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there is a large and complex literature that addresses the question of optimally employing science in environmental policy. That literature mostly focuses on the challenges of efficient and effective interactions; it is probably fair to say it is long on identifying problems and short on answers. As a complement to the existing literature as well as the BDCP and the DSC's science plan, we invited nine experts each to write a 2000 word essay addressing the statement that science will guide policies concerning water supply reliability and ecosystem restoration in the Bay-Delta.

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OCTOBER 2013

SF E&W S
San Francisco
Estuary & Watershed Science:
A Broad Perspective

Essays on Science and Policy in California's Bay–Delta

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California Governor Jerry Brown and former Secretary of the Interior Kenneth Salazar, in releasing the Bay–Delta Conservation Plan (BDCP) on July 25, 2012, stated that:

> "*Science will guide how to best restore the [Bay–Delta] ecosystem and how much water can be exported.*" (Natural Resources Agency 2012)

The proclamation did not state how this would be accomplished, but set a deadline at the close of 2013 for establishing decisions about how science will guide policy. Phil Isenberg, Chairman of the Delta Stewardship Council (DSC), noted that "policymakers need the scientific community to tell us what [the scientific community] needs, how their involvement should be structured, and when and where they should get involved." California is poised to take the next step in building a science-based water policy and our leaders want to hear from the science community about what that should look like.

The DSC's Science Program released a draft Science Plan for public comment on June 18, 2013. That plan addresses many of the basic questions about structuring science for the Bay–Delta. But a broader dialogue on science–policy partnership might also be in order to complement the Science Plan and the BDCP. *San Francisco Estuary and Watershed Science* might be one logical outlet to continue the non-partisan dialogue initiated by the release of the Science Plan, especially given the journal's role as a partner in the DSC's Science Program.

To that end, I invited nine experts each to write a 2,000-word essay addressing the statement that science will guide policies concerning water supply reliability and ecosystem restoration in the Bay–Delta. The idea came from a discussion with two editorial board members and Phil Isenberg. The experts that were invited are all leaders with substantial experience in working between science and policy. Their backgrounds vary: from natural scientists and engineers to social scientists and policymakers and influencers. Some of the authors are independent outside experts, some are people

who are deeply involved in Bay–Delta issues. Few constraints were placed on the essays' content other than addressing the science–policy question and restricting its length. The fact that nine people of this stature, leaders in both California and elsewhere in the nation, were willing to spend time thinking and writing about Bay–Delta issues speaks to the global interest in how we address our challenges with water in California, as well as the importance of the science–policy question in this context.

"The Bay–Delta essays add to this literature in three ways... The diversity of approach reflects how complex it is to optimally mesh science into policy."

There is a large and complex literature that addresses how to optimally use science to guide environmental policy. That literature mostly focuses on the difficulties of establishing efficient and effective interactions. It is probably fair to say the literature is long on identifying problems and short on success stories. The Bay–Delta essays add to this literature in three ways: Some take a broad perspective; some deal directly with science and policy for the Bay–Delta; and some are case studies. The diversity of approach reflects how complex it is to optimally mesh science into policy. There is not one science and one policy, yet we do need bridges to tie them together. The essays identify many nuances in both science and policy that can facilitate or hinder interaction. Considering these nuances, many bridges are probably needed. Our essays suggest that in some cases we can predict aspects of the outcome with reasonable certainty should successful bridges be built. In other cases, there is more uncertainty.

We have made progress in building a solid base of scientific knowledge about the Bay–Delta. The draft Science Plan presents a vision for next steps and a general vision for policy progress may also be taking form. But there is a uniform consensus among the essays that we can do better. There are serious problems with the approach that dominated the last decade, and that approach must change. The future is likely to hold even greater challenges than today, making it paramount that change begin immediately. Words used to characterize these challenges included: "complexity," "uncertainties," "institutional fragmentation," "disrespect and distrust among parties with different interests," "combat science," "value-driven choices," "obstacles to change," and "cultural divide." Yet there is also a clear, unanimous opinion that there are ways to move beyond the dysfunctions of the past. Scientists have (perhaps new) responsibilities if we are to change the approach, as do policymakers and influencers. Clarifying goals, building trust and facilitating linkages are common themes and some insightful approaches are identified for doing so. "Vision," "collaboration," "coalitions," "supportive leadership," "means for changing policy," and "sustained commitment" are words that described the broad recognition that it is time to begin working together in new ways. Adaptive management is seen as one bridge between science and policy, albeit a challenging one to implement. Better communication is another. And specific examples are given of how we might make progress with both.

