadership
- F2.12 Certain entities not having a seat at the table
- F2.13 Time/effort required (includes challenges of building relationships/trust)
- F2.14 Disconnect between monitoring and management needs (monitoring driven by scientific interest, rather than management needs; or generally not monitoring what we need for management)
- F2.15 Other

<u>F3. Suggestions for coordination</u>

Annotate relevant text with code F3 and compile in separate document. After compiling all relevant text, cluster as appropriate. Create additional spreadsheet if necessary.

<u>F4. Role of current organization in improving coordination/reorganization</u>

Code F4 as follows: 0 no role, 1 some role(s), 97 unclear.

For child codes (e.g., F4.1), code as follows: 0 absent, 1 present, 97 unclear, 99 N/A (F4 coded 0). Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details.

- F4.1 General
- F4.2 Leadership role
- F4.3 Supporting role as participant
- F4.4 Facilitator role (helping others convene/coordinate)
- F4.5 Advocate for coordination
- F4.6 Other role (specify)

<u>F5. Other organizations involved in improving coordination/reorganization</u>

Code F5 as follows: 0 no other organizations named, 1 some organization(s) named, 97 unclear.

For child codes (e.g., F5.1), code as follows: 0 absent, 1 present, 97 unclear, 99 N/A (F4 coded 0). Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to track which organizations were named, and other relevant details.

- F5.1 General
- F5.2 Leadership role

- F5.3 Supporting role as participant
- F5.4 Facilitator role (helping others convene/coordinate)
- F5.5 Advocate for coordination
- F5.6 Other role (specify)

F6. Mechanisms of reorganization

Code each category (e.g., F6.1) as follows: 0 absent, 1 present, 97 unclear. Annotate text to mark where theme appears (if present) and keep notes in the spreadsheet to highlight important details.

- F6.1 Financial
- F6.2 Regulatory
- F6.3 Other (specify)

F7. Examples from other systems of improved coordination/re-organization

- 0 No
- 1 Yes (specify)
- 97 Unclear

Section G. Other important content

Annotate relevant text with code G only if it does not belong in any of the coding categories above but is important not to lose. After coding is complete, compile all text marked G in a separate document and cluster/code as appropriate. Create a separate spreadsheet if necessary.

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Other Reviews

A review of the monitoring enterprise in the Sacramento-San Joaquin Delta is just one of the themes/topic areas that the Delta ISB has reviewed to meet its legislative mandate of providing oversight of the scientific research, monitoring, and assessment programs that support adaptive management in the Delta. Completed reviews are below

Restoration

Delta ISB. 2013. Habitat Restoration in the Sacramento-San Joaquin Delta and Suisun Marsh: A Review of Science Programs. Sacramento, CA.

Flows and Fishes

Delta ISB. 2015. Flows and Fishes in the Sacramento-San Joaquin Delta. Research Needs in Support of Adaptive Management. Sacramento, CA.

Adaptive Management

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Levees

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Delta as an Evolving Place

Delta ISB. 2017. Review of Research on the Sacramento-San Joaquin Delta as an Evolving Place. Sacramento, CA.

Water Quality

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Interagency Ecological Program

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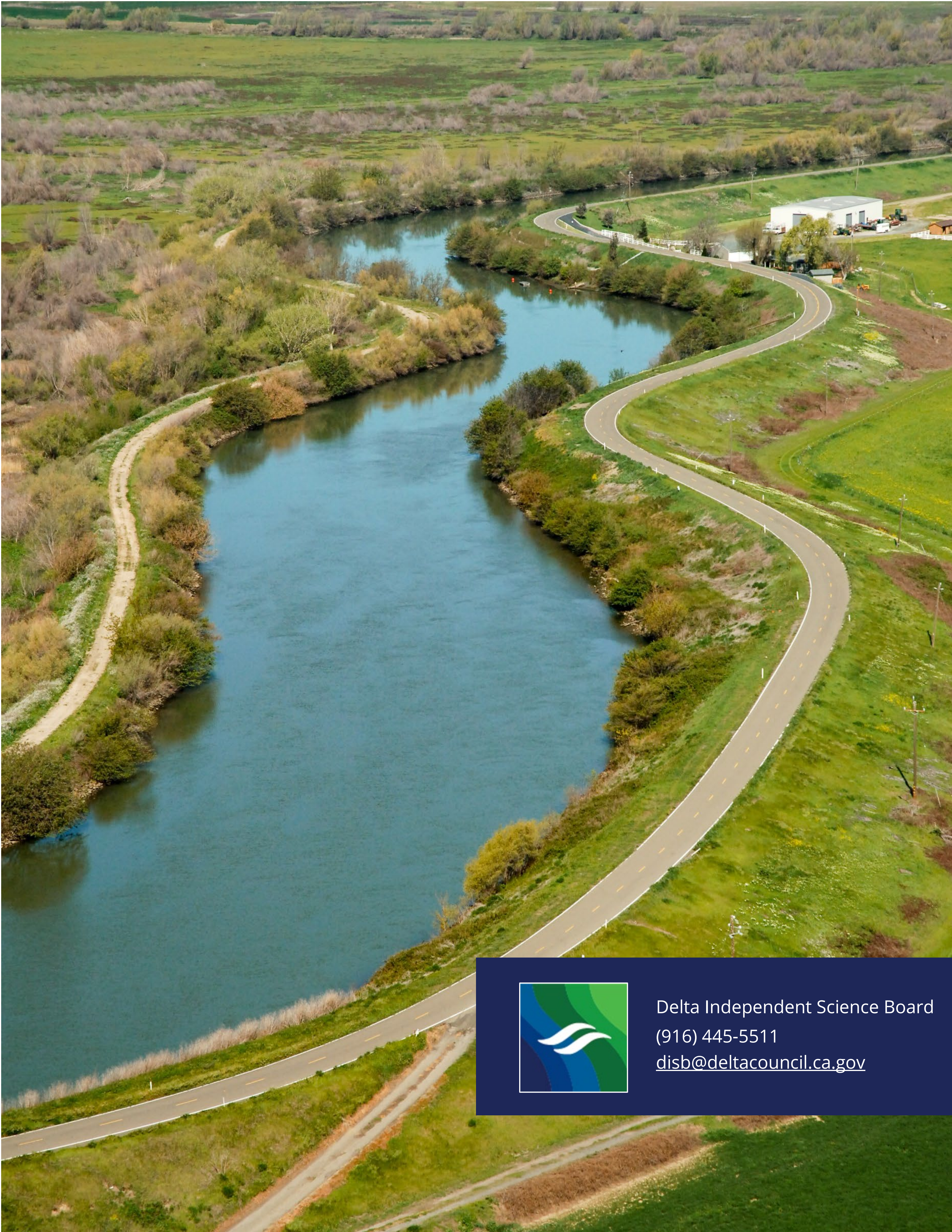
Non-Native Species

Delta ISB. 2021. The Science of Non-native Species in a Dynamic Delta. Sacramento, CA.



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