2012

PULSE OF THE DELTA

LINKING SCIENCE & MANAGEMENT THROUGH REGIONAL MONITORING

A REPORT OF THE DELTA REGIONAL MONITORING PROGRAM

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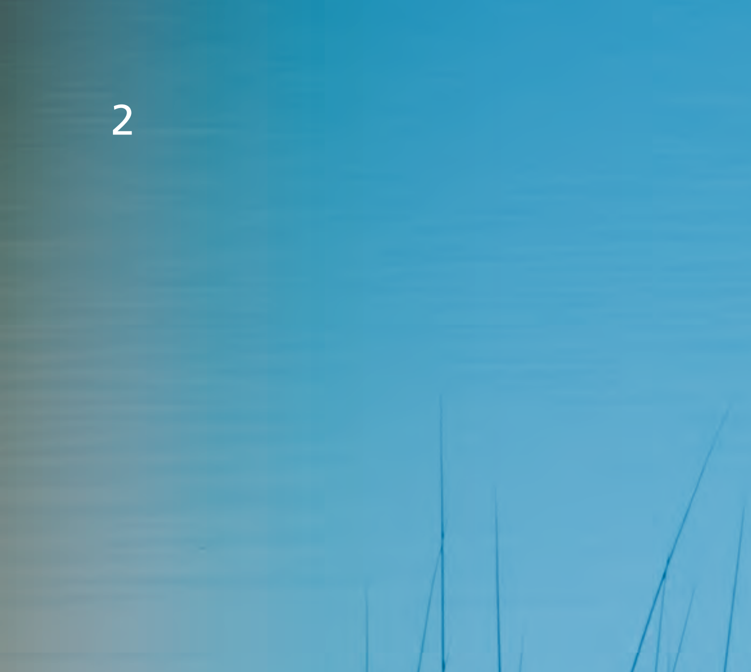

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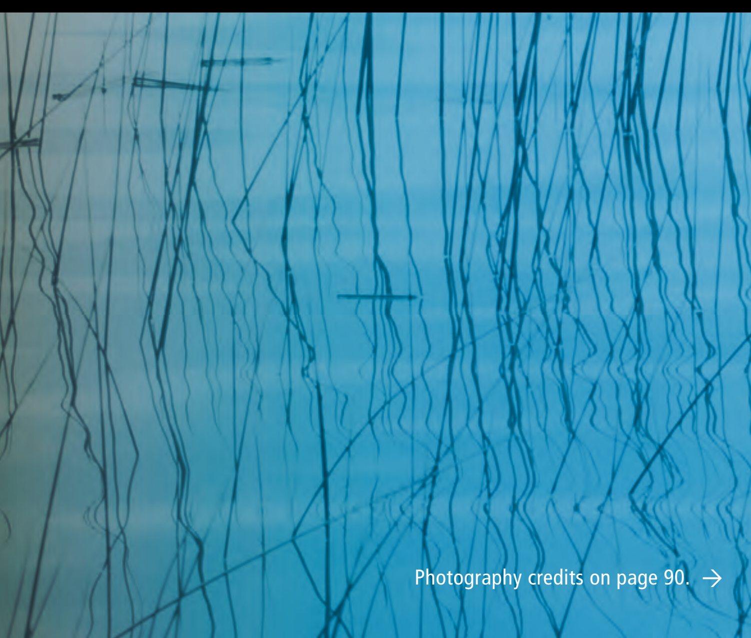

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COMMENTS OR QUESTIONS REGARDING THE PULSE OR THE REGIONAL MONITORING PROGRAM CAN BE ADDRESSED TO DR. THOMAS JABUSCH, 510) 746-7340 OR THOMAS@AQUATICSCIENCE.ORG

Introduction

THOMAS JABUSCH, Aquatic Science Center, thomas@aquaticscience.org

↑ Aerial view of Sycamore Slough. Photograph by Bill Miller.

The Chair of the Delta Stewardship Council, Phil Isenberg, asked attendees at the State of the Estuary (SOE) 2011 Conference this question:

"How do we get the courts out of trying to run water operations, ecosystem restoration, and second-guessing the judgment of scientists?"

For one, this requires improved collaboration and communication among the various Delta stakeholders outside the courts. It also requires a common basis of reliable and objective scientific information. Sharing understanding about the Delta's problems through joint fact-finding processes, while not the only requirement, creates opportunities for transcending positions and a shared commitment to possible solutions.

The Delta Regional Monitoring Program (RMP)'s goal is to contribute in both ways. First, the Delta RMP will serve as a forum for collaboratively defining and solving water quality issues in the Delta. And second, the Program will provide a common foundation of sound scientific information. The Pulse of the Delta intends to do its part to advance the debate on the issues, by making information on important water quality topics available to Delta managers. At SOE 2011, Friends of the Estuary awarded the Pulse of the Delta with an Outstanding Environmental Project Award in the category of Public Involvement and Education. Receiving the award was a tremendous encouragement for our work and we feel obliged to work even harder at meeting and exceeding expectations and establishing an access point to good water quality information for managers, decision-makers, scientists, and the general public.

In essence, we are developing the Pulse of the Delta as a "voice" for the fledgling Delta RMP. The Pulse of the Delta supports the Program's goals of better defining water quality issues of regional concern and making water quality monitoring information more useful and accessible.

This second edition of the Pulse of the Delta includes the following sections:

The KEY TOPIC article introduces this year's theme, LINKING SCIENCE AND MANAGEMENT THROUGH REGIONAL MONITORING (PAGE 6).

The MANAGEMENT UPDATE section provides updates on Delta RMP development (PAGE 12) and the U.S. Environmental Protection Agency (EPA)'s Delta Clean Water Act evaluation (PAGE 18). It further provides an update on the development of Nutrient Numeric Endpoints for San Francisco Bay, due to the relevance of this topic to Delta stakeholders (PAGE 28). And as a new feature, the Management Update section now also provides a regulatory status update for pollutants of concern.

This edition of the Pulse of the Delta introduces a NEW STATUS AND TRENDS section with updates on important monitoring results (PAGE 44) and leading indicators (PAGE 50) for the Delta.

The STATUS AND TRENDS section was made possible thanks to significant contributions by the Interagency Ecological Program, U.S. Geological Survey, the Central Valley Regional Water Board, California Department of Fish and Game, California Department of Water Resources, and scientists at the UC Berkeley and San Francisco State University Romberg Tiburon Center.

Two FEATURE ARTICLES provide an overview of recent research findings that could help wetland managers reduce the methylmercury problem and a glimpse into the future of the Interagency Ecological Program (IEP).

One of the main challenges as ecosystem restoration efforts are moving forward will be the mercury problem. Large-scale restoration of wetland areas will be required to provide a sufficient amount of aquatic habitat for restoring the Delta ecosystem. At the same time, water quality managers will need to identify actions to protect people and wildlife from exposure to methylmercury that may originate from restored wetlands, due to a legacy of mercury contamination in Delta soils. Recently completed and ongoing studies in the Yolo Bypass provide new information on management options for controlling methylmercury production in wetlands and offsite transport (PAGE 66).

IEP scientists have been monitoring and researching the San Francisco Estuary since 1970. Now the IEP has arrived at an important crossroads, and its future is being decided at the same time as environmental managers are determining what a desirable future ecosystem would look like, how it would function, and how it can be established (PAGE 76).

SCIENCE FOR MANAGERS THAT BRINGS ECONOMIES OF SCALE

A strong link between science and management is critical for defining and solving water quality problems in the Delta. Good decisions on policies and actions depend on reliable and objective knowledge, based on sound science and high-quality data that specifically address important questions and are collected using appropriate methods and sampling designs, at appropriate scales of time and geography. Experience in other regions has shown that good science at the regional scale improves regulatory decisions about water quality (KEY TOPIC article, PAGE 6). It provides a solid foundation for water quality decisions such as TMDLs (Total Maximum Daily Loads) and other regulatory actions affecting the entire Delta: permit limitations, 305(b) reporting, 303(d) listings, application of the Antidegradation Policy, adjustments to the Irrigated Lands Regulatory Program, to name a few. It helps to illuminate a clear path toward solutions to Delta water quality issues.

Benefits can be realized based on the economies of scale a Delta RMP brings. In other regions, a shift from isolated monitoring of individual discharges to pooling of resources provided the opportunity to perform comprehensive, consistent monitoring across waterbodies and watersheds with minimal administrative costs. Several other benefits resulting from economies of scale in other regions include coherent data management systems that facilitate assessments beyond individual program boundaries, an overarching quality assurance program, and effective reporting. Moreover, pooling of resources helps to identify and respond to problems in an adaptive manner.

Key Topic

Monitoring Through Regional Partnerships: A Well Proven Win-Win-Win for Managers, Regulators, and the Environment

BROCK BERNSTEIN, brockbernstein@sbcglobal.net

Snowy egret. Photograph by Bill Miller.

HIGHLIGHTS

Managers responsible for water quality have long struggled to create a complete picture of environmental conditions in the Delta

Regional monitoring results can help managers do a better job of setting priorities

Regional programs provide a structure for the more systematic analysis of local compliance monitoring data

Regional programs invest in coordinated sampling and analysis methods and comparable levels of quality assurance and control

One key ingredient to successes is the active and collaborative involvement of multiple parties with differing and complementary perspectives and resources

Delta-wide information will improve the quality of decision making

Managers responsible for water quality, aquatic habitat, and natural resources in the Sacramento-San Joaquin Delta have long struggled to create a complete picture of environmental conditions in the Delta and understand the processes that affect them. They are not alone in this effort. Over two decades ago, in 1990, a National Academy of Sciences report on marine monitoring in southern California found that, despite extensive and technically sophisticated monitoring efforts, it was impossible to present a picture of conditions in the Southern California Bight as a whole. The large majority of monitoring was concentrated around individual waste discharges, with little attention to cumulative impacts or the health of larger-scale ecosystems. Despite the collection of high-quality data, differences among monitoring programs hindered efforts to integrate data from multiple programs. Even more important, managers had no systematic structure for asking questions that cut across multiple programs and encompassed larger areas. There was therefore little if any ability to describe conditions or track changes at large scales or to assess cumulative impacts from multiple sources. This finding inspired a coordinated effort among regulators and dischargers to develop the Southern California Bight Regional Monitoring Program, which has expanded since the early 1990s to include over 100 participants and to encompass processes that extend from the inland boundaries of coastal watersheds across the continental shelf.

Since 1990, we have become increasingly aware that the problems identified in the Southern California Bight were widespread. To address these problems, other regional monitoring programs were initiated throughout the state (**TABLE 1**). These and other similar programs vary in scale, from individual watersheds to a statewide scope that focuses on specific habitat types or issues. However, they all share three core objectives:

- Assessing conditions, and trends in conditions, consistently across larger geographic scales
- Improving the quality and coordination of monitoring and assessment methods
- Maximizing the value of existing monitoring efforts by strengthening their links to decision making

This clear focus has enabled these programs to achieve significant successes, such as updating management priorities, improving regulatory frameworks, and enhancing the quality of data. The following sections examine each of these in more detail.

ADJUSTING MANAGEMENT PRIORITIES

Regional monitoring results can help managers do a better job of setting priorities, as the following examples demonstrate. In southern California, the Southern California Stormwater Monitoring Coalition, Los Angeles River Watershed Monitoring Program, and San Gabriel River Regional Monitoring Program have documented unexplained water column toxicity as well as lower than expected biological community scores in natural streams with no direct sources of contamination. In contrast, toxicity is lower than expected in urban areas. These counterintuitive findings have resulted in adjustments to management priorities (less concern about toxicity in urban areas) and emphasized the need to add objectives for biological condition to the previous heavy reliance on chemical-specific water quality criteria. Michael Lyons is the Surface Water Ambient Monitoring Program (SWAMP) coordinator at the Los Angeles Regional Water Quality Control Board spearheading the development of the two regional watershed programs. He says, "Both of these watershed programs are great examples of the benefits of partnerships…I am really happy with them because everyone involved feels they are producing much better results than in the past."

In the Monterey Bay area, CCLEAN (**TABLE 1**) data helped identify management actions with the greatest returns. "CCLEAN has provided information that has helped dischargers and water quality regulators focus management actions on the areas that will provide the greatest benefits to stakeholders", says CCLEAN Director Dane Hardin. For example, after detecting the presence of DDT and PCB contamination in sediments of Monterey Bay, results from the program were used to estimate the relative contributions of these contaminants from river and wastewater discharges, information that can be used to identify and prioritize corrective actions.

IMPROVING REGULATORY FRAMEWORKS

In the San Francisco Bay area, joint fact-finding through regional monitoring has increased regulatory efficiency. Tom Mumley of the San Francisco Bay Regional Water Quality Control Board recalls that data from the RMP that were trusted by all parties supported the development of "site-specific objectives for copper that were protective of beneficial uses but provided relief from what would otherwise have been costly effluent limits for all dischargers to the Bay." The RMP also tracked a declining Bay-wide trend in water column toxicity that allowed management agencies to adjust their priorities more quickly than they otherwise would have been able to. According to Mike Connor, General Manager of the East Bay Dischargers Authority, one important benefit of the RMP is that "in the absence of data, regulatory agencies are often overly conservative in their assumptions.

Most important, coordinated Delta-wide information will enhance our understanding of the nature of the threats facing the Delta and improve the quality of decision making about how to meet these threats

Regional monitoring provides a way to conduct joint fact-finding that allows everyone to focus on data that are mutually acceptable."

The perspective enabled by regional information can lead to more appropriate and cost effective regulatory strategies. SWAMP's statewide survey of fish tissue contamination in lakes confirmed the magnitude of problems due to legacy pollutants such as mercury, DDT, and PCBs, helping managers at the State Water Resources Control Board revise their thinking about how to address the problems associated with each contaminant. For example, reliable information about the broad extent of mercury contamination prompted more serious consideration of a single statewide Total Maximum Daily Load (TMDL) rather than multiple local TMDLs. Similarly, widely trusted data from the San Francisco Bay RMP allowed adoption of load allocations and implementation strategies for the PCBs TMDL that were less restrictive and costly than what would have been possible without the RMP.

And finally, regional programs also provide a structure for the more systematic analysis of local compliance monitoring data. Scott Johnson, the consultant who conducts the Los Angeles and San Gabriel Rivers programs, notes that these programs for the first time analyzed all receiving water data collected by NPDES dischargers over the long term. This documented the extremely low number of exceedances and thus the effectiveness of management policies and treatment technologies.

BETTER AND MORE RELIABLE DATA

The ability of the regional monitoring programs to conduct larger-scale assessments depends on the comparability of data across the region—apples should be compared to apples. Regional programs thus invest in coordinated sampling and analysis methods and comparable levels of quality assurance and control. For example, all members of the Southern California Bight Regional Monitoring Program participate in laboratory intercalibration studies. These have proved so valuable in establishing confidence in monitoring data that some dischargers are now required by permit conditions to send all samples to laboratories that have participated in intercalibration efforts. Similarly, several laboratories operated by municipal treatment plants participated in intercalibration studies during the early phases of the San Francisco Bay RMP and were able to take on analysis of sediment samples themselves.

Coordinated sampling methods not only increase confidence in routine monitoring data. They also allow programs to rapidly ramp up special studies without the need for large amounts of upfront planning that would otherwise be necessary to synchronize sampling designs and methods. Eric Stein, the scientist at the Southern California Coastal Water Research Project (SCCWRP) who coordinates the Southern California Stormwater Mointoring Coalition (SMC)'s efforts, describes how the SMC was able to implement an off-the-shelf rapid response plan for examining the effects of the large fires that swept much of southern California in 2007. These special studies examined the fires' impacts on contaminant inputs and water quality, information useful for mitigating effects on downstream areas and for understanding post-fire changes in compliance monitoring results. As another example, the San Gabriel River program was able to quickly implement a sediment sampling program for polybrominated diphenyl ethers (PBDEs) to follow up on the 2008 Bight Program's finding of high concentrations of these emerging contaminants in estuaries and harbors throughout the region. This sediment sampling program will help to determine the scale of contributions from the watershed.

Regional programs typically extend monitoring coverage to areas that were undersampled by traditional compliance monitoring programs. As mentioned above, this can result in surprises, such as the finding of lower-than-expected biological community scores in undeveloped areas. One pleasant surprise in the Los Angeles and San Gabriel rivers watersheds was the discovery of sites with very high habitat quality, despite intense pressures from development, water management, and dense human population in much of each watershed. These results, because they were based on highly reliable monitoring data, changed assumptions about the possibility of preserving high quality habitat in developed watersheds.

Vineyards on Ryer Island. Photograph by Thomas Jabusch. →

MULTIPLE PATHWAYS TO COLLABORATION

One key ingredient to these successes is the active and collaborative involvement of multiple parties with differing and complementary perspectives and resources. This is very different from the traditional program structure, in which a single agency acts independently, focused on a relatively narrow range of issues. However, there is no single recipe, and successful collaborative programs have followed a number of different pathways as they transition to a collaborative structure that includes a wider range of participants and viewpoints.

Many permits now include a requirement for participation in regional monitoring. For example, permits for all major dischargers in southern California require both routine compliance monitoring and regional monitoring and also provide for short-term special studies. Some programs have resulted from permit requirements that give major dischargers the responsibility to spearhead development of regional monitoring plans and programs. In some instances, regulatory agencies allow resources usually spent on compliance monitoring to be either temporarily or permanently reallocated to regional-scale questions. Some regional programs, such as the SMC, begin as voluntary collaborative efforts that after a time become incorporated into permits. Some, such as the Los Angeles River and San Gabriel River watershed programs, operate relatively informally, while others, such as the larger Bight Program and San Francisco Bay RMP, operate much more formally. In all cases, however, they remain tightly focused on the three core objectives described above.

MOVING FORWARD IN THE DELTA

A multi-party, collaborative regional monitoring program for the Delta, as envisioned by the Delta RMP, would offer tangible benefits to participants. It would offer enhanced opportunities for partnering among the Delta's many monitoring and assessment efforts, opportunities not provided by traditional compliance or single agency monitoring approaches. It would provide the ability to more efficiently and comprehensively address critical questions about water quality and aquatic habitats and achieve the types of benefits described above. Most important, coordinated Delta-wide information will enhance our understanding of the nature of the threats facing the Delta and improve the quality of decision making about how to respond to these threats. ■

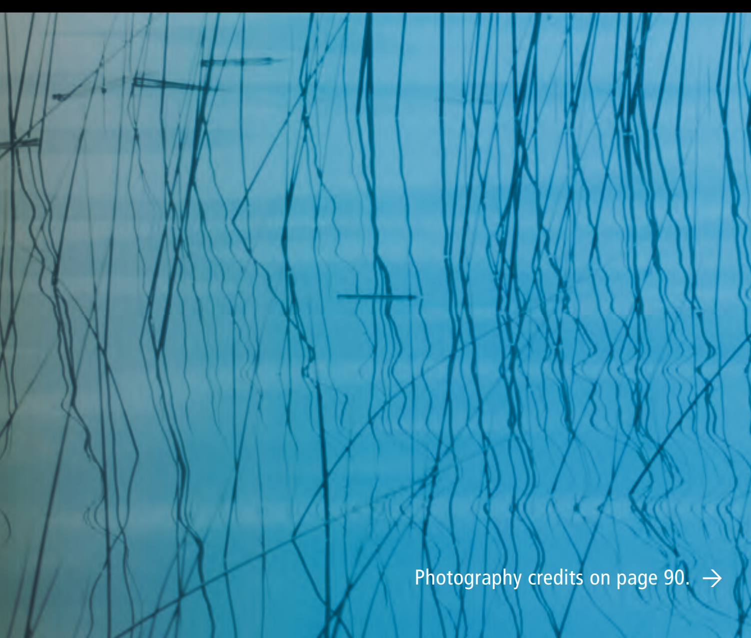
TABLE 1.

REPRESENTATIVE REGIONAL MONITORING PROGRAMS ACTIVE IN CALIFORNIA.

	RMP	BIGHT PROGRAM	LAKE TAHOE	CCLEAN	SMC	LA & SG RIVERS
	RMP: Regional Monitoring Program in San Francisco Bay	**Bight Program:** Southern California Bight Regional Monitoring Program	**Lake Tahoe:** Tahoe Basin Regional Stormwater Monitoring Program	**CCLEAN:** Central Coast Long-term Environmental Assessment Network	**SMC:** Southern California Stormwater Monitoring Coalition	**LA&SG Rivers:** Los Angeles River Watershed Monitoring Program and San Gabriel River Regional Monitoring Program
Start date	1993	1994	pending	2001	2001	2006 / 2008
Operational Lead	NGO	JPA	NGO	Consultant	JPA	NGO
Budget (approximate)	$3M	$8 – 9M	$236K	$350-400K	NA	$0.7M
Program Structure	Three-tiered • Steering committee • Technical review committee • Issue workgroups	Two-tiered • Steering committee • Issue workgroups	Working group	Working group	Two-tiered • Steering committee • Participants	Working Group
Participants	Dischargers Regulators Scientists Environmental groups	Dischargers Regulators Resource managers Scientists Environmental groups	Regulators Resource managers Planning agencies	Dischargers Regulators	Dischargers Regulators	Dischargers Regulators Local Government Environmental groups

NGO: Non-governmental organization, **JPA:** Joint powers authority.

MANAGEMENT UPDATE



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Laying the Foundation for the Delta Regional Monitoring Program

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↑ Seasonally flooded wetlands at the Sacramento Regional County Sanitation District Bufferlands. Photograph by Thomas Jabusch.

HIGHLIGHTS

The ultimate goal of the Delta RMP is to provide comprehensive monitoring of contaminants in the Delta to ensure protection of beneficial uses

The Regional Water Board identified multiple opportunities for improving receiving water monitoring programs by critically reviewing discharge permit requirements

Improvements in receiving water monitoring have the potential to free resources for regional scale monitoring needed to protect beneficial uses

"Are contaminants in the Delta at levels of potential concern?" is the focus question during the pilot phase of the Delta RMP

Identifying and engaging regional assessment capability and a continued funding source are critical steps for meeting the goal of the Delta RMP

The Regional Water Board identified multiple opportunities for improving receiving water monitoring programs by critically reviewing discharge permit requirements

THE DELTA RMP: COMPREHENSIVE ASSESSMENTS OF THE DELTA

The Delta RMP is being established to enact coordinated and comprehensive monitoring, analysis, and reporting, in order to provide the information necessary to steward the Delta's resources for future generations. Sampling under existing monitoring programs does not produce monitoring data that informs a regional evaluation of Delta water quality or potentially impacted beneficial uses. More information on the reasons and goals for the Delta RMP can be found in last year's The Pulse of the Delta article **DELTA RMP: RE-THINKING WATER QUALITY MONITORING IN THE DELTA**.

THE INITIAL FOCUS OF THE DELTA RMP

The RMP development process began with a broad vision of regularly compiling, assessing, and reporting information about contaminants and their effects, using data collected by a wide range of agencies and programs. The first Pulse of the Delta highlighted intentions and opportunities of the RMP. It is an example of clear, accessible reporting that the Program intends to provide. We have been developing the overall framework, governance structure, and monitoring objectives of the RMP since the release of the first Pulse. Moving forward, workgroups will guide pilot projects, answer questions, and suggest improvements, while helping to identify the most suitable approach to implement the long-term program.

Because of the variety of programs, agencies, jurisdictions, and interests involved in monitoring in the Delta, we have initiated a phased approach to create a successful RMP. The first step is coordinating compliance monitoring programs under the direct authority of the Central Valley Regional Water Board (**FIGURE 1**). The Delta RMP Planning Team and Water Board staff identified opportunities to improve receiving water monitoring programs by interviewing dischargers, understanding common complaints, and reviewing discharge permits. Receiving water monitoring programs are required in NPDES permits to monitor the waters that receive wastewater discharges. Finding solutions for issues identified in this process will further engage dischargers, enhance the capabilities of the Regional Board, and provide a solid base for an effective and efficient regional monitoring program.

We will build a strong foundation for a long-term program by implementing some of the ideas derived from stakeholder discussions. We will continue to focus on specific improvements and develop the program in phases that build upon each other. Staff from various programs at the Regional Water Board supports the Delta RMP effort and we continue to work with staff at the State Water Board on data management issues (**SIDEBAR: BETTER DATA COMPARABILITY AND ACCESS WITH THE CALIFORNIA ENVIRONMENTAL DATA EXCHANGE NETWORK**). In addition to working closely with NPDES dischargers, future steps will include additional participants, such as the Irrigated Lands Regulatory Program, Interagency Ecological Program (IEP), and others, to ensure full representation of water quality monitoring within the Delta.

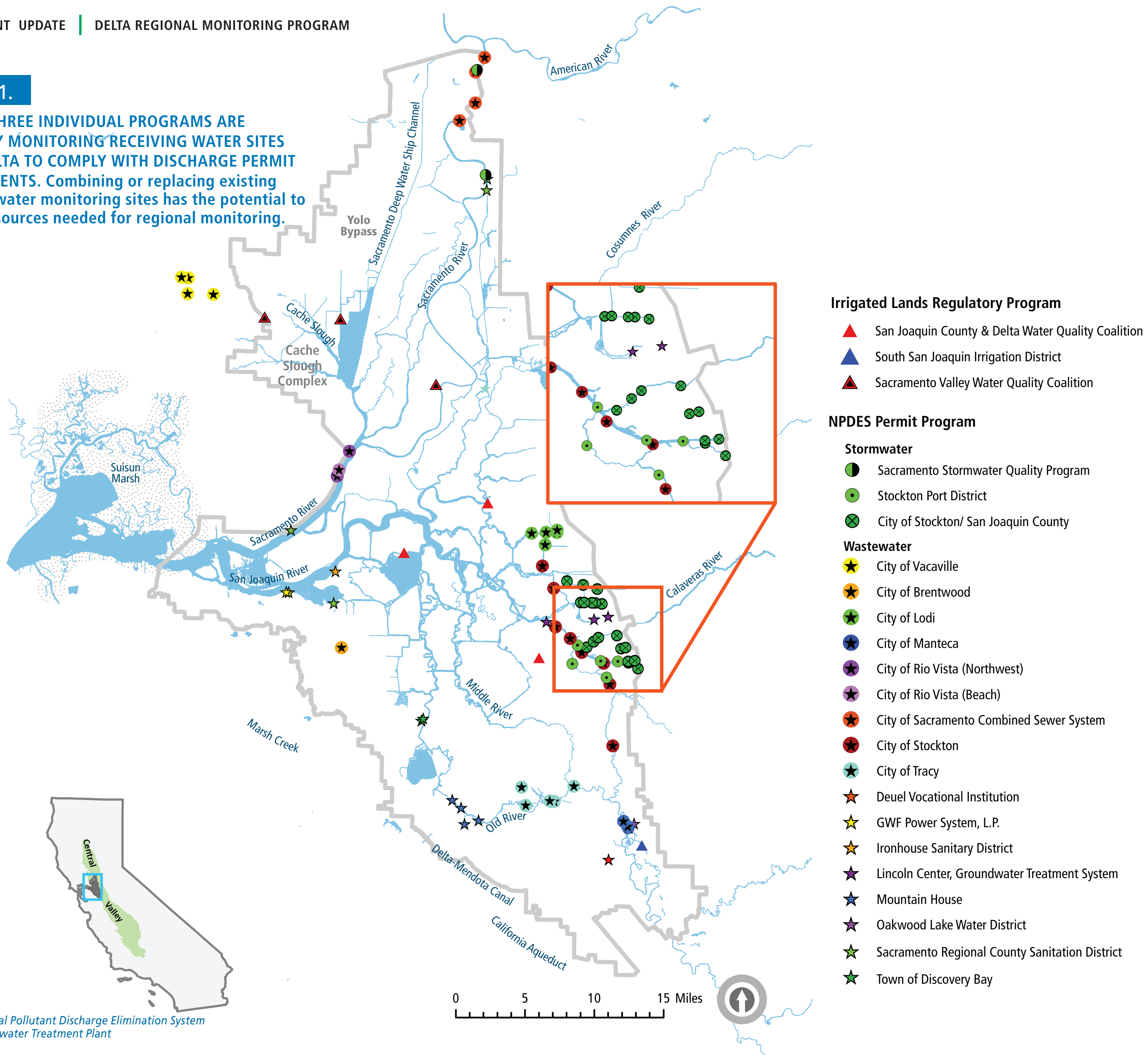
MODIFYING MONITORING REQUIREMENTS

The Regional Water Board identified multiple opportunities for improving receiving water monitoring programs by critically reviewing permit requirements for wastewater and stormwater discharges. The review focused on the location, frequency, and constituents in monitoring requirements. There is general agreement that maximizing the use of readily available information, including information from sources other than Regional Board monitoring, may lessen the monitoring requirements for some constituents. Staff is exploring the possibility of adaptive monitoring based on records of compliance, sampling frequencies, and likelihood of exceedances. There may also be opportunities to relocate or combine receiving water monitoring stations. These improvements have the potential to free resources for the regional scale monitoring needed to protect beneficial uses.

View of Snodgrass Slough. Photograph by Sarah Pearce. →

FIGURE 1.

TWENTY-THREE INDIVIDUAL PROGRAMS ARE ROUTINELY MONITORING RECEIVING WATER SITES IN THE DELTA TO COMPLY WITH DISCHARGE PERMIT REQUIREMENTS. Combining or replacing existing receiving water monitoring sites has the potential to free up resources needed for regional monitoring.



Footnote:
NPDES= National Pollutant Discharge Elimination System
WWTP = Wastewater Treatment Plant

"Are contaminants in the Delta at levels of potential concern?"

WHAT QUESTIONS ARE WE TRYING TO ANSWER

Explicit management questions will be used to guide the next phase of the Delta RMP. The Regional Water Board and stakeholders agree that explicit management questions are the foundation of effective and efficient monitoring designs. This approach will result in purposeful and efficient compliance monitoring from the local and regional perspectives. Specific questions will be identified to more specifically focus compliance monitoring. These questions will guide revisions to receiving water monitoring requirements and coordination with other agencies that monitor water quality in the Delta, such as the Department of Water Resources and the Department of Fish and Game.

The primary management question in the pilot phase of the Delta RMP is likely to be: "Are contaminants in the Delta at levels of potential concern?" (**SIDEBAR: PROPOSED CORE QUESTIONS FOR THE DELTA RMP**). Answering this question is a priority for the Central Valley Water Board staff. An improved understanding of the spatial and temporal distribution of contaminants is necessary to answer this question. Monitoring data collected to answer this question will identify locations and contaminants where additional regulations or controls are needed to protect beneficial uses.

Revised compliance monitoring requirements and clearly stated management questions will be the foundation for the long-term program. An initial monitoring plan will be developed through a workgroup process. Identifying discharges that are in close proximity and coordinating monitoring to address questions about localized cumulative impacts will test our regional monitoring concepts on a small scale and identify challenges as we expand the program. Additionally, these pilot projects will provide an opportunity to work with the data management system developed by the State Water Board and test its utility for compiling, analyzing, and reporting data.

Another important near-term goal is to more broadly foster collaboration. This next phase of RMP development is focused on programs under the direct regulatory control of the Central Valley Water Board. However, we recognize that answering many of the broad regional questions will require collaboration with other programs, such as the IEP.

CRITICAL STEPS: ASSESSMENTS & FUNDING

Identifying regional assessment capability and a continued funding source are critical steps toward meeting the goal of the Delta RMP, providing comprehensive monitoring of contaminants in the Delta to ensure protection of beneficial uses. Identifying systematic assessment capability is essential for using information gathered in the pilot projects to answer specific questions. The initial pilot projects are focused on the reorganization and coordination of monitoring and designed to gather the information needed. The reorganization and improvements in monitoring coordination won't do much good unless the collected data are actually analyzed and synthesized into those answers. We have not yet developed these systematic assessment capabilities.

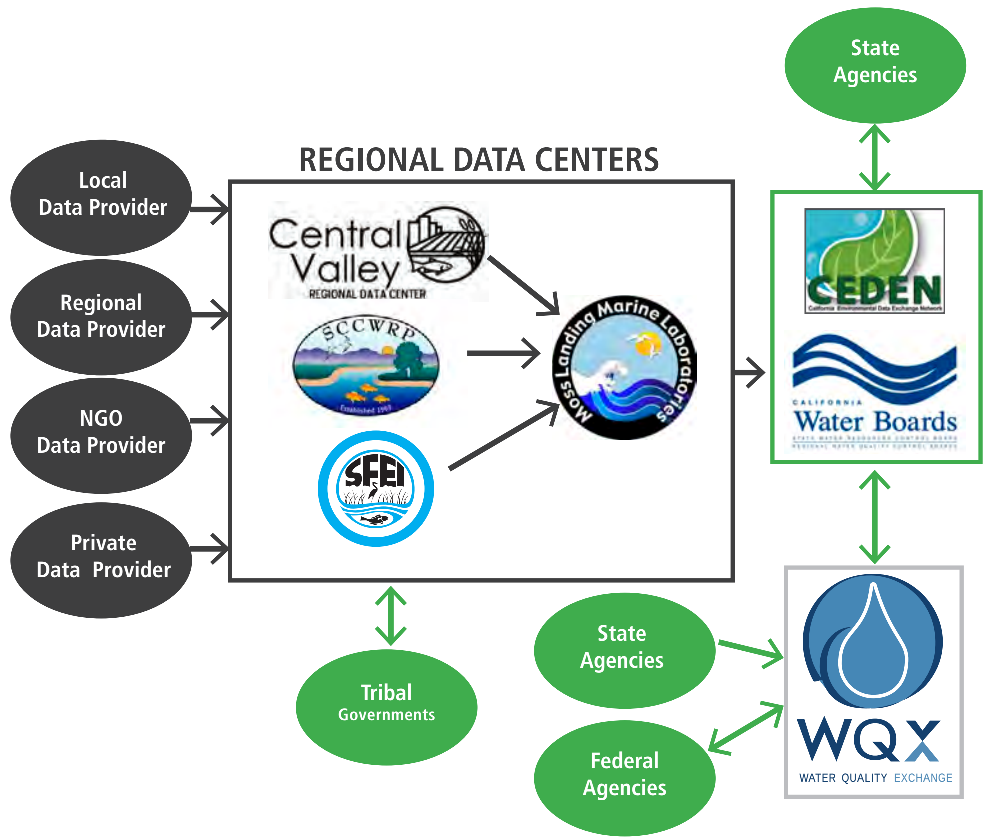
A successful Delta RMP will not only perform the monitoring that is needed, but also regularly compile, synthesize, and report the information. A successful RMP must identify and establish a trusted entity to compile and relate these assessments. Further, that entity will require stable funding to perform and publish these syntheses. The Pulse of the Delta is an example of the type of reporting that could be provided, but its production requires a substantial amount of time, expertise, and funding. Finding solutions to these challenges will fulfill the goals of the RMP over the long-term: generating, compiling, synthesizing, and regularly reporting information that managers need to protect the beneficial uses of this important ecosystem.

BETTER DATA COMPARABILITY AND ACCESS WITH THE CALIFORNIA ENVIRONMENTAL DATA EXCHANGE NETWORK

A better understanding of the effects of contaminants will depend in parts on improved data quality and access. In an attempt to evaluate the role of contaminants in the Pelagic Organism Decline (POD), the State Water Resources Control Board (State Water Board) and the Central Valley Regional Water Quality Control Board (Regional Water Board) sponsored a review by U.C. Davis researchers of the available data (Johnson et al 2010). Their evaluation was impeded by the difficulty in integrating data of varying quality from multiple sources. As a result, a definitive conclusion could not be reached and the report recommended improvements in data management and integration in order to provide more consistent quality and easier access.

The State Water Board recognized the need to increase data access while also enhancing coordination among the various entities collecting water quality data. The State Water Board is now committed to making water quality data accessible to all interested parties. To this end, Water Board staff are coordinating with a variety of organizations and agencies to make data available via the California Environmental Data Exchange Network (CEDEN).

More consistent data quality and easier access will make monitoring more effective and efficient. The cost of water quality monitoring in California has been estimated at a staggering $60 million annually. As the POD report illustrated, in the past it has been difficult, even cost-prohibitive, to access and combine this wealth of data to conduct comprehensive assessments of water quality condition. These assessments are needed to answer questions important to resource managers, the Legislature, and the public. In our current budget climate, when we are being asked to accomplish more with fewer resources, it is of great benefit to the Water Boards to invest in data comparability and access.



To ensure data quality and usability, the State Water Board developed a Minimum Quality Assurance (QA) and Data Reporting system. The Minimum QA System defines the minimum criteria for data and is based on standard quality control methods, processes, documentation, and reporting requirements that are already commonly in use. Data reports must include "Minimum Data Elements" to ensure that the data are usable and can be combined with other data in CEDEN.

CEDEN has made significant progress over the last year. Water Board staff have amassed surface water quality data collected by a variety of government agencies and non-profit organizations. Data from Water Board programs, the U.S. Environmental Protection Agency, the Department of Water Resources, the U.S. Geological Survey, and other federal and state agencies will be available for download on the CEDEN website. Since data accepted into CEDEN has, as its foundation, a minimum set of data elements, users can evaluate the appropriateness of combining data sets for assessment purposes. CEDEN provides descriptive metadata for each dataset and establishes standard terms for characterizing individual data points.

CEDEN is a vehicle through which data comparability and integration can be achieved in California. It will do so through coordination with data providers and by providing a single point of access for ambient water quality data collected by the Water Board and other organizations.

The California Environmental Data Exchange Network (CEDEN) is a system for integrating and sharing data collected by many different participants. It is a growing statewide cooperative effort open to federal, state, county, and private organizations interested in sharing data. The purpose of CEDEN is to allow the exchange and integration of water and environmental data between groups and to make it accessible to the public. Local and private data providers work with and through the regional data centers. The regional data centers assist the data providers to ensure quality control and assurance. Additionally, the Water Boards have begun to build connections to other databases. The idea is that data available through other agency databases, like the U.S. Environmental Protection Agency's Water Quality Exchange (WQX), can be retrieved through a query in CEDEN and vice versa. The Water Boards are committed to continuing to build these connections to allow seamless retrieval of data.

PROPOSED CORE QUESTIONS FOR THE DELTA RMP

THE PROPOSED CORE QUESTIONS AND ASSOCIATED MONITORING QUESTIONS OF THE DELTA RMP.

STRAW CORE QUESTION 1:
Are contaminants in the Delta potentially at levels of concern?

Associated Monitoring Question 1-1.
What is the spatial and temporal distribution of contaminants?

Associated Monitoring Question 1-2.
What are appropriate water quality guidelines?

Associated Monitoring Question 1-3.
Are there particular regions of concern?

STRAW CORE QUESTION 2:
What are the sources, pathways, loadings, and processes leading to water quality impacts in the Delta?

Associated Monitoring Question 2-1.
Which sources, pathways, loadings, and processes contribute most to impacts?

Associated Monitoring Question 2-2.
What are the effects of management actions?

STRAW CORE QUESTION 3:
What are the projected water quality conditions and associated impacts in the Delta?