Each of these essays, in its own right, is thought provoking and insightful. My overall impression from them is that the challenges in addressing water policy issues in California are great, but it is feasible to improve how science can and should be used to guide policy. If we can do that, progress toward solving the larger problems is pos-

sible. At *SFEWS* we are humbled that we can publish these essays in one place. I urge you, our readers, to read all of them and think about their messages. I encourage our leaders do so as well. There is much that is applicable, in a positive way, to aid us in our journey toward a sustainable water future in California.

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SF E&W S San Francisco Estuary & Watershed Science: A Broad Perspective

Six Lessons Learned in Applying Science to Coastal Ecosystem Restoration

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INTRODUCTION

The commitment of the state and federal leadership for the Bay Delta Conservation Plan (BDCP) stating that "science will guide how to best restore the ecosystem and how much water can be exported" is welcome, of course. Further, the invitation from the Delta Stewardship Council to the scientific community to indicate what is needed and how the scientific engagement should be structured offers an opportunity to provide that guidance.

However, excellent and internationally recognized science has long been generated on the Bay–Delta ecosystem and programs and structures to develop and apply science in Bay–Delta decision-making have existed for several decades. Is this new commitment to science-guided decision-making merely lip service or does it present an unprecedented opportunity? If so, how can scientific engagement be more effective going forward? And, is the scientific and engineering community really up to it?

Here I offer six lessons learned from 40 years of experience conducting and applying science for the management and restoration of coastal ecosystems in many parts of the United States and internationally. In particular, I have worked many years on the Chesapeake Bay, the Mississippi Delta, the Florida Everglades, and the Baltic Sea. Recently, I was called on by President Obama to serve on the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (Oil Spill Commission 2011). In that effort, I was on the other side of the fence, gaining rare experience for a practicing scientist in sifting though voluminous information to determine what really matters for making decisions and policies, and on a very condensed time-table.

From these experiences I offer this advice to scientists, engineers, and technical managers on how best to take advantage of the opportunity available for science-based decision-making under the BDCP, recognizing that policymaking itself is outside of

my expertise and influence. My six lessons are not in any way exhaustive, but merely identify ways to overcome some common pitfalls that limit the effectiveness of science applied to policy.

SIX LESSONS FOR APPLYING SCIENCE TO POLICY

1. Focus diligently on what is known, while working to advance knowledge. Avoid the "little is known" rhetorical trap into which scientists often fall—it only puts science out of the game. By nature of their practice, scientists focus on things that are unknown or imperfectly known, particularly as they relate to their own disciplinary interests, often producing more new questions than answers. Many scientific questions cannot be fully resolved or do not really matter in decision-making. The fact is that we know quite a lot about how the riverine-coastal systems we study work. So, we should not start making laundry lists of research needs until we have done our best to address the questions based on existing knowledge and reasoned inference. Only then can we understand what new and attainable information will truly better inform decisions.

2. Scientists should get out of their skins and understand the larger contexts of both real-world consequences and policy formulation. While workshops and other synthetic processes can help, it is fundamentally the responsibility of all participating scientists to spend time to educate themselves about these larger contexts. In following the scientific findings and debates related to the effects of the BP Deepwater Horizon oil spill, both as a broadly experienced oceanographer and a former Commissioner, I am dismayed by the misconceptions and irrelevance in many of the writings and presentations of my scientific colleagues. Extrapolations from experiments or limited observations betray lack of understanding of the broader biophysical processes at work in the Gulf of Mexico. And, many passionately pursued scientific questions and debates are, as far as I can see, irrelevant to policy or management decisions or improvements.

3. Computational models have become essential to the quantitative integration and application of scientific information, but scientists and decision-makers should have a healthy respect for the limitations in their accuracy and uses. We should remember the aphorism of the pioneering statistician George Box: "All models are wrong, but some are useful." The Chesapeake Bay Program is justifiably proud of its development and application of linked atmospheric, land-use, watershed, and estuarine models to guide efforts to alleviate eutrophication and restore water quality and ecosystem health. But participants in the program become entrained in a singular and deceptively precise model world without remembering that the environment and the society that affects it is the reality—not the model. Actions are delayed while waiting for the models' next version, which, as Box admonished us, will never be right. Critical assumptions go untested and outcomes unverified because of over-reliance on the models (NRC 2011). Instead, the adaptive management that the Chesapeake Bay Program and many other ecosystem restoration programs are attempting to apply requires that models are

closely integrated with and reconciled by observations. It also recognizes the uncertainties not represented in deterministic models and provides a basis both for narrowing these uncertainties and for making decisions in the face of them.

4. Too often, high quality and relevant scientific information goes unheeded in decision-making because it is buried in an esoteric paper or, even worse, an un-reviewed technical report. New modes for effective integration and application of science are required that incorporate communication strategies, not just as an afterthought, but as an integral component. For example, my own University of Maryland Center for Environmental Science has attempted to do this by creating an Integration and Application Network (*http://ian.umces.edu/*). These modes must be efficient and timely because expertise is a rare commodity that should not be wasted in endless meetings, but focused sharply and critically. The scientific community must organize for more timely and decisive resolution of controversies that can paralyze decision-making. An example from my own experience concerns the efficacy and unintended consequences of diversions along the lower Mississippi River as a means of sustaining and restoring tidal wetlands. Even then, a position paper on the controversy (Teal et al. 2012) was released nearly 2 years after the workshop airing the conflicting perspectives. Certainly, the Bay–Delta has seen its share of paralyzing controversies that need to be addressed in an objective and timely manner and, to the degree possible, decisively.

5. Scientists must become more adept at understanding and using complex networks through which science influences decision-making. Structures for scientific engagement usually assume a linear model wherein scientists communicate their findings and recommendations to a professional analyst, who communicates with an agency administrator, who communicates with policymakers. Science-based decision making rarely works through such a simplified linear model, but through more complex networks that shape opinions among key influencers, contributing to levels of certainty acceptable to prompt action (Keller 2009). Public awareness as shaped by the news media can play a key role in this regard, and I have had numerous personal experiences in which high-level political leaders only understood or paid attention to the issues after reading about it in newspapers (Boesch 2013). As a result, I have placed emphasis on developing skills and building networks for communication with the news media and even, somewhat timidly, through social media. Boundary organizations, such as COMPASS (Smith et al. 2013), help scientists connect themselves and their science to the wider world and are important in ensuring that science is better understood and used by society.

6. We can no longer treat climate change as a separate issue in ecosystem restoration and resource conservation, one that can be avoided because of controversy or postponed for later consideration. The evidence is clear that climate change is already affecting ecosystems and resources and will have even greater influence over the coming decades. This means coastal scientists have to factor in warming, sea-level rise (NRC 2012), changes in water resources, and other consequences in research, modeling, and

assessment. However, this must be done in a measured way to avoid confusion about or postponement of the issues at hand. For example, it is clear that climate change will affect the temperature, depth, and circulation of the Chesapeake Bay—and very likely the amount and timing of runoff—in ways that will change the reductions of nutrient loads that are required to achieve restoration goals (Najjar 2010). However, it is nothing but distracting to attempt to change the load reduction goals set for 2025 now, when the changes expected in that time frame, particularly about runoff, are highly uncertain. Rather, the focus should be on achieving the 2025 goals, given that subsequent adaptation, whether it is to population growth, changes in agriculture, or climate change, will be perpetually required. But this does not mean ignoring climate change adaptation, which can be considered in designing solutions such as improved stormwater management systems. Furthermore, recognizing future requirements for reducing greenhouse gas emissions can lead to a broader array of now more feasible solution sets for watershed and estuarine restoration.

So, colleagues, consider the invitation for a new scientific engagement in the BDCP a real opportunity, yet to exploit it we will have to pick up our game by applying these and other lessons learned from many years of work in the Bay–Delta and around the world.

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San Francisco Estuary & Watershed Science: Science & Policy for the Delta

Using Science to Restore California's Bay-Delta

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The State of California and the U.S. Department of Interior have committed to relying on science as a guide to both restoring the Bay–Delta ecosystem and deciding how much water can be exported from that system. In theory, upholding this commitment should be straightforward. In practice, however, figuring out how science can and should guide policymaking is challenging when the problem at hand is complex and multifaceted, and features a cast of savvy, powerful stakeholders with sharply different interests. One reason is that participants in such controversies have long used debates over science as proxies for debates over values. The conflict over the Bay–Delta is no different; recently, for example, representatives of large-scale water users dismissed the suggestion that too much water is being exported from the Bay–Delta system, although more than three-quarters of the scientists surveyed by the Public Policy Institute of California (PPIC) believe that excessive water withdrawals pose a problem (Anonymous 2013).

To make progress in this situation, state and federal policymakers should take a series of bold steps. First, they should articulate a single, clear, overarching goal of ecological restoration for the Bay–Delta. Next, they should establish an adaptive process for soliciting scientific advice and adjusting management to ensure it is consistent with that goal. And finally, they should emphasize the translation of scientific research into compelling political stories that highlight both the intrinsic value of ecological restoration and its necessity for achieving other highly valued goals.

My argument is rooted in the recognition that improvements in the scientific understanding of a problem do not necessarily lead to "better" or more rational policies to address that problem (Layzer 2012). In fact, more science can actually exacerbate policy conflicts, particularly when a policy dispute features players with sharply different values (Graham et al. 1988). In part, this is because additional science can reveal new sources of uncertainty, which advocates can exploit. But, more important,

it is because when we ask scientists to answer policy-relevant questions the results are not scientific but trans-scientific; that is, they require scientists to make judgments about risk based on the best-available information (Rushefsky 1986; Weinberg 1972). Embedded in any scientific judgment are value-based assumptions about acceptable levels of risk and the relative importance of various factors contributing to that risk (Litfin 1995). Participants in environmental policy disputes often capitalize on the inherent uncertainty of and judgments involved in regulatory science to promote their own versions of science as authoritative—a phenomenon Robert Service (2003) calls "combat science." The result is intractable technical disputes that conceal fundamental value differences.

The longstanding effort to devise a plan for the Bay–Delta ecosystem is no exception to this pattern; despite decades of negotiations, conflicts over values continue to underpin disputes over science. Underscoring this reality are the conclusions of the PPIC. In its recent report, *Scientist and Stakeholder Views on the Delta Ecosystem*, the PPIC notes:

> The lack of shared understanding on Delta science is a major obstacle to effective ecosystem investments. Most engaged stakeholders consult scientific and government reports regularly, but *key groups that would be affected by change often come to different conclusions than most scientists (and other stakeholder groups) on the nature of both the problem and solutions.* (Hanak et al. 2013, p. 3; emphasis mine).

In short, despite being exposed to the same information, stakeholders draw very different conclusions about what is wrong and what ought to be done.

Counter-intuitively, conflict in the Bay–Delta is exacerbated by the fact that, historically, policymakers have set multiple, co-equal goals. CALFED pursued four goals: (1) restoring the ecosystem, (2) ensuring water supply reliability, (3) enhancing the integrity of the levee system, and (4) improving water quality. More recently, the 2009 Delta Protection Act made ecological restoration and water supply reliability co-equal objectives. And in spring 2013, Jerry Meral, deputy secretary of the California Natural Resources Agency, argued in the *Sacramento Bee* that the recently released draft Bay Delta Conservation Plan (BDCP) offered California the opportunity to attain four goals simultaneously: (1) make its water supplies safer and more secure, (2) avoid the impacts of a natural disaster, (3) restore the ecological health of the Delta, and (4) enhance Delta communities. Insistence on meeting multiple, co-equal goals ostensibly ensures that all stakeholders feel enfranchised. As long as all stakeholder demands are considered equally legitimate, however, disagreements over science are likely to persist—even as policymakers strive (unsuccessfully) to satisfy everyone, or at least to avoid imposing perceptible costs on anyone—at the expense of long-term ecological health.

To mitigate this phenomenon, leaders should establish ecological restoration as the single, overarching goal of management, while seeking to meet other objectives—from water supply reliability to economic development in the Delta—within that constraint. Establishing ecological restoration as the primary goal of management alters the questions we ask of scientists. For example, in effect, policymakers currently ask: What is the minimum amount of water we can leave in the ecosystem without destroying it? If the overall goal is a healthy, functioning Bay–Delta system, however, policymakers might ask: How much water does the ecosystem need to be resilient in the face of variations in climate? Once scientists have established a probabilistic range, policymakers can legitimately select a precautionary water level. They can then work with scientists to allocate the remaining water in ways that impose minimal risk on the health of the ecosystem. This framing will, of course, lead to uncomfortable questions and answers, and require substantial sacrifices among water users. But our early experience with large-scale ecosystem restoration suggests it is the only framing that is likely to result in ecological improvement over time (Layzer 2008).

Of course, even with an overarching commitment to restoration, scientific disagreements will arise. For example, scientists will differ over what constitutes a healthy, functioning Bay–Delta ecosystem in the 21st century, in light of the massive changes that have been made. They will debate when and where water withdrawals can be made without impairing the resilience of the system as a whole. Therefore, it is essential to create an adaptive process that engages scientists in the establishment of criteria and benchmarks for success, as well as the development of mechanisms likely to yield the desired results and facilitate adjustments in response to learning over time. Unfortunately, we have few working models of this kind of adaptive process; the most widely cited example involves governing the waterfowl harvest in the Northeast—a situation in which the management objective was clear (to maximize the long-term utility of the harvest) and the benefits of reducing uncertainty were high (Nichols et al. 2007).

More commonly, planners have used adaptive management as an excuse to incur ecological risk, reasoning that management can be adjusted in the future as necessary (Layzer 2008). The BDCP appears to take this tack; for example, in April 2013 the National Marine Fisheries Service raised concerns that the (current draft of the) BDCP assumes its restoration measures will achieve the plan's goals, yet contains little scientific evidence on which to base this assessment (Weiser 2013). This is typical of how large-scale projects like the Everglades Restoration treat scientific uncertainty: by adopting optimistic assumptions about the efficacy of minimalist conservation and restoration measures while ensuring that the demands of water users are met, explaining that adaptive management will correct any deficiencies over time. By contrast, if the overarching goal of the Bay–Delta plan were ecological restoration, planners would work closely with scientists to build in buffers to accommodate uncertainty, so that the risk of failure would fall on water users, not the ecosystem. The emphasis of adaptive management would be on devising experiments to test the efficacy of

mechanisms for meeting agricultural and urban water needs (as opposed to demands) with minimal environmental effects.

To build political support for ecological restoration, and for an adaptive management process in service of that goal, policymakers must support not just basic (or even applied) research, but also translation of science into language that policymakers and the public can understand. Scientists working in the Bay–Delta have undergone a decades-long process of "learning" that science alone does not move policy, but rather that science must be converted into stories that resonate with the media, policymakers, and the public. The CALFED Science Program, created in 2000 to inform the collaborative process while remaining neutral, yielded high-quality scientific research and enhanced scientists' knowledge of the Bay–Delta system, but had little discernible impact on policy or politics. In an effort to exert greater influence, beginning in 2007 scientists at the University of California at Davis and the PPIC collaborated on a series of white papers directed at policymakers and the expert community. These papers explicitly pointed out the policy implications of their research, while emphasizing that their recommendations were rooted in credible science (Simmons 2013). Most recently, the San Francisco Estuary Institute collaborated with radio station KQED's Quest science program to create a series of radio stories and interactive materials that convey Bay–Delta history, ecology, and management issues to a broad audience. The hope of its creators was that the series would engage a wider swath of the public than has traditionally been engaged in Bay–Delta politics (Simmons 2013).

While this evolution in tactics is revealing, being asked to translate their research into compelling political narratives creates discomfort among scientists because most strive to maintain a posture of neutral objectivity. They worry that generating simple narratives rooted in explicit values will jeopardize colleagues' perceptions of their professional legitimacy and credibility. Moreover, few are comfortable in the political spotlight or have received training in how to communicate with non-technical audiences. As Andrew Cohen, founder of the Center for Research on Aquatic Bioinvasions, explains, "people go into science to remove themselves from politics. That's what I wanted, but it didn't work out that way" (quoted in Simmons 2013). The science–policy translation challenge has only deepened with the fracturing and polarization of the media. No longer does the public have access to just a handful of information sources; over the past two decades, ideologically based websites have become the norm, with the result that many citizens receive only the news they seek out. During the same period, traditional media outlets—and particularly local newspapers like the *Contra Costa Times*, the *Sacramento Bee*, the *Stockton Record*, and even the *San Francisco Chronicle*—have dramatically curtailed their staff and therefore coverage of Delta-related issues; many of the trained science writers are gone, and generalists are now expected to cover the state's complex, long-standing water controversies (Simmons 2013).

Designating knowledge brokers who are credible and legitimate, and capable of synthesizing the available science, can enable researchers to maintain their professional status while devoting some of their resources to the translation function. Supporting scientists who undergo training in communication, like the kind that organizations such as COMPASS provide, can empower those with strong credentials but little confidence in the public realm. And creating rewards—within academia as well as within state and federal agencies—for those who are skilled at integrating scientific information into policy recommendations will improve the likelihood that scientists with strong communication skills will emerge and opt to take that path.

These recommendations will be controversial. As it turns out, prescribing a process for effectively incorporating science into policymaking is relatively straightforward. The difficulty lies in choosing the goal we are asking science to serve—at least in the realm of ecological restoration. We have no such qualms about, say, cancer or diabetes research; we readily acknowledge that disease is a scourge and that we conduct scientific research in hopes of "curing" it. When it comes to restoring the ecological systems that support life on earth, we are unwilling to make the same commitment. But doing so will strengthen the science–policy link while greatly improving the prospects for achieving all of our goals for the Bay–Delta ecosystem.

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San Francisco Estuary & Watershed Science: Science & Policy for the Delta

Mutual Benefits: Linking Science and Policy in the Delta

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Introduction

Scientists and decision-makers in the San Francisco Bay–Delta are not unique. Ecosystem management programs worldwide are exploring ways to better link science and policy as a means to enhance and restore the services that ecosystems provide to society. Improving the effectiveness of this link requires policy-relevant scientific research, effective communication of research findings, and an efficient means of altering policy when the desired outcomes are not achieved or when relevant scientific understanding changes.

Enhancing Policy-relevant Scientific Research

Science will not provide clear policy solutions, but it can be useful in establishing the boundary conditions within which a policy decision can be reached.

Fostering policy-relevant scientific research requires dynamic leaders in both science and policy arenas and interactions that build trust among them. To be effective, the science needs to address relevant questions, meet standards of scientific rigor, and be unbiased politically (Clark et al. 2002 in Van Cleve et al. 2004). This requires scientists who are independent and informed about the issues that managers and policymakers face and who recognize that increased scientific understanding can result from research inspired by policy questions. Yet research shouldn't be driven only by current policy questions. Long-term and anticipatory research is essential to develop the scientific knowledge base that will be needed for future decisions. These goals are facilitated by respectful interaction between both researchers and the policymakers whose decisions will be informed by the information gathered.

An effective structure for policy-relevant science acknowledges that disagreements among scientists are inevitable (e.g., differing interpretations of data or competing restoration proposals) and provides mechanisms for resolving these disagreements. Means of resolution include establishing a scientific assessment process (e.g., workshops aimed at achieving a consensus-based scientific understanding from exist-

ing studies); engaging a diverse community of scientists to develop conceptual and numerical models to explore the consequences of differing management alternatives (Van Cleve et al. 2004); and designing a series of experiments or a monitoring program to resolve disagreements.

Science will not provide clear policy solutions, but it can be useful in establishing the boundary conditions within which a policy decision can be reached (Meyer et al. 2010) and in articulating the likely consequences of policy alternatives. One compendium of lessons learned from several ecosystem management programs recommended scientific involvement early in program development (Van Cleve et al. 2004). They observed that when science was involved after program structure was fixed, the alternatives that could be evaluated were limited (e.g., only engineering solutions were considered). As a consequence, stakeholders were more likely to question whether all technically viable alternatives had been examined.

Although it is not a panacea (Shreiber et al. 2004), *adaptive management remains the most promising approach to managing complex ecosystems in the face of incomplete knowledge and changing conditions.*

Communicating Science Effectively

Scientists all too often want to present the facts and then step back from the process. However, both policymakers and the public to whom they are responsible require clear and compelling images and statements that convey scientific findings and their relevance to policy decisions. Simply reporting data without providing the policy context is not a productive approach (Groffman et al. 2010). Effective communication among scientists, policymakers and the public requires dialogue and an exchange of perspectives with an attention to user-friendliness (Groffman et al. 2010). Dennison et al. (2007) emphasize development of "a common knowledge base by combining syntheses of key scientific results with information-rich [as opposed to information-dense] visual elements." Well-designed conceptual diagrams can provide visual descriptions of current scientific understanding that transcend scientific jargon (Dennison et al. 2007). Report cards based on comprehensible and scientifically valid indicators are a proven tool for communicating ecosystem condition and evaluating the progress that results from management actions (Pantus and Dennison 2005). Research programs that are policy-relevant will provide scientists with the time and support to develop those key syntheses, as well as effective communication tools.

Changing Course

Ecosystems are complex and dynamic, and scientific understanding of ecosystem processes grows continually, while remaining incomplete. This means mechanisms for efficiently altering policy in the face of new findings are essential. Adaptive management has been embraced as the way to accomplish this, although few examples exist where adaptive management experiments have been entirely successful. The lack of success has been attributed to a lack of leadership, inadequate funding, and the failure by decision-makers to see the need for this approach (Walters 2007). Although it is not a panacea (Schreiber et al. 2004), adaptive management remains the most promising

approach to managing complex ecosystems in the face of incomplete knowledge and changing conditions.

Monitoring is a critical but often insufficiently planned and inadequately funded step in the adaptive management process (Schreiber et al. 2004). Monitoring programs support adaptive management if "information is collected on the parameters identified in the development of the initial models of the system and in relation to the specific goals identified in the planning phase of a project" (Schreiber et al. 2004). The restoration program in the Florida Everglades has used this approach (Gentile et al. 2001). Two types of conceptual models were developed, and outcomes of different management actions were explored using these models. The first modeled the societal activities and drivers that created the existing environmental stressors. The second modeled ecosystems in 20 landscape units using the stressors as drivers, and the ecological endpoints identified in these models provided the basis for performance measures around which monitoring programs were designed (Gentile et al. 2001). Beginning with a list of 1,000 possible indicators, the number to be tracked was reduced to 50, and–after distilling, integrating, and prioritizing–eventually fewer than 10 were reported to high-level decision-makers (Van Cleve et al. 2004).

Advantages of this approach include its provision for direct links among policy decisions, stressors, ecological outcomes, and monitoring programs that measure indicators for assessing performance. If the decision-making structure enables management actions to be modified based on these performance measures, effective adaptive management is possible.

Improving the Science–Policy Link in The Delta

Yet without performance measures based on clear conceptual models and an associated monitoring program, adaptive management cannot be successful.

Having observed the science-policy interface in the Delta for over a decade, I have concluded that implementation of a limited and carefully chosen suite of performance measures is a crucial missing link in the adaptive management cycle. Although programs and restoration projects are proposed, performance measures to assess ecological outcomes of these programs and projects are often long, unranked lists of ecological indicators with many remaining "to be developed" and without attention to the monitoring program needed to measure them. For example, the Ecosystem Restoration Program's (ERP) Draft Conservation Strategy from July 2011 (*https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=31232*) lists 156 performance measures for ecological outcomes, 36 of which are "to be determined;" targets for 129 are also "to be determined." Many measures identified are vague, and monitoring priorities are not clear. This document offers no evidence that the winnowing process used in the Everglades example has occurred. ERP and other Delta programs are not unique in this respect: an evaluation of several ecosystem restoration projects found that "few programs have actually established performance measures " (Van Cleve et al. 2004). Yet without performance measures based on clear conceptual models and an associated monitoring program, adaptive management cannot be successful.

Many of the pieces needed to link science and policy exist in the Delta, providing cause for optimism. The recently released second draft of the Delta Science Plan (*http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta%20Science%20Plan%20-%20Second%20Draft_082213_Final.pdf*) has many elements that incorporate the ideas discussed in earlier parts of this essay. In particular it proposes mechanisms to foster and support synthesis and to enhance communication between scientists and decision-makers. It could be effective if adequately funded and if embraced by both science and policy communities in the Delta. To reiterate, many of the pieces needed to link science and policy exist in the Delta; it remains to be seen whether the political will exists to ensure that these pieces can be assembled to create an effective science–policy landscape.

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San Francisco Estuary & Watershed Science: Case Study

We Can Do Better: Longfin Smelt and a Case Study in Collaborative Science

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Dedicated to Mike Taugher, an extraordinary colleague and friend.

There should be no question that flows into, through, and out of California's Delta are biologically important. Equally true is that water is a limited resource. Competing demands for Delta water include flows for native fish, water supply for farms and cities, and cold water held back in large reservoirs to cool salmon streams.

With the Delta Reform Act of 2009, the California Legislature established as overarching state policy the co-equal goals of a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. Since water is limited, there are inevitable trade-offs. This is where science and policy intersect.

For too long, this tension has been handled one species at a time, one crisis at a time, and usually in court. This has fostered "combat science," where regulatory agencies, water contractors, and environmental advocates line up their own hypotheses, studies, and conclusions like artillery in the courtroom. It has fed distrust and stymied collaboration. This is a failed approach.

A growing number of species dependent on the Delta are listed pursuant to the federal or state endangered species acts. Absent a change in how we manage the Delta, there is no evidence to suggest the situation will improve. We can do better. We must do better.

The Bay Delta Conservation Plan (BDCP) (*http://baydeltaconservationplan.com/PlanningProcess/BDCP/BDCPProcess.aspx*) takes a more comprehensive approach than the single-species management that has developed pursuant to Section 7 of the U.S. Endangered Species Act. In addition to providing a higher standard of protection for listed species, the plan proposes to develop a more robust and collaborative science program that engages the same parties who historically have met in court to resolve disputes. Of course, this plan is not yet final. More environmental review and public input is scheduled, and ultimately our two departments have different roles: the California Department of Water Resources will propose a plan and the California

Department of Fish and Wildlife (CDFW) will review and consider permitting such a plan. Yet, a commitment to a more robust and collaborative science program is also emerging between many of the long-term litigants and between several state and federal agencies involved in the Delta.

All of these positive developments involve a fundamental shift in the way water agencies and regulators interact. We seek a framework where science and policy can meet that has real buy-in from all parties. Disparate sides would develop and implement a consensus approach to identify areas of disagreement. It is essential that we all collectively understand the specific questions that need to be answered, and test them using hypotheses to generate results that all parties can understand. Different sides may have different policy overlays, but the science will be the science.

Longfin