Associated Monitoring Question 3-1.
What is the water quality forecast under various management scenarios?

USEPA Completes Delta Stressor Investigation

ERIN FORESMAN, U.S. Environmental Protection Agency, foresman.erin@epa.gov

Runoff from a January 1997 storm caused this levee on the Cosumnes River to break, temporarily re-creating the floodplains that were a regular feature of the aboriginal Delta. Photograph by Tom Myers.

HIGHLIGHTS

The U.S. Environmental Protection Agency (EPA) recently released an Action Plan that identifies priority actions to accelerate restoration of aquatic life protection in the Bay-Delta Estuary

The Action Plan is based on an EPA review of aquatic life protection by Clean Water Act programs in the Bay-Delta Estuary

The review considered seven aquatic stressors: ammonia, selenium, pesticides, contaminants of emerging concern, declining estuarine habitat, fragmented migratory corridors, and aquatic habitat loss

The EPA review suggests that Clean Water Act programs are not adequately protecting aquatic resources in the Bay-Delta Estuary

The EPA highlights six critical activities:

1) updating standards protecting estuarine habitat
2) advancing regional monitoring and assessment programs in the Central Valley
3) comprehensively identifying Bay-Delta Estuary impairments
4) improving implementation of Total Maximum Daily Loads
5) providing relevant and timely water quality data to consider in national pesticide registration reviews
6) developing methylmercury controls in wetlands

ACHIEVING WATER QUALITY PROTECTION GOALS

EPA recently completed an investigation into the effectiveness of current water quality programs influencing the health of the Bay-Delta Estuary. This effort was launched in February 2011, with an Advance Notice of Proposed Rulemaking (ANPR) for Water Quality Challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The assessment was one of EPA's commitments in the December 2009 Interim Federal Action Plan, which outlined actions and investments by EPA and five other federal agencies to help address ecological and water supply crises in the Bay-Delta Estuary.

THE ANPR:

1. Identifies the key water quality issues affecting Bay-Delta aquatic resources and summarizes current research for each of these issues, including ammonia, selenium, pesticides, emerging contaminants, conditions restricting estuarine habitat, migratory corridors for anadromous fish, and aquatic habitat losses;
2. Explains the status of regulatory efforts under the federal Clean Water Act and the State's clean water laws; and
3. Solicits public input on specific scientific and policy questions.

FOCUSING ON THE FISH DECLINE AND SEVEN ASSOCIATED STRESSORS

The long-term decline of fisheries in the Bay-Delta over several decades is dramatic and well-documented (see **ECOSYSTEM HEALTH TRENDS AT A GLANCE, PAGE 50**). After 2000, four open water fish species, including two species that were previously the most abundant in the Estuary (striped bass and threadfin shad), suffered nearly simultaneous, sharp population declines. Salmonid fish populations also show dramatic declines since the year 2004, resulting in the closing of commercial and sport fishing in 2008 and 2009.

Identifying the most harmful stressors to aquatic life in the Bay-Delta is challenging. Currently, water quality data is collected by multiple agencies, with little standardization of monitoring procedures, data quality assurance, or presentation protocols, and often is not readily accessible. This makes regional assessments of water quality trends, identification of regional problems, and evaluation of solutions difficult and costly. Development of regional monitoring programs in the Delta and in the San Joaquin Basin is a high priority for EPA and the Central Valley Regional Water Quality Control Board.

EPA's assessment focuses on the most significant water quality stressors affecting fish and other aquatic life in the Estuary. A substantial amount of research links these stressors to the pelagic organism decline (POD) and the subsequent decline of salmonid species. The assessment summarizes current knowledge as follows:

CONTAMINANTS

Elevated ammonia levels are linked to changes at the base of the aquatic foodweb by suppressing algal growth and causing toxicity to invertebrates (see article on Ammonia in the Delta in The Pulse of the Delta 2011). Wastewater treatment plants are the primary sources of ammonia to the Estuary.

Selenium is highly bioaccumulative and can be toxic to juvenile salmon, sturgeon, and waterfowl. The primary sources of selenium to the Estuary are selenium-rich soil and crude oil. Selenium is mobilized through agricultural return flows on the west side of the San Joaquin Valley. It is also discharged by refineries located in northern San Francisco Bay that process selenium-rich crude oil.

Organophosphate and pyrethroid pesticides are increasingly found in urban runoff and have been identified as a cause of aquatic toxicity in multiple investigations. Aquatic life in the Estuary can be exposed to multiple current-use pesticides for extended periods of time, with some pesticides causing acute and chronic toxicity. Pesticide sources include urban and agricultural runoff, wastewater treatment plants, and atmospheric deposition (see **FIGURE 1**).

Contaminants of emerging concern (CECs) are compounds such as pharmaceuticals and personal care products that may have significant negative effects on aquatic species. Numerous pharmaceuticals and personal care products are being evaluated for potential effects on aquatic life, such as developmental problems and skewed gender ratios. Sources of CECs include wastewater, urban and agricultural runoff, and animal husbandry.

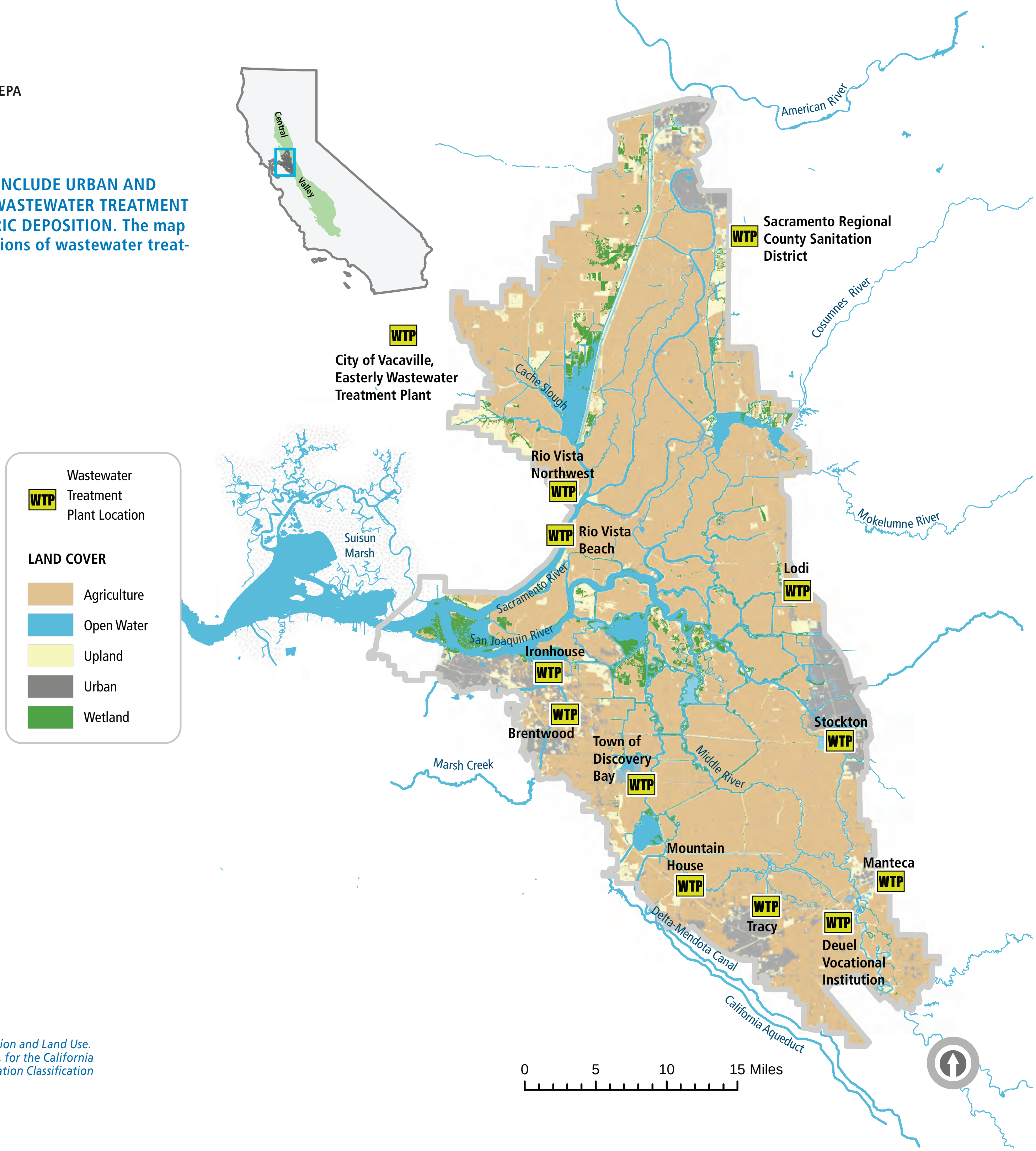
AQUATIC HABITAT

Declines in estuarine habitat quantity and quality are primary drivers of plummeting resident fish populations. The Estuary's freshwater-saltwater interface, or the low salinity zone, contains the greatest abundance of many open water estuarine organisms. The low salinity zone is often referred to by its indicator measurement "X2" (see **FIGURE 2**), which is equal to the distance (in kilometers) from the Golden Gate to the 2 ppt isohaline, the location where the salinity of water near the bottom is two parts per thousand (about 6% seawater).

One of the main concerns is the apparent loss of low salinity habitat during the fall months. Since the year 2000, the low salinity zone in fall months has been consistently upstream of Suisun and Honker Bays, effectively reducing the area of low salinity zone habitat available in fall by 78%. Prior to the year 2000, the location and size

FIGURE 1.

CONTAMINANT SOURCES INCLUDE URBAN AND AGRICULTURAL RUNOFF, WASTEWATER TREATMENT PLANTS, AND ATMOSPHERIC DEPOSITION. The map shows land uses and locations of wastewater treatment plants in the Delta.



Footnote: Data source: Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc., for the California Department of Fish and Game, Vegetation Classification and Mapping Program.

of the low salinity zone varied more from year to year, in some years providing an extended area of fall low salinity habitat in Suisun Bay.

As the low salinity zone moves eastward from Suisun Bay into the western Delta, its area shrinks and habitat quality for estuarine species declines substantially. The brackish tidal marsh habitats of Honker Bay, Suisun Bay, and Suisun Marsh offer more abundant food, cooler water, sufficient dissolved oxygen, turbidity, structural diversity, and protection from predators. By contrast, deep channels and armored banks characterize the western Delta, along with higher water temperatures, less food, and considerably more exposure to predators. Since the year 2000, the low salinity zone during the fall months has been consistently located in the poor habitat of the western Delta in all water year types, until the very wet conditions of fall 2011.

Physical and chemical conditions in Delta waterways also block migratory corridors for fish on their journey through the Estuary and contribute to declining populations of salmonid species. Water quality barriers include low dissolved oxygen, elevated temperature, and altered hydrology (**FIGURE 3**). Low dissolved oxygen conditions in the Stockton Deep Water Ship Channel, the lower San Joaquin River, and in Old and Middle Rivers can entirely block upstream migration of Chinook salmon to the San Joaquin River. Water temperatures in salmon streams of the San Joaquin basin can prevent migration and recruitment for salmonids and exceed EPA temperature thresholds for Chinook salmon. Dams and diversions modify natural hydrology by removing San Joaquin River water from the Delta and filling San Joaquin River channels with Sacramento River water. This modification scrambles the chemical cues adult salmon need to navigate from the ocean into San Joaquin River freshwater spawning sites.

Extensive destruction of marshes, sloughs, floodplain, wetlands, and riparian areas (see **PAGE 61, STATUS AND TRENDS UPDATE: LAND COVER**) eliminated aquatic habitat that supported a great diversity of species. Remnants of high value habitat remain in the brackish tidal marsh and sloughs along the edge of Suisun Bay and Marsh, but these habitats have been eliminated from the western Delta. Seasonally flooded habitat supports rearing of migratory fishes, such as juvenile salmon, and spawning of estuarine fish, such as splittail. However, 1100 miles of levees in the Delta separate active river channels from floodplains, effectively eliminating the majority of these habitats.

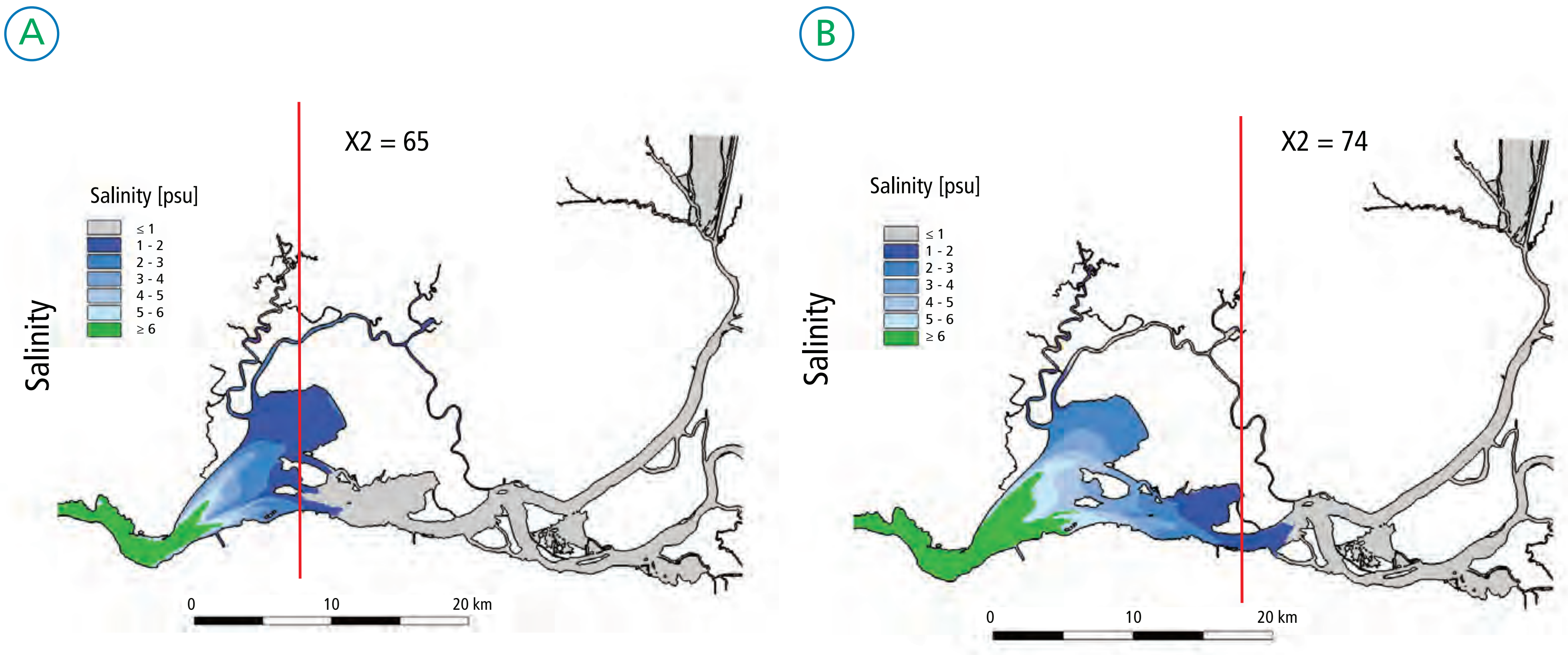
Large-scale wetland restoration is proposed in the Delta to begin to reverse habitat loss. Proposed wetland restoration sites include areas with mercury-contaminated soils. Mercury can transform to methylmercury in low oxygen conditions that are present in wetlands. Methylmercury negatively affects aquatic life, aquatic dependent wildlife, fish consumption, and public health. These circumstances make it critical to develop methods for minimizing the formation and transport of methylmercury as Delta wetland restoration projects are planned.

Extensive destruction of marshes, sloughs, floodplain, wetlands, and riparian areas over the past 160 years eliminated aquatic habitat that supported a great diversity of species

↑ Agricultural drain discharge at Ulatis Creek. Photograph by Don Weston.

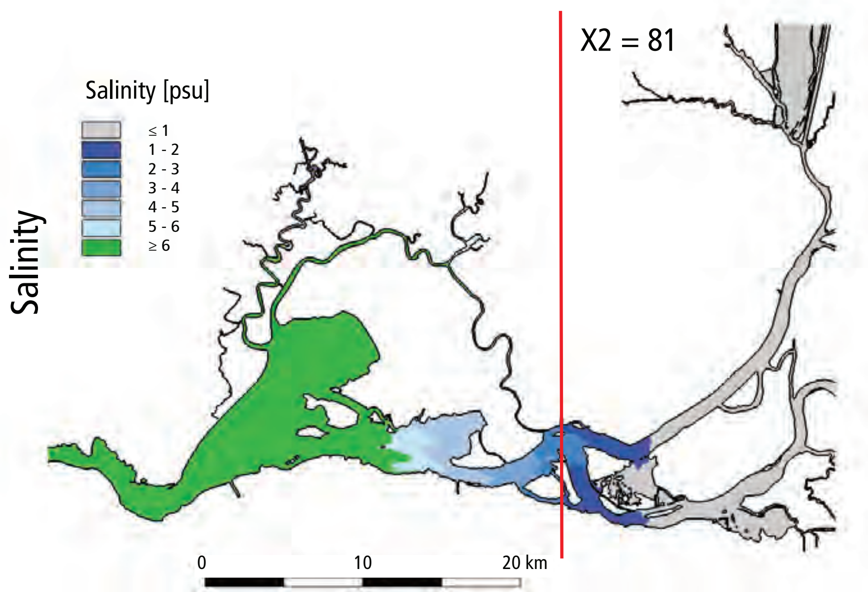
FIGURE 2.

THE LOW SALINITY ZONE CONTAINS THE GREATEST ABUNDANCE OF MANY ESTUARINE OPEN WATER ORGANISMS. The low salinity zone is often referred to by its indicator measurement "X2", which is equal to the distance (in kilometers) from the Golden Gate to the 2 ppt isohaline, the location where the salinity of the water near the bottom is two parts per thousand (about 6% seawater). Since 2000, the low salinity zone during the fall months has been consistently located in the poor habitat of the western Delta in all water year types. Prior to 2000, the location of the low salinity zone during the fall varied between the western Delta and Suisun Bay, providing access in some years to high quality estuarine habitat in Suisun Bay. After 2000, the low salinity zone in the fall has been consistently further upstream in the poorer habitat of the western Delta, until the very wet conditions of fall 2011 extended it again further downstream. The figures illustrate the relationship between the low salinity zone and the X2 indicator: (A) When X2 = 65 km (downstream of Roe Island), the low salinity zone (in shades of blue from 1-6 ppt) stretches across the broadest regions of Suisun Bay adjacent to Suisun Marsh and covers 7704 hectares. (B) When X2 = 74 km (at Chipps Island), the low salinity zone increases 19% to 9140 hectares, but it is less optimal with higher salinities in Grizzly Bay and the lowest salinities found only in smallish Honker Bay. (C) When X2 = 81 km (at the confluence of the Sacramento and San Joaquin rivers), the low salinity zone is compressed into the relatively deep river channels of the Western Delta, where its areal extent drops 36% to 4914 hectares. (D) When X2 = 85 km, the isohaline approaches Antioch, and all connections to Suisun Bay and Marsh are lost. A relatively high salinity zone moves into Suisun, Grizzly, and Honker bays, and the areal extent of the low salinity zone drops to 4262 hectares.



Footnote: Maps are from Dr. Michael MacWilliams (Delta Modeling Associates, Inc.) and were generated using the UnTRIM San Francisco Bay-Delta model.

C


Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
X2 = 81
0
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20 km

D

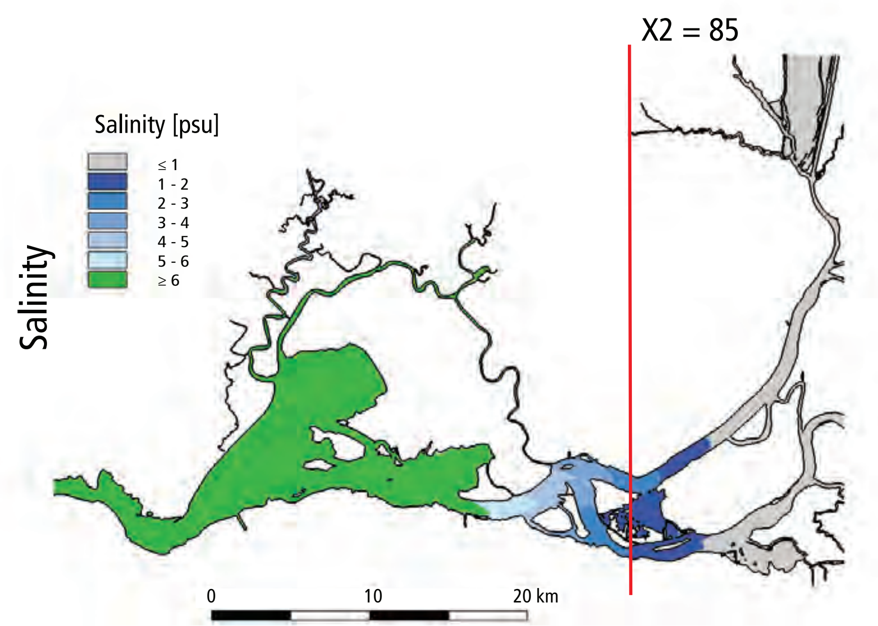
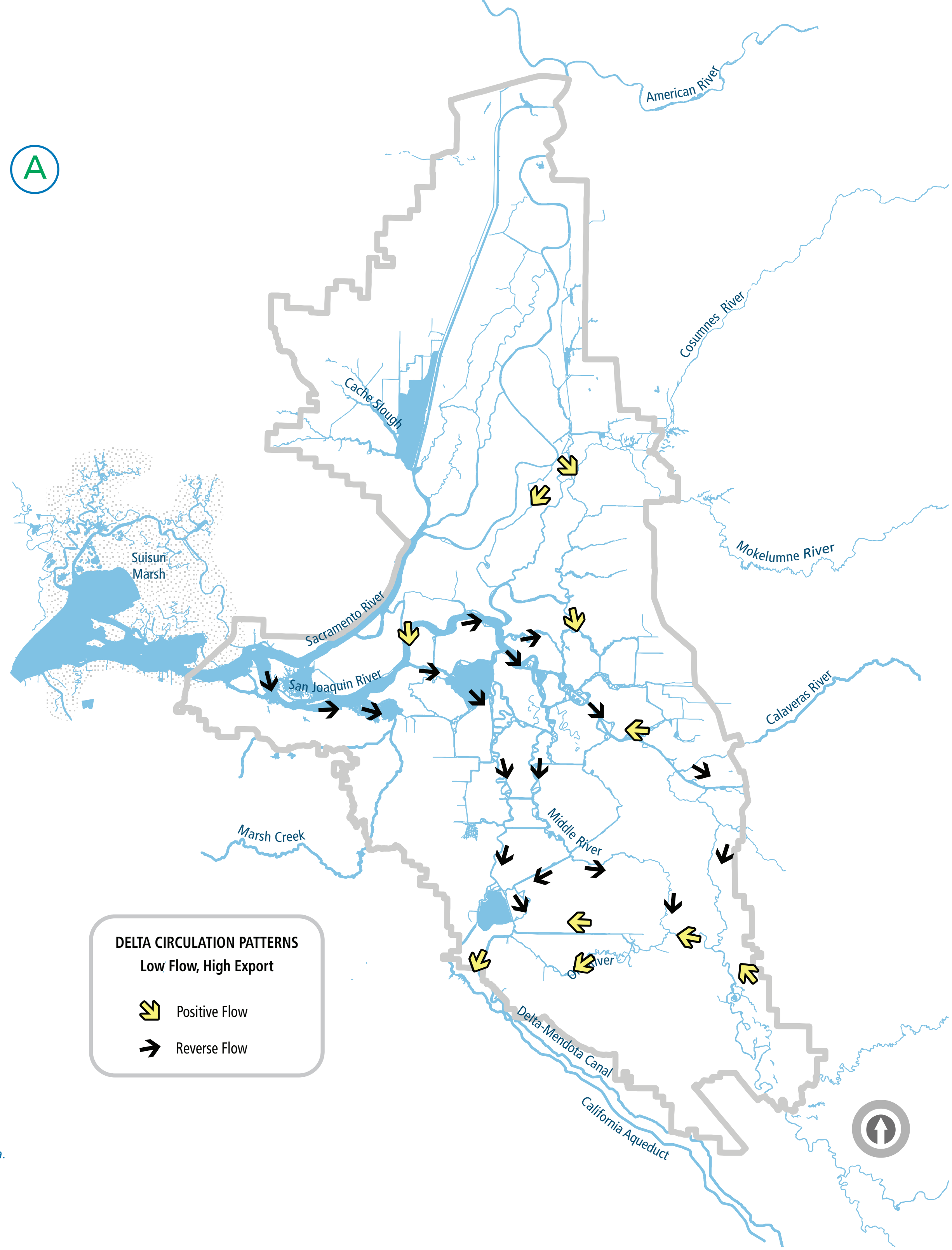
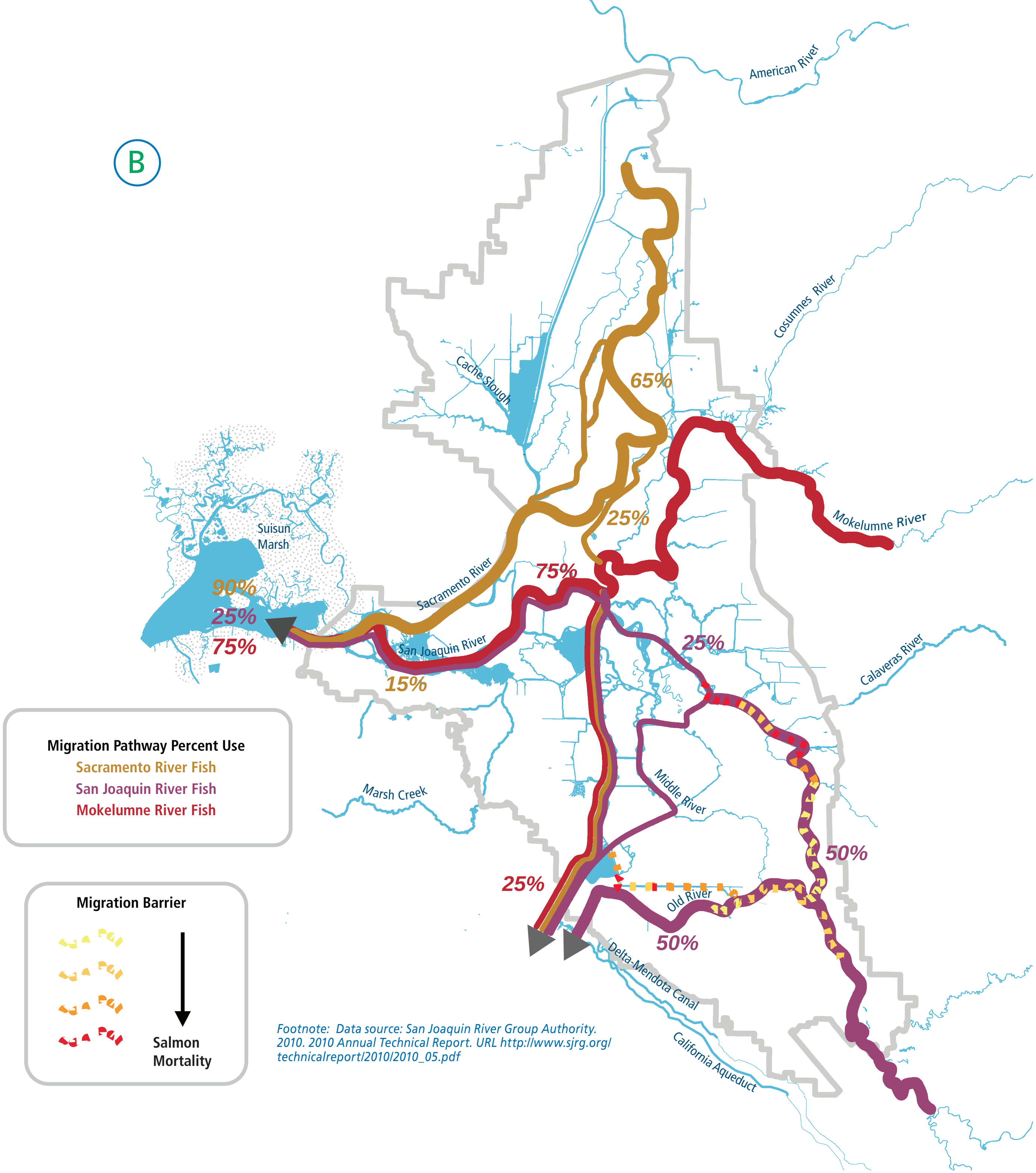

Salinity
Salinity [psu]
≤ 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
≥ 6
X2 = 85
0
10
20 km

FIGURE 3.

LOW DISSOLVED OXYGEN, HIGH WATER TEMPERATURE, AND CHANGED FLOW PATTERNS IN THE DELTA ACT AS MIGRATORY BARRIERS TO FISH AND CONTRIBUTE TO DECLINING SALMON POPULATIONS. The map shows the main Delta migration corridors for Central Valley Chinook salmon, in relation to a) Delta water circulation patterns under low flow, high export conditions and b) survival of outmigrating juvenile salmon from the San Joaquin River. Low dissolved oxygen conditions in the Stockton Deep Water Ship Channel, the lower San Joaquin River, and in Old and Middle Rivers can block upstream migration of Chinook salmon to the San Joaquin River. Dams and diversions modify natural hydrology by removing San Joaquin River water from the Delta and filling San Joaquin River channels with Sacramento River water. These modifications mask the hydraulic connection and chemical cues adult salmon need to navigate from the ocean into San Joaquin River freshwater spawning sites.



Footnote: Data source: 1. California Urban Water Agencies. 1993. The Delta.



Footnote: Data source: San Joaquin River Group Authority. 2010. 2010 Annual Technical Report. URL http://www.sjrg.org/technicalreport/2010/2010_05.pdf

Clean Water Act programs are not adequately protecting aquatic resources in the Estuary

EVALUATION OF CHANGES TO EPA PROGRAMS BASED ON PUBLIC INPUT

EPA requested comment on what the agency might do to respond to the Estuary's ecological collapse. EPA received 55 comment letters, from a range of state, local, and federal government agencies, non-governmental organizations, businesses, and individuals. Some comments provided additional technical information. Comments generally supported protection of Bay-Delta aquatic resources. Many comments related to the challenges in addressing cumulative and interactive effects of multiple stressors on aquatic resources. Many respondents encouraged pollution prevention as a less costly, more effective method of protecting aquatic resources and attaining water quality standards than removing pollutants from urban and agricultural runoff. Several stakeholders supported EPA's evaluation of Clean Water Act program efficacy, while other stakeholders expressed concerns about increased regulation. A comment summary and the comment letters are posted on the EPA website at www.epa.gov/sfbaydelta.

EPA'S CONCLUSIONS AND RECOMMENDED ACTIONS

EPA evaluated public comments, reviewed additional scientific information, and consulted with state and federal regulatory partners to determine how Clean Water Act programs can better protect aquatic resources in the Estuary. The conclusions of this work are as follows:

ARE CLEAN WATER ACT PROGRAMS ADEQUATELY PROTECTING AQUATIC RESOURCES?

Clean Water Acts programs are not adequately protecting aquatic resources in the Estuary. This conclusion is supported by the long-term decline and recent sharp drops in populations of estuarine species, combined with decades of elevated levels of contaminants.

AGENCIES ARE RESPONDING TO THE LACK OF ADEQUATE PROTECTION

EPA, the Water Boards, and other partners are actively working toward achieving water quality conditions that support and protect aquatic resources. The State Water Board plans to address the quantity and quality of estuarine habitat by updating Delta water quality standards to better protect fish and invertebrate populations. The Board began this review in 2009 and plans to conclude in 2014. The State Water Board is also reevaluating San Joaquin River Flow objectives, with the goal of restoring fish and wildlife designated uses.

State regulatory agencies made progress addressing the Delta's priority water quality issues. The Water Boards moved to control the largest known source of ammonia to the Estuary, in December 2010, when they added ammonia removal to the Sacramento Regional Wastewater Treatment Plant discharge permit. The California Department of Pesticide Regulation recently finalized pesticide regulations for protecting surface waters from urban pyrethroid applications, and the Water Boards are implementing and developing Total Maximum Daily Load Programs for organophosphate, pyrethroid, and other pesticides known to impact aquatic resources.

Nationally, EPA is updating ammonia guidance criteria for freshwater aquatic life and completing technical work to support new selenium criteria. The Total Ammonia Nitrogen Aquatic Life Guidance Criteria were released in draft form in 2009 and would provide stronger protection of freshwater invertebrates. Site-specific, numeric selenium criteria are being developed by EPA Region 9 and partners to protect Bay-Delta aquatic and terrestrial species while EPA updates national selenium guidance criteria for freshwater aquatic life. EPA is also developing the "Common Effects Methodology," a consistent approach under the Federal Insecticide Rodenticide and Fungicide Act (FIFRA) and Clean Water Act for estimating the effects of pesticides on aquatic life.

WHAT CRITICAL ACTIONS SHOULD EPA AND OTHERS TAKE TO PROTECT AQUATIC RESOURCES?

Together, the completion of ongoing water quality work and the critical actions outlined below will support our goal to accelerate restoration and protection of aquatic resources in the Bay-Delta Estuary

EPA'S REVIEW HIGHLIGHTS PRIORITY AND CRITICAL ACTIVITIES:

1. STRENGTHEN THE ESTUARINE HABITAT WATER QUALITY STANDARD. The State Water Board recently initiated review of the estuarine habitat protection standard in the Bay-Delta Water Quality Control Plan, which requires EPA review and approval. EPA provided technical support for updating the water quality control plan by synthesizing findings from a March 2012 workshop that convened scientists to discuss aquatic resource responses to different locations of the low salinity zone.

2. ADVANCE REGIONAL WATER QUALITY MONITORING AND ASSESSMENT PROGRAMS. EPA will continue to provide financial and technical support as the Water Boards establish regional monitoring programs in the Delta and Central Valley. In February 2012, EPA gathered stakeholders for the "Who's Watching the San Joaquin River" forum to identify shared interests in water quality monitoring and assessment in the San Joaquin Valley.

3. IDENTIFY ALL DESIGNATED USE IMPAIRMENTS. The Clean Water Act requires states to identify as "impaired" those waterways that do not meet water quality standards. Standards include designated uses, water quality criteria, and an antidegradation requirement. Water quality standards are not attained, if any one of the three components of standards is not supported by water quality. There is substantial documentation that water quality in the Delta does not support aquatic life designated uses, including estuarine habitat; rare, threatened, or endangered species; and migration of aquatic organisms. We recommend that the Water Boards identify the cause of these aquatic habitat losses and include waterways not supporting these designated uses as impaired in the next Clean Water Act 303(d)/305(b) report.

4. IMPROVE TMDL DEVELOPMENT AND IMPLEMENTATION. EPA will support the Central Valley and San Francisco Bay Water Boards in developing and implementing TMDLs. We will identify outstanding and high priority actions in adopted TMDLs for targeted funding and add more accountability and transparency to documenting TMDL progress. Twenty-seven TMDLs have been approved in the Bay-Delta watershed, and fourteen others are under development.

5. FOCUS ON PESTICIDE POLLUTION PREVENTION. Some water pollution problems are caused by pesticides, even though they are registered under FIFRA and applied in full compliance with regulatory requirements. EPA is committed to improving the national pesticide registration review process to prevent such problems in the future. Data from water quality monitoring programs in California will help EPA to better assess and characterize potential risks. With a more complete understanding of water quality risks, EPA will be able to develop the necessary use guidance and restrictions that can help prevent similar water quality problems in the future.

6. DEVELOP METHYLMERCURY CONTROL METHODS. EPA is supporting the Delta Mercury and Methylmercury TMDL by funding projects that will identify methods for minimizing the formation and transport of methylmercury. EPA is contributing to the development of methods for methylmercury and carbon sequestration by the U.S. Geological Survey and to the Dutch Slough restoration project by the California Department of Water Resources, which includes management of methylmercury formation and transport.

These critical actions are designed to complement ongoing water quality work and are essential for improving water quality for the benefit of aquatic resources in the Estuary. Together, the completion of ongoing water quality work and the critical actions outlined above will support our goal to accelerate restoration and protection of aquatic resources in the Bay-Delta Estuary. ■

Protecting the Estuary from the Harmful Effects of Nutrient Enrichment: The Numeric Nutrient Endpoint Framework

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DAVID SENN, San Francisco Estuary Institute/Aquatic Science Center, davids@sfei.org

↑ Invasive Brazilian waterweed (*Egeria densa*) on a boat trailer at the Luis Park boat launch area in Stockton. Photograph by Thomas Jabusch.

HIGHLIGHTS

Nutrient Numeric Endpoints is the State's approach to managing nutrients

The San Francisco Bay-Delta Estuary is characterized by a low abundance of algae despite relatively high nutrient concentrations; however, there is evidence that the resilience of the Estuary to harmful effects of nutrient enrichment may be weakening

The State is establishing nutrient water quality objectives as part of a holistic approach to managing nutrients in State waters and protecting beneficial uses

Nutrient Numeric Endpoints consist of two components: 1) an "assessment framework", which establishes a suite of numeric endpoints for indicators of an estuary's response to nutrients (e.g., algal biomass, dissolved oxygen) and 2) the use of models that link the response indicators with nutrient inputs

Development of Nutrient Numeric Endpoints for San Francisco Bay, and eventually the Delta, should proceed by choosing indicators, establishing endpoints, developing nutrient load-response models, and assessing estuary condition through monitoring

Successful nutrient management requires coordination of monitoring and research in the Bay and the Delta

LOSING RESILIENCE?

The San Francisco Estuary is characterized by a low abundance of phytoplankton, the microscopic algae that are the basis for the food web, despite relatively high nutrient concentrations. San Francisco Bay receives loads of nitrogen and phosphorus comparable to or greater than Chesapeake Bay, an estuary with a high abundance of algae and well known as being nutrient-enriched. Nonetheless, the abundance (biomass) of phytoplankton is substantially lower in San Francisco Bay than would be expected in an estuary with such high nutrient enrichment. Sources of nutrients to the Bay include treated wastewater discharge and riverine inputs dominated by agriculture and urban land uses (Smith and Hollibaugh 2006).

The Bay does not suffer from typical symptoms of nutrient overenrichment. Oxygen depletion and high algal biomass are two of the most common symptoms of high levels of nutrients and these conditions have not characterized the Bay for the last two decades. In fact, primary productivity (a measure of algae and aquatic plant growth) in the Bay is considered to be very low (**FIGURE 1**). Therefore, regulators and managers have not previously prioritized reducing inputs of nitrogen and phosphorus to San Francisco Bay. Studies suggest that phytoplankton abundance in the Bay is limited by a combination of factors, including strong tidal mixing of the water column, short water residence times, light limitation due to high turbidity, and extensive grazing by clams.

However, monitoring data suggest that the resilience of the Estuary to harmful effects of nutrient enrichment may be weakening. Regions of the Bay, from Suisun to South Bay, have experienced significant increases in phytoplankton biomass (30- 105%) and small but significant declines in dissolved oxygen (Cloern et al. 2007, 2010; **FIGURE 2**) since the late 1990s. Increased frequency of blooms of the toxin-producing cyanobacteria Microcystis aeruginosa in San Pablo, Suisun Bay, and some areas of the Delta further signal changes in the Estuary (**FIGURE 3**).

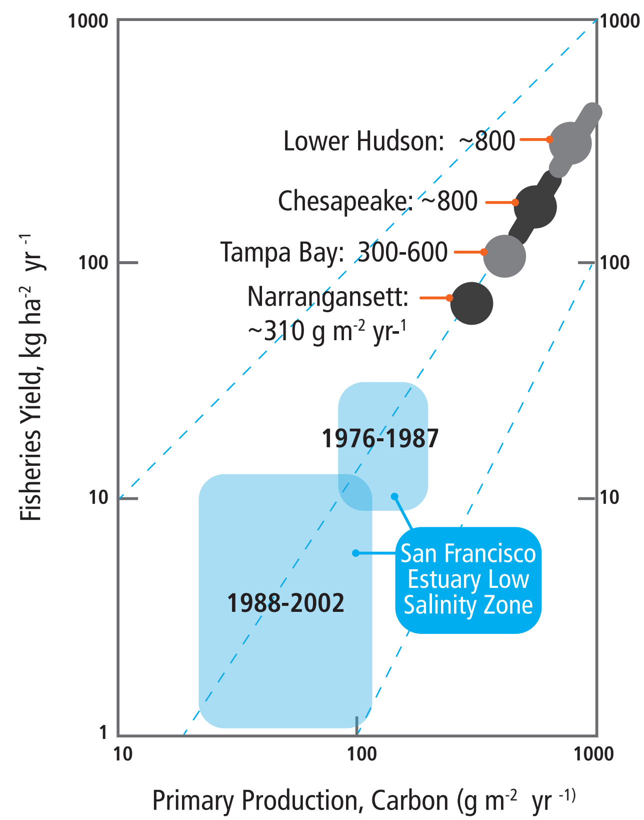
Invasive aquatic plant species, such as water hyacinth (*Eichhornia crassipes*) and Brazilian waterweed (*Egeria densa*), are expanding in the Delta, clogging waterways and industrial water intake pipes. These nuisance species now consume over 60% of the California Department of Boating and Waterways aquatic pest control budget according to the agency's website.

The causes of reduced resilience are complex and not uniform throughout the Estuary. For example, Cloern et al. (2010) demonstrated that increasing chlorophyll a (a measure of phytoplankton biomass) in the South Bay was linked to climate-driven increases in the populations of fish, crabs, and shrimp that feed on phytoplankton-grazing bivalves. Productivity in Suisun Bay and in the Delta may be controlled by different factors than in the South Bay. Dugdale et al. (2007) argue that elevated levels of ammonium in surface waters actually limit phytoplankton production in Suisun Bay and the lower Sacramento River. Lehman et al. (2008) found that flow and temperature exert major controls on the occurrence of *Microcystis* blooms in the Delta.

The complexity of mechanisms controlling the biological response of the Estuary to nutrient loading highlights the importance of continued monitoring, research, and synthesis of science.

FIGURE 1.

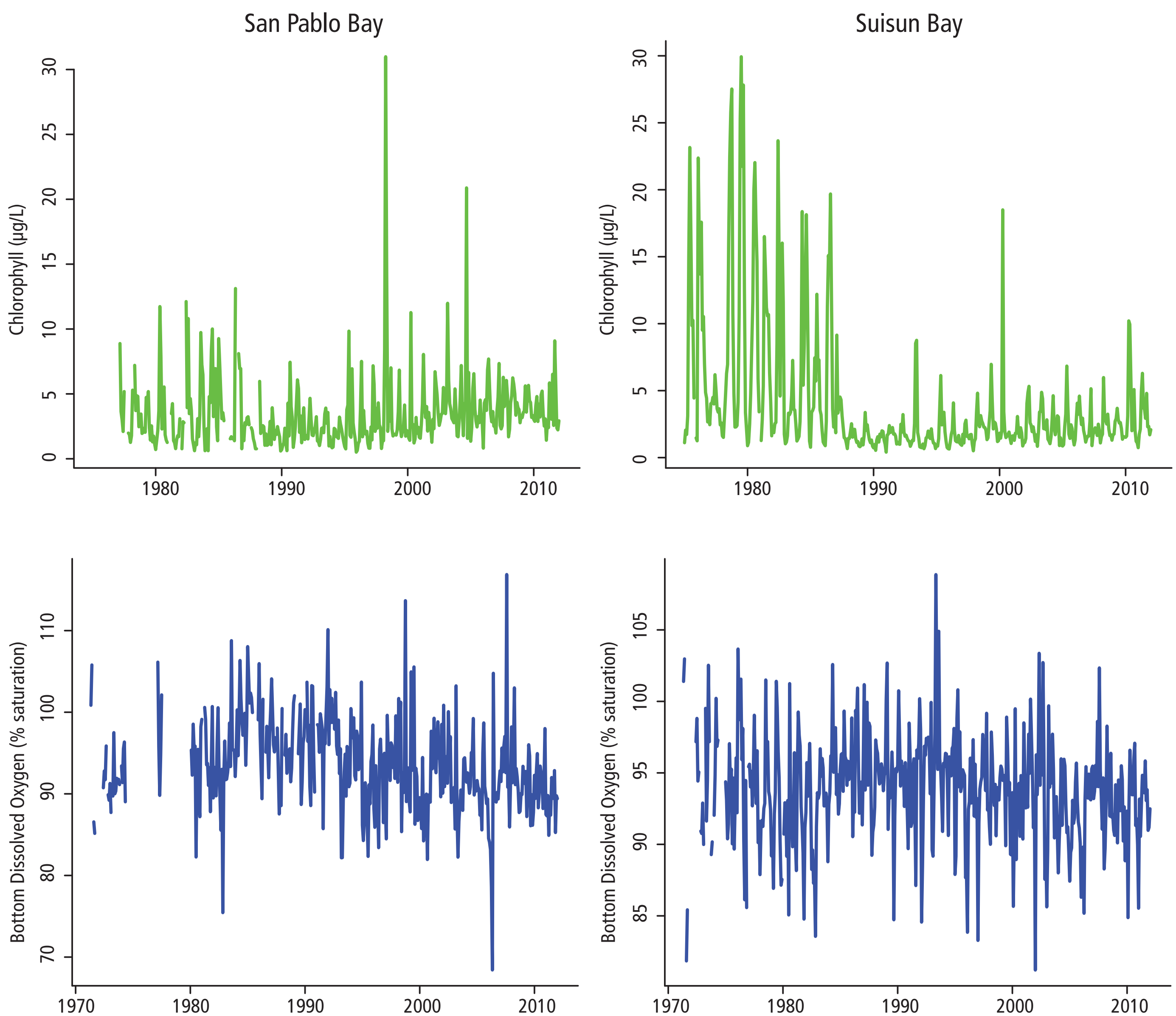
PRIMARY PRODUCTION AND FISHERIES YIELD IN THE BAY-DELTA ESTUARY ARE LOW COMPARED TO OTHER ESTUARIES.



Footnote: Figure adapted from Anke Mueller-Solger, Alex Parker, Jim Cloern and Alan Jassby, (personal communications), based on Nixon (1988).

FIGURE 2.

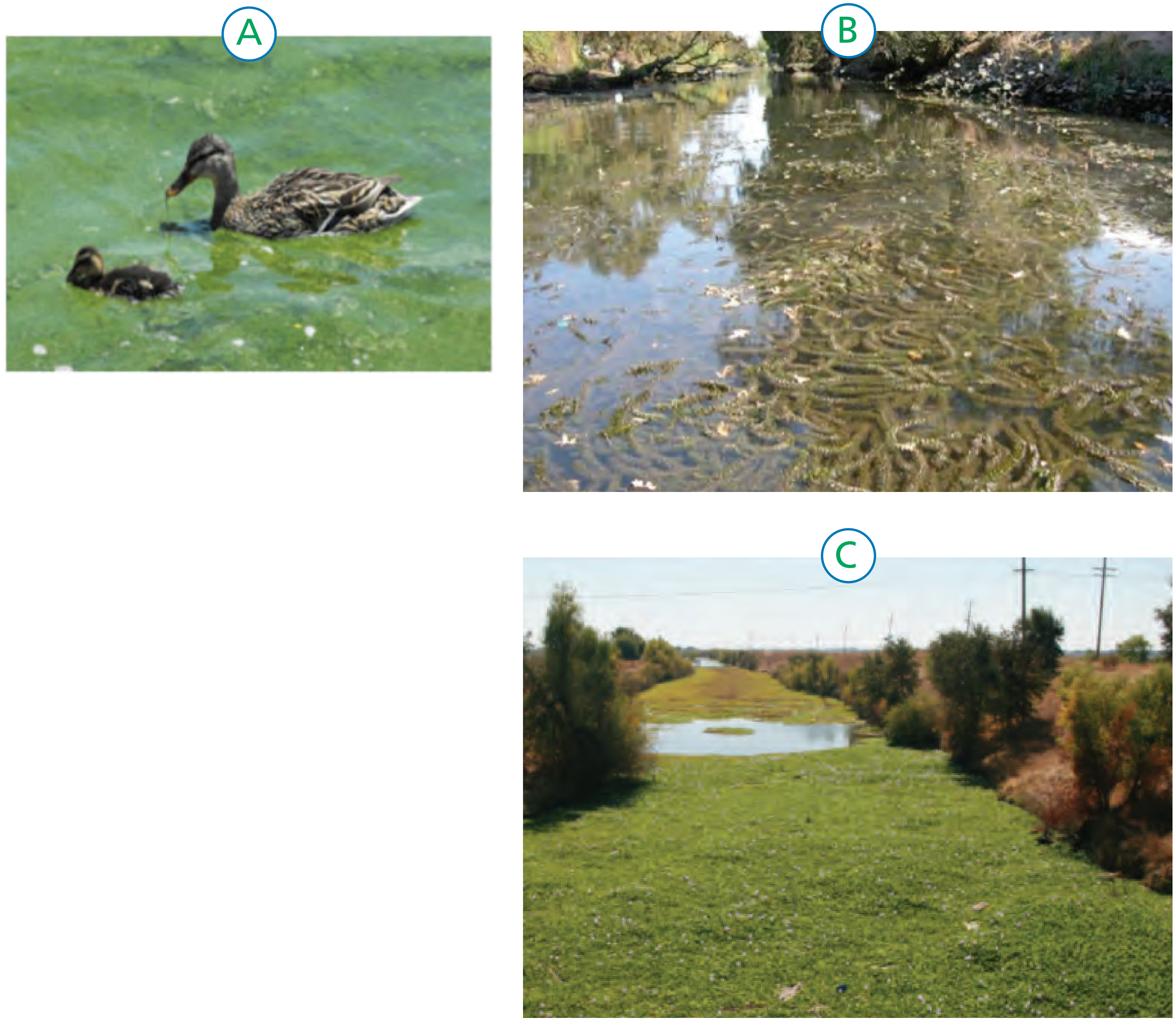
WILL THE BAY TURN EUTROPHIC? Increases in phytoplankton and decreases in dissolved oxygen observed in San Francisco Bay have triggered concerns over the possible risks of eutrophication. The graphs show trends in phytoplankton biomass (as indexed by chlorophyll a concentrations) and dissolved oxygen (as % saturation) for two regions of San Francisco Bay. A sharp drop of chrlorophyll concentrations in Suisun Bay follows the invasion by the overbite clam *Corbula amurensis*.



Footnote: The graphs show monthly averages of surface chlorophyll (averaged over the top 3 meters, in microgram per liter) and minimum bottom dissolved oxygen (in percent saturation) for San Pablo Bay (stations D41, s11, s12, s13, s14, s15) and Suisun Bay (stations D10, D8, D7, D6, s4, s5, s6, s7). "D" indicates IEP stations and "s" indicates USGS stations), Data were compiled and provided by Alan Jassby (U.C. Davis).

FIGURE 3.

SYMPTOMS OF EUTROPHICATION IN THE DELTA. From left to right: ducks feeding in A) a *Microcystis* bloom, B) a dense bed of the invasive Brazilian waterweed *Egeria densa*, and C) a tidal slough choked with the invasive water hyacinth *Eichhornia crassipes*.



Footnote: a. Photograph provided by Peggy Lehman and Regina Linville. Courtesy of the California Office of Environmental Health Hazard Assessment. b. Photograph by Erin Hestir. Courtesy of the Center for Spatial Technology and Remote Sensing, UC Davis. c. Photograph by Thomas Jabusch.

THE CHALLENGE OF ESTABLISHING NUTRIENT OBJECTIVES

San Francisco Bay water quality managers are increasing efforts to reduce nutrient loads and concentrations in response to changing trends in dissolved oxygen, algal biomass, and aquatic plant community composition.

The complexity of managing nutrients makes it challenging to use traditional approaches to water quality protection, such as establishing water quality objectives (WQOs). WQOs are regulatory tools used to establish levels of pollutants (e.g. nutrients) that are protective of a waterbody's beneficial uses.

Setting WQOs for nutrients is scientifically challenging. Nutrients are required to support life, but identifying how much is "too much" is not straightforward. The typical approaches used to set WQOs for toxic pollutants do not apply, in part because adverse effects of nutrient overenrichment occur at concentrations far below recognized toxicity thresholds. In addition, WQOs establish ambient nutrient concentrations, rather than identify inputs or "loads", to the waterbody. Nutrient load to an estuary is often a better predictor of productivity than ambient surface water concentration because it accounts for total delivery of nutrients over time, whereas concentration only provides a snapshot of available nutrients at a given point in time.

A water quality objective based on a one-size-fits-all nutrient concentration is not appropriate. Estuaries are highly variable in how they respond to nutrient concentrations due to site-specific differences in light availability, salinity, freshwater flows, and tidal mixing (NRC 2001). This combination of "co-factors" results in differences in how nutrients are used within an estuary. A recent synthesis by Cloern and Dugdale (2010) has shown that ambient nutrient concentrations do not correlate with measures of primary productivity in San Francisco Bay, in part because of important co-factors that override simple nutrient limitation of primary production. Therefore, an alternative approach is needed.

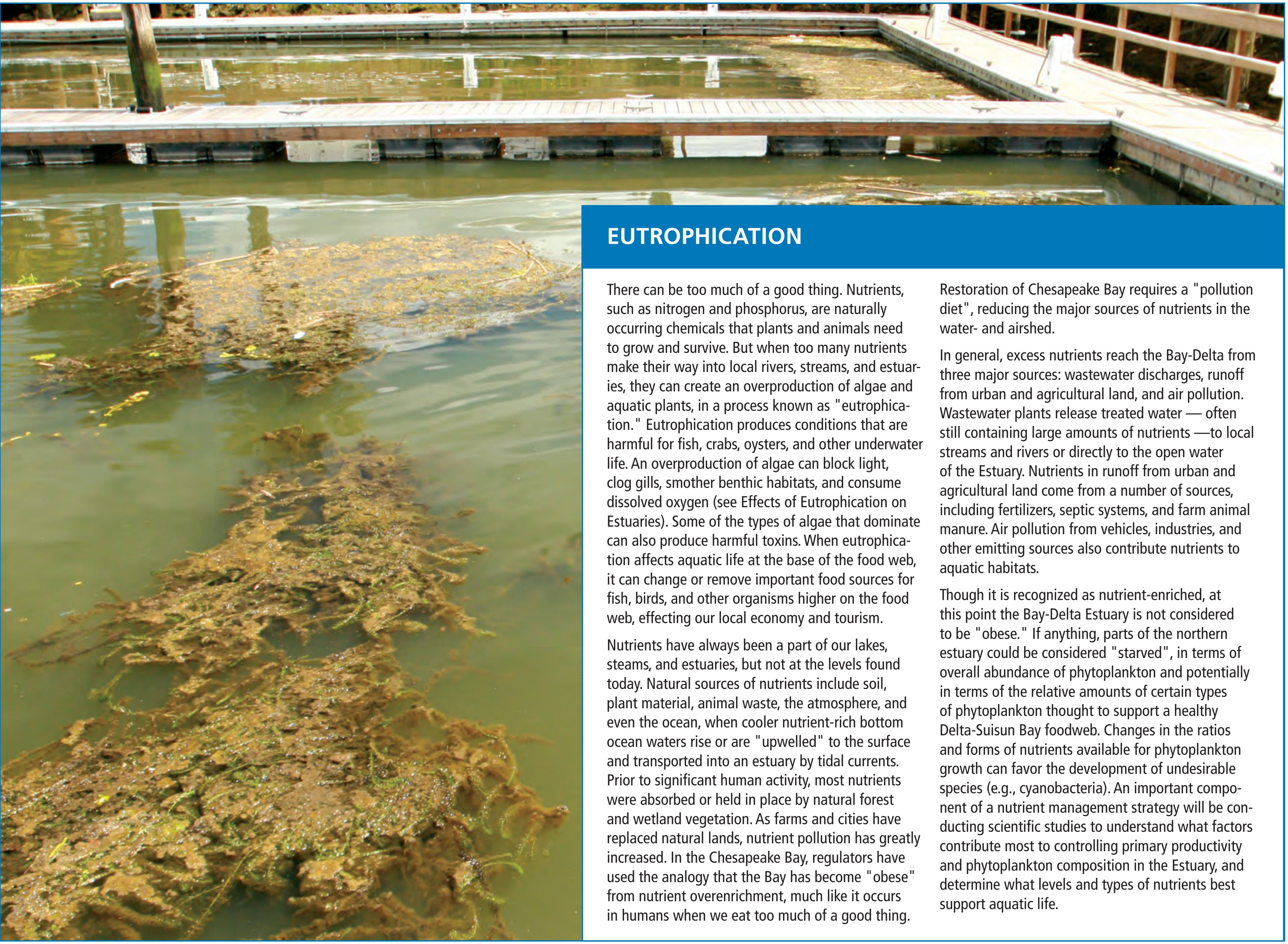
The cause-effect approach is an alternative for identifying nutrient objectives that are suitable for estuaries. The cause-effect approach involves setting numeric endpoints for indicators of estuary response to nutrient overenrichment. Response indicators can generally be placed in three main categories: 1) primary producers, 2) water and sediment chemistry, and 3) consumers (**SIDEBAR: CONCEPTUAL MODEL FOR SELECTION OF INDICATORS**). The numeric endpoints for these response indicators are then calculated to estimate appropriate nutrient loads. Equations used for this process incorporate important co-factors such as flow, tidal mixing, or grazing by consumers. The advantage of the cause-effect approach is that the resulting response indicators are linked strongly to beneficial uses (**SIDEBAR: EUTROPHICATION EFFECTS ON ESTUARIES**).

EFFECTS OF EUTROPHICATION ON ESTUARIES

Eutrophication has a variety of negative effects on estuary beneficial uses and ecosystem services:

- Changes in the abundance and composition of primary producers (i.e., algae), which are the base of the food web and support all aquatic life.
- Decreased biodiversity, with reductions and, in some cases, local extinction of rare, threatened, and endangered species.
- Toxin producing algal blooms that may harm people, dogs, and aquatic life.
- Increased frequency of low-oxygen "dead zones" in water and sediments. Hypoxia is the number one cause of fish kills and can also have chronic effects on aquatic life, affecting survival, growth, and reproduction.
- Increased production of bacteria, including pathogens, resulting in poor water quality and increased frequency of waterborne diseases.
- Clogging of navigable waterways and industrial and municipal intake pipes with macroalgae and other floating or submerged aquatic vegetation.
- Shading or smothering of seagrass, shellfish beds, and other important habitats.
- Changes in nutrient cycling that can further worsen the symptoms of eutrophication. For example, sediments of eutrophic water bodies tend to release nutrients back to the water at a faster rate, which increases internal nutrient loads. Eutrophic water bodies also lose their capacity for denitrification, a process carried out by microorganisms that converts nitrate to nitrogen gas, which subsequently becomes lost to the atmosphere.
- Poor aesthetics and odors from decomposing algae and plants and increasing sulfide production.
- Subsequent decrease and changes in community structure of invertebrates, birds, and fishes, and in some cases, collapse of fisheries.

Together, these adverse effects impair estuary beneficial uses. Affected uses include recreation, habitat quality, aquatic life, fisheries, navigation, drinking water, and industrial use.



EUTROPHICATION

There can be too much of a good thing. Nutrients, such as nitrogen and phosphorus, are naturally occurring chemicals that plants and animals need to grow and survive. But when too many nutrients make their way into local rivers, streams, and estuaries, they can create an overproduction of algae and aquatic plants, in a process known as "eutrophication." Eutrophication produces conditions that are harmful for fish, crabs, oysters, and other underwater life. An overproduction of algae can block light, clog gills, smother benthic habitats, and consume dissolved oxygen (see Effects of Eutrophication on Estuaries). Some of the types of algae that dominate can also produce harmful toxins. When eutrophication affects aquatic life at the base of the food web, it can change or remove important food sources for fish, birds, and other organisms higher on the food web, effecting our local economy and tourism.

Nutrients have always been a part of our lakes, steams, and estuaries, but not at the levels found today. Natural sources of nutrients include soil, plant material, animal waste, the atmosphere, and even the ocean, when cooler nutrient-rich bottom ocean waters rise or are "upwelled" to the surface and transported into an estuary by tidal currents. Prior to significant human activity, most nutrients were absorbed or held in place by natural forest and wetland vegetation. As farms and cities have replaced natural lands, nutrient pollution has greatly increased. In the Chesapeake Bay, regulators have used the analogy that the Bay has become "obese" from nutrient overenrichment, much like it occurs in humans when we eat too much of a good thing. Restoration of Chesapeake Bay requires a "pollution diet", reducing the major sources of nutrients in the water- and airshed.

In general, excess nutrients reach the Bay-Delta from three major sources: wastewater discharges, runoff from urban and agricultural land, and air pollution. Wastewater plants release treated water — often still containing large amounts of nutrients —to local streams and rivers or directly to the open water of the Estuary. Nutrients in runoff from urban and agricultural land come from a number of sources, including fertilizers, septic systems, and farm animal manure. Air pollution from vehicles, industries, and other emitting sources also contribute nutrients to aquatic habitats.

Though it is recognized as nutrient-enriched, at this point the Bay-Delta Estuary is not considered to be "obese." If anything, parts of the northern estuary could be considered "starved", in terms of overall abundance of phytoplankton and potentially in terms of the relative amounts of certain types of phytoplankton thought to support a healthy Delta-Suisun Bay foodweb. Changes in the ratios and forms of nutrients available for phytoplankton growth can favor the development of undesirable species (e.g., cyanobacteria). An important component of a nutrient management strategy will be conducting scientific studies to understand what factors contribute most to controlling primary productivity and phytoplankton composition in the Estuary, and determine what levels and types of nutrients best support aquatic life.

↑ Patches of invasive Brazilian waterweed (*Egeria densa*) and greenish water at the Driftwood Marina in Oakley. Photograph by Thomas Jabusch.

THE NUTRIENT NUMERIC ENDPOINT FRAMEWORK

The State Water Board is proposing the cause-effect approach as the principal means to establish nutrient water quality objectives for California waterbodies. Their approach involves creating guidance that will be used to translate a narrative nutrient water quality objective into numeric values. That guidance, referred to as "Nutrient Numeric Endpoint (NNE) framework," consists of two components: 1) an "assessment framework", which establishes a suite of numeric endpoints based on response indicators (for example, algal biomass, dissolved oxygen) and 2) the use of models (equations) that link response indicator numeric endpoints with nutrient loads and other factors.

The NNE framework has already been developed for California streams and lakes (TetraTech 2006). Numeric endpoints were established for benthic algal biomass in streams and phytoplankton biomass in lakes. Endpoints were also established for water chemistry indicators such as dissolved oxygen and pH. Simple models were developed to link numeric endpoints to waterbody-specific nutrient load targets. They allow the user to account for the site-specific co-factors that modify the response to available nutrients. If increased precision is required, stakeholders are encouraged to develop more complex models or alternative peer-reviewed approaches to establish site-specific nutrient targets.

DEVELOPING THE NNE FRAMEWORK FOR SAN FRANCISCO BAY

The NNE framework is under development for all California estuaries. This process began through the selection of response indicators applicable to all estuaries and a review of science supporting the selection of numeric endpoints for each indicator (Sutula 2011).

A site-specific NNE framework needs to be developed for the San Francisco Estuary, because it is the largest of California's estuaries and a complex ecosystem that represents more than one-third of all estuarine habitat statewide. This effort is first focused on the lower estuary, extending to and including Grizzly Bay (and hereto referred to as the San Francisco Bay NNE). Work on nutrient objectives for the Delta is in the planning stages.

Work on the San Francisco Bay San NNE began with an extensive literature review. The review identified candidate NNE indicators, summarized the status of symptoms of eutrophication in San Francisco Bay using these indicators, reviewed available nutrient loading data, and identified key data gaps and next steps (McKee et al. 2011). A separate review and process would be appropriate for the Delta at some point in the future.

The literature review and data gaps analysis resulted in four main recommendations for moving forward with the development of the San Francisco Bay NNE: 1) finalize response indicator selection and designate numeric endpoints, 2) develop load-response models, 3) conduct monitoring to support load-response model development and implementation of the NNE, and 4) coordinate nutrient management and monitoring activities with the Delta.

CHOOSING RESPONSE INDICATORS

NNE response indicators should be: 1) strongly linked to Bay-Delta beneficial uses, 2) quantitatively coupled to nutrient loads and other co-factors using predictive models, 3) scientifically well-vetted and cost-effective to measure, and 4) reliably used to assess eutrophication or other adverse effects of nutrients (i.e., good signal/noise ratio).

Appropriate response indicators vary by habitat type in an estuary. **FIGURE 4** shows the four main habitat types found in all estuaries: 1) unvegetated subtidal, 2) seagrass and brackish submerged aquatic vegetation, 3) intertidal flats, and 4) marsh. Depending on what habitat types are dominant, the appropriate indicators can sometimes be different among estuaries, or even within an estuary.

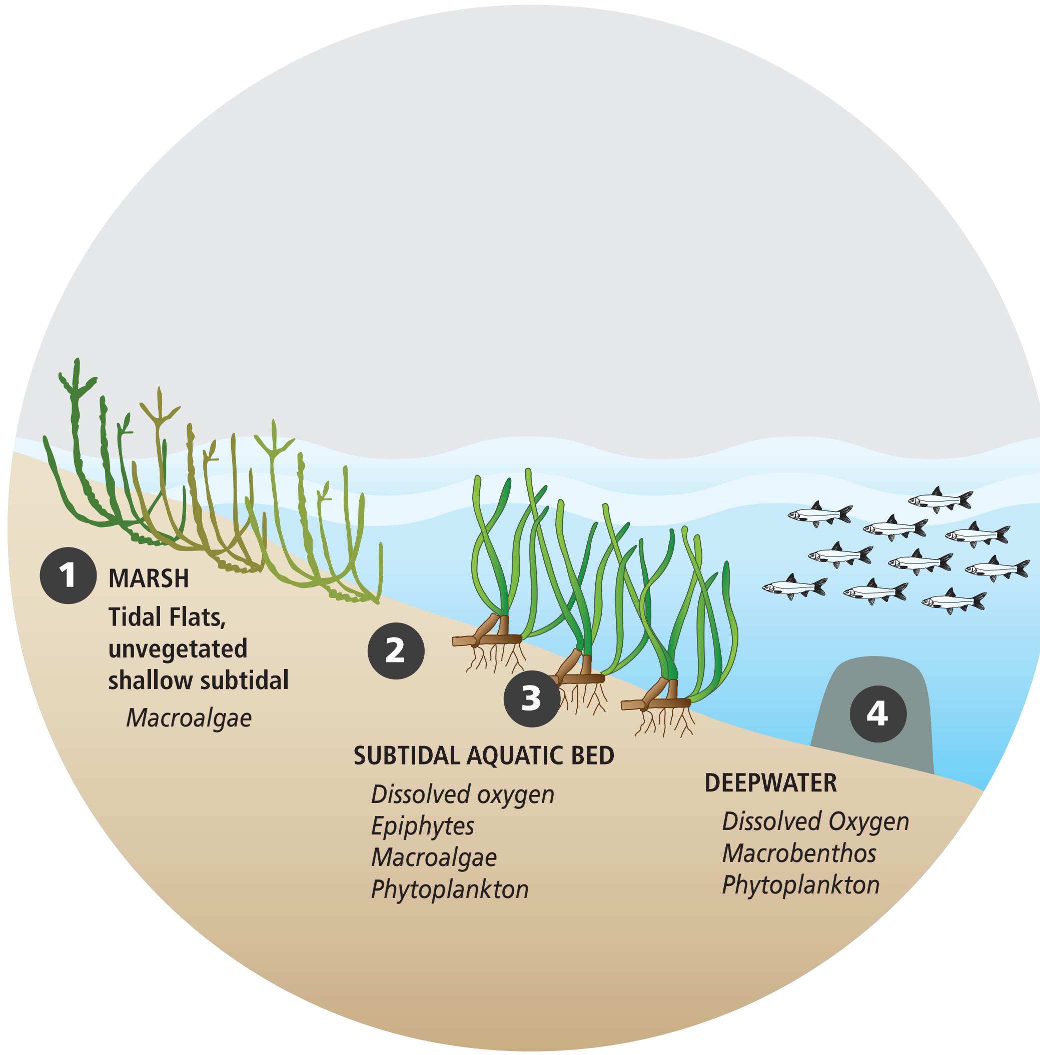
The Bay is dominated by subtidal habitat, with only a minor amount of seagrass and submerged aquatic vegetation. Therefore, the priority indicators recommended by McKee et al. (2011) are heavily weighted toward unvegetated subtidal habitat: dissolved oxygen and phytoplankton (e.g., biomass, productivity, assemblage, cyanobacterial abundance, and toxin concentration).

Other habitat types require additional or different indicators. For example, macroalgal biomass and cover may be appropriate in the Bay's managed ponds or in tidal sloughs with sluggish circulation.

Ammonium is under consideration as a potential indicator for the Bay, due to its hypothesized role in limiting phytoplankton production (Dugdale et al. 2007; Jabusch 2010). This hypothesis is still being explored, because the potential importance of ammonium inhibition of diatom blooms relative to other factors controlling primary productivity Bay-wide is not yet well understood.

FIGURE 4.

PRIMARY RESPONSE INDICATORS VARY BY ESTUARINE HABITAT TYPE. The figure shows primary response indicators to be used in three of the four main habitat types found in an estuary. The habitat types are found along a gradient from shoreline to open water: 1) marsh, 2) intertidal flats, 3) submerged aquatic vegetation, and 4) unvegetated subtidal habitat. Additional supporting indicators may be used (for example, light attenuation, nutrient concentrations).



Additional review and synthesis on this topic are recommended, pending completion of currently funded studies.

Appropriate indicators for the Delta may overlap somewhat with this for the Bay (for example, dissolved oxygen and phytoplankton) but could also include some unique indicators such as the abundance of floating macroalgae or water hyacinth (**FIGURE 3**).

SELECTING ENDPOINTS

The next steps in the process for San Francisco Bay include determining how to set appropriate numeric endpoints for selected indicators and assessing whether beneficial uses are met. Because subtidal habitat dominates, development of numeric endpoints for this habitat type is a priority. As mentioned above, the two primary indicator groups for this habitat type are dissolved oxygen and phytoplankton (**SIDEBAR: CONCEPTUAL MODEL FOR SELECTION OF INDICATORS**). The next steps in the process for San Francisco Bay include determining how to set appropriate numeric endpoints for these indicators and assessing whether beneficial uses are met.

Dissolved oxygen objectives already exist for the Bay. Site-specific objectives for some subhabitats are needed and a proposal to review science supporting revision of dissolved oxygen objectives for the Bay is being considered by the San Francisco Bay Water Board.

The process for developing NNE for phytoplankton begins with synthesizing existing data and engaging local scientific experts. Scientists must provide advice on what are the most appropriate attributes of phytoplankton to use (e.g., biomass, productivity, and taxonomic composition), how to account for spatial and temporal variability in phytoplankton when making an assessment, as well as summarizing information on how the magnitude, duration, and frequency of phytoplankton blooms relates to beneficial uses. This information would be synthesized into multiple categories of "condition" using best professional judgment. The Water Boards would then make a final decision on the numeric endpoints through a public process.

A MAJOR EMPHASIS ON LOAD-RESPONSE MODELS

Developing models that can simulate the ecological response to nutrient loads is an important component of implementing the San Francisco Bay NNE. Two types of models need to be developed: 1) loading models, which estimate the load of nutrients reaching the Bay and where they originate, and 2) Bay water quality models, which simulate the ecosystem response to nutrient loads. Loading models can give managers insight into how they might best control nutrient loads. A water quality model aims to predict a system's response to a given load and may reveal ways to alter the response if necessary. Combining these tools produces load-response models (**SIDEBAR: LOAD-RESPONSE MODELS**).

Numeric model development should begin with conceptual models. Conceptual load-response models in the Bay should be region-specific to incorporate spatial variability of co-factors within the Bay. The Regional Monitoring Program for Water Quality in the San Francisco Estuary (Bay RMP) has funded the development of load and response conceptual models for the Bay in 2012.

Dynamic simulation models are the most complex type of model and promise the most accurate predictions of ecological response to nutrient loads within San Francisco Bay. They require considerable data and knowledge about nutrient dynamics, co-factors (including complex hydrodynamics), and indicator responses in the system. It will take several years and a large investment in research and monitoring to develop such models.

Testing key concepts and assumptions in simple models will advance the development of dynamic simulation models. Simple box models can be used to develop coarse nutrient budgets for the Bay, estimate the sensitivity of the Bay's response to key co-factors, and identify critical data gaps. A review of existing models and their applications should be undertaken to identify the most useful existing tools.

Effective nutrient management in San Francisco Bay includes addressing upstream nutrient inputs from the Central Valley and the Delta.

There is a strong opportunity for building synergies between models (and monitoring) for San Francisco Bay and the Delta. Considerable effort has already gone into water quality modeling and synthesis of science for the Delta, and the process of identifying models that are appropriate for the Bay should include consideration of models already developed for the Delta.

NUTRIENT MONITORING: AN OPPORTUNITY TO INVOLVE DELTA STAKEHOLDERS

A monitoring program is needed to support regular NNE assessments of San Francisco Bay and, as mentioned before, develop and validate nutrient load-response models. Evaluation of how to assess nutrient sources and pathways from the Delta to San Francisco Bay is a clear nexus for discussion with stakeholders and coordination of monitoring programs.

Developing the San Francisco Bay nutrient monitoring program should leverage monitoring resources available in other large-scale programs. The U.S. Geological Survey has operated one of the world's premier estuarine water-quality research programs in the Bay since 1969. This program collects monthly samples between the South Bay and the lower Sacramento River to measure nutrients, dissolved oxygen, chlorophyll a, and associated parameters, but future funding is uncertain. The Interagency Ecological Program also conducts long-term monitoring that extends from the Delta into the Bay and covers many indicators that are relevant to a nutrient monitoring program for the Bay. In addition, the Central Valley Regional Water Board is developing the Delta Regional Monitoring Program.

MAJOR STRIDES TOWARDS A SAN FRANCISCO BAY NUTRIENT STRATEGY

The development of the NNE assessment framework is one component of the San Francisco Nutrient Science and Management Strategy (Nutrient Strategy). The San Francisco Bay Nutrient Strategy will lay out the steps to develop the necessary scientific understanding to support informed decisions about managing nutrient loads and maintaining beneficial uses within the Bay. The nutrient strategy will focus on informing upcoming management decisions related to nutrients and eutrophication. The strategy will prioritize work elements, identify sources of funding for those elements, and ensure efficient use of the available resources. The San Francisco Bay Water Board is working collaboratively with stakeholders and scientists to develop this strategy and to identify the technical studies required to support decisions regarding nutrient management.

The San Francisco Bay Nutrient Strategy will lay out the steps to develop the necessary scientific understanding to support informed decisions about managing nutrient loads and maintaining beneficial uses within the Bay

↑ Invasive water hyacinth overgrowing boat berths at the Stockton Marina. Photograph by Thomas Jabusch.

CONCEPTUAL MODEL FOR SELECTION OF INDICATORS: A CAUSE-EFFECT APPROACH

THE NUTRIENT NUMERIC ENDPOINT (NNE) FRAMEWORK RELIES ON A CAUSE-EFFECT APPROACH TO MODEL THE RELATIONSHIPS BETWEEN NUTRIENT LOADS, IMPORTANT CO-FACTORS, AND AN ESTUARY'S RESPONSE. AN ESTUARY'S ECOSYSTEM RESPONSE TO INCREASED NUTRIENT LOADS CAN BE DESCRIBED AS A CASCADE OF CHANGE:

1

Changes to aquatic primary producers. Examples: increased biomass and productivity accompanied by changes in the relative species composition of the algae and aquatic plants

MAY LEAD TO...

2

Changes in water and sediment biogeochemistry. Examples: declines of dissolved oxygen, increase in the water pH, and occurrence of toxic metabolites such as algal toxins and sulfide

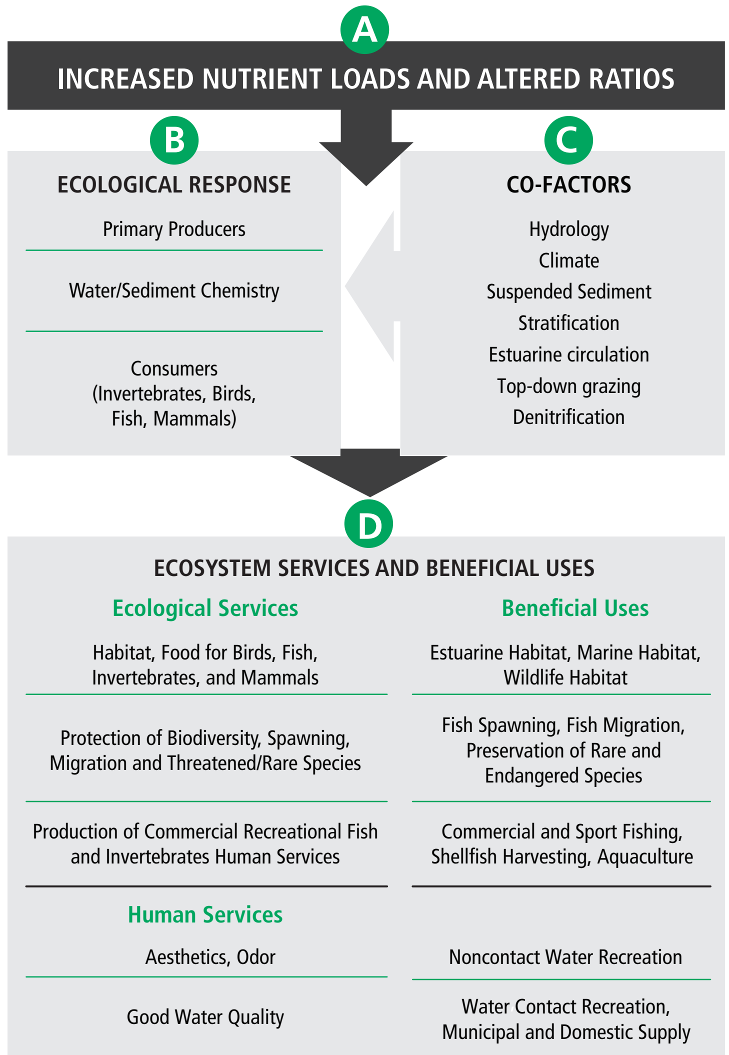
MAY LEAD TO...

3

Changes to the community structure. Examples: changes observed in secondary (invertebrates) and tertiary consumers (fish, birds, mammals).

This cascade of change has a direct effect on the ecosystem services and beneficial uses an estuary provides (see **EFFECTS OF EUTROPHICATION ON ESTUARIES**). These three types of change can be used to organize possible indicators for eutrophication.

The following diagram represents a conceptual framework of the linkage between nutrient loading (**A**), ecological response (**B**), co-factors modulating response (**C**), and altered ecological services and beneficial uses (**D**). Ecological response indicators are selected because they provide a closer linkage to beneficial uses and integrate the effects of co-factors.



Footnote: Conceptual framework showing the linkage of (A) nutrient loading, (B) ecological response, (C) co-factors modulating the ecological response, and (D) altered ecological services and beneficial uses. The ecological response (B) includes altered primary producer abundance and species composition, sediment and water biogeochemistry, and secondary and tertiary consumer abundance and species composition. Beneficial uses affected by nutrient loading include aquaculture (AQUA), commercial and sport fishing (COMM), estuarine habitat (EST), marine habitat (MAR), fish migration (MIGR), municipal and domestic supply (MUN), water contact recreation (REC1), noncontact water recreation (REC2), preservation of rare and endangered species (RARE), shellfish harvesting (SHELL), fish spawning (SPWN), and wildlife habitat (WILD). From Sutula (2011).

LOAD-RESPONSE MODELS

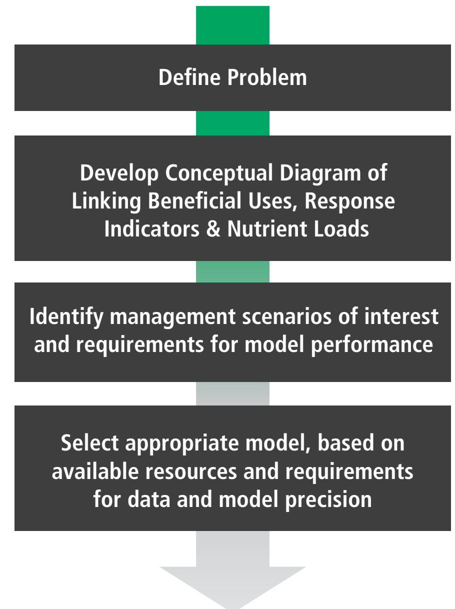
The goal of load-response models is to determine what load of nutrients the estuary can sustainably assimilate. The process of developing a load-response model begins with defining the problem: stating how is eutrophication expressed in the estuary and how are those symptoms linked to beneficial uses. The linkages between beneficial uses, eutrophication response indicators, and nutrient loads are explained in a detailed "conceptual model". The conceptual model must also identify the important "co-factors" — site-specific factors such as light, temperature, tidal mixing — that can modify the estuary's response to nutrient loads. It must also identify the important sources and pathways in which nutrients enter the estuary.

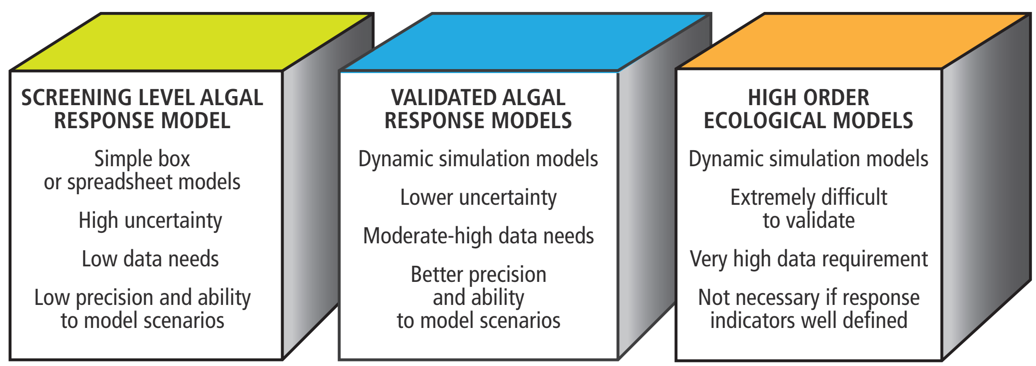
Process to develop load-response models.

The next development step is to determine what type of model is appropriate. This depends on the types of management scenarios to which the model should be responsive, the state of the science; the required level of precision or certainty in the answer, and the resources and data available to develop and validate the model. Models also vary in complexity -- from screening level box models to complex dynamic simulation models that represent the estuary as thousands of small boxes (both spatially and with depth) and require a high level of computing power. While dynamic simulation models can give a more precise answer and are generally capable of modeling more advanced management scenarios, they are also very resource intensive to build and validate, requiring many years of observational data and special studies to capture all of the relevant processes. Models that simulate algal response are generally easier to develop than those attempting to simulate dissolved oxygen or high trophic level response. However, algal response models for the Bay-Delta may be atypically complex due to the multitude of processes controlling primary production.

Different types of load-response models, ranging in complexity from simple screening level models to dynamic simulation models.

There is no clear-cut answer to whether a simple or a complex load-response model is more appropriate for the San Francisco Estuary. Over the long-term, it will be desirable to develop a complex, dynamic simulation model of estuary load-response, because nutrient management decisions (for example, nutrient limits for wastewater or stormwater permits) will be very expensive to implement and therefore a high level of precision is required to answer what loads of nutrients are sustainable. However, focusing first on simpler screening level box models can help to test important assumptions in the conceptual diagram, refine data gaps, identify critical model requirements, and focus limited resources to best move the process forward.





The 303(d) List

The "303(d) List" is short for a state's official list of impaired and threatened waters. Section 303(d) of the 1972 Federal Clean Water Act requires that states develop a list of water bodies that do not meet water quality standards, prioritize the list based on the severity of the problem, and develop action plans, called Total Maximum Daily Loads (TMDLs), to improve water quality. In some cases other regulatory action plans can substitute for a TMDL. The list of impaired water bodies and the pollutants responsible is updated periodically (typically every two years).

The U.S. Environmental Protection Agency must approve a state's 303(d) List before it is considered final. On October 11, 2011, the USEPA approved California's 2010 303(d) List, thereby replacing the 2006 California Clean Water Act 303(d) List.

The Delta is on the 2010 303(d) List.
The primary pollutants/stressors identified for the Delta include:

Metals/Metalloids
Copper, Mercury, and Zinc

Pesticides
Chlordane, Chlorpyrifos, DDE, DDT, Diazinon, Dieldrin, Group A Pesticides, Organophosphorus Pesticides, and Toxaphene

Salinity
Chloride, Electrical Conductivity, Salinity, and Total Dissolved Solids

Bacteria
E. coli, Pathogens

Nutrients
Low Dissolved Oxygen, Organic Enrichments

Chlorinated Compounds
Dioxin, Furan Compounds, and PCBs

Others
Invasive Species, Temperature, Sediment Toxicity, and Unknown Toxicity

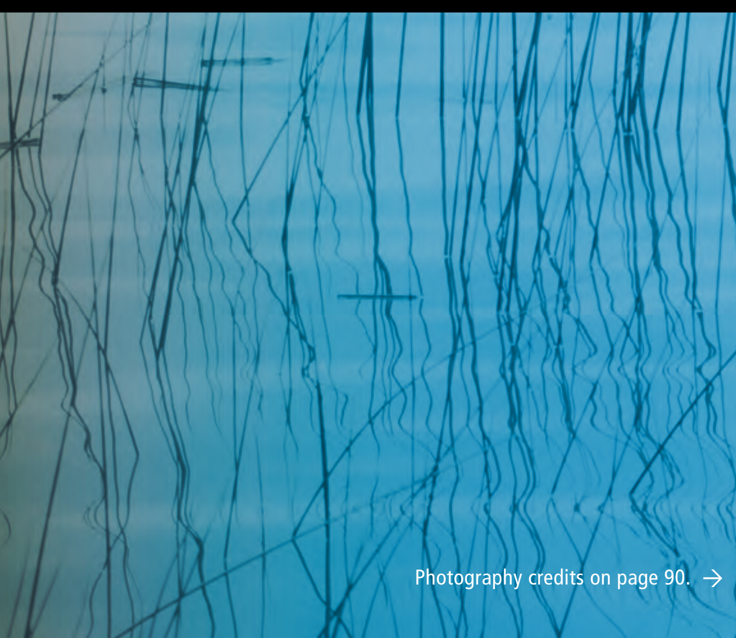
The Regional Water Board and State Water Board are currently developing the draft 2012 303(d) List. The State Water Board received over 100 data submissions to support the 303(d) List development, each including multiple data sets for one or more pollutants. Among those submitting data were government agencies, municipalities, environmental groups, citizen groups, and National Pollutant Discharge Elimination System (NPDES) dischargers. USEPA approval of the 2012 303(d) list is expected in 2013.

Regulatory Status of Pollutants of Concern

POLLUTANT	STATUS
Mercury	TMDL approved in 2011 (Delta Methylmercury TMDL)
Pathogens	TMDL approved in 2008 (Stockton Urban Waterbodies Pathogen TMDL)
Diazinon and Chlorpyrifos	TMDL approved in 2007
Salt and Boron	Evaluation of water quality objectives Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) initiated in 2006
Dissolved Oxygen	TMDL approved in 2005 (San Joaquin River Deep Water Ship Channel TMDL)
Organochlorine Pesticides	TMDL in early development stage
Pyrethroid Pesticide	TMDL in early development stage

Approved: State Water Board and USEPA approval

STATUS AND TRENDS UPDATE



Photography credits on page 90. →

NUTRIENTS

Nutrients have become a topic of much interest and debate in the Delta. One area of current consideration and concern is whether and how changes in nutrient loadings over the past three decades have impacted the productivity and structure of algae and plant communities. Recent studies suggest that elevated ammonium levels may be linked to low algal growth in Suisun Bay and the Delta, and continuing research assesses the role of total ammonia nitrogen in impacting the Delta's food web. Nutrients may play an increasingly important role in regulating productivity: because water has been getting clearer since 1999, the availability of light is thought to be less of a limitation on plant and algal growth.

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NUTRIENT SOURCES, PHYTOPLANKTON BIOMASS, AND SPECIES COMPOSITION

Fewer diatoms and other phytoplankton in Sacramento River. One of the issues Delta scientists, managers, and regulators are concerned about are the impacts of increased ammonium levels on the Bay-Delta ecosystem. They are currently evaluating how altered ammonium levels and nutrient balances are affecting the Delta's biological productivity and algal community composition. One hypothesis currently examined is that different phytoplankton functional groups occur in waters where elevated levels of ammonium (NH_4^+) prevent the phytoplankton from using nitrate (NO_3^-), compared with waters where ammonium levels are low and phytoplankton are using nitrate. To test the hypothesis, San Francisco State University (SFSU) researchers monitored the Delta portions of the Sacramento (ammonium-dominated) and San Joaquin (nitrate-dominated) rivers in April 2010. Both rivers receive significant portions of their nitrogen loadings from municipal wastewater discharges. The Sacramento Regional Wastewater Treatment Plant (SRWTP) discharges approximately 145 million gallons of effluent per day (mgd) to the Sacramento River and is currently the largest identified source of ammonium nitrogen to the Delta (**FIGURE 1**). The Stockton Wastewater Treatment Plant (WWTP) releases approximately 53 mgd and is a significant source of nitrate to the San Joaquin River (**FIGURE 2**). Compared to the Sacramento River, the San Joaquin River had greater biomass (more algae) overall and a different phytoplankton community with roughly 45% diatoms (mostly centric diatoms) and 55% made up by cryptophytes, chlorophytes, and flagellates (**FIGURE 3**). The SFSU researchers observed that the upper Sacramento River (with low ammonium) from station I-80 to station RM44 (ignoring the anomalous TOW location) had a high proportion of diatoms (40%) with 60% cryptophytes, chlorophytes, and flagellates (Kress 2012). They also observed that the lower portion of the Sacramento River from Hood to Rio Vista (with high ammonium) had an algal community composed of only 20% diatoms and 80% cryptophytes, chlorophytes, and flagellates. The abundance of diatoms is of interest because they are assumed to be a more nutritious food source to primary consumers such as zooplankton than some of the other, smaller-sized phytoplankton groups. Studies are continuing to understand the role that ammonium and other nutrients play, along with other factors, in affecting the phytoplankton composition and productivity of the Delta.

Footnote: Data and figures from Erica Kress (MSc student), Romberg Tiburon Center, SFSU. Project 1039 funded by Delta Science Program (when CALFED Science Program). Principal Investigators: Drs. Richard Dugdale, Frances Wilkerson, and Alex Parker.

Nitrate (NO_3) concentrations in (blue) and ammonium (red) concentrations in micromoles per liter (μM). Algal cell numbers are based on microscope counts of phytoplankton groups (x 10^6 cells per liter) obtained using the Utermohl method and an inverted microscope.

FIGURE 1.

SACRAMENTO RIVER

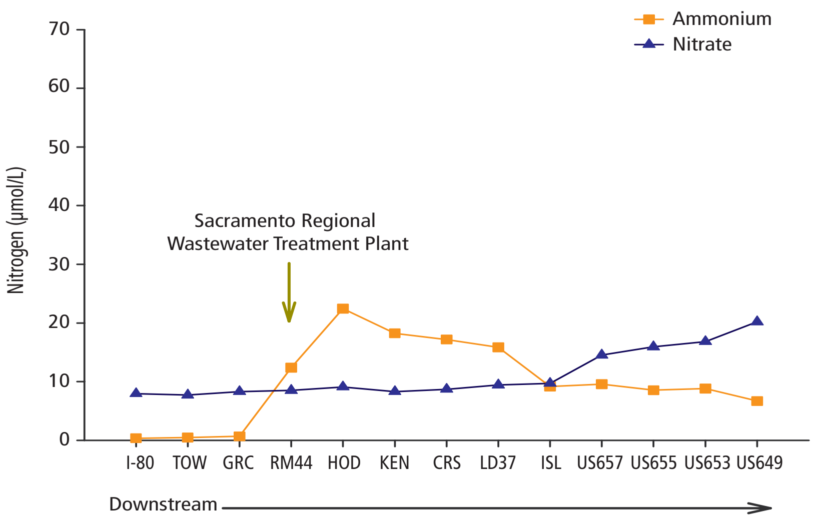


FIGURE 2.

SAN JOAQUIN RIVER

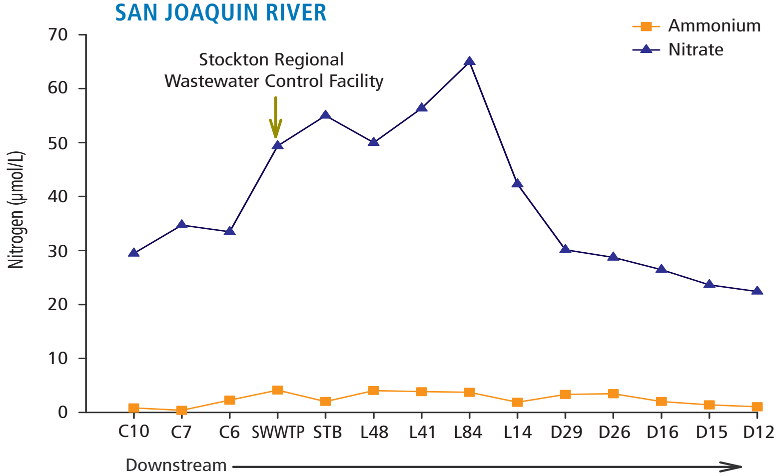
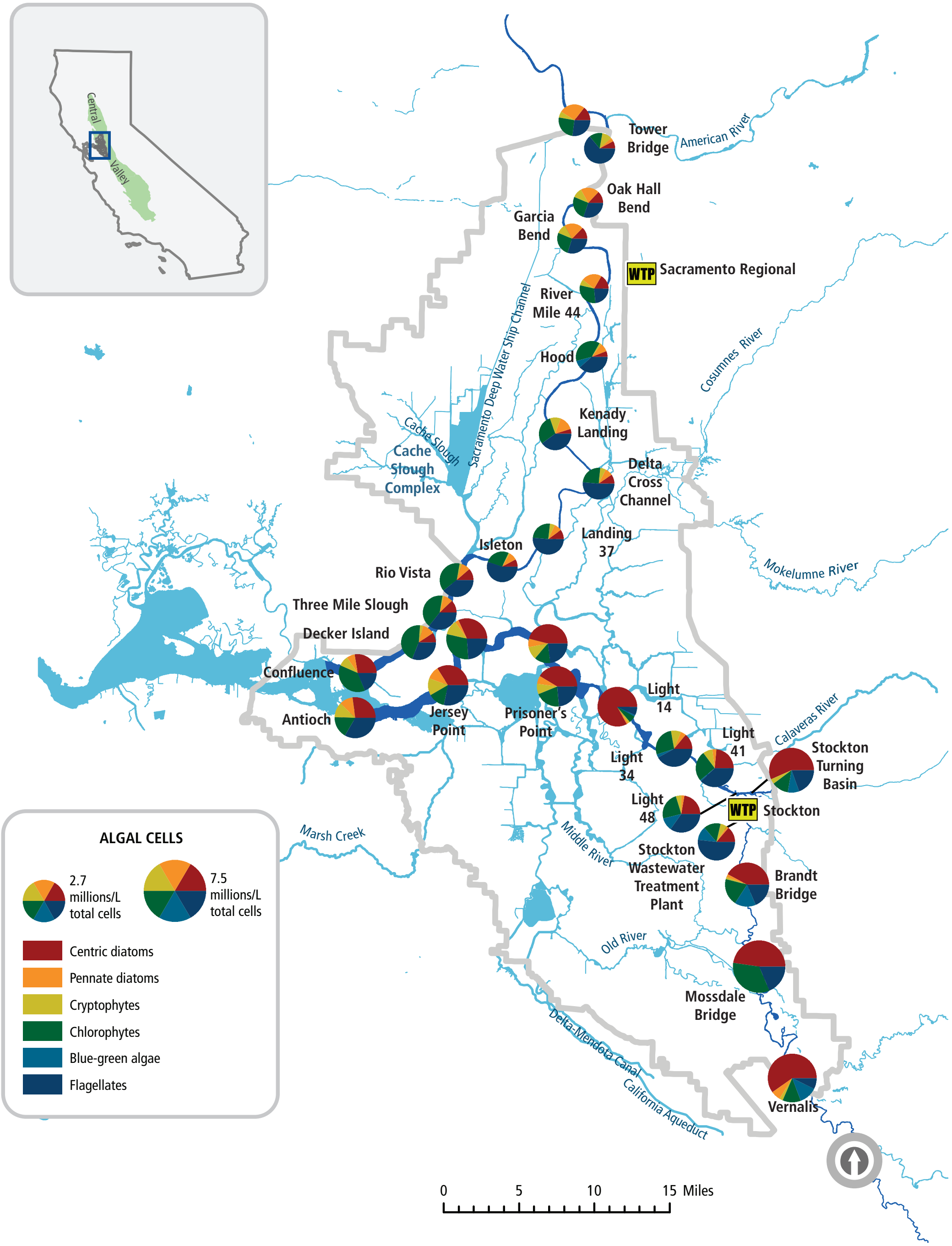


FIGURE 3.



NUTRIENTS

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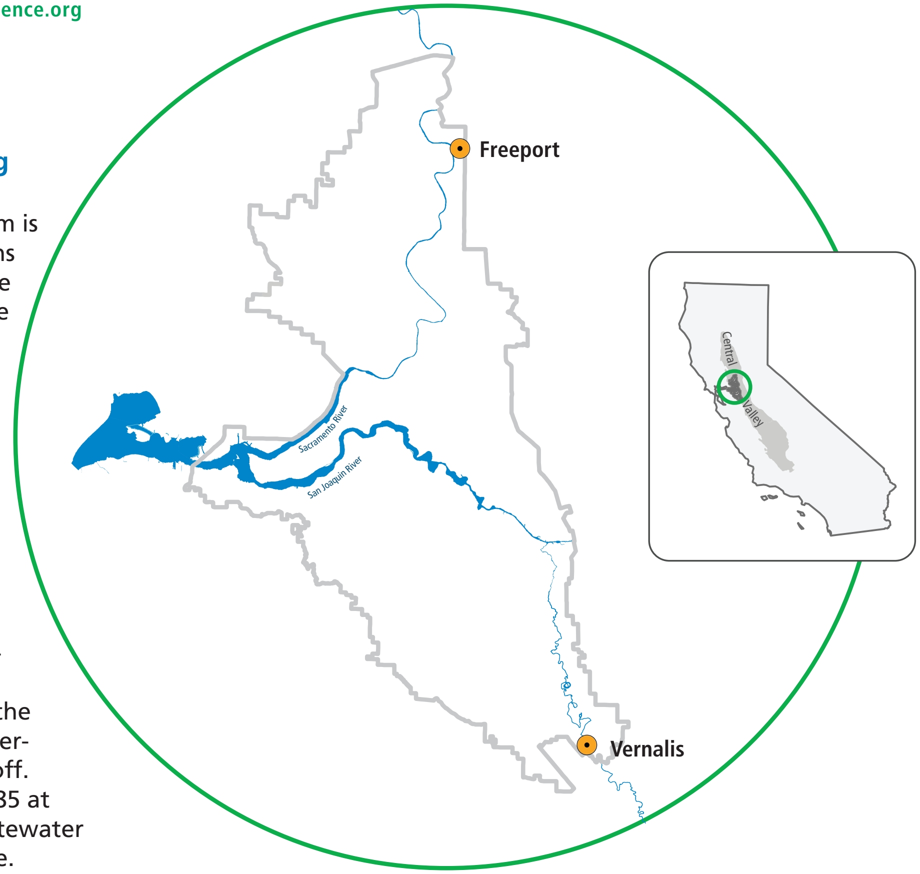
TRENDS IN NUTRIENT INPUTS FROM THE SACRAMENTO AND SAN JOAQUIN RIVER



Long-term monitoring by the U.S. Geological Survey is revealing trends in Delta nutrient inputs from upstream sources. The U.S. Geological Survey National Water Quality Assessment (NAWQA) Program is designed to assess historical, current, and future water quality conditions in representative river basins and aquifers nationwide. Investigations are conducted within "study units." The Sacramento and San Joaquin-Tulare Basins represent two of the 51 study units in this program. The NAWQA program also monitors the mouths of large watersheds, including the Freeport and Vernalis sites, where flows from the Sacramento and San Joaquin Rivers enter the Delta.

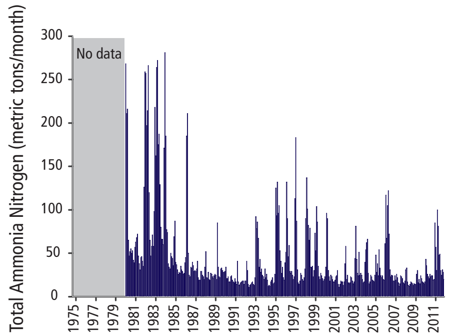
An interpretative assessment report for nutrient trends from 1975 to 2004 is now available (pubs.usgs.gov/sir/2010/5228/). Shown in the graphs displayed on this page are modeling results for nutrient loads at the Freeport and Vernalis sites that include all currently available nutrient data from the National Water Information System (NWIS) database.

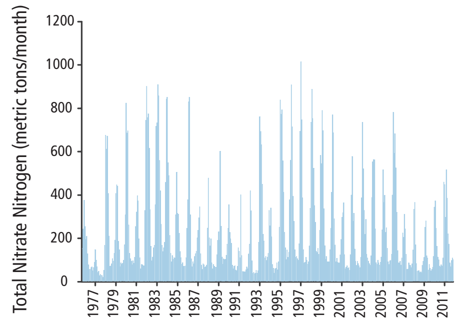
Seasonal patterns for nutrient loads at both sites are cyclical, with maximums in winter/spring during high flow and minimums in summer/fall during low flow. Nitrate, total nitrogen, and total phosphorus loads at the Freeport sites are mostly from non-point sources in the Sacramento watershed and annual loads are generally following variations in annual runoff. For ammonia, there was an overall decrease in measured loads after 1985 at Freeport, when the point of discharge of the Sacramento Regional Wastewater Treatment Plant moved to a location downstream of the monitoring site.

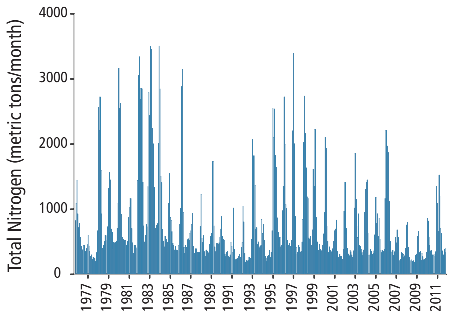
Patterns in point source loads varied by station and analyte. As revealed in a source analysis for the period 1985 – 2004, point sources accounted for about 4 percent of total nitrogen and 7 percent of total phosphorous loads in the Sacramento River at Freeport and for about 8 percent of total nitrogen and 17 percent of total phosphorous loads in the San Joaquin River near Vernalis. Point source contributions to total phosphorous loads at Freeport and total phosphorous and -nitrogen at Vernalis decreased over the 20 years.

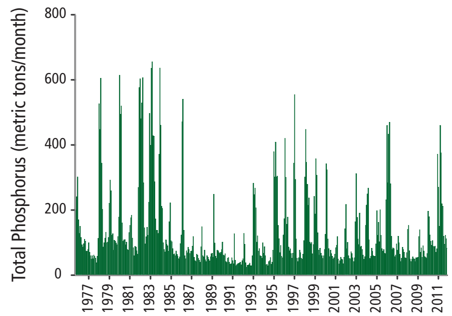
The most recent data (2005 -2011) have not yet been fully analyzed and interpreted.

Freeport

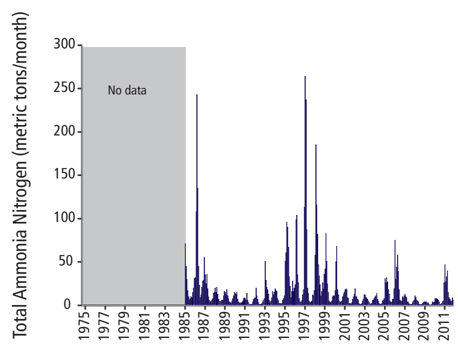


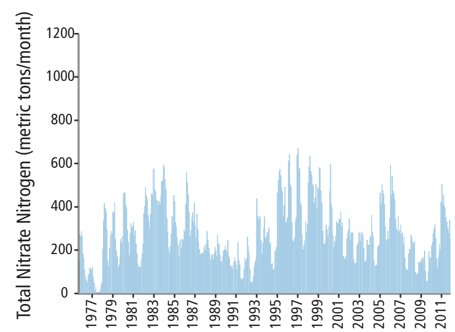


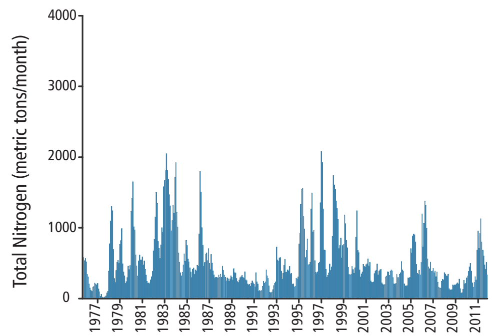


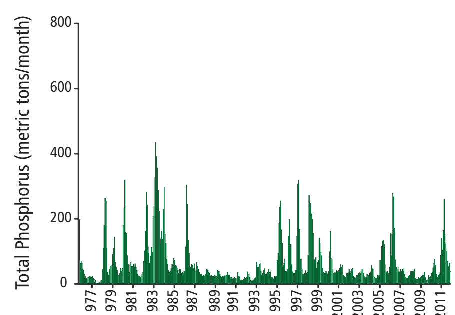


Vernalis









CURRENT USE PESTICIDES

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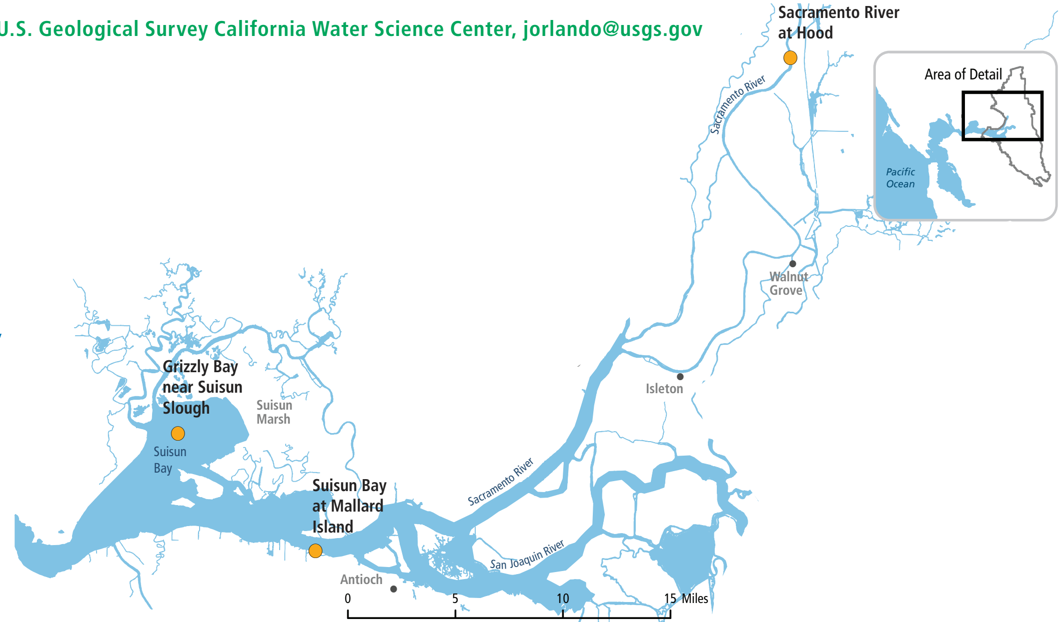
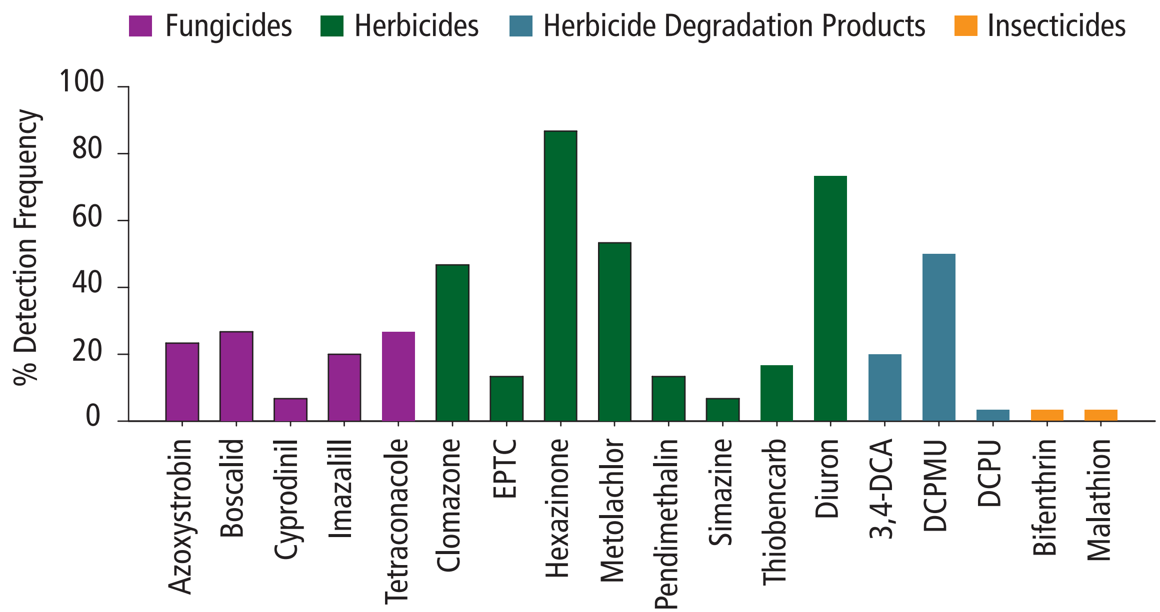
Pesticide use in the Estuary watershed is constantly changing, presenting a challenge for resource managers and policy makers trying to understand the fate and effects of these contaminants. Less than half of the pesticides currently applied in the watershed are routinely analyzed in monitoring studies and new pesticides are continually being registered for use.

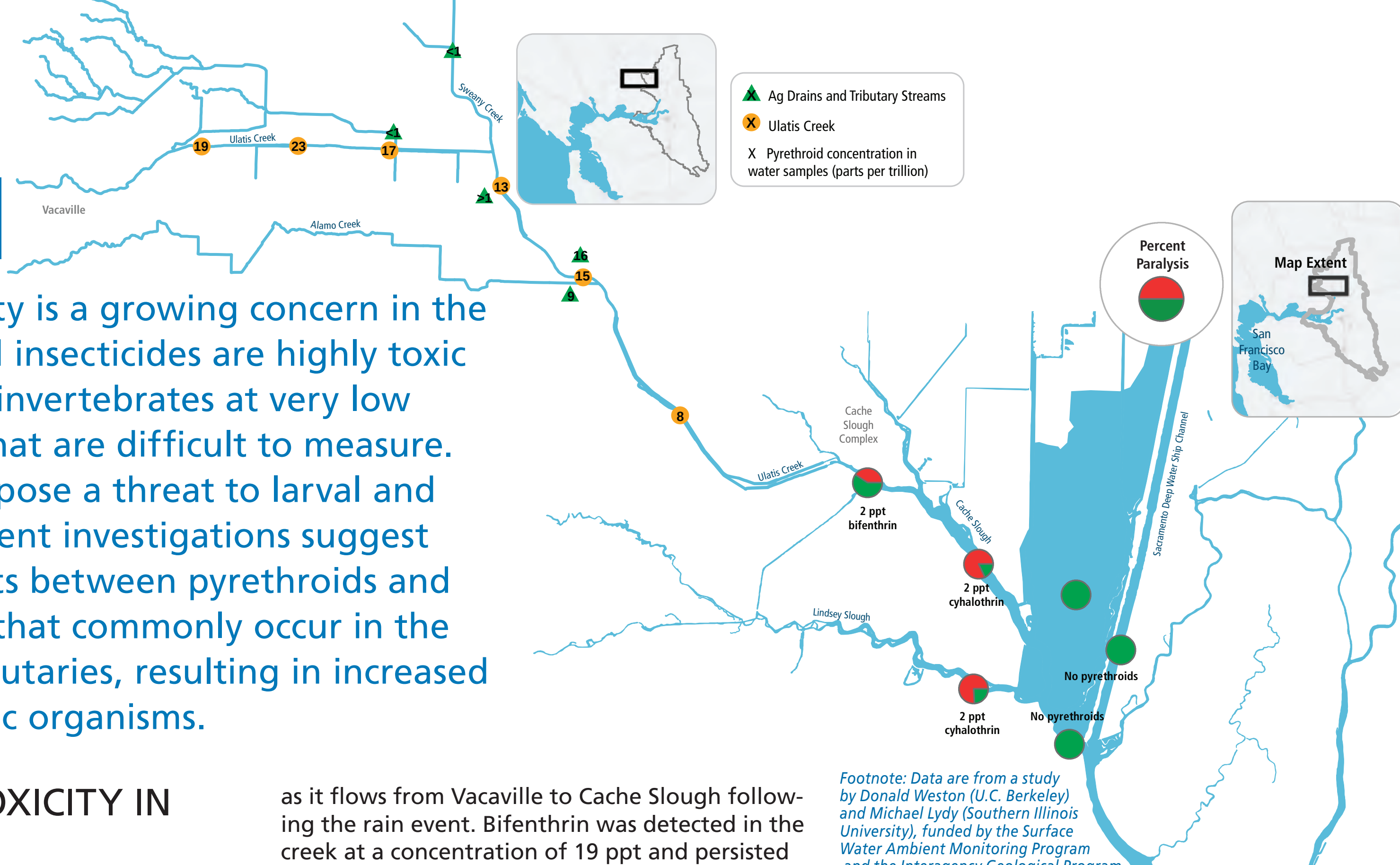


Creek selection from the National Hydrography Dataset 2011.
Basemap from Esri 2011, Gray Basemap



In a recent USGS study of pesticides entering Suisun Bay, water samples were collected weekly from April through June of 2011 at three sites and analyzed for more than 100 compounds. Eighteen pesticides were detected, including five rarely monitored fungicides. The herbicides hexazinone, diuron, and metolachlor were detected most frequently. The pyrethroid insecticide bifenthrin was linked to the exceedance of the EPA aquatic life criteria for invertabrates in one sample. Pesticides that have water quality standards were well below those standards; others that are detected do not have any established water quality standards.

PYRETHROIDS



Footnote: Data are from a study by Donald Weston (U.C. Berkeley) and Michael Lydy (Southern Illinois University), funded by the Surface Water Ambient Monitoring Program and the Interagency Geological Program. Creek selections from the NHD 2011. Basemap from Esri 2011, Gray Basemap

Pyrethroid toxicity is a growing concern in the Delta. Pyrethroid insecticides are highly toxic to some aquatic invertebrates at very low concentrations that are difficult to measure. Pyrethroids also pose a threat to larval and juvenile fish. Recent investigations suggest interactive effects between pyrethroids and other pesticides that commonly occur in the Delta and its tributaries, resulting in increased toxicity to aquatic organisms.

PYRETHROID TOXICITY IN CACHE SLOUGH

Pyrethroid insecticides in urban and agricultural runoff cause toxicity in Cache Slough Complex. The Cache Slough area is of special interest because of the spawning habitat it provides for Delta smelt and as a potential site for future ecosystem restoration activities. Recent research indicates that pyrethroid insecticides are reaching Cache Slough, and that they originate from both urban and agricultural runoff.

Ulatis Creek and several agricultural drains and tributaries entering the creek were monitored for the presence of bifenthrin following a rainstorm (about 0.8 inches total precipitation) on March 18, 2011. The YELLOW CIRCLES on the upper figure indicate the concentration (parts per trillion or ppt) of the pyrethroid bifenthrin in Ulatis Creek as it flows from Vacaville to Cache Slough following the rain event. Bifenthrin was detected in the creek at a concentration of 19 ppt and persisted along much of its distance to Cache Slough. For comparison, acute toxicity (mortality or other adverse effect from a short-term exposure) to sensitive aquatic species occurs at about 1 ppt for most pyrethroids.

Urban runoff from Vacaville was identified as the major source of bifenthrin in the creek. Three agricultural drains, a creek dominated by agricultural runoff (Sweany Creek), and a creek influenced by urban and agricultural land uses (Alamo Creek draining southern Vacaville) also contributed bifenthrin to Ulatis Creek. Among these additional inputs, an agricultural drain contained the highest observed concentration of 16 ppt bifenthrin. The same agricultural drain also contained 1235 ppt of the pyrethroid lambda-cyhalothrin.

The day following the rainstorm (March 19, 2011), Cache Slough and adjacent water bodies were tested for toxicity using the amphipod *Hyalella azteca*. *Hyalella* is a resident species that is very sensitive to pyrethroids and increasingly used for monitoring their presence. Toxicity was observed in both upstream and downstream portions of Cache Slough and in adjacent Lindsey Slough. A Toxicity Identification Evaluation was inconclusive but suggested bifenthrin may have caused the toxicity observed in upper Cache Slough. Lambda-cyhalothrin detected in downstream portions of Cache Slough and Lindsey Slough may have caused the toxicity observed in these reaches.

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PELAGIC ORGANISM DECLINE

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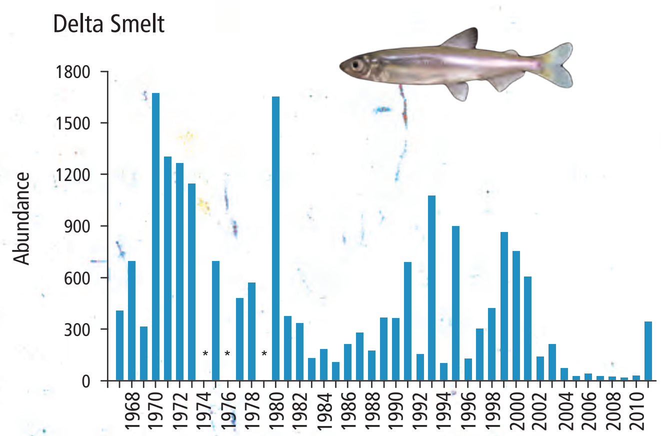
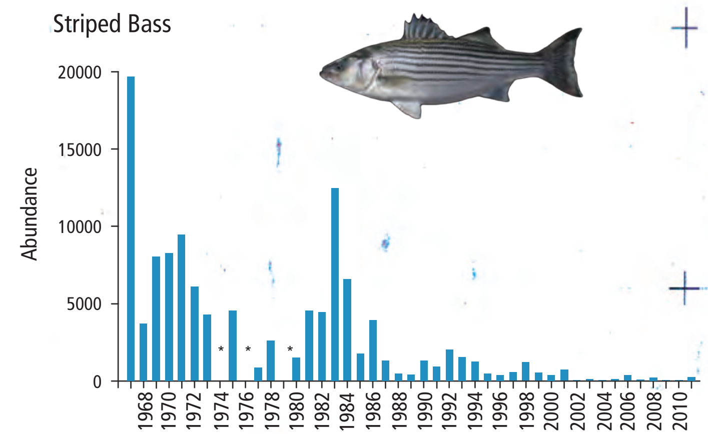
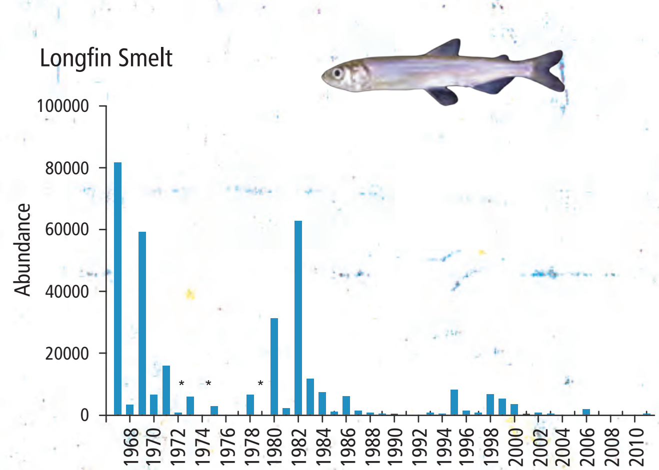
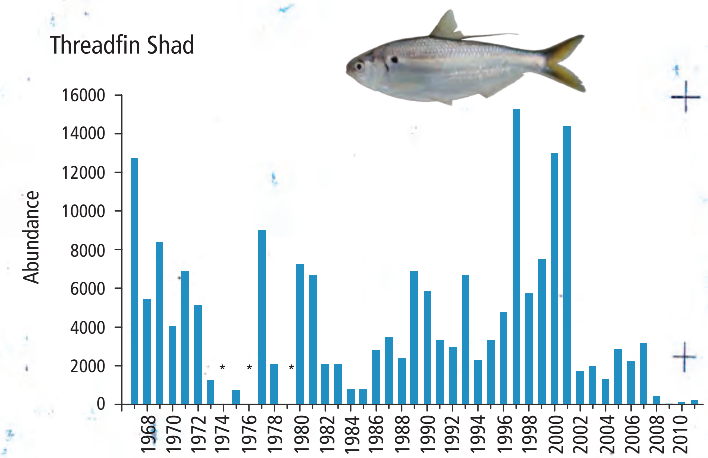
In 2011, three of four pelagic fish species remain in decline; delta smelt abundance jumps. For the last ten years, fall abundance indices for four pelagic fishes in the northern estuary have hovered at or near record low levels. Declines in these fish beginning after 2000 became known as the "pelagic organism decline". The fall indices have been collected for all but three of the last 44 years. In 2011, numbers of delta smelt caught during the fall survey increased significantly and were the highest since 2001. Numbers of caught age-0 striped bass and longfin smelt were still low, but highest since 2006. The threadfin shad index is the third lowest in the 44-year data record. For more information about the pelagic organism decline and studies to investigate its causes, see www.water.ca.gov/iep/.









Footnote: Fish abundance data are from the Fall Midwater Trawl Survey, which is conducted by the California Department of Fish and Game as part of the Interagency Ecological Program (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT). No indices were calculated in 1974, 1976, and 1979.

CENTRAL VALLEY SALMON RETURNS

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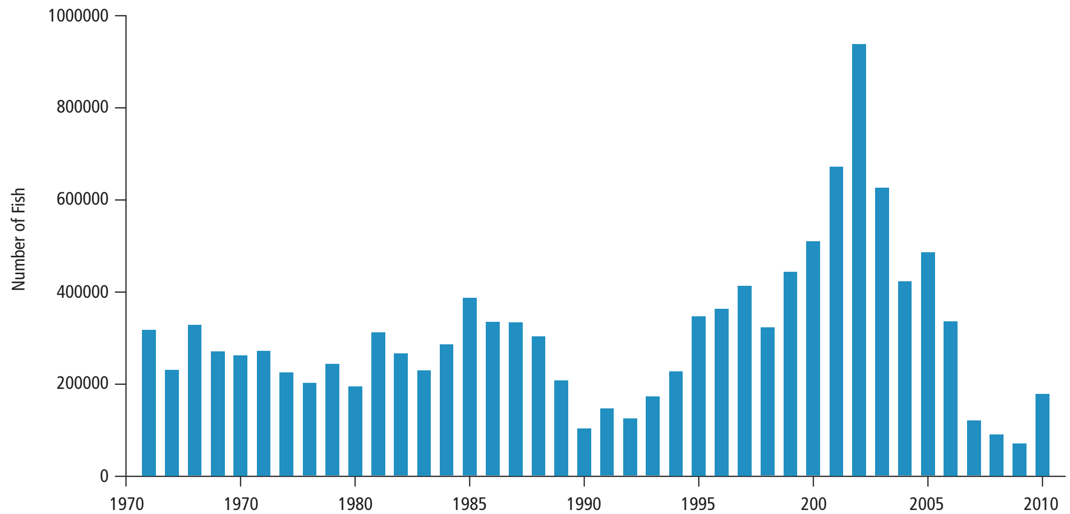
After record lows, more salmon return to Central Valley in 2010. The decline of salmon populations in the Sacramento and San Joaquin river systems over the past several decades has been well documented. Signs of recovery throughout the 1990s with an increasing trend in populations were followed by a decline to record low numbers in 2008 (91,437) and 2009 (71,449), resulting in the complete closure of both fishing seasons. In 2010, the escapement estimate for Chinook salmon returning to hatcheries and natural areas of the Central Valley was the highest since 2006 (178,464 fish), and a very limited season was authorized. The decline after 2005 appears to be due to poor feeding conditions in the ocean leading to poor ocean survival of one- or two-year-old fish. The rapid and likely temporary deterioration in ocean conditions is believed to be acting on top of a long-term decline in freshwater and estuarine conditions, caused by multiple stressors including pollution, water diversion, and loss of shallow habitats.



Footnote: Central Valley escapement data are from the GrandTab report, which is compiled by the California Department of Fish and Game (http://www.calfish.org/tabid/104/Default.aspx). The GrandTab report is a compilation of escapement estimates of the late-fall, winter, spring, and fall-run Chinook salmon in the California Central Valley, based on counts of fish entering hatcheries and migrating past dams, carcass surveys, live fish counts, and ground and aerial redd counts. Source: Jason Azat, California Department of Fish and Game (jazat@dfg.ca.gov).

↑ Fishing at the Antioch municipal fishing pier. Photograph by Thomas Jabusch.

References

Azat J. 2011. Central Valley Chinook harvest and escapement. IEP Newsletter, V. 24(1), p. 40-43.

Bennett WA, Moyle P. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary, in: Changing ecosystems: a brief ecological history of the Delta, p. 519-542. http://cdm15025.contentdm.oclc.org/cgi-bin/showfile.exe?CISOROOT=/p267501ccp2&CISOPTR=1722&filename=1723.pdf

Lindley ST, Grimes CB, Mohr MS, Peterson W, Stein J, Anderson JT, Botsford LW, Bottom DL, Busack CA, Collier TK, Ferguson J, Garza JC, Grover AM, Hankin DG, Kope RG, Lawson PW, Low A, MacFarlane RB, Moore K, Palmer-Zwahlen M, Schwing FB, Smith J, Tracy C, Webb R, Wells BK, Williams TH. 2009. What caused the Sacramento River fall Chinook stock collapse? National Marine Fisheries Service, Long Beach, California. http://swr.nmfs.noaa.gov/media/SalmonDeclineReport.pdf

Moyle PB, Bennett WA, Dahm C., Durand JR, Enright C, Fleenor WE, Kimmerer W, Lund JR. 2010. Changing ecosystems: a brief ecological history of the Delta. http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/intro_delta_history_14feb2010.pdf

FRESHWATER INFLOW INTO THE DELTA

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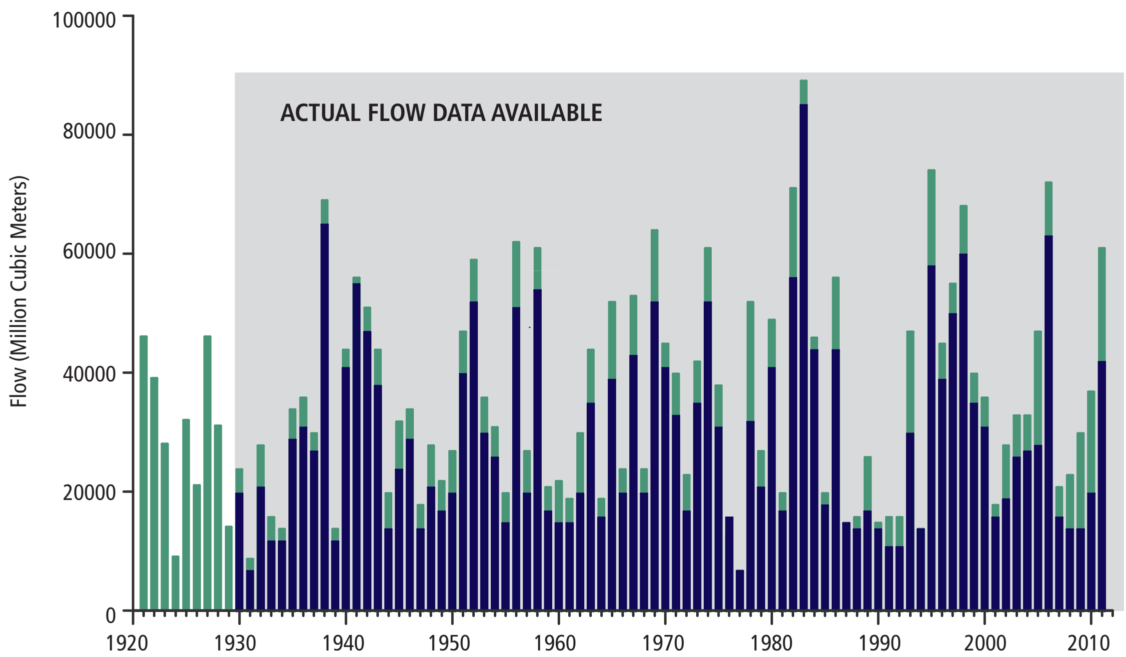
High annual freshwater inflow into the Delta in 2011. This graph compares actual annual inflows to the Delta (**BLUE**) with unimpaired flow (**GREEN**), which is runoff that would have occurred, had water flow remained unaltered in rivers and streams, instead of stored in reservoirs, imported, exported, or diverted. It is indicative of the total water supply available. Streamflow totals, as indicated by unimpaired runoff, fluctuate widely from year to year, making it challenging for water resource managers to balance supplies, water rights, environmental-flow requirements, and conveyance capacities. The fluctuations also make it more challenging to measure trends in pollutant inputs and water quality, which are heavily influenced by flow. Flow records for the Central Valley date back to October 1921. Following the 2007-09 drought and a lower-than-average year in 2010, 2011 was the ninth-wettest year (61,449 million cubic meters) on record.



Footnote: Data from the California Department of Water Resources. Estimated unimpaired flows from 1921 to 2003 are from the California Central Valley Unimpaired Flows Dataset. For 2004-2010, annual and monthly unimpaired flows were calculated by a regression developed from the Central Valley unimpaired flow data (using the 1930-1994 period) and the corresponding unimpaired runoff estimates from the "Full Natural Flows" (FNF) dataset for the ten largest rivers in the watershed (Christina Swanson, personal communication). Delta inflow data are from Dayflow (http://www.water.ca.gov/dayflow/).

Source: California Department of Water Resources

↑ The Sacramento River upstream of the I-80 bridge. Photograph by Thomas Jabusch.

References:

Dettinger MD, Ralph FM, Tapash D, Neiman PJ, Cayan DR. 2011. Atmospheric rivers, floods and the water resources of California. Water (3): 445-478.

DWR. 2007. California Central Valley unimpaired flow data. Fourth edition. http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf

OUTFLOWS AND EXPORTS FROM THE DELTA

Contact:
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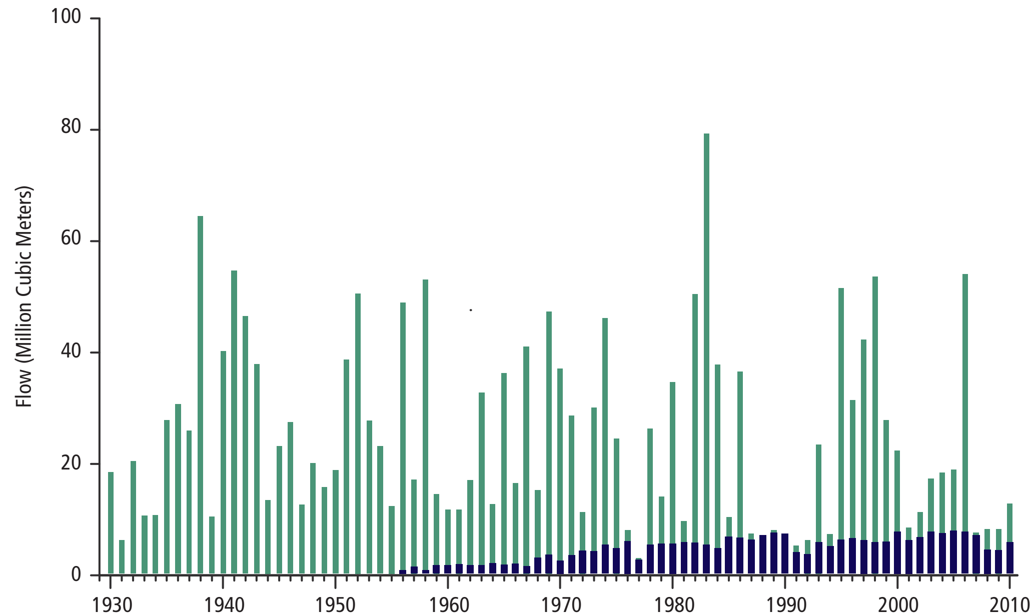
Annual outflows and exports from the Delta. This graph shows combined annual water exports from the Delta via the Central Valley Project and State Water Project (**BLUE**) and Delta outflows (**GREEN**), which is an estimate of "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is indicative of the physical, chemical, and biological state of the northern reach of the San Francisco Estuary. Generally, outflows are higher in wet years compared to average and dry years. Since the beginning of water export operations in the Delta in the 1950s, the exports of water taken from the Delta and taken elsewhere have gradually gone up to reach approximately 15-17% of total flows for the past forty years (Blue Ribbon Task Force 2007). Annual water exports in 2008-10 were the lowest since 1994, as a result of the 2007-09 drought conditions combined with court-ordered pumping restrictions to protect the endangered delta smelt.



Footnote: Delta outflow and export data are from Dayflow (http://www.water.ca.gov/dayflow/).

The Dayflow estimate of Delta outflow is referred to as the "net Delta outflow index", because it does not account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is a quantity that never actually occurs in real time. Rather it is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island, aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much higher or lower than the Dayflow estimate.

Source: California Department of Water Resources

↑ The California Aqueduct upstream of the Banks Pumping Plant. Photograph by Thomas Jabusch.

References:
Blue Ribbon Task Force. 2007. Delta Vision: Our Vision for the California Delta http://deltavision.ca.gov/BlueRibbonTaskForce/FinalVision/Delta_Vision_Final.pdf

SALINITY

Contact:
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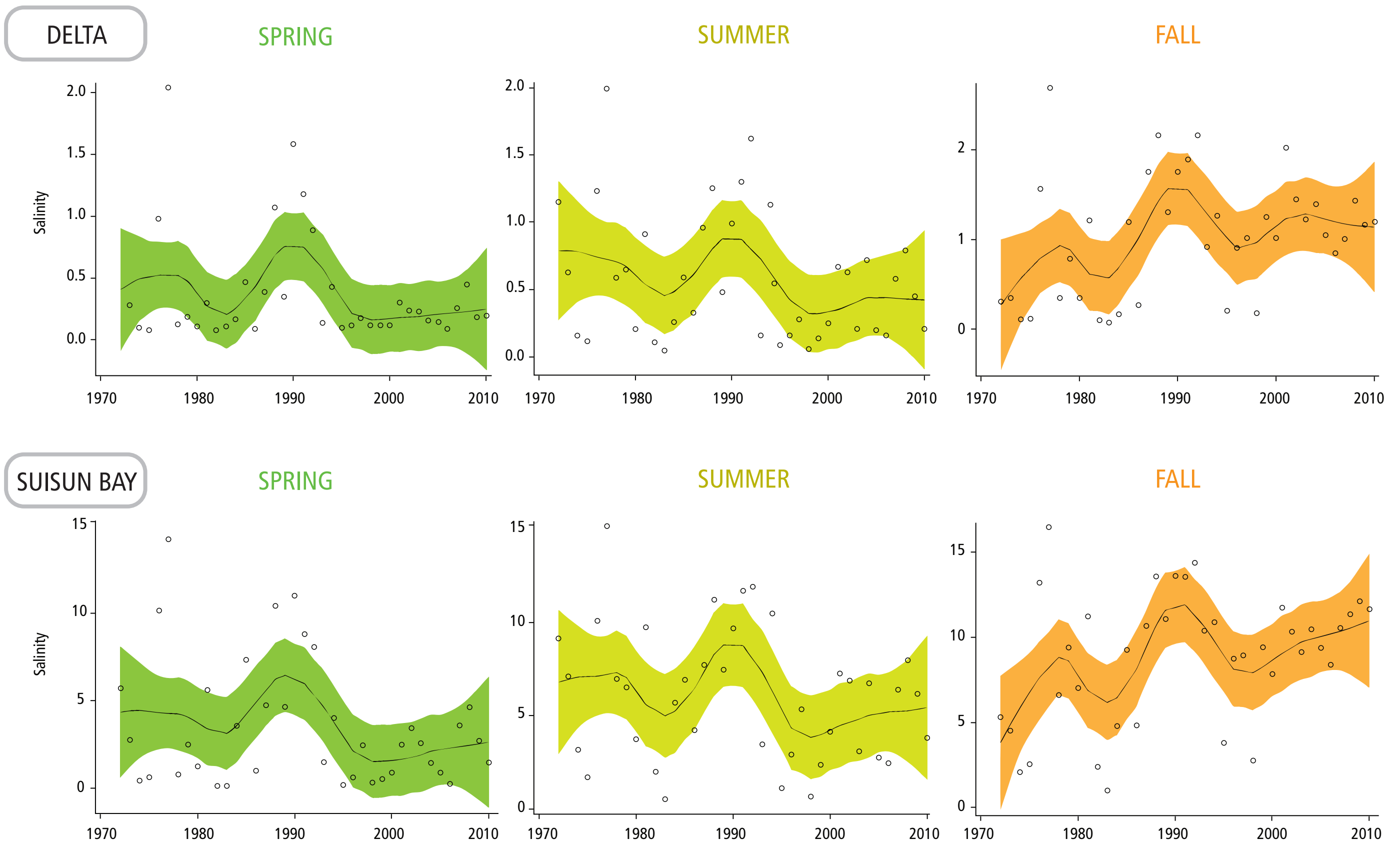
Annual and Seasonal Trends in Salinity.

Brackish, or low salinity, habitat is one of the most important features of the Estuary and linked to the health of estuarine species and the ecosystem. Salinity in the Delta and Suisun Bay mirrors freshwater inflows from upstream and varies greatly among years and seasons. Generally, salinity is lower in spring and then increases in summer and fall. According to recent analyses by Monika Winder and Alan Jassby from the John Muir Institute of the Environment at UC Davis, salinity did increase significantly on an annual basis in both regions during 1995 – 2008. This upward trend follows a marked rise and fall in salinity centered on the dry years from 1987 to 1994. The results of the analysis also indicate a pronounced trend in Suisun Bay of increasing salinity in the fall.



Footnote: Practical salinity values were calculated from surface electrical conductivity values using the Practical Salinity Scale (PSS). The PSS is the conductivity ratio of a sea water sample to a standard potassium chloride solution. Data points are seasonal averages (spring: March –May, summer: June – August, fall: September – November). The trend line displays a Loess fit and the shaded area represents the 95% confidence limits. Data included in the analysis are ancillary data from IEP's zooplankton monitoring collected at IEP's discrete sampling sites (Winder & Jassby 2011).

References:

Kimmerer WJ. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2(1). URL http://repositories.cdlib.org/jmie/sfews/vol2/iss1/art1

Winder M, Jassby AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

SELENIUM FROM THE SAN JOAQUIN RIVER

Contact:
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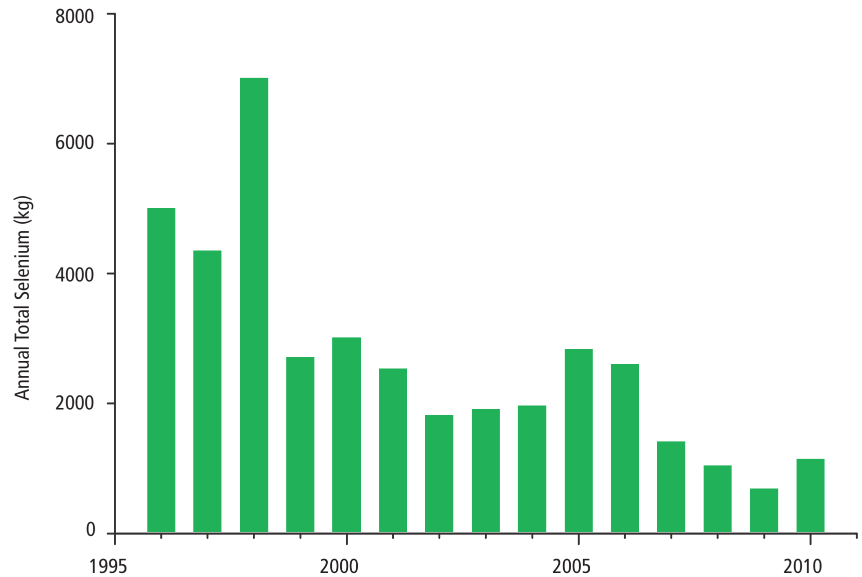
Annual Loads of Selenium from the San Joaquin River Have Significantly Declined Due to An Agricultural Drainage Control Program. Although there is currently no strong evidence for selenium-related problems in the Delta, it is found in clams from adjacent North San Francisco Bay at levels commonly associated with toxicity and reproductive impairment in fish and other wildlife. The San Joaquin River carries significant loads of selenium and other pollutants from the intensely farmed and increasingly urbanized San Joaquin Valley into the Delta. The main controllable source of selenium is agricultural drainage from the Grasslands Drainage Area on the western side of the San Joaquin Basin, where soils have naturally high selenium contents. Studies by the Surface Water Ambient Monitoring Program allow estimation of loads from 1996 to the present. Selenium loads have declined since 1996, in response to a drainage control program in the Grasslands area. The annual loads for 2009 (689 kg), 2008 (1045 kg), and 2010 (1148 kg) are the lowest estimated for the 15-year period. The long-term declining trend is indicative of the rigorous management of discharges to meet annual load values and water quality objectives. Based on statistical results, annual runoff seems to be driving some of the year-to-year fluctuations, but not the overall trend.



Footnote: Total loads for each water year (Oct 1 – Sep 30). Loads are estimated for the Vernalis monitoring site. Daily loads were summed up to estimate annual loads. Daily load values were generated by linear interpolation from weekly total selenium concentration data collected by the SWAMP and USGS daily flow data. Information about the SWAMP studies and data are available on the Central Valley Regional Water Board's SWAMP webpages: http://www.waterboards.ca.gov/centralvalley/water_issues/swamp/sanjoaquin_river_basin/index.shtml.

> The long-term declining trend is indicative of the rigorous management of discharges to meet annual load values and water quality objectives

References:

Kleckner AE, Stewart AR, Elrick K, Luoma SN. 2010, Selenium concentrations and stable isotopic compositions of carbon and nitrogen in the benthic clam Corbula amurensis from Northern San Francisco Bay, California: May 1995–February 2010: U.S. Geological Survey Open-File Report 2010-1252, 34 p.

DISSOLVED OXYGEN IN THE LOWER SAN JOAQUIN RIVER

Contact:
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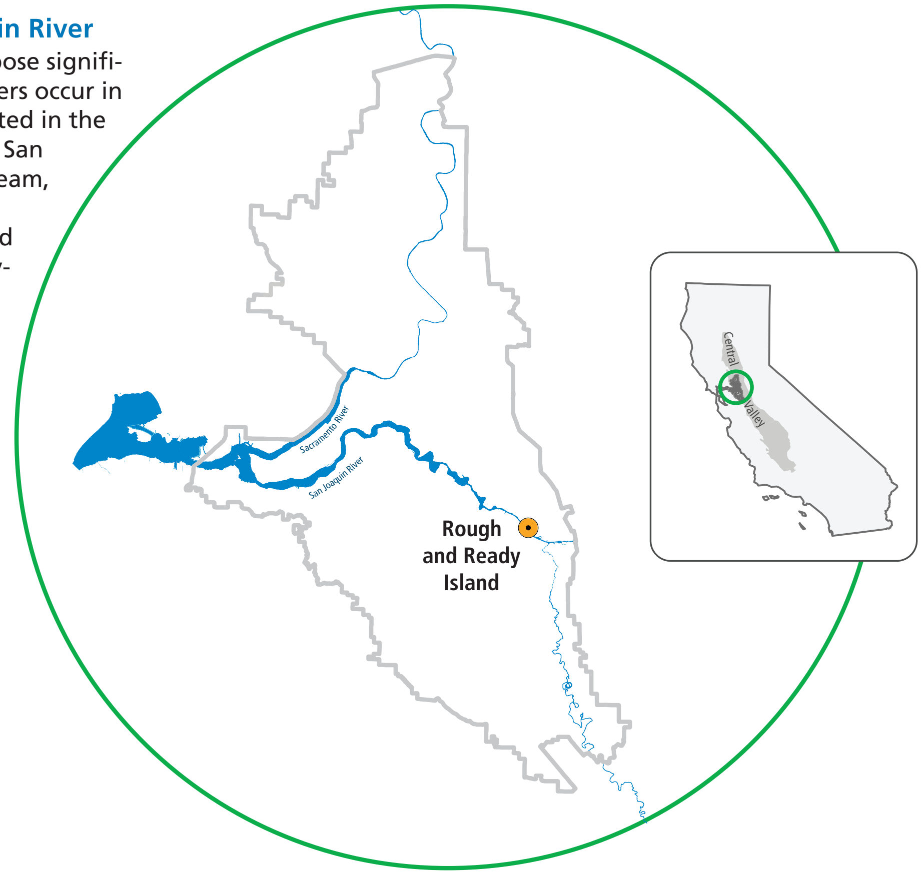
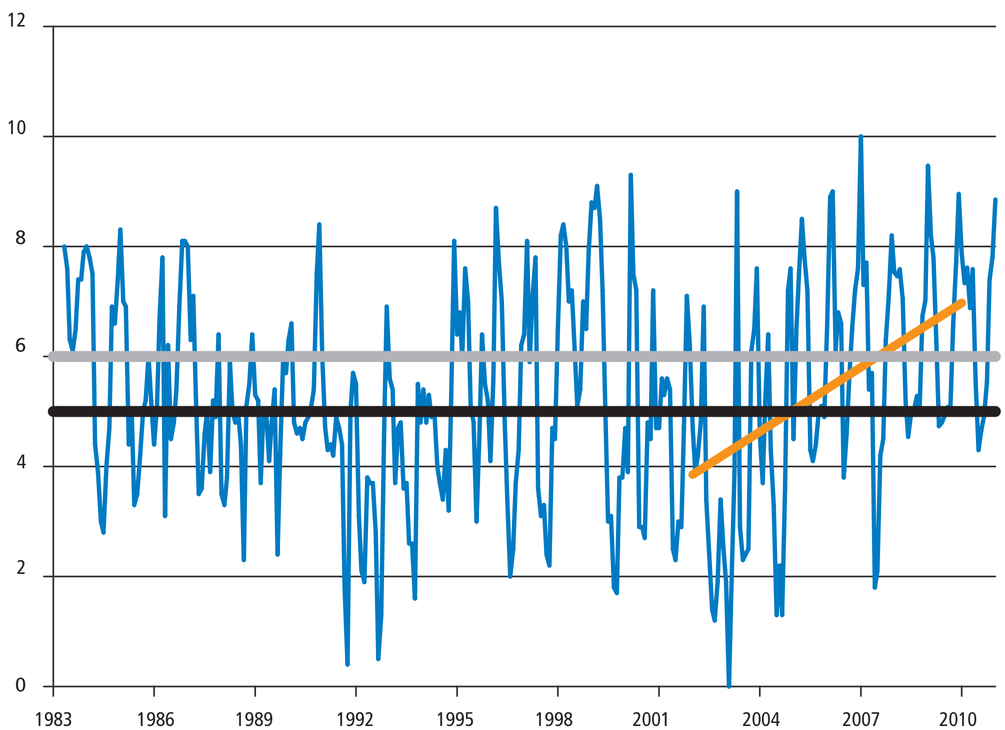
Minimum Monthly Dissolved Oxygen (DO) Values in the Lower San Joaquin River Improved but Still Falling Below Limits. Low dissolved oxygen in Delta waters pose significant migration barriers to salmon and other migrating fishes. Dissolved oxygen barriers occur in the Stockton Deep Water Ship Channel and on Old and Middle Rivers and have resulted in the establishment of a Total Maximum Daily Load to control low dissolved oxygen in the San Joaquin River. The deepened channel, reduced flows, decomposing algae from upstream, and oxygen-demanding substances from the City of Stockton wastewater treatment plant all contribute to the low dissolved oxygen issue. Seasonal variability of dissolved oxygen is mainly due to seasonal variability in river flow, but fluctuations in river phytoplankton and wastewater effluent also play a role. Dissolved oxygen in the lower San Joaquin River has increased since the early 2000s (see trend line), primarily due to the implementation of algae removal ponds and nitrification treatment by the City of Stockton wastewater treatment plant. However, monthly minimum values continue to fall frequently below the statutory limits of 5 mg/L (December 1 to August 31) and 6 mg/L (September 1 to November 30).





Footnote: Minimum monthly values of dissolved oxygen measured at the Rough and Ready Island monitoring station in the Stockton Deep Water Ship Channel. The Middle River and Old River split off from the mainstem of the San Joaquin River upstream of the DWSC. The orange trend line represents a linear regression of the annual averages of minimum monthly dissolved oxygen concentration 2002 – 2010 vs. time.

Black line (December 1 - August 30) and Grey line (September 1 - November 30) indicate TMDL targets. Data are from the Continuous Multiparameter Monitoring by the IEP Environmental Monitoring Program.

References:

Jassby AD, Van Nieuwenhuyse EE. 2005. Low dissolved oxygen in an estuarine channel (San Joaquin River, California): mechanisms and models based on long-term time series. San Francisco Estuary and Watershed Science, V. 3(2). http://escholarship.org/uc/item/0tb0f19p

↑ View of the Stockton Deep Water Ship Channel near the Port of Stockton. Photograph by Thomas Jabusch.

PHYTOPLANKTON BIOMASS

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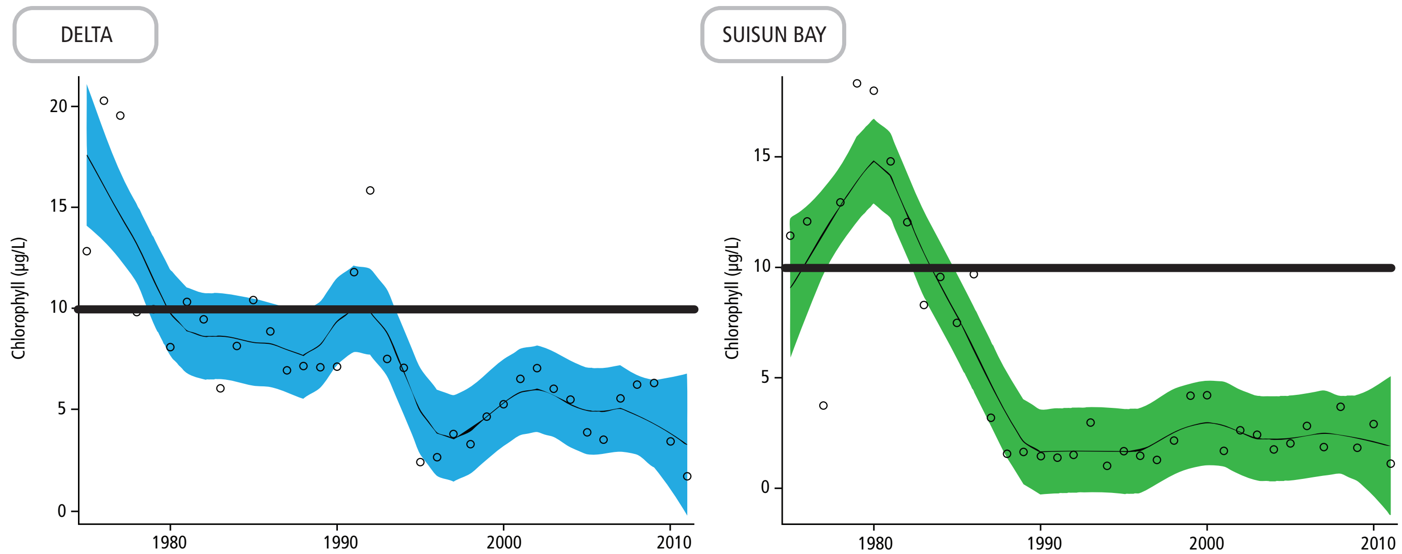
Annual Trends in Phytoplankton Biomass Remain in Decline. Since the mid-1970s, chlorophyll concentrations (an indicator of phytoplankton biomass) in the Delta have declined 4-fold. There are many reasons for this decline, including reduced phosphorus loadings, increased nitrogen loadings, grazing by invasive clams, and water diversions. Other more nuanced aspects of flow may also be playing a role, such as altered flow patterns, which have changed chlorophyll loadings from upstream rivers to the Delta. The downward trend in the abundance and productivity of algae in the Delta over the last few decades is combined with "demographic" changes in the phytoplankton community from large diatoms to flagellates, blue-green algae, and smaller species of diatoms. The large decline in phytoplankton biomass (as measured by chlorophyll a) in Suisun Bay occurred mostly after the introduction of the overbite clam *Corbula amurensis* in 1986, but several other drivers are thought to play a role in the observed changes to the algal community. Among them are a reduction in phosphorus loadings, increased ammonia loadings, and water diversions. Chlorophyll values below 10 µg/L (black line ▬) are considered an indication of a food shortage for zooplankton.



Footnote: Delta- and Suisun Bay-wide averages. The trend line displays a Loess fit and the shaded area represents the 90% confidence limits for the trend line. Data from the IEP Environmental Monitoring Program. Monitoring stations included in the Delta-wide averages: C3, C3A, C7, C9, C10, C10A, D2, D4, D10, D11, D12, D14A, D15, D16, D19, D22, D24, D26, D28A, MD7, MD7A, MD10, MD10A, P2, P8, P10, P10A, P12, P12A. Suisun Bay: D2, D7, D8, D9, NZS42, NZ032, S42.

Data source: Tiffany Brown, California Department of Water Resources.

References:

Baxter R., Breuer R., Brown L., Conrad L., Feyrer F., Fong S., Gehrts K., Grimaldo L., Herbold B., Hrodey P., Mueller-Solger A., Sommer T., Souza K. 2010. Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and synthesis of results. University of California, Davis, California. URL http://www.water.ca.gov/iep/docs/FinalPOD-2010Workplan12610.pdf

Brown T. 2009. Phytoplankton community composition: the rise of the flagellates. IEP Newsletter 22(3): 20–28.

Mueller-Solger AB, Jassby, AD, Muller-Navarra, DC. 2002. Nutritional quality of food resources for zooplankton (Daphnia) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnology and Oceanography 47(5): 1468-1476.

Jassby AD. 2008. Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science, V. 6(1). URL http://escholarship.org/uc/item/71h077r1

Jassby AD, Cloern JE. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Freshwater and Marine Ecosystems 10(5):323–352.

Van Nieuwenhuyse E.E. 2007. Response of summer chlorophyll concentration to reduced total phosphorus concentration in the Rhine River (Netherlands) and the Sacramento-San Joaquin Delta (California, USA). Canadian Journal of Fisheries and Aquatic Sciences 64: 1529–1542.

Winder M, Jassby AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

ZOOPLANKTON IN THE DELTA

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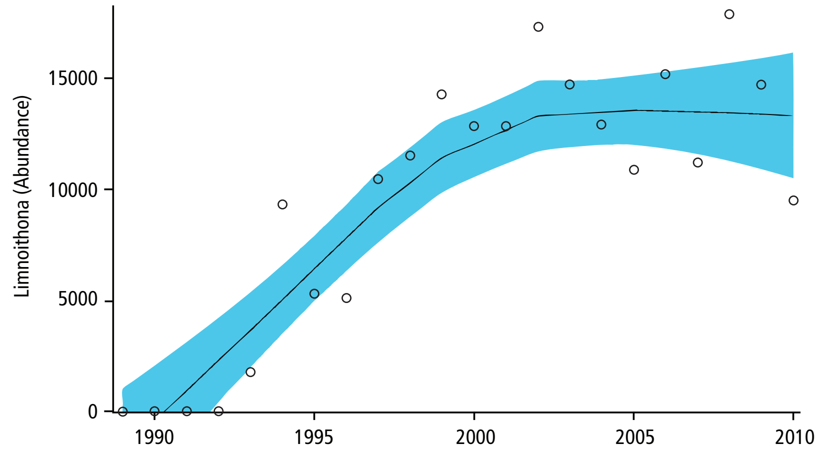
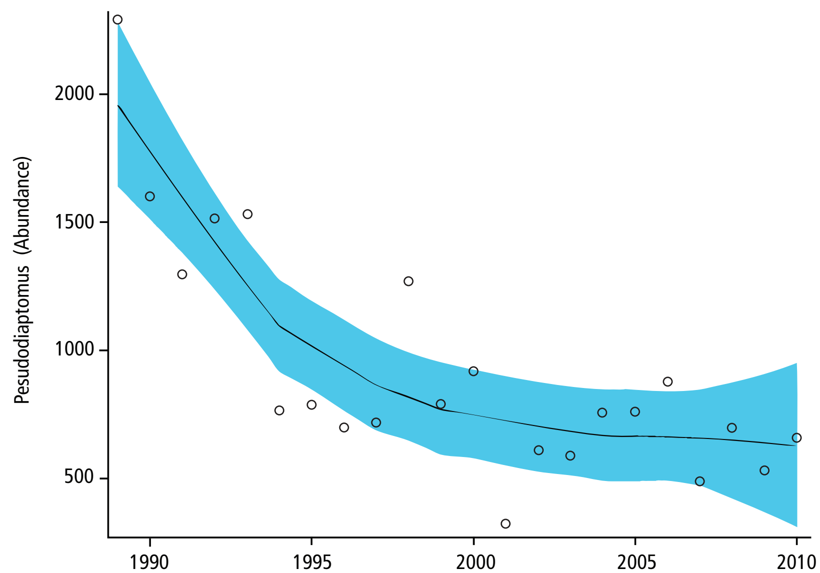
Annual Trends in Zooplankton Abundance Vary. *Limnoithona tetraspina* and *Pseudodiaptomus forbesi* are the two dominant zooplankton species of the Low Salinity Zone. Both are non-native species that belong to a group of small crustaceans called copepods ("oar-feet"). *P. forbesi* was first discovered in the Delta and Suisun Bay in 1988 and has declined slightly since then. It remains relatively abundant compared to other copepods and is thought to be an important forage species for larval fish in the Delta. *L. tetraspina* was first recorded in 1993 and has since mostly supplanted the historically common and slightly larger *L. sinensis*. Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like Delta smelt, due to its small size and relatively motionless behavior in the water column. As an ambush predator that feeds on motile prey, it may have benefitted from phytoplankton composition changes from non-motile diatoms to motile flagellates.





Footnote: Data are yearly March – November abundance averages per cubic meter of water (reported as catch-per-unit effort). Limnoithona abundance is the abundance of L. tetraspina and L. sinensis combined for the IEP core monitoring stations. L. tetraspina was not identified separately from L. sinensis until 2007. Data from the IEP Environmental Monitoring Program (EMP). The trend line displays a Loess fit and the shaded area represents the 95% confidence limits.

References:

Bouley P, Kimmerer WJ. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series (324): 219-228.

Brown T. 2009. Phytoplankton community composition: the rise of the flagellates. IEP Newsletter, V. 22(3), p. 20–28.

Winder M, Jassby AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34: 675-690

DELTA POPULATION

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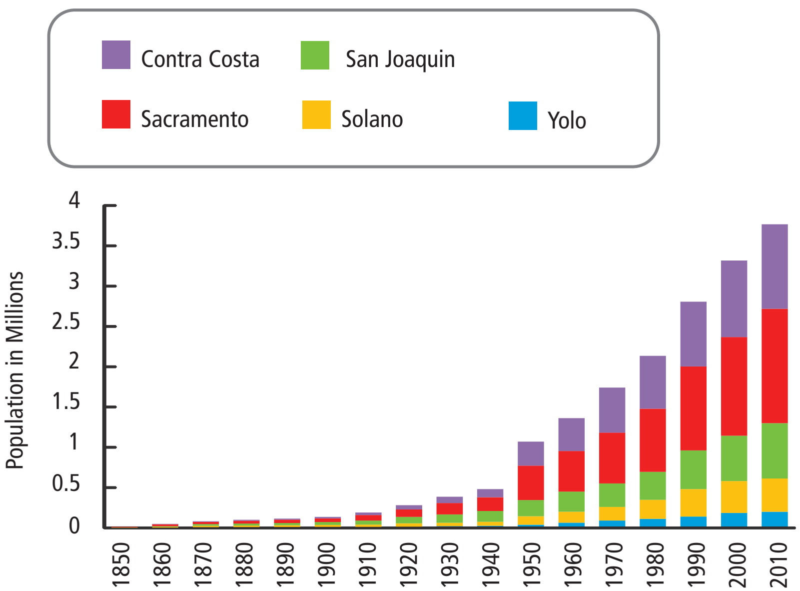
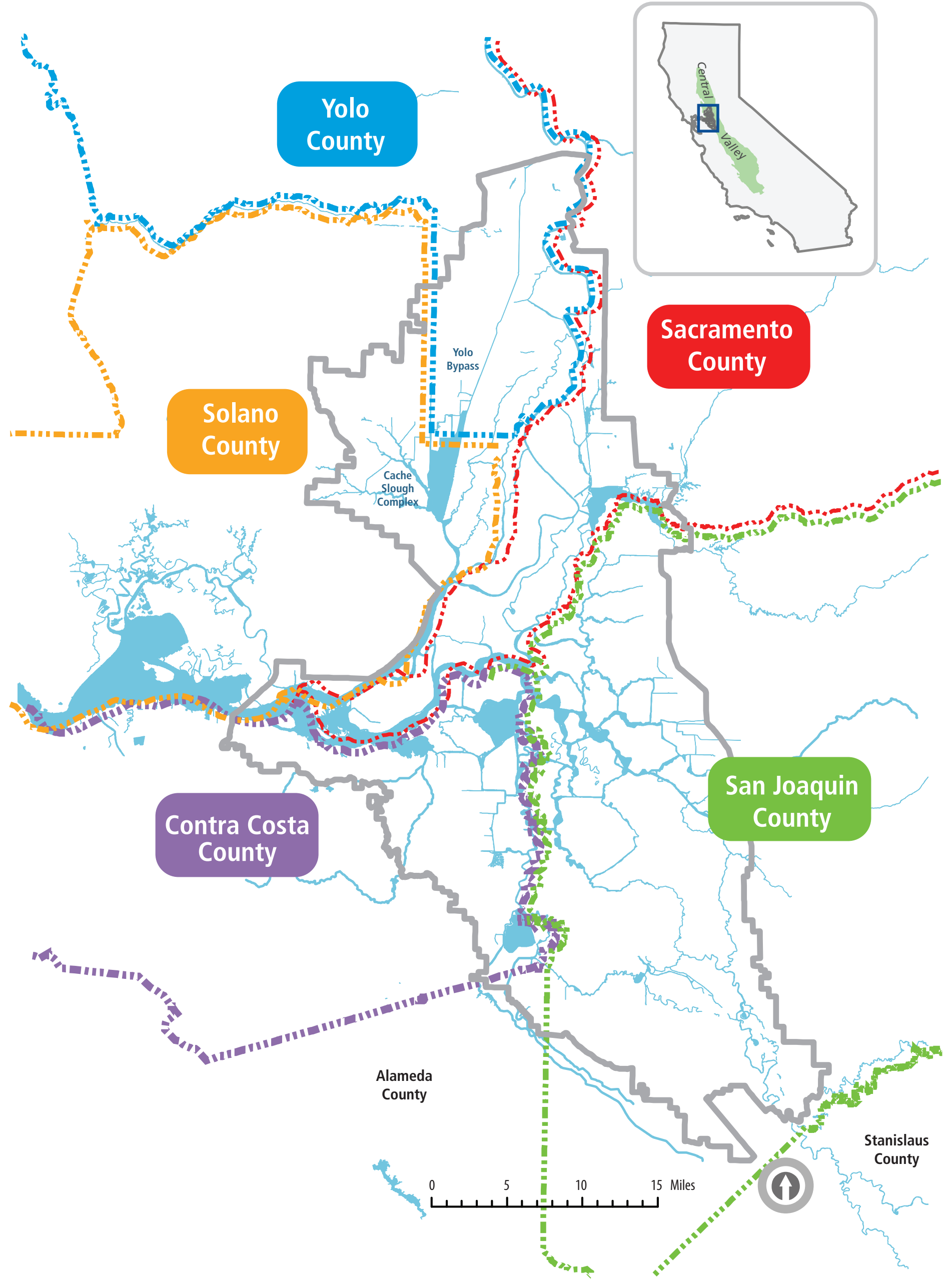
Delta Population Steadily Increasing. The large and growing human population in the Delta's watershed places increasing pressure on Delta water quality through mechanisms that include expanding urbanization, water demands, commercial activity, recreational activity, and vehicle usage. The population of the Delta counties reached 3.8 million in 2010, compared to 3.3 million in 2000, and is predicted to grow to 4.6 million by 2020.



Footnote: Data from the U.S. Census Bureau. Population projection for 2020 by the California Department of Finance (http://www.dof.ca.gov/html/demograp/reportspapers/projections/p1/documents/p1_press_release_7-07.pdf).



LAND COVER IN THE DELTA

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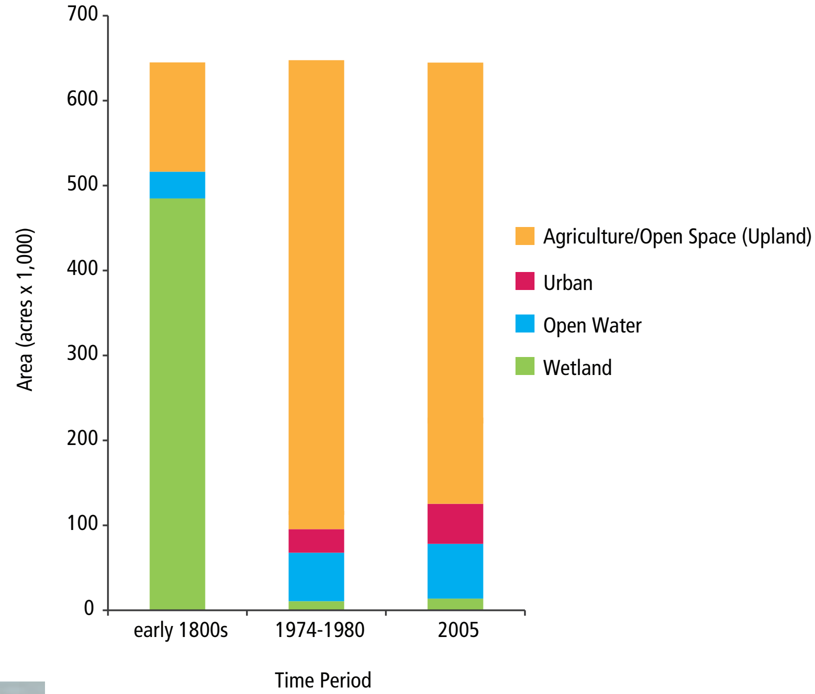
Comparison of early 1800s and early 2000s open water and wetlands in the Delta. Most apparent is the significant loss in wetland extent. The comparison also reveals a reduction in historical tidal channel complexity as a result of the damming of smaller waterways, widening of channels, and cutting of short connecting channels across the necks of meanders and between waterways. This loss of the wetland landscape has profoundly affected the resilience of the Delta's ecosystem, such that contaminants, invasive species, and other stressors have a relatively greater negative impact on ecological function. For example, contaminants are concentrated in leveed river channels rather than filtered within expansive wetlands, and native species are missing the habitat complexity that historically would have offered refugia from predators and abnormal flow conditions.



Footnote: The agriculture/open space category includes all non-wetland native land cover, as well as agricultural (e.g., rice fields), fallow, and ruderal (with pioneering plants, after disturbance) land cover types. In the early 1800s period, this category consists entirely of native land cover that is not permanent wetland or open water. Urban area (purple) includes cities and suburb lands. The open water category includes all tidal channels, ponds, lakes, rivers, creeks, and streams, as well as areas classified as floating aquatic vegetation. The wetland category (green) includes all permanent wetlands. Seasonal natural wetlands are included in this category, however, for the two most recent time periods as they are not distinguished from other wetland types in the available geospatial layers.

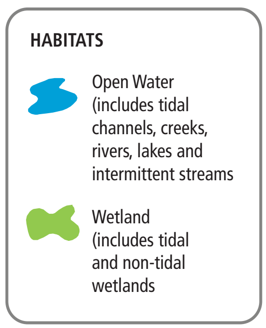
Data sources: 1. Historical Ecology of the Sacramento-San Joaquin Delta Study. Draft data. San Francisco Estuary Institute/ Aquatic Science Center for the California Department of Fish and Game. 2. Wetlands and Deepwater Habitats of the Conterminous United States, National Wetlands Inventory (NWI). 1985. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. URL http://www.fws.gov/wetlands/Data/DataDownload.html. 3. Land Use and Land Cover (LULC) data. 1974. Earth Resources Observation and Science (EROS) Center, United States Geological Survey. URL http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/LULC. 4. CALVEG77, 1977. United States Forest service and The California department of Forestry. URL http://www.fs.fed.us/r5/rsl/projects/gis/data/calcovs/CALVEG77.zip. 5. Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc. for the California Department of Fish and Game, Vegetation Classification and Mapping Program.

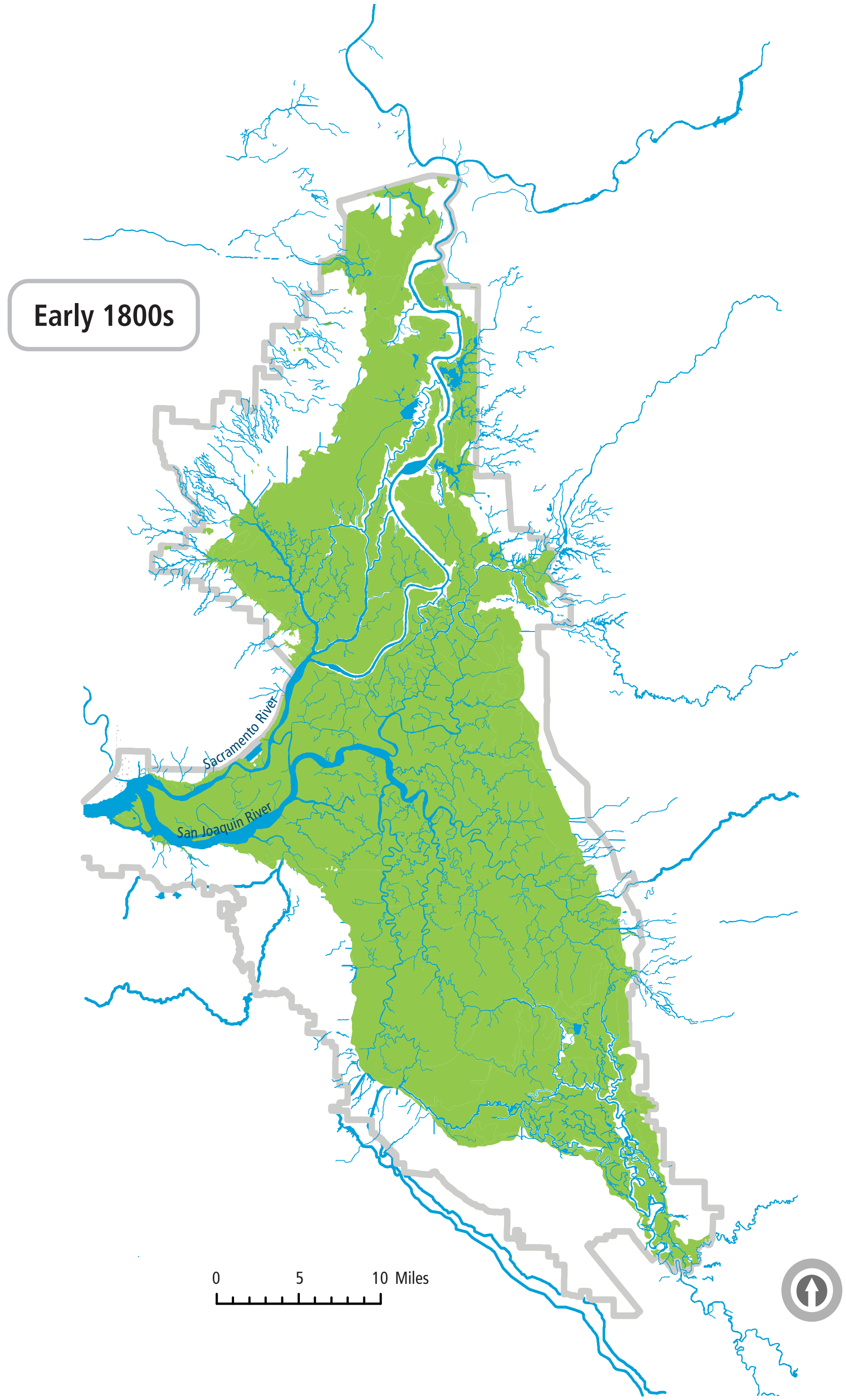
↑ Orchard on Grand Island. Photograph by Thomas Jabusch.

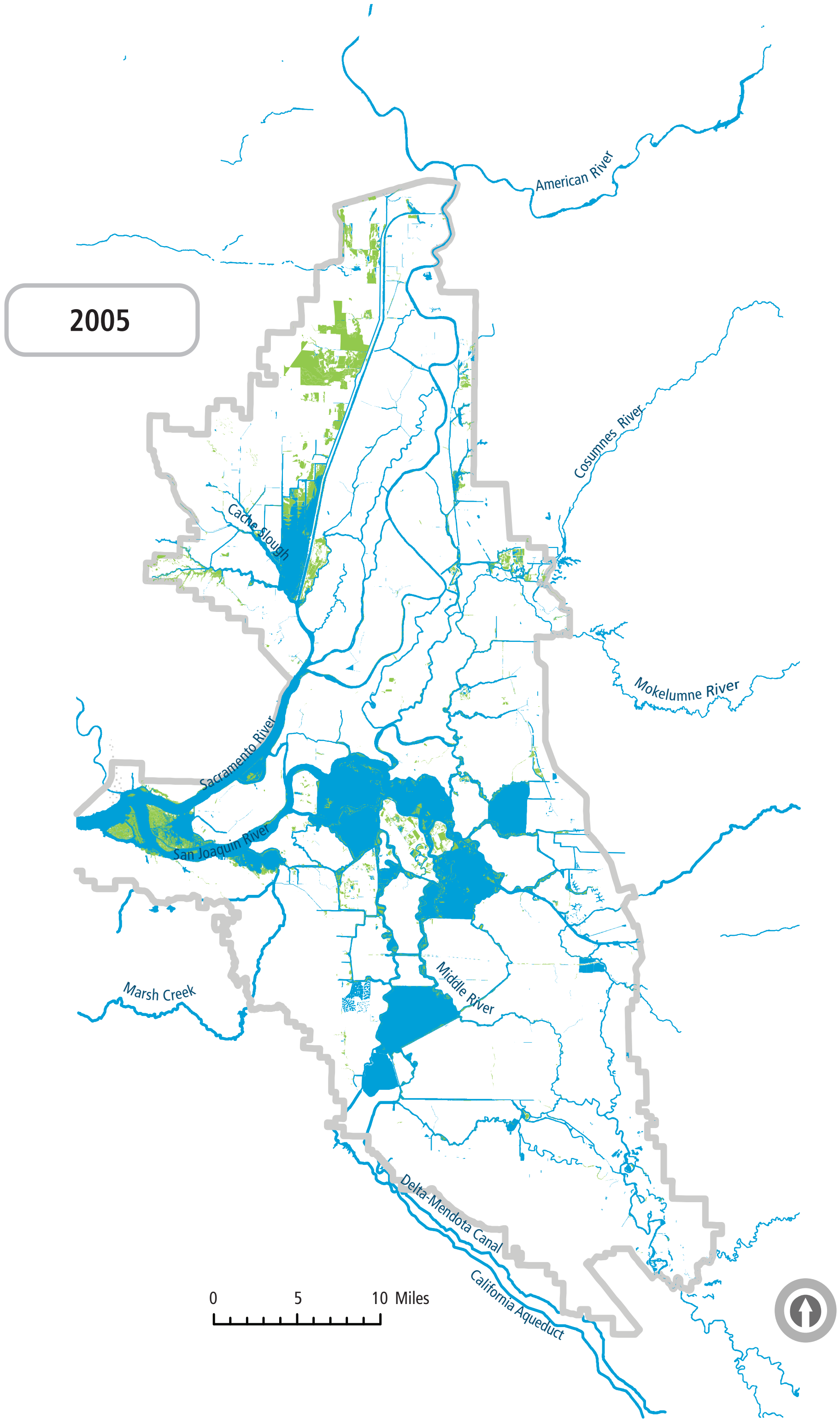
LAND COVER IN THE DELTA *CONTINUED*

FROM WETLAND TO AGRICULTURE TO ENCROACHMENT BY DEVELOPMENTS.

Over the past 160 years, the Delta has seen dramatic transformation, beginning with the conversion of wetlands to agricultural lands. Within the last 30 years, there has been a nearly two-fold increase in urban area. This rapid conversion of open space in the Delta, primarily agricultural land, to residential and commercial uses, raises concerns for the potential consequences on the Delta's water quality. The dramatically reduced extent of wetlands, compared to historical conditions, has diminished the system's capacity to filter contaminants, while urban expansion has increased the inputs of some of those contaminants. The increase in open water since historical times is primarily attributable to the presence of several large flooded islands, such as Franks Tract, in the Delta today.



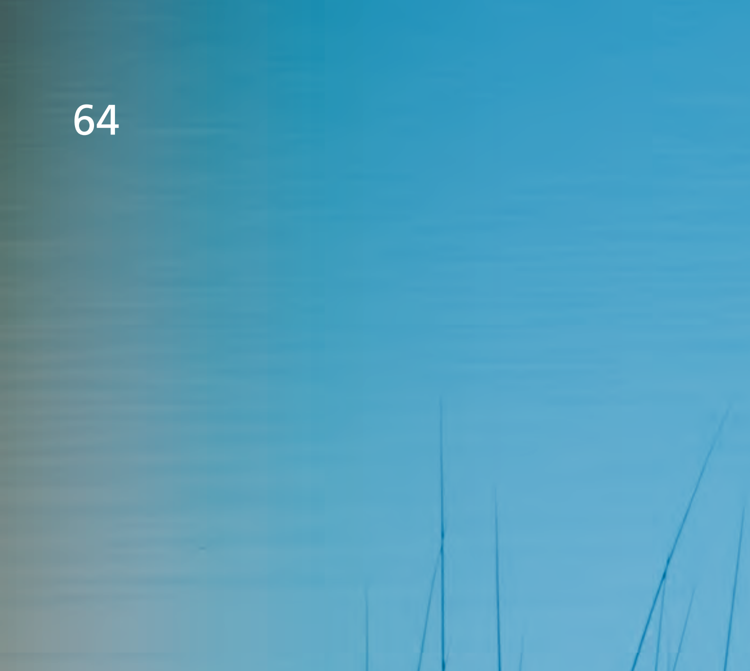




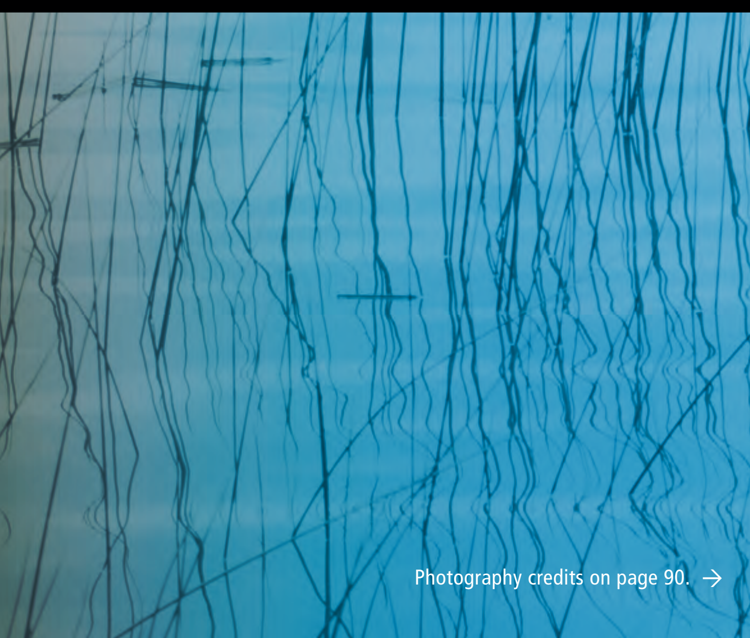
Footnote: Wetlands include both tidal and non-tidal wetlands. The comparison may be conservative because, due to classification differences, seasonal wetlands are not included in the early 1800s historical mapping, but many seasonal wetlands are in the modern mapping. Waterways include tidal channels, lakes, ponds, rivers, creeks, and intermittent streams. Tidal and non-tidal water bodies are not distinguished.

Historical data sources: 1. Historical Ecology of the Sacramento-San Joaquin Delta Study. Draft data. San Francisco Estuary Institute-Aquatic Science Center for the California Department of Fish and Game. 2. Bay Area EcoAtlas. 1999. San Francisco Estuary Institute. Note: Detailed mapping of Suisun marsh is not available at this time.

Modern data sources: 1 Bay Area Aquatic Resources Inventory Dataset [geographic information system file type]. 2007-2011. San Francisco Estuary Institute; U.S. Bureau of Reclamation, MPGIS Service Center. 2. Delta Vegetation and Land Use. 2007. Aerial Information Systems, Inc. for the California Department of Fish and Game, Vegetation Classification and Mapping Program.



FEATURE ARTICLES



Photography credits on page 90. →

Yolo Bypass Findings Could Help Wetland Managers Reduce the Methylmercury Problem

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THOMAS JABUSCH, Aquatic Science Center

Studies in experimental rice fields on Twitchell Island are helping planners to evaluate habitat restoration and water treatment options. Photograph by Thomas Jabusch.

HIGHLIGHTS

Bacteria in wetland soils can convert mercury into methylmercury, its most toxic form

Seasonally flooded wetlands in the Yolo Bypass had higher net methylmercury production and export rates than permanently flooded wetlands

Winter is the peak season for methylmercury transport from Yolo Bypass wetlands to the Delta

The first flooding following a dry period is a critical period in which control measures for minimizing movement of methylmercury might be most important and most effective

Controlling methylmercury production and transport from seasonal managed wetlands may be achieved by: 1) managing plant growth and litter to control organic carbon supplies, and 2) adjusting the timing of flows on and off wetlands to limit methylmercury discharges and promote internal removal processes

Managers need to evaluate potentially negative consequences of flow and carbon supply manipulations on local wetland food webs

Promising treatment technologies for reducing methylmercury in wetland runoff include tailwater treatment ponds and low intensity chemical dosing of coagulants

THE MERCURY CHALLENGE

"How can we increase fish populations by expanding wetland and floodplain habitat and at the same time control the exposure of people and wildlife to mercury?" is a question on the minds of many resource managers in the Yolo Bypass and Delta. An estimated 95% percent of the historical wetland and floodplain habitat of the Delta has been lost (Land Cover in the Delta, PAGE 61). Wetland and floodplain restoration is proposed in the Yolo Bypass to boost fish populations that have been steadily declining for decades and have experienced recent steep population drops. However, Yolo Bypass soils are contaminated with mercury from 19th century gold mining and runoff from active and abandoned mines. Bacteria in wetland soils can convert mercury into methylmercury, which is highly toxic to humans and wildlife. And the methylmercury produced in wetland soils can enter the water flowing through the wetland and be transported downstream, where it may accumulate in fish and other biota and expose consumers to health risks (SIDEBAR: DRIVERS OF MERCURY EXPOSURE). In essence, more wetland and floodplain habitat is needed to restore fish populations but will likely result in more methylmercury production and could potentially increase the risk of methylmercury exposure. That said, not all wetlands are equally large sources of methylmercury and there might be options on the horizon for focusing control efforts effectively.

The focus of methylmercury control efforts has been turning to seasonal managed wetlands. There are several advantages to focusing control efforts initially on this class of wetlands. For one, they represent an abundant land use type in the Delta that includes rice fields, wildlife refuges, and duck clubs. There are more seasonal managed wetlands than permanent natural wetlands in today's Delta (FIGURE 1). Second, seasonally flooded wetlands are widely acknowledged as a potential source of methylmercury export to open waters of the Delta. And third, the facilities for managing flows in seasonal wetlands can be readily used to implement control measures.

Recently completed and ongoing studies in the Yolo Bypass provide new information on how managers may manipulate these seasonal wetlands to control methylmercury production and exports. One central idea that is emerging from these studies is to focus control efforts in seasonal managed wetlands during peak periods of methylmercury production and critical time windows of downstream releases. The studies show how wetland conditions vary in time and space, with large shifts in the relative importance of different processes responsible for methylmercury production and transport. Key conclusions from these collaborative studies are changing our picture of methylmercury production in wetlands and potential control options. The scientists responsible represent both federal and state agencies as well as private consultants.

> How can we increase fish populations by expanding wetland and floodplain habitat and at the same time control the exposure of people and wildlife to mercury?

↑ Pelicans in Yolo Bypass fallow field. Photograph by Mark Marvin-DiPasquale.

DRIVERS OF METHYLMERCURY EXPOSURE

Methylmercury exposure – via supply, production, and degradation – is regulated by complex conditions that move and transform mercury. In wetlands, mercury attached to suspended particles in water can settle onto the bottom sediments, where it can diffuse back into the water, be resuspended, be buried by other sediments, or be methylated (converted to methylmercury). Mercury methylation is primarily attributed to the activity of anaerobic bacteria in oxygen-free sediments and is believed to be an accidental consequence of a metabolic process. Methylmercury can be taken up by biota, stored, and transferred up the food chain, or broken down (demethylated) by bacteria or UV, at which point the elemental mercury can be released to the atmosphere (volatilization). Dissolved organic compounds originating from plants enhance the solubility of mercury in water, thus making it more likely to remain in the water and enter the food chain.

Rates of methylmercury production, transport, and accumulation in biota vary strongly over time and space. The relative importance of different factors affecting methylmercury cycling are described in more detail in the Mercury Conceptual Model developed for the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP, Alpers 2008),

More information:

CONCEPTUAL MODEL: http://science.calwater.ca.gov/pdf/drerip/DRERIP_mercury_conceptual_model_final_012408.pdf

CALFED REPORTS: http://mercury.mlml.calstate.edu/

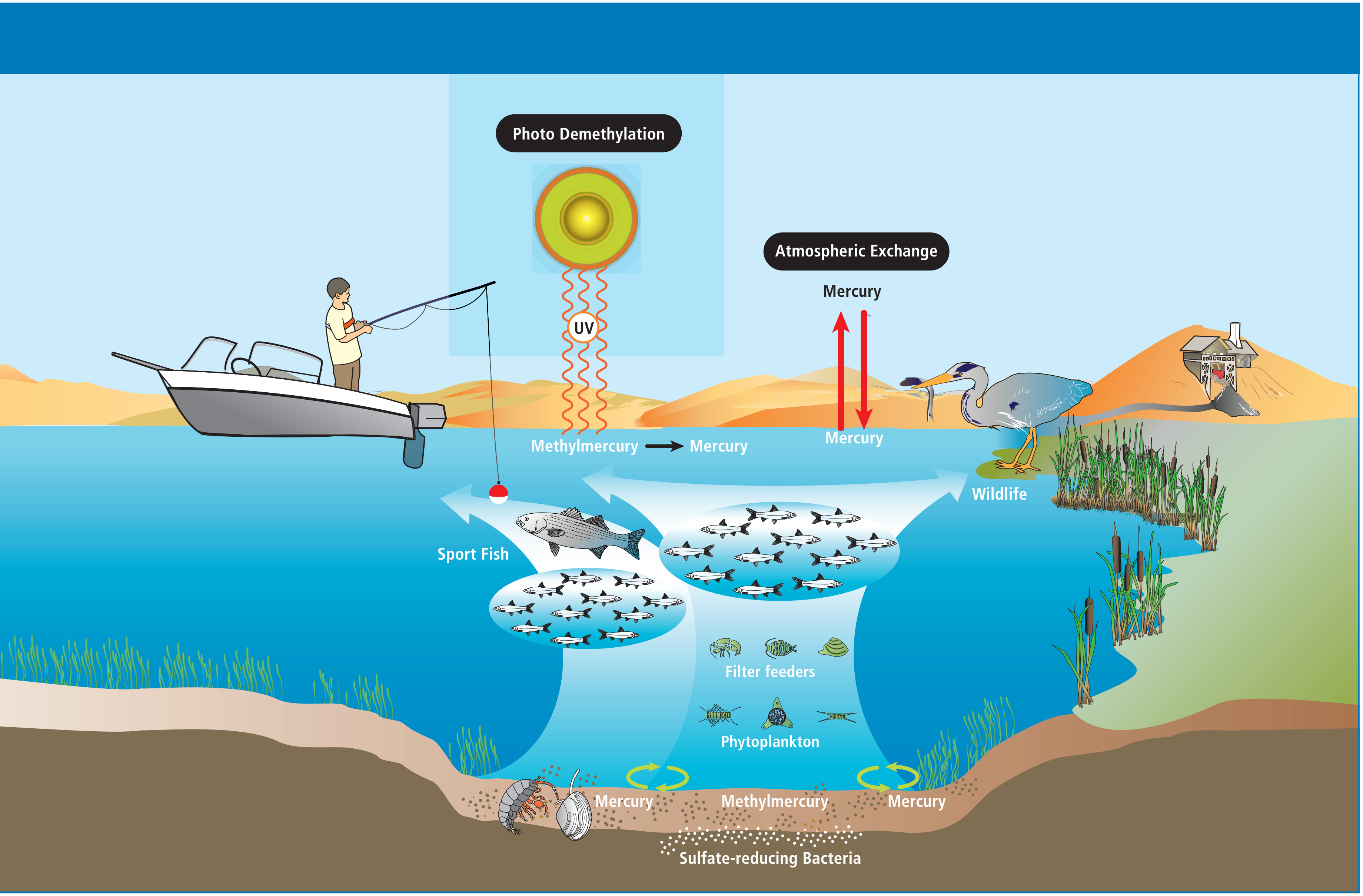
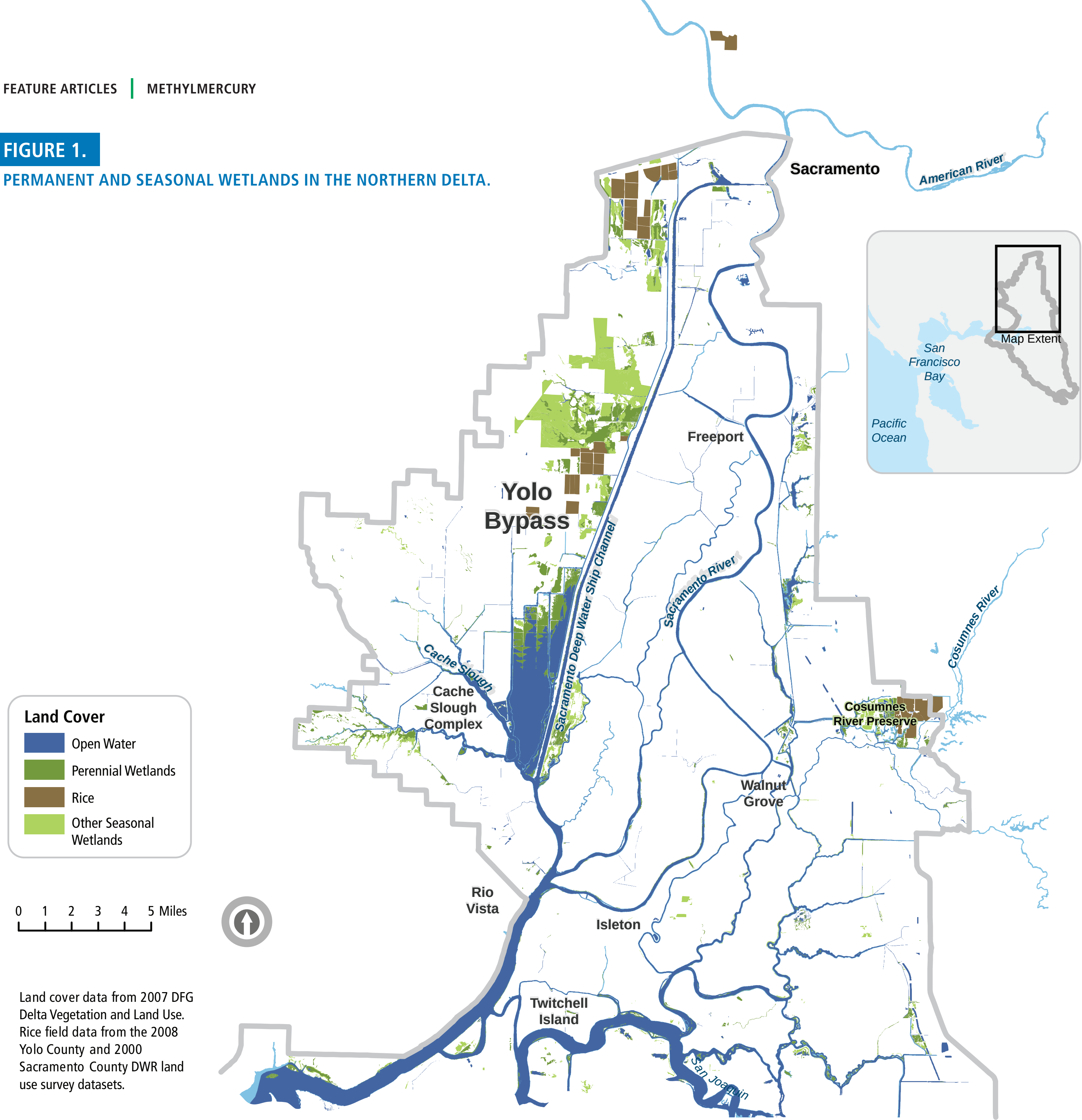


Photo Demethylation
UV
Atmospheric Exchange
Mercury
Methylmercury → Mercury
Mercury
Wildlife
Sport Fish
Filter feeders
Phytoplankton
Mercury
Methylmercury
Mercury
Sulfate-reducing Bacteria

FIGURE 1.

PERMANENT AND SEASONAL WETLANDS IN THE NORTHERN DELTA.



Land cover data from 2007 DFG Delta Vegetation and Land Use. Rice field data from the 2008 Yolo County and 2000 Sacramento County DWR land use survey datasets.

SEASONAL WETLANDS HAVE HIGHER METHYLMERCURY PRODUCTION

Seasonal wetlands in the Yolo Bypass were found to have higher net methylmercury production when flooded than permanent wetlands. This is consistent with what we know about the processes driving methylmercury production and degradation. Across wetland environments, the conditions favoring methylmercury production are those in which the responsible soil bacteria are active and the needed ingredients are available and in good supply: “reactive” inorganic mercury as a mercury source and organic materials (from decaying plants) as an energy source. These conditions are common upon flood up in seasonal wetlands.

Soil and water flow conditions in seasonal wetlands can contribute to increased methylmercury concentrations in the surface water. Researchers have observed that methylmercury concentrations in the shallow surface water of a rice field can rise up to 10-fold as it flows from inlet to outlet. This order of magnitude increase was found partially due to methylmercury production in the soil but was mainly a concentration effect due to transpiration by plants (accounting for 50-75% of water losses from summer-flooded wetlands) and evaporation from the water’s surface.

Conditions in permanently flooded wetlands are somewhat less ideal for net methylmercury production. In contrast to rice fields, surface water flowing through permanent wetlands generally decreased in methylmercury concentrations from inlet to outlet (Windham-Myers et al. 2010). The greater depth of water and longer residence time in permanent wetlands promotes the settling of particle-bound methylmercury from surface water to sediments for longer-term storage. Vegetation-free areas of open water in permanent wetlands are particularly low in net methylmercury production, as their soils are often low in microbially available mercury and organic matter. The lack of plant cover in open-water areas also means less shading, which allows the degradation of methylmercury by ultraviolet radiation (UV), thus reducing the amount of methylmercury transported off the wetland.

WINTER AS A PEAK SEASON OF METHYLMERCURY EXPORTS

One key conclusion from the recent Yolo Bypass studies is that winter is the peak season for methylmercury exports from wetlands. Several independent findings from these investigations (summarized in Windham-Myers et al. 2010, Heim et al. in review) indicate that methylmercury transport from rice fields is highest during winter flooding, when the overall microbial activity and methylmercury production in the soil is fueled by the decomposition of grasses and rice straw, and when flow is maximal. For example, U.S. Geological Survey researchers observed that surface soils in rice fields contained the highest concentrations of methylmercury in the winter season (3-6 nanograms, or parts per trillion, methylmercury per gram dry weight. Similarly, Moss Landing Marine Laboratories researchers found that over the first month of winter flooding, surface water methylmercury concentrations rose by a factor of ten in seasonal wetlands.

The importance of winter in annual methylmercury budgets is surprising to many researchers and managers because the summer months were generally thought of as the most significant period of methylmercury production and transport. Mercury-methylating bacteria in wetland soils are more active during summer flooding than winter flooding, due to the higher temperatures. However, results from the recent Yolo Bypass investigations suggest that warmer temperatures may limit mercury availability to bacteria and that more intensive solar radiation in summer accelerates the degradation of methylmercury by UV, offsetting the enhanced activity of methylmercury-producing bacteria.

CRITICAL TIME WINDOWS OF DOWNSTREAM RELEASES

The recent results from the Yolo Bypass studies also show that the first flush following a dry period is a critical time window when control measures to reduce methylmercury transport might be most important and most effective. Dry soils that have been previously flooded can retain previously produced methylmercury. When flooded again, these soils rapidly release their methylmercury into the water. In most of the rice fields studied, surface water concentrations of methylmercury showed an early peak during initial flooding in June. Similarly, surface water methylmercury peaked in most seasonal wetlands at initial flooding in October or November, followed by a decrease and a leveling off after January (Heim et al. in review, Marvin-DiPasquale et al, 2009a). Therefore, an effective way to reduce methylmercury transport from seasonal wetlands may be limiting releases during the first month of flooding following a dry period.

TWO MAIN CONTROLS: WATER FLOWS AND ORGANIC CARBON SUPPLY

Investigations conducted over the past decade and led by Moss Landing Marine Laboratories and U.S. Geological Survey have provided valuable insights into the processes controlling methylmercury production and transport. A number of controls determine the rate at which methylmercury is produced and degraded in and exported from wetlands. They include source water concentrations, water flow rates, soil and water properties (e.g. organic carbon content and quality), and physical conditions (e.g. solar radiation). Net rates of methylmercury production and export may thus be regulated by control of these factors, where possible. From these, two factors have emerged as important and controllable drivers: water flows and organic carbon supply.

Three key findings from recent field and lab experiments support the idea that carbon supply is a significant driver of methylmercury production across field types and seasons. First, methylmercury production in laboratory experiments was commonly enhanced by the addition of a bacterial carbon source (Heim et al. in review, Marvin-DiPasquale et al 2009a). Second, methylmercury production rates measured in rice fields in winter correlated with the amounts of crop residues and the presence of acetate, a plant-derived bacterial carbon source, in the soil porewater (Marvin-DiPasquale et al. in review). And third, removal of above-ground plant tissues in all wetland types of the Yolo Bypass Wildlife Area during the growing season limited acetate carbon supplies in porewater by an average of 84% and bacterial mercury-methylation by 49% (Windham-Myers et al. 2009).

Yolo Bypass researchers found that lower water flow rates were generally associated with lower methylmercury transport from rice fields. The researchers evaluated best management practices for reducing methylmercury production and transport in Yolo Bypass rice fields by combining detailed flow measurements with water chemistry data. The results from the study indicate that high flow rates and shortened residence times can limit natural processes of methylmercury retention (particle settling, transpiration-driven downward movement in the water column) and degradation (reduced exposure to UV), leading to an increase in transport of methylmercury from rice fields with increased flows.

TECHNIQUES TO REDUCE METHYLMERCURY PRODUCTION AND EXPORTS

These findings suggest that some of the most effective techniques for reducing methylmercury production and transport from wetlands may be controls applied to water flows and organic carbon supplies. Improvements could then be achieved in one of two ways: 1) managing plant growth and litter to control organic carbon supplies, and 2) adjusting the timing of flows on and off wetlands to limit methylmercury discharges and promote internal removal processes.

Limiting plant growth and litter on freshly flooded seasonal wetlands – and thereby limiting carbon sources for bacteria - may be one way of limiting methylmercury production. These techniques are practicable during winter, which may be the most difficult window for controlling methylmercury transport offsite. Organic carbon at the soil surface is the main energy source for mercury methylating microbes. Possible management options for controlling this carbon pool prior to flooding a field include crop residue removal (Windham-Myers et al. 2010) and enhanced grazing. Heim and colleagues (in review) demonstrated that surface water concentrations of methylmercury in the winter are lower on fields that had been grazed by cattle, compared to non-grazed fields. They also report that fresh plant litter stimulates methylmercury production in simulated rice field conditions in the laboratory.

Flow control options for limiting methylmercury exports include adjusting of flow rates during flooding periods and managing the cycle of wetting and drying. Initial and final flushes of methylmercury from seasonal wetlands during flooding periods are critical time windows, during which targeted flow control may capture methylmercury and remove some or all of it prior to offsite transport.

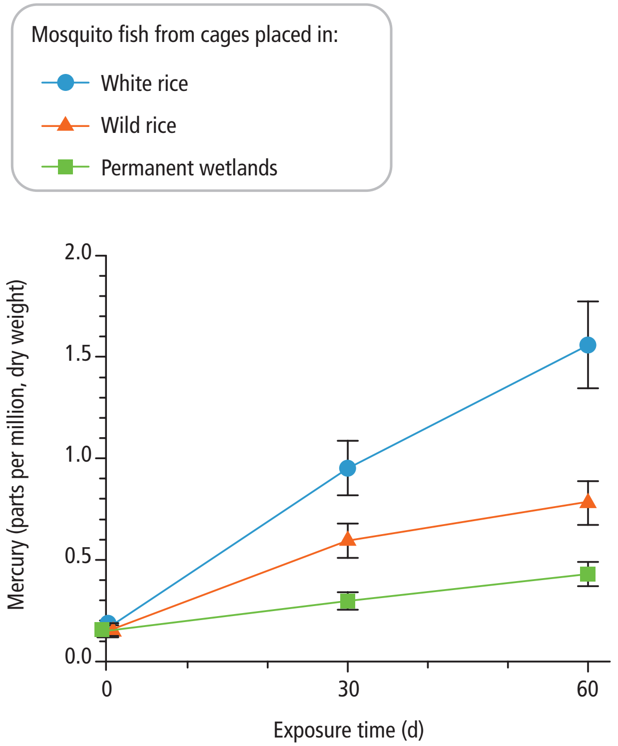
Data from the Yolo Bypass, Twitchell Island, and the Cosumnes River Preserve suggest that slowing flows and recycling water between fields promote internal methylmercury removal processes in wetlands. These management practices take advantage of a range of methylmercury removal processes occurring in the water, including settling of methylmercury-containing particles, downward movement of water by plant transpiration, and degradation by UV.

EVALUATING TRADE-OFFS

It is important to consider any unintended adverse consequences these techniques may have. Local wetland food webs will likely be affected negatively by manipulations of flows and carbon that are intended to reduce downstream loads.

MORE METHYLMERCURY IN FISH FROM RICE FIELDS, A TYPE OF SEASONAL WETLAND

Fish in rice fields tend to accumulate more methylmercury than those in permanently flooded areas (Ackerman and Eagles-Smith 2010), although this does not necessarily apply to all components of wetland foodwebs. Recent U.S. Geological Survey studies found that the elevated methylmercury levels in pelagic fish of seasonal wetlands were strongly related to methylmercury levels found in the wetland water. This is in contrast to methylmercury concentrations detected in invertebrate organisms, which appear to be more associated with methylmercury concentrations in wetland soils. Thus, understanding the controls on methylmercury bioaccumulation in rice fields requires an understanding of the specific foodweb pathways involved.



Whole-body total mercury concentrations (μg/g dry weight) in western mosquitofish (*Gambusia affinis*) introduced into cages (time zero), removed from cages after 29 days, and removed from cages after 60 days of exposure at the outlets of white rice (circles), wild rice (triangles), and permanent wetlands (squares) within the Yolo Bypass Wildlife Area.

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For example, understanding the net effect of carbon limitation on other important ecosystem functions, such as habitat support for migrating waterfowl, is an important caveat to consider. While reductions in carbon supplies may reduce methylmercury production in a wetland, they may also reduce forage for over-wintering wildlife populations.

There is also a potential drawback to slowing flows. While slowed flows will help enhance internal methylmercury removal processes, they may temporarily increase methylmercury concentrations inside a wetland and its tailwater (water immediately downstream), leading to greater bioaccumulation in these water bodies (SIDEBAR: MORE METHYLMERCURY IN FISH FROM RICE FIELDS) and concerns for the wildlife feeding there (Ackerman and Eagles-Smith, 2010). Based on observations in rice fields of the Yolo Bypass, warm weather may exacerbate the effect, when evaporation from a field with slowed flows further concentrates methylmercury in the surface water.

Tailwater treatment has emerged as a promising control option for capturing pulses of high methylmercury flows

Rice field irrigation. Photograph by Thomas Jabusch.

EMERGING TREATMENT TECHNOLOGIES

Tailwater treatment has emerged as a promising control option for capturing pulses of high methylmercury flows. Scientists from Moss Landing Marine Laboratories are assessing the feasibility of treating rice field outflows in "polishing ponds," permanent wetlands with slow flows that enhance naturally occurring removal processes such as particle settling and the decomposition of methylmercury by UV sunlight.

Amendment approaches have also been suggested. For example, in salt marsh soils, the availability of mercury for methylation may be limited through the addition of reduced iron (Ullrich and Sedlak, 2010). Iron amendment experiments, however, show extreme variability in their results and indicate that responses of natural wetlands to amendments will be highly unpredictable. Depending on conditions at the onset of an application, an iron amendment could either stimulate or inhibit methylation rates (Marvin-DiPasquale et al, 2009a).

Chemical dosing is emerging as a new and promising water treatment method that may be applied directly to a wetland or its tailwaters. This technique uses metal-based salts as coagulants to flocculate dissolved organic carbon and remove any mercury and methylmercury bound to it. In the lab, coagulants have effectively removed up to 95% of total mercury and 80% of all methylmercury from drainage water collected on Twitchell Island (Henneberry et al. 2010). The feasibility of using these coagulants to maximize methylmercury removal in the field is currently being tested in constructed wetlands used as tailwater treatment ponds.

NEXT STEPS IN EVALUATING POTENTIAL CONTROL MEASURES

Important questions still remain about the feasibility of implementing possible control measures:

- It is technically feasible to implement these control measures on a large scale?
- Which control measures achieve (or potentially achieve) significant load reductions to help land managers meet their targets?
- Where and when do potential control measures have the greatest effect in a real-world management setting?
- What are the unintended consequences of implementing certain controls in a managed wetland?
- How can those unintended consequences be mitigated?

The Adaptive Management Plan For Implementing the Delta Methylmercury Control Program and the Delta Methylmercury Total Maximum Daily Loads Phase 1 Control Study Guidance seek to address these questions through coordinated, comprehensive studies. Several ongoing studies on wetlands and rice fields in the Delta are supporting these goals. A two-year study in the Cosumnes River Preserve is underway to test whether carbon management – by removal of rice straw through discing or bailing – can limit methylmercury production in rice fields.

The Cosumnes River Preserve study is also testing whether and how the onset of seasonal flooding in winter and drainage in spring may be used to regulate annual methylmercury loads, by decoupling periods of production from periods of export. A study on Twitchell Island addresses how in situ low intensity chemical dosing (LICD) of metal-based salts might be applied to remove methylmercury and organic carbon in runoff from rice farms and wetlands. Both the Cosumnes River Preserve and the Twitchell Island studies seek to determine whether load reductions are achievable, whether there are unintended consequences for wildlife and, if so, how they could be addressed.

The Interagency Ecological Program – Cooperative Ecological Investigations in the Bay-Delta Estuary since 1970

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↑ San Joaquin River near the Antioch Bridge. Photograph by Thomas Jabusch.

HIGHLIGHTS

The mission of the Interagency Ecological Program (IEP) is to provide ecological information and scientific leadership for managing the Bay-Delta ecosystem

The Bay-Delta ecosystem is at an important crossroads. Environmental managers must determine what a desirable future ecosystem would look like, how it would function, and how it can be established

Like the Bay-Delta ecosystem, the IEP has been changing. What it will look like in the future is now being decided

SCIENCE INFORMS SOLUTIONS

The Interagency Ecological Program (IEP) for the San Francisco Estuary is a long-term state and federal science partnership that conducts cooperative ecological investigations in the Delta and in San Francisco Bay.

The IEP was founded in 1970 to implement, coordinate, and integrate scientific activities in the Estuary that were then carried out by two state and two federal agencies. The goal was to provide better scientific information to managers and decision-makers about changes in the ecosystem. The original focus was on the effects of operating the State and Federal water projects on fish and wildlife. The water projects include large storage and flood control reservoirs on nearly all tributary rivers to the Delta, a network of channels and gates that route water through the Delta, and two large pumping facilities in the southwestern part of the Delta that export fresh water to the San Joaquin Valley and southern California (see COMPANION ARTICLE: SMALL VESSELS, BIG CHANGES, PAGE 84).

Over time, the focus and membership of the IEP has broadened – the IEP "Science Tree" has grown (SIDEBAR: THE IEP "SCIENCE TREE": SCIENCE FOR APPLICATION). The IEP now has six federal and three state member agencies (see FIGURE 1). IEP teams include scientists, managers, and policy makers from

- all IEP member agencies,
- two partner organizations (Delta Stewardship Council and San Francisco Estuary Institute),
- universities,
- stakeholder groups,
- private companies, and
- the public.

Together, they represent much of the Bay-Delta's "science family."

The current mission of the IEP is, in collaboration with others, to provide ecological information and scientific leadership for use in management of the San Francisco Estuary. IEP science is long-term and cooperative "science for application." It is intended to inform management solutions for the Estuary such as the two long-term Delta plans that are currently under development by the Delta Stewardship Council and by a multi-entity group (SIDEBAR: BIG PLANS FOR THE DELTA). IEP science includes monitoring, research, modeling, analysis, and synthesis (SIDEBAR: 2011 IEP PROJECTS). Communication of results is essential if IEP Science is to be used by managers. IEP science results are communicated in many ways, for example on the IEP web site, in the quarterly IEP Newsletter, and in IEP reports, journal publications, and presentations at the annual IEP meeting and elsewhere.

One recent example of IEP science is the IEP "Pelagic Organism Decline" (POD) investigation. IEP fish monitoring showed a sudden, steep decline in four pelagic fish species in the Delta and Suisun Bay in 2002. Research into possible causes was initiated in 2005. It is currently thought that multiple interacting environmental drivers have caused the POD and that it may represent a rapid shift to a new, unfavorable ecological regime. Rapid ecological regime shifts are often the result of gradual long-term changes that accumulate until the system reaches a tipping point. Understanding the long- and short-term changes that lead up to regime shifts is essential to finding ways to ameliorate or reverse them.

The mission of the IEP is, in collaboration with others, to provide ecological information and scientific leadership for use in management of the San Francisco Estuary

FIGURE 1.

The IEP was founded in 1970 and has six Federal and three State member agencies. Federal member agencies are the National Marine Fisheries Service (NMFS), U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation (USBR), U.S. Environmental Protection Agency (USEPA), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS). State member agencies are the California Department of Fish and Game (DFG), Department of Water Resources (DWR), and State Water Resources Control Board (SWRCB).

THE IEP "SCIENCE TREE": SCIENCE FOR APPLICATION

"There are no such things as applied sciences, only applications of science"
–Louis Pasteur, French chemist and microbiologist who created the first vaccine for rabies and anthrax (September 11, 1872)

"Our mission is to get the science nailed down"
–Dr. Randy Brown (in DWR People, 1998)

THE FRENCH SCIENTIST LOUIS PASTEUR FAMOUSLY WROTE: "NO, A THOUSAND TIMES NO; THERE DOES NOT EXIST A CATEGORY OF SCIENCE TO WHICH ONE CAN GIVE THE NAME APPLIED SCIENCE. THERE ARE SCIENCE AND THE APPLICATIONS OF SCIENCE, BOUND TOGETHER AS THE FRUIT TO THE TREE WHICH BEARS IT" (PASTEUR 1871).

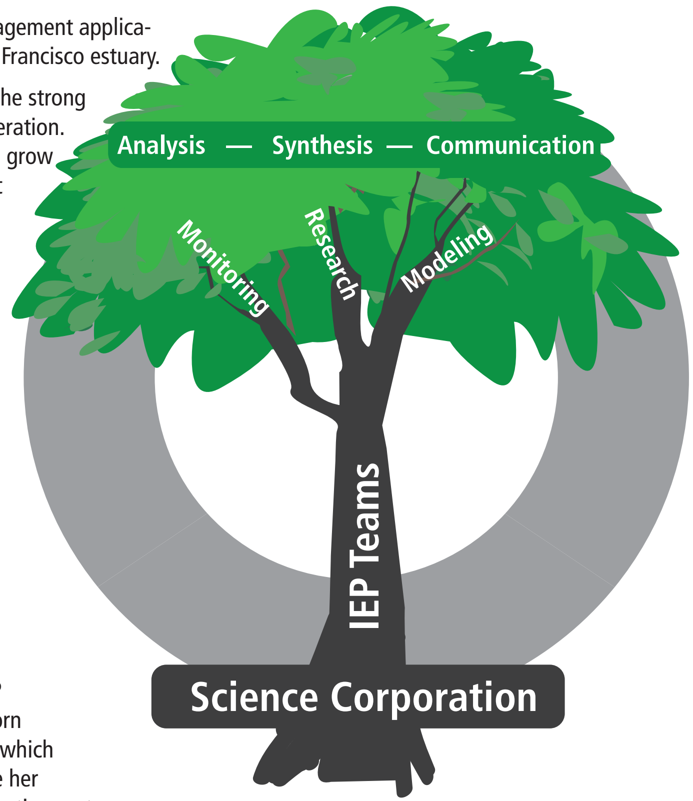
The IEP conducts science that informs practical policy and management applications. The fruits of the IEP science tree are solutions for the San Francisco estuary.

The success and longevity of the IEP science tree are rooted in the strong commitment of member agencies and partners to science cooperation. The IEP's cooperative technical, coordination, and review teams grow out of this commitment. The IEP teams form the solid trunk that supports the IEP science tree's crown.

The crown has three large branches that support smaller branches and leaves: monitoring, research, and modeling

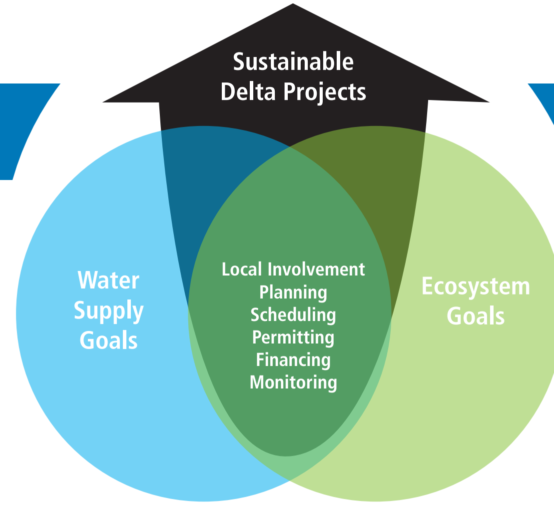
Monitoring tells what is happening, research tells why something is happening, and modeling helps tell what can happen. Analysis, synthesis, and communication of the results form the tree's smaller branches and leaves. They are needed to understand and tell the whole story. All parts are needed to let the IEP science tree bear fruit for consumption by policymakers, managers, and the public.

The IEP science tree has grown to its current size and shape over more than four decades. Many dedicated arborists have cultivated it. They include IEP leaders such as the late Dr. Randy Brown who in his down to earth way defined the IEP as: "Our mission is to get the science nailed down" (Randy Brown in DWR People 1998). They also include the many dedicated IEP scientists and field and lab technicians such as Sally Skelton (born Davis). She discovered a new zooplankton species in the Delta, which was named Oithona davisii in her honor, and continues to share her expertise in zooplankton taxonomy with the IEP even after her retirement from the Department of Fish and Game.



More information: http://www.water.ca.gov/iep/

BIG PLANS FOR THE DELTA



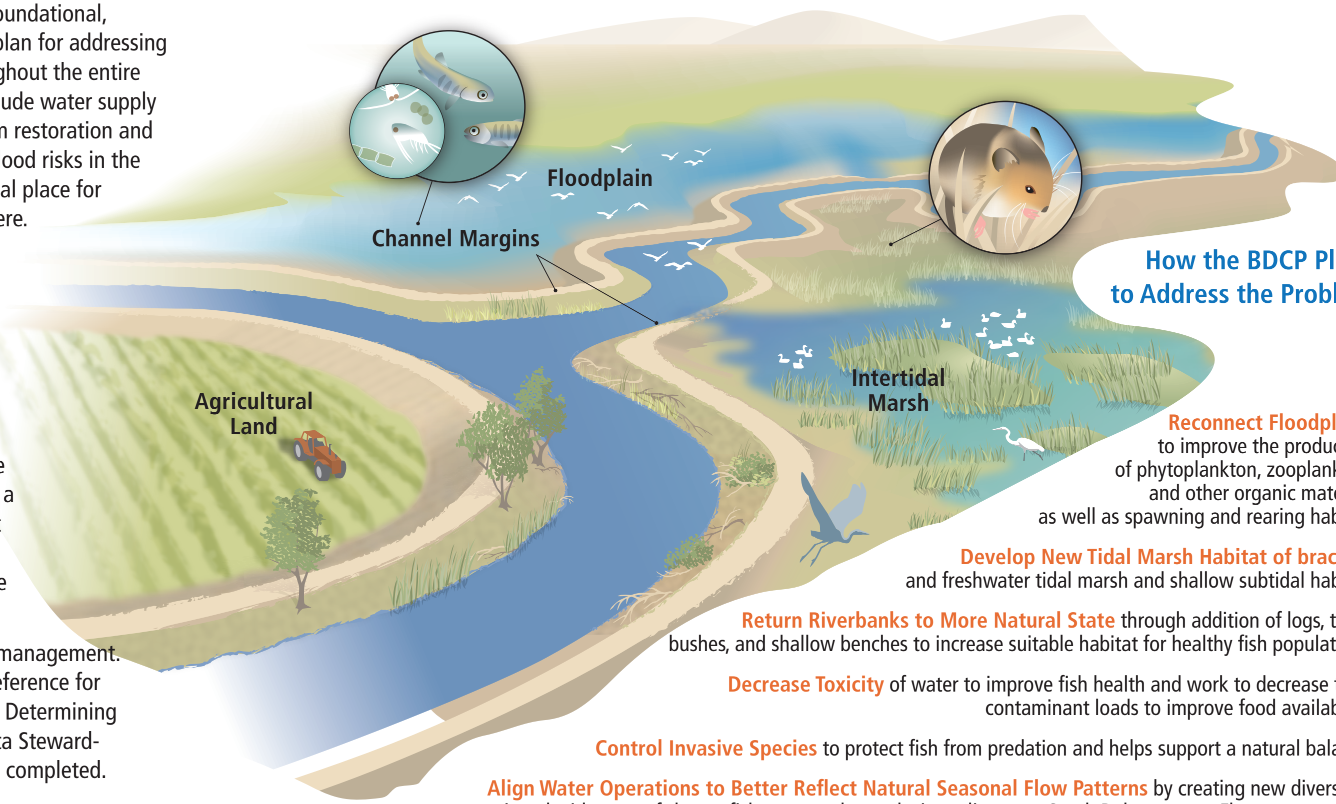
The Delta Plan is being developed to achieve the coequal goals of protecting and enhancing the Delta ecosystem, and providing for a more reliable water supply for California in a manner that protects and enhances the Delta as an evolving place.

The Delta is an important place for many people and there are many large and small plans for its future. Currently, two especially large planning efforts are under way to achieve the "co-equal goals" of "providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem." The co-equal goals were written into California law by the Sacramento–San Joaquin Delta Reform Act of 2009. They are to be achieved "in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place" (CA Water Code §85054). Science and adaptive management (**SIDEBAR: ADAPTIVE MANAGEMENT DEPENDS ON SCIENCE**) are important components of both plans.

1. The Delta Stewardship Council is developing the Delta Plan. The Delta Plan is intended as a "foundational, adaptable, practical, and enforceable" plan for addressing all aspects of Delta management throughout the entire 21st century. Delta Plan focus areas include water supply reliability for California, Delta ecosystem restoration and water quality improvements, reducing flood risks in the Delta, and promoting the Delta as special place for people who live, work, and recreate there.
2. Multiple agencies and other organizations are developing the Bay Delta Conservation Plan (BDCP). This plan is aimed at large-scale improvements in water conveyance and ecosystem restoration in the Delta over the next 50 years, in a way that will preserve threatened and endangered species. The BDCP is intended to eventually become a component of the Delta Plan, but it first has to meet a number of requirements, including those in California Water Code Section 85320.

There are also many other plans for Delta management. The Delta Plan will be used as a point of reference for many other planned activities in the Delta. Determining consistency will be a major role of the Delta Stewardship Council, once the Delta Plan has been completed.

More information: http://deltacouncil.ca.gov/ and http://baydeltaconservationplan.com/Home.aspx



How the BDCP Plans to Address the Problem

Reconnect Floodplains to improve the production of phytoplankton, zooplankton, and other organic material, as well as spawning and rearing habitat.

Develop New Tidal Marsh Habitat of brackish and freshwater tidal marsh and shallow subtidal habitat.

Return Riverbanks to More Natural State through addition of logs, trees, bushes, and shallow benches to increase suitable habitat for healthy fish populations.

Decrease Toxicity of water to improve fish health and work to decrease toxic contaminant loads to improve food availability.

Control Invasive Species to protect fish from predation and helps support a natural balance.

Align Water Operations to Better Reflect Natural Seasonal Flow Patterns by creating new diversions equipped with state-of-the-art fish screens, thus reducing reliance on South Delta exports. Flow management would allow for greater seasonal variability in flows when fish need it most.

2011 IEP PROJECTS

In 2011, the IEP coordinated and tracked 144 projects with a combined budget of $39 million

THESE PROJECTS FELL INTO THREE LARGE PROGRAM CATEGORIES:

1. **IEP Core Program:** Bay-Delta monitoring that provides key long-term and real-time data sets. These data are used in many studies, status and trends assessments, daily water project operations, and for regulatory purposes. Monitoring includes water quality, phytoplankton, benthic invertebrates, zooplankton, and fish. Most of this monitoring is required by State Water Right Permits or Federal Biological Opinions for the coordinated operation of the State and Federal Water Projects (OCAP). 2011 program: 30 projects, $16.8 million. www.water.ca.gov/iep/activities/monitoring.cfm

2. **IEP Pelagic Organism Decline (POD) Program** an integrated set of studies to investigate the causes of the POD. The POD program is currently broadening its scope to include other species and biological communities in the Bay-Delta. 2011 program: 34 active projects, $4.5 million. www.water.ca.gov/iep/pod/

3. **IEP Coordinated Studies Program:** additional short-term studies and some monitoring not funded by the IEP but relevant to its mission and goals. This includes studies funded by the Delta Science Program (www.deltacouncil.ca.gov/science-program) and the CALFED Ecosystem Restoration Program (www.dfg.ca.gov/ERP/). It also includes studies selected by the Federal Science Task Force (which was set up to coordinate federal science efforts aimed at better managing water supplies in California and the Bay-Delta ecosystem) and monitoring required by the Central Valley Project Improvement Act (CVPIA, www.usbr.gov/mp/cvpia/index.html). IEP coordination helps make these independently funded studies more efficient and effective. 2011 program: 80 active projects, $17.8 million. www.water.ca.gov/iep/activities/research.cfm

← San Francisco State University master's student Erica Kress collecting water samples from a Niskin bottle aboard the Research Vessel Questuary. Photograph by Alex Parker.

THE VALUE OF LONG-TERM MONITORING AND COLLABORATION

The long-term monitoring conducted by the IEP is essential for detecting ecological changes. Ecological changes may be rapid, such as past declines in fish populations (Thomson et al. 2010). Or they may happen slowly and gradually, like future ecological changes that may be observed due to climate change (Cloern et al 2011). Detecting and understanding changes affecting the Delta ecosystem also require ongoing collaborative and multi-disciplinary analysis and synthesis of IEP and other available data. The POD investigation, for example, included work with the National Center for Analysis and Synthesis (NCEAS) in Santa Barbara, California. The IEP collaboration with NCEAS also led to a new system for finding, understanding, and effectively using the diverse IEP data. This system combines the "Metacat" software developed at NCEAS with Google maps and is expected to come online in 2012.

IEP ROLES, PARTNERS, AND THE FUTURE OF THE DELTA

The IEP and the Bay-Delta ecosystem are now at an important crossroads that will define their futures. For the ecosystem, the questions are what a more desirable future ecosystem regime would look like and how it would function, how and if such a regime could be established and maintained, and if it would have enough resilience to persist in the face of climate change, continued species invasions, changing water demands, and other changes. Scientific information collected by the IEP will be critical to answering these fundamental questions. The IEP may also be called upon to serve as a coordinator or collaborative partner in several major initiatives revolving around adaptive management of the Bay-Delta ecosystem and California water, including the Delta Plan and the Bay-Delta Conservation Plan (**SIDEBAR: ADAPTIVE MANAGEMENT DEPENDS ON SCIENCE**).

The IEP recently formed a partnership with the California Water Quality Monitoring Council's new California Estuary Monitoring Workgroup. This group is developing an online "web portal" with information about the ecological health of the San Francisco Estuary and other California estuaries (**SIDEBAR: A NEW WAY TO SEE THE DELTA**). The IEP also continues to partner with the Delta Stewardship Council's Delta Science Program and the San Francisco Estuary Institute. A partnership with the State and Federal Water Contractors Science Program is evolving. The IEP is also currently reinvigorating its long-standing partnership with the California Water and Environmental Modeling Forum (CWEMF). CWEMF is a non-profit organization that was formed in 1994 to increase the usefulness of models for assessing California's water-related problems. For many years, the IEP and CWEMF held back-to-back annual meetings with a jointly held "overlap" day at the Asilomar State Conference Center in Pacific Grove. Recent travel restrictions for State agencies interrupted these highly valued joint meetings, but they will resume in 2012 in Folsom.

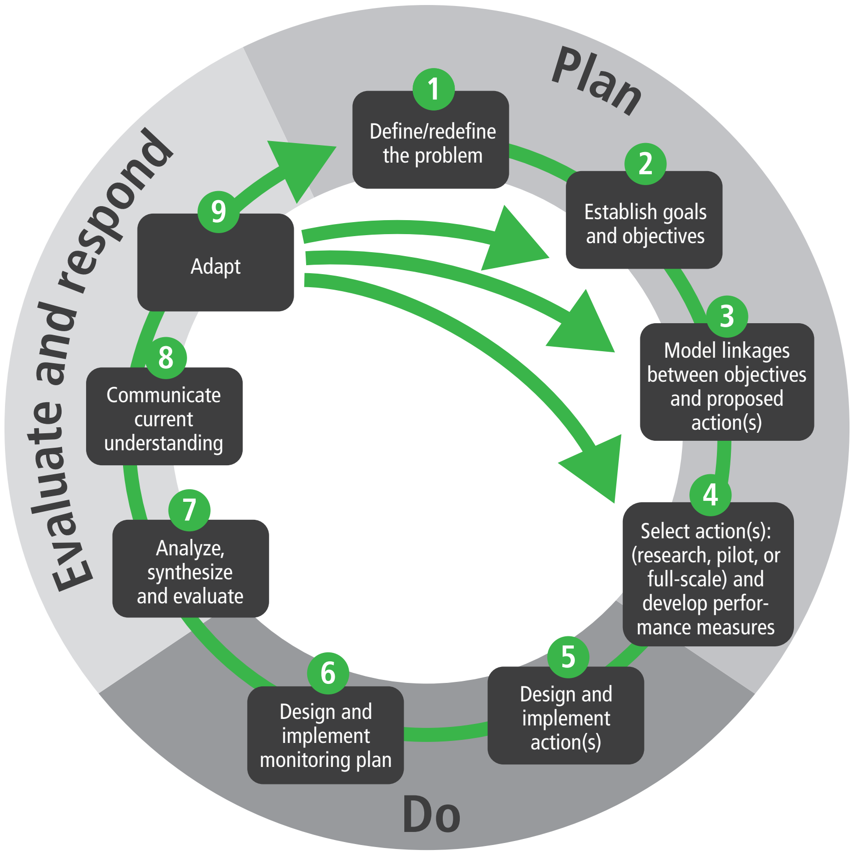
In the near future, the IEP may gain new member agencies. These potential new members would bring new information needs, stakeholders, and science programs to the IEP science partnership. This may include the Central Valley Regional Water Quality Control Board with its developing Delta Regional Monitoring Program (RMP) for Contaminants (see **MANAGEMENT UPDATE: DELTA RMP, PAGE 81**). Closely coordinating and integrating the Delta RMP's contaminant-focused monitoring with existing IEP monitoring and research will allow quantitative assessments of contaminants effects on fish and other organisms monitored by the IEP (e.g., Brooks et al. 2011). Data and information cooperatively produced by the IEP and Delta RMP could be displayed and accessed on the California Estuary Web Portal and would fill a critical gap in tracking and understanding the ecological health of the Estuary. It would also better connect water quality information provided by the Bay and Delta RMPs with the biological information provided by the IEP and help inform management strategies and science plans for the whole estuary.

New members, partnerships, and roles pose questions for the IEP that are quite similar to the questions for the ecosystem: what should the future IEP look like and how will it function and persist? The IEP started a conversation about its future at its 2010 annual meeting; the conversation continues. To learn more about the IEP visit its website (www.water.ca.gov/iep/).

ADAPTIVE MANAGEMENT DEPENDS ON SCIENCE

Adaptive management takes action when the outcome is uncertain. Adaptive management includes a learning process that uses many branches of science. Modeling helps in choosing the most promising actions by predicting their effects. Monitoring determines whether the chosen action achieves its goals. Hypothesis-driven experimentation and research is particularly useful when working to shrink large uncertainties about existing conditions and potential management outcomes. Analyses, synthesis, and communication of results close the loop. Adaptive management means actions may be continued, abandoned, or adjusted. As with the IEP science tree, adaptive management must be rooted in and supported by close cooperation among decision-makers, managers, scientists, stakeholders, and the public (**SIDEBAR: THE IEP "SCIENCE TREE": SCIENCE FOR APPLICATION**).

The IEP has supported adaptive management of the Estuary since before the ecologists C.S. Holling and Carl Walters coined the term in the late 1970s. Older examples include providing fish data and information that are used to adjust weekly and longer-term water project operations. A new example is the IEP's involvement in implementing the science plan included in the "Fall Outflow Adaptive Management Plan" (U.S. Bureau of Reclamation 2011). Adaptive management of outflow from the Delta to San Francisco Bay in the fall is required under the 2008 Delta Smelt Biological Opinion (U.S. Fish and Wildlife Service 2008). The scientific evaluation of the effectiveness of the currently required fall outflow levels may lead to adjusted levels that help better serve the co-equal goals of water supply reliability and ecosystem health. In the future, IEP science will likely also play a large role in adaptive management required under the Delta Plan and Bay-Delta Conservation Plan (**SIDEBAR: PLANS TO HELP THE DELTA**).



A Nine-step Adaptive Management Framework for the Delta. The shading represents the three broad phases of adaptive management (Plan, Do, and Evaluate and respond), and the boxes represent the nine steps within the adaptive management framework. The circular arrow represents the general sequence of steps. The additional arrows indicate possible next steps for adapting (for example, revising the selected action based on what has been learned.).

Source: Fifth Staff Draft Delta Plan (Delta Stewardship Council 2011)

More information about adaptive management:

IN THE DRAFT DELTA PLAN: http://www.deltacouncil.ca.gov/delta-plan (see chapter 2)

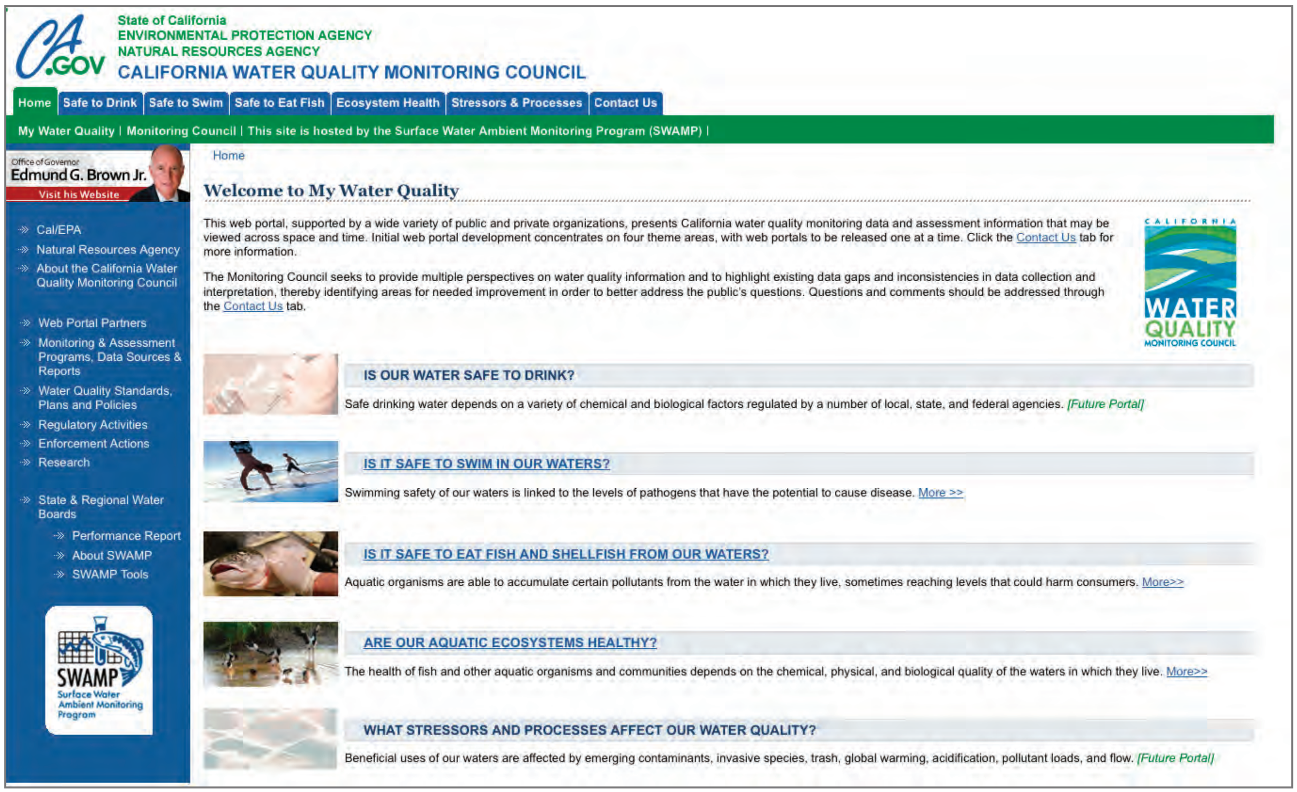
RECOMMENDED BY INDEPENDENT ADVISORS FOR THE BDCP: http://www.bdcpweb.com/Libraries/Background_Documents/BDCP_Adaptive_Management_ISA_report_Final.sflb.ashx

OF WATER PROJECT OPERATIONS: http://www.water.ca.gov/swp/operationscontrol/calfed/index.cfm

IN THE DELTA SMELT BIOLOGICAL OPINION: http://www.fws.gov/sfbaydelta/ocap/

THE ESTUARIES PORTAL - A NEW WAY TO SEE THE DELTA

A 2006 California Senate Bill (SB 1070) required California agencies to integrate and coordinate their water quality and related ecosystem monitoring, assessment, and reporting. This led to the establishment of the California Water Quality Monitoring Council (Council) in 2007. The Council is making water quality information available to the public through an online portal called "My Water Quality." Portal content is provided by the Council's workgroups. The recently formed "California Estuary Monitoring Workgroup" will initially focus its efforts on the San Francisco Estuary and will provide content for a new California Estuaries Portal. The first steps include identifying key questions to assess the ecological health of the San Francisco Estuary, the data and methods available and needed to address the questions, and the methods to access, display, and work with the data and information. In the process of developing this Portal, the Workgroup is also expected to identify redundancies, data gaps, and inefficiencies in current monitoring activities and develop solutions for improvements and better data integration. The IEP is a lead participant in the work group and an important data and information provider for the Portal, along with other science partners from the Delta and Bay.



The California Estuary Monitoring Workgroup is developing an Internet portal focused on the health of the Bay-Delta ecosystem.

COMPANION ARTICLE

200 Years of Small Boats and Big Changes

ANKE MUELLER-SOLGER, Interagency Ecological Program/Delta Stewardship Council,
anke.mueller-solger@deltacouncil.ca.gov

↑ Residences on Bethel Island, boats moored at Taylor Slough. Photograph by Thomas Jabusch.

The IEP agencies share a fleet of 32 monitoring and research vessels to document and investigate changes in the Delta ecosystem. The Department of Water Resources-owned Research Vessel (RV) San Carlos is the IEP's primary water quality monitoring vessel and one of its longest serving vessels. The RV San Carlos set out on her maiden voyage from San Diego, CA, in early 1976. After stops in Morro and Monterey Bays, the 56-foot, 48-ton, custom-built ship entered San Francisco Bay in February 1976 and soon commenced her IEP service in the Delta under Captain Lloyd Brenn. Today, the RV San Carlos is captained by Eric Santos and is used to document changes in Bay-Delta water quality, plankton, and benthic invertebrates as well as for various special studies. She will be replaced by a new RV San Carlos in the next few years.

The San Carlos was the first European ship to enter the San Francisco Estuary.

Some of the changes in the Estuary seen since the arrival of the RV San Carlos in 1976 have been dramatic. For example, numbers of native zooplankton species and diatoms have plummeted while those of non-native zooplankton, jellyfish, and clams have soared. Aquatic weeds and harmful blue-green algal blooms have become commonplace. Water quality has also changed – some constituents such as inorganic nitrogen have greatly increased while others such as phosphorus and suspended sediments have decreased (Jassby 2008). But the new RV San Carlos is just the latest in a line of small research vessels that have tracked big changes in the Bay and Delta.

The first one of these small vessels was the 79-foot Spanish "paquebot" (supply ship) San Carlos, after which the RV San Carlos was named. The original San Carlos sailed from San Diego and Monterey to San Francisco almost exactly two centuries before the maiden voyage of the RV San Carlos. In August 1775 she became the first European ship to enter San Francisco Bay. Her captains Juan Manuel de Ayala and Jose Joaquin Moraga were the first Europeans to map San Francisco and San Pablo Bay, Suisun Bay, and the western Delta. The arrival of the San Carlos brought big changes to San Francisco Bay, but the Delta remained relatively uncharted and unchanged over the next five decades. During this period, California had a population of less than 10,000 Europeans, but at least 150,000 Native Americans, many of whom lived in and around the Delta, where they hunted native fish, shellfish, waterfowl, and seals in canoes

IEP Environmental Monitoring Program crew on the RV San Carlos, summer of 1999. From left to right: Cindy Messer (California Department of Water Resources), John Yokomizo (U.S. Geological Survey), Eric Santos (California Department of Water Resources), Gregg Schmidt (California Department of Fish and Game), Lloyd Brenn (California Department of Water Resources), Scott Waller (California Department of Water Resources), Kitty Triboli (California Department of Water Resources). Photograph provided by Scott Waller.

made from native tule reeds that grew abundantly in the Delta's expansive wetlands. Tules were also used to build homes and weave baskets. The lives of these Native Americans were so closely linked with the wet Delta environment that to one early ethnologist they appeared "almost amphibious" (Powers 1877).

The rapid transformation of the Delta arguably started in August 1839, when two small schooners (sail boats), the 22-ton Isabella and the smaller Nicolás, along with a four-oared row boat, made their way from San Francisco up the Sacramento River to the mouth of the American River. The schooners belonged to the wealthy American merchant Nathan Spear and were commanded by his 17-year-old nephew William "Kanaka Bill" Heath Davis. On board was the Swiss immigrant John Augustus Sutter with a few German and Hawaiian companions and a bulldog. Sutter had chartered the vessels to explore the Delta in search of land for other European immigrants. Sailing through the Delta's labyrinthine waterways, it took the three boats several days of searching to find the mouth of the Sacramento River. After more than a week, they finally reached the mouth of the American River, where Sutter established "New Helvetia", which later became the city of Sacramento. Davis reports that upon their arrival at this site, they encountered "some seven or eight hundred Indians … in canoes made of tules." Davis returned to San Francisco the next day. He gave a vivid description of the Delta as he saw it from the Isabella that day: "As we moved away, Captain Sutter gave us a parting salute of nine guns—the first ever fired at that place—which produced a most remarkable effect. As the heavy report of the guns and the echoes died away, the camp of the little party was surrounded by hundreds of Indians, who were excited and astonished at the unusual sound. A large number of deer, elk and other animals on the plains were startled, running to and fro, stopping to listen, their heads raised, full of curiosity and wonder, seemingly attracted and fascinated to the spot, while from the interior of the adjacent wood the howls of wolves and coyotes filled the air, and immense flocks of waterfowl flew wildly over the camp" (Davis 1929, www.sfgenealogy.com/sf/history/hb75yb.htm).

The schooner Isabella made several more trips up and down the Sacramento River. In 1840 and 1841, her owner, Nathan Spear, followed an invitation by John Sutter to go salmon fishing in the Sacramento River. He reportedly filled the hold of the Isabella with large numbers of fish, which he sold for a profit in San Francisco. The Isabella thus became the first commercial salmon fishing vessel on the west coast.

On November 28, 1847, the small 37-foot vessel "Sitka" became the first steamboat in the still largely pre-European Delta landscape. No one foresaw then the dramatic transformations that would begin just two months later, on January 24, 1848. That day, James Marshall was building a sawmill for John Sutter when he accidentally discovered gold on the south fork of the American River. Marshall's discovery started the great human mass migration to California that became known as the California gold rush. Within a year, 100,000 adventurers from all over the world rushed into California. By 1860, the non-Native American population of California had risen to almost 400,000 while the Native American population had plummeted to 30,000. This sudden change in human demographics and cultural backgrounds changed California forever. And nowhere were the changes greater than in the California Delta.

When the Isabella first sailed up the Sacramento River, the Delta was a 700,000-acre mosaic of diverse landscape types and components. Large flood basins occupied by both tidal and non-tidal wetlands dominated the north Delta landscape, many large and small tidal islands covered the central Delta, and the South Delta was a complex landscape of river branches, secondary overflow channels, and habitat patches (SIDEBAR: USING THE PAST DELTA TO INFORM ITS FUTURE). Historical Delta landscape patterns varied predictably along physical gradients. Change was driven by tides, river flows, seasons, and the Delta's variable Mediterranean climate. Native Americans had long learned to live with these cyclical changes. They also changed the Delta landscape themselves to increase animal and plant production. But these historical changes preserved the overall character of the Delta landscape. In contrast, the changes that began with the first Delta voyage of the schooner Isabella in the mid-19th century fundamentally altered the Delta landscape. Today, Ayala, Moraga, Davis, Sutter, and their contemporaries would hardly recognize it as the same place that they saw from the San Carlos and the Isabella.

When Eric Santos and his IEP colleagues stand on the bridge of the current RV San Carlos, they can see across 1,115 miles of artificial levees onto large tracts of agricultural lands that have replaced most of the historical tidal wetlands and islands. Drained peat soils have subsided and the land elevation of many agricultural islands is now lower than the water elevation in the channels through which the RV San Carlos travels on its monthly monitoring cruises. Over the years, the IEP crews on the RV San Carlos have seen several breached levees and flooded islands. A few flooded islands were never drained and are now artificially large, The dramatic changes in the Delta and its watershed over the past 160 years have had many ecological consequences

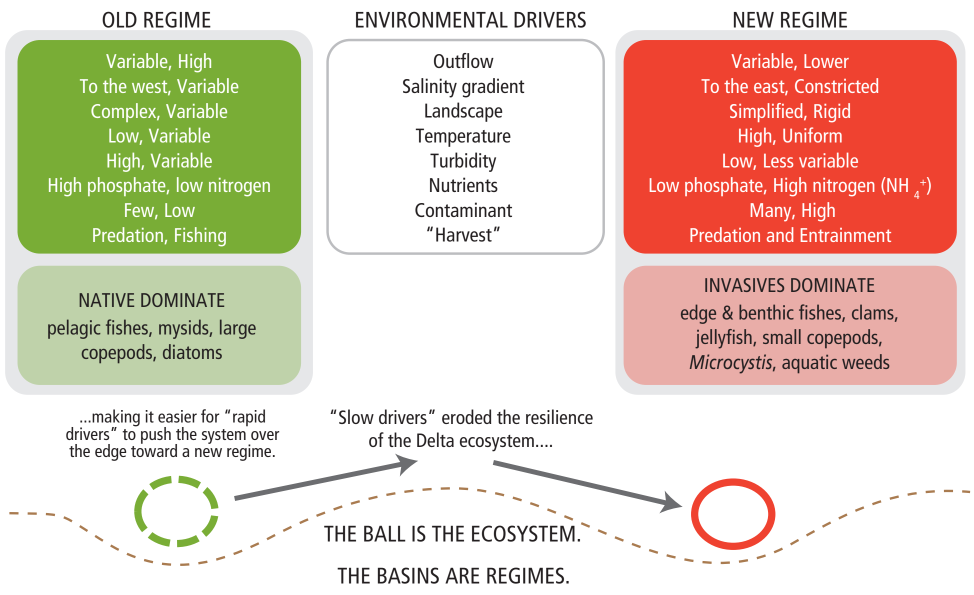
open lakes. The dynamic, branching river channels of the past gave way to a static and almost linear grid of straightened canals with steep and often rip-rapped banks. These artificially interconnected canals are used for north to south and east to west water conveyance and shipping. The once highly dynamic water flows have also changed. Most tributary rivers flowing to the Delta have been dammed and diked. This has made the flows coming into the Delta more predictable, with much fewer extremely high or low flows. Pumping of water from the Delta to the San Joaquin Valley and Southern California often leads to reversed (upstream) net flows in the channels of the central and southern Delta. Frequently, the amount of fresh water from the Delta that is pumped south is greater than the amount of Delta water that flows into San Francisco Bay. Flow alterations have led to changes in water clarity, increased salinity in the Bay, and a spatially constricted and more stable low salinity zone in the western Delta (Baxter et al. 2010, Enright and Culberson 2010, Shellenbarger and Schoellhamer 2011, Schoellhamer 2011). Other large changes in the Delta include deteriorating water quality due to increasing pollution by chemical contaminants and nutrients, and several waves of non-native species invasions that may have made the San Francisco Estuary "the most invaded estuary in the world" (Cohen and Carlton 1998) and have fundamentally changed the Delta's food web.

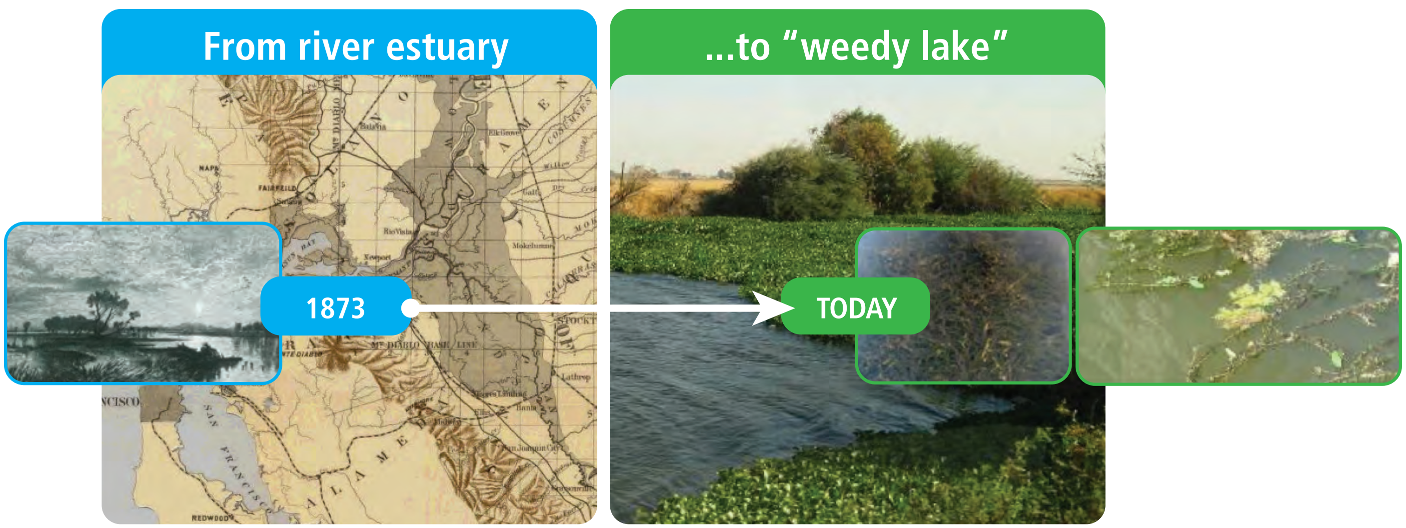
Not surprisingly, the dramatic changes in the Delta and its watershed over the past 160 years have had many ecological consequences. When the original San Carlos and Isabella plied the waters of the Delta, salmon and sturgeon were the kings of the rivers and the Delta, huge flocks of migrating birds darkened the skies, and elk and pronghorn still roamed the land. Today, non-native striped and largemouth bass have edged out the native salmon. Migrating birds, while still quite plentiful, no longer darken the skies, and human crops, cattle, and roads now cover the land. The most recent, rapid changes in the Delta have been described as an "ecological regime shift" (**SIDEBAR: REGIME SHIFT IN THE DELTA**). But this shift is only the latest in a series of dramatic changes that started 160 years ago and continue to this day. More changes are expected in response to Delta management plans (**SIDEBAR: BIG PLANS FOR THE DELTA**), changes in human water and land uses, additional species invasions, and global climate change. And there will likely be unanticipated causes of additional change. Nobody knows exactly what these changes will be. But small vessels, including the successor of the RV San Carlos, will continue to witness these big changes and monitor and study their effects. ■

More information about the RV San Carlos: http://www.water.ca.gov/bdma/sancarlos/history.cfm

A depiction of the native south Delta, along the San Joaquin River, shows winding channels, grasslands, and tule marshes, supporting populations of tule elk, sandhill cranes, white-faced ibises, white pelicans, and various ducks and geese. From Bay Nature magazine (The Once and Future Delta, in 2010 April-June issue). Original artwork by Laura Cunningham, 2010.

REGIME SHIFT IN THE DELTA





The IEP developed several conceptual models to help explore and understand the reasons for the recent "Pelagic Organism Decline" (POD) in the Delta (Baxter et al 2010). Conceptual models attempt to identify the important components of a system and determine how they affect each other. The current conceptual model posits that the POD represents a rapid ecological "regime shift" that followed a longer-term erosion of ecological resilience. This model is currently guiding ongoing and future investigations. The hypothesis is that environmental drivers that changed slowly over decades ("slow drivers") eroded the resilience of the Delta ecosystem and made it more vulnerable to the effects of drivers that changed more rapidly around the time of the POD. According to this model, the slow drivers include Delta outflow and salinity, configuration of the Delta landscape, water temperature, turbidity, nutrients, contaminants, and direct mortality of the POD fishes due to "harvest" (fishing, predation, and entrainment into the water project pumping facilities).

USING THE PAST DELTA TO INFORM ITS FUTURE

Despite broad recognition of the need to take decisive action to restore the Delta ecosystem, determining what to do where remains particularly challenging. In a place that has been altered so significantly, the most sustainable and effective actions are not obvious. We know that restoration should be performed on a large scale and not piece-meal, should take advantage of existing physical processes, and should include interconnected habitats and heterogeneous habitat mosaics (DFG et al. 2010, Moyle et al. 2010). But when it comes to developing priorities and making decisions, there is often little guidance available. Improving our understanding of historical conditions can address some of these uncertainties, allowing us to better identify fundamental restoration principles, including the effects of large-scale restoration on various aspects of water quality (e.g., nutrient availability, primary production, chemical transformations; Dahm et al. 1995, Swetnam 1999, Turner 1995)

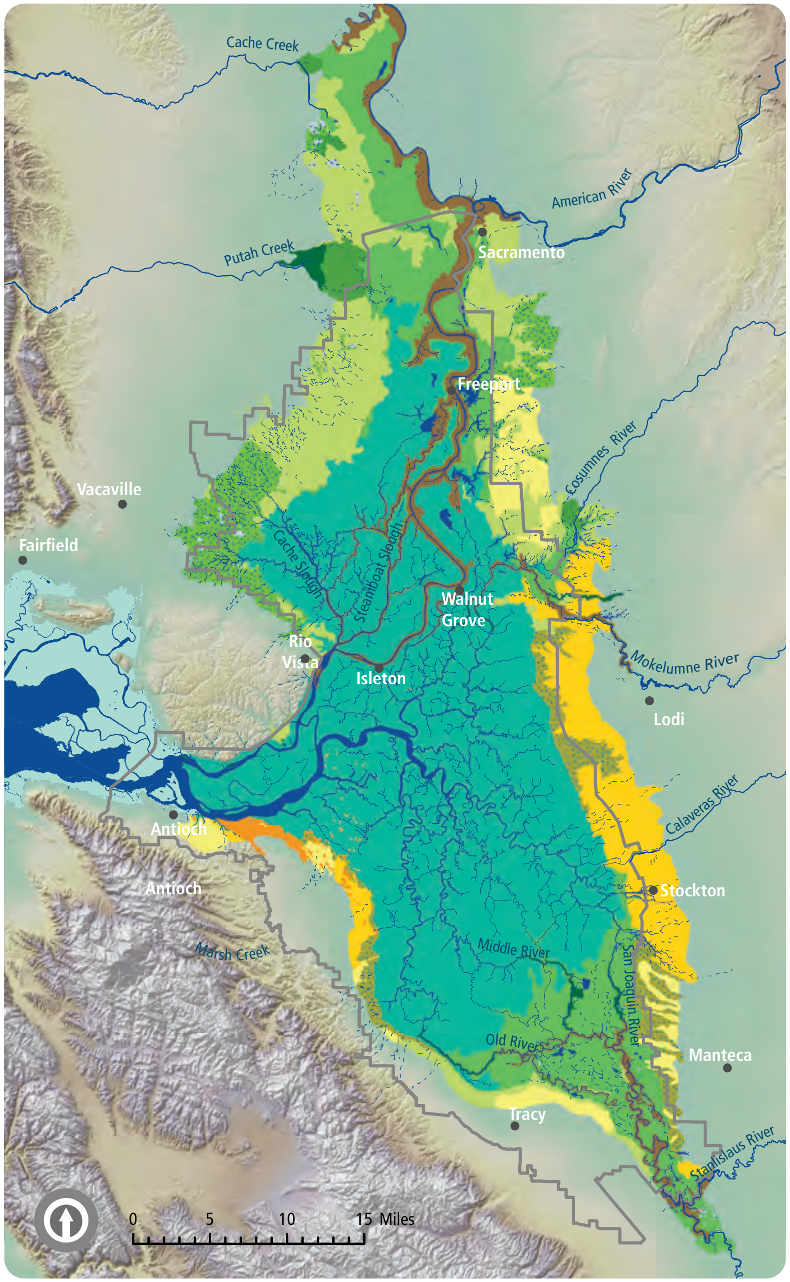
The Aquatic Science Center, in collaboration with the California Department of Fish and Game, has developed an early 1800s land cover map of the Delta. The map and an accompanying report will be finalized in the upcoming months. This work provides a glimpse into the rich landscapes of the natural Delta and offers clues to the processes that formed and maintained certain features and patterns. This new view of the Delta can be used to reset assumptions about the past, interpret the ecological functions of the historical landscape, identify priority functions and habitat mosaics for particular locations, determine measures of restoration success, and contribute to guiding landscape visions (Mika et al. 2010, Atwater 2011).

What was the Historical Delta Like?

The Delta prior to Euro-American modification was diverse at many scales. Complex habitat mosaics were arranged in distinct patterns across broad physical gradients. Over 350,000 acres of tidal freshwater wetlands lay at elevations just below high tide, and well over 1,000 miles of tidal channel wove across the plain. In the central Delta, the landscape was arranged in large islands of emergent vegetation and willows intersected by networks of sinuous tidal channels and - to the west - by sand mounds rising above the tides. Extending north along the Sacramento River, broad zones of tidal wetland transitioned into non-tidal wetlands within flood basins. Broad riparian forests bordered the flood basins. The basins received annual overflow, a portion of which was retained in ponds and lakes and slowly released through the summer months. Such conditions provided habitat for fish and waterfowl and capacity for nutrient exchange between the aquatic and wetland environments. The tidal margins of the south Delta along the San Joaquin River consisted of a maze of former meander bends and active and abandoned channels. This floodplain landscape was flooded in the spring, by snowmelt delivered by the San Joaquin River, and largely dry by late fall. Locally-complex habitat patterns existed, where riparian forest, patches of willow thicket, seasonal wetlands, and grassland intermixed with expanses of tule and perennial and intermittent ponds

Supporting a Landscape-Level Restoration Framework

The science of restoration ecology has shown that selecting and prioritizing restoration actions within a landscape framework, using landscape ecology principles, is critical to re-establishing ecological functions (Simenstad et al. 2006, Greiner 2010). Historical information can be the foundation of a landscape framework for identifying restoration strategies in the contemporary and projected future Delta. The historical Delta does not serve as a restoration template, but it provides insight into what, where, and how future functional patterns may be supported. In 2012, a new Aquatic Science Center project funded by the Department of Fish and Game will address these needs by describing aspects of the historical Delta and relating them to important ecological functions in ways directly relevant to planning and management. Development of landscape-level conceptual models, guiding principles, and metrics (that help define what "large and interconnected" means) will provide tools with which managers can better evaluate and prioritize actions. This project will also produce graphics and illustrations that present possible future landscapes of the Delta. Together, this information can help establish more resilient, functional habitat mosaics that have the capacity to adapt along with projected future physical changes (for example, those brought by climate change, sea level rise, and changing land and water use). The goal is not to recreate the past, but to develop new ideas and options that are more likely to provide the benefits we need in terms of ecological function, flood protection, and water quality (Kondolf et al. 2001, Walter and Merritts 2008).



Habitat type extent and distribution in the early 1800s Delta. This map, developed using historical sources, shows broad patterns of habitats arranged across topographical, hydrological, soil, and tidal gradients. A forthcoming report documents in detail the historical habitat characteristics of the Delta prior to significant Euro-American modification. The historical perspective can facilitate the identification of patterns and processes relevant to restoration and planning.

Historical habitat types (draft)

- Water
- Tidal brackish emergent wetland
- Tidal freshwater emergent wetland
- Nontidal freshwater emergent wetland
- Valley foothill riparian
- Willow riparian scrub/shrub
- Willow thicket
- Alkali seasonal wetland complex
- Vernal pool complex
- Wet meadow/seasonal wetland
- Interior dune scrub
- Grassland
- Woodland/savanna

References:

Atwater, B. 2011. Loss of the Delta's historical landscape as an ecological stressor. Delta Independent Science Board. http://archive.deltacouncil.ca.gov/delta_science_program/pdf/isb/d-isb_200110112_stressor_atwater_template_habitat_loss.pdf

California Department of Fish and Game, National Marine Fisheries Service, U.S. Fish and Wildlife Service. 2010. Ecosystem Restoration Program Conservation Strategy for Stage 2 Implementation: Sacramento-San Joaquin Delta Ecological Management Zone. http://www.dfg.ca.gov/ERP/reports_docs.asp

Dahm, CN, Cummins KW, Valett HM, et al. 1995. An Ecosystem View of the Restoration of the Kissimmee River. Restoration Ecology 3(3):225-238.

Greiner CM. 2010. Principles for strategic conservation and restoration. Puget Sound Nearshore Ecosystem Restoration Project.

Kondolf, GM, Smeltzer, MW, Railsback, SF. 2001. Design and performance of a channel reconstruction project in a coastal California gravel-bed stream. Environmental Management 28(6):761-776.

Mika S, Hoyle J, Kyle G, et al. 2010. Inside the "Black Box" of River Restoration: Using Catchment History to Identify Disturbance and Response Mechanisms to Set Targets for Process-Based Restoration. Ecology and Society 15(4):8.

Moyle PB, Bennett WA, Fleenor WE, et al. 2010. Habitat Variability and Complexity in the Upper San Francisco Estuary. Center for Watershed Sciences, University of California, Davis.

Simenstad C, Reed D, Ford M. 2006. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecological Engineering 26:27-39.

Swetnam TW, Allen CD, Betancourt JL. 1999. Applied Historical Ecology: Using the Past to Manage for the Future. Ecological Applications 9(4):1189-1206.

Turner MG. 1989. Landscape ecology: The effect of pattern on process. Annual Review of Ecology and Systematics. 20: 171-197.

Walter RC, Merritts DJ. 2008. Natural streams and the legacy of water-powered mills. Science 319:299-304.

REFERENCES

MANAGEMENT UPDATE

FORESMAN

Interim Federal Action Plan for the California Bay-Delta (Dec. 22, 2009), available at http://www.doi.gov/documents/CAWaterWorkPlan.pdf

Jabusch, T. 2010. Ammonia in the Delta: state of the science, implications for management. Pulse of the Delta, Aquatic Science Center, Oakland, CA, p. 30-39. URL http://www.aquaticscience.org/2011_ASC_PulseOfThe-Delta_final.pdf

USEPA. 2011. Water quality challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Unabridged Advanced Notice of Proposed Rulemaking. URL http://www.epa.gov/region9/water/watershed/sfbay-delta/pdf/BayDeltaANPR-fr_unabridged.pdf

SUTULA

Cloern, J.E., Jassby, A.D., Thompson, J.K., Hieb, K.A. 2007. A cold phase of the East Pacific triggers new phytoplankton blooms in San Francisco Bay. Proceedings of the National Academy of Sciences, V. 104(47), p. 18561-18565.

Cloern, J.E., Hieb, K.A., Jacobson, T., Sansó, B., Di Lorenzo, E., Stacey, M.T., Largier, J.L., Meiring, W., Peterson, W.T., Powell, T.M., Winder, M., Jassby, A.D. 2010. Biological communities in San Francisco Bay track large-scale climate forcing over the North Pacific. Geophysical Research Letters, V. 37, L21602. URL http://www.agu.org/pubs/crossref/2010/2010GL044774.shtml

Cloern, J.E., Dugdale, R.C. 2010. San Francisco Bay. Nutrients in Estuaries: A summary report of the National Estuarine Experts Workshop 2005-2007, p. 117-127. URL http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/Nutrients-in-Estuaries-November-2010.pdf

Dugdale, R.C., Wilkerson, F.P., Hogue, V.E., Marchi, A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science, V. 73, p. 17-29.

Jabusch, T. 2010. Ammonia in the Delta: state of the science, implications for management. Pulse of the Delta, Aquatic Science Center, Oakland, CA, p. 30-39. URL http://www.aquaticscience.org/2011_ASC_PulseOfThe-Delta_final.pdf

Lehman, P.W., Boyer, G., Satchwell, M., Waller, S. 2008. The influence of environmental conditions on the seasonal variation of Microcystis cell density and microcystins concentration in San Francisco Estuary. Hydrobiologia, V. 600, p. 187-204.

McKee, L.J., Sutula, M., Gilbreath, A.N., Beagle, J., Gluchowski, D., Hunt, J. 2011. Numeric nutrient endpoint development for San Francisco Bay - Literature review and Data Gaps Analysis. Technical Report 644. Southern California Coastal Water Research Project, Costa Mesa, CA. URL http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarineNNE/SFBay%20NNE%20Literature%20Review%20Draft%20Final%204-27-%202011.pdf

Nixon, S.W. 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnology and Oceanography, V. 33, p. 1005–1025.

Smith, S.V., Hollibaugh, J.T. 2006. Water, salt, and nutrient exchanges in San Francisco Bay. Limnology and Oceanography, V. 51, p. 504-517.

Sutula, M. 2011. Review of candidate indicators for development of nutrient numeric endpoints in California estuaries. Technical Report 646. Southern California Coastal Water Research Project, Costa Mesa, CA.

FEATURE ARTICLES

WINDHAM-MYERS

Ackerman, J.T., Eagles-Smith, C.A. 2010. Agricultural wetlands as potential hotspots for mercury bioaccumulation: experimental evidence using caged fish. Environmental Science and Technology, V. 44, p. 1451–1457.

Alpers, C.N., Eagles-Smith, C., Foe, C., Klasing, S., Marvin-DiPasquale, M.C., Slotton, D.G., Windham-Myers, L. 2008. Mercury conceptual model. Mercury conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. http://www.science.calwater.ca.gov/pdf/drerip/DRERIP_mercury_conceptual_model_final_012408.pdf

California Regional Water Board. 2007. Control of methylmercury in the Delta, Draft Basin Plan Amendment Staff Report, Revised Draft Basin Plan Amendment (February 2007). Central Valley Regional Water Quality Control Board, Rancho Cordova, California.

Foe, C., Davis, J., Schwarzbach, S., Stephenson, M., and Slotton, D. 2003. Conceptual Model and Working Hypotheses of Mercury Bioaccumulation in the Bay-Delta Ecosystem and its Tributaries http://mercury.mlml.calstate.edu/reports/2003-reports/

Heim, W.A., Stephenson, M., Byington, A., Feliz, D., Sousa, L., Coale, K. In review. Best Management Practices to Reduce Methylmercury Concentrations and Exports from Seasonal Wetlands in the Yolo Wildlife Area, California. Science of the Total Environment.

Henneberry, Y.K., Kraus, T. E.C., Fleck, J.A., Krabbenhoft, D.P., Bachand, P. M., Horwath, W.R. 2010. Removal of inorganic mercury and methylmercury from surface waters following coagulation of dissolved organic matter with metal-based salts. Science of the Total Environment, V. 409, p. 631-637.

Marvin-DiPasquale, M., Alpers, C.N., Fleck, J.A. 2009a. Mercury, methylmercury, and other constituents in sediment and water from seasonal and permanent wetlands in the Cache Creek Settling Basin and Yolo Bypass, Yolo County, California, 2005–06. Open File Report 2009-1182. U.S. Geological Survey, Menlo Park, California, URL http://pubs.usgs.gov/of/2009/1182. Supplemental Data, available on request.

Marvin-DiPasquale, M., Windham-Myers, L., Agee, J.L., Kakouros, E., Kieu, L.H., Fleck, J., Alpers, C.N., Stricker, C. In review. Methylmercury production in sediment from agricultural and non-agricultural wetlands in the Yolo Bypass, California. Science of the Total Environment.

Slotton, D.G., Ayers, S.M., Suchanek, T.H., Weyand, R.D., Liston, A.M., Asher, C., Nelson, D.C., Johnson, B. 2002. The effects of wetland restoration on the production and bioaccumulation of methylmercury in the Sacramento-San Joaquin Delta, California. University of California, Davis, California. URL http://loer.tamug.edu/calfed/Report/DraftFinal/UCD_Delta_Report.pdf

Ulrich, P., Sedlak, D. 2010. Impact of iron amendment on net methylmercury export from tidal wetland microcosms. Environmental Science and Technology, V. 44, p. 7659-7665.

Windham-Myers, L., Marvin-DiPasquale, M., Krabbenhoft, D.P., Agee, J.L., Cox, M.H., Heredia-Middleton, P., Coates, C., Kakouros, E. 2009. Experimental removal of wetland emergent vegetation leads to decreased methylmercury production in surface sediment. Journal of Geophysical Research - Biosciences, V. 114, G00C05. URL http://www.agu.org/pubs/crossref/2009/2008JG000815.shtml

Windham-Myers, L., Marvin-DiPasquale, M., Fleck, J.A., Alpers, C.N., Ackerman, J., Eagles-Smith, C., Stricker, C., Stephenson, M., Feliz, D., Gill, G., Bachand, P., Rice, A. Kulakow, R. 2010. Methylmercury cycling, bioaccumulation, and export from natural and agricultural wetlands in the Yolo Bypass. San Jose State University Research Foundation, Moss Landing, California. URL http://water.usgs.gov/nrp/proj.bib/Publications/2010/windham-myers_marvin-dipasquale_etal_2010.pdf

MUELLER-SOLGER

Brooks, M.L., Fleishman, E., Brown, L.R., Lehman, P.H., Werner, I., Scholz, N., Mitchelmore, C., Johnson, M.L., Schlenk, D., van Drunick, S., Drever, J., Stoms, D.M., Parker, A.E., Dugdale, R. 2012. Life Histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. Estuaries and Coasts: in press.

Cloern, J.E., Knowles, N., Brown, L.R., Cayen, D., Dettinger, M.D., Morgan, T.L., Schoellhamer, D.H., Stacey, M., van der Wegen, M., Wagner, W.R., and Jassby, A.D. 2011. Projected evolution of California's San Francisco Bay-Delta-River system in a century of climate change. PLoS ONE, V. 6(9). URL http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0024465

Delta Stewardship Council. 2011. Fifth Staff Draft Delta Plan. URL http://www.deltacouncil.ca.gov/sites/default/files/documents/files/Fifth_Staff_Draft_Delta_Plan_080211.pdf

Thomson, J.R., Kimmerer, W. J., Brown, L. R., Newman, K. B., Mac Nally, R., Bennett, W.A., Feyrer, F., Fleishman, E. 2010. Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications, V. 20: p. 181-198.

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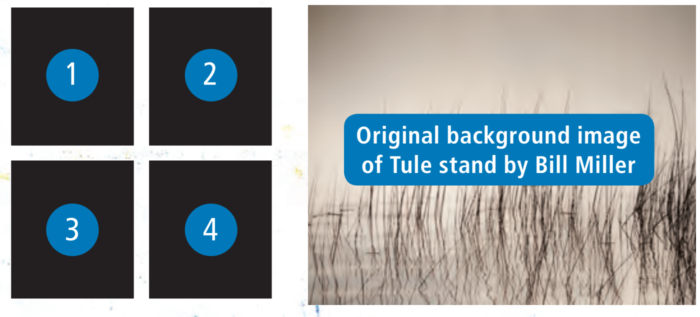

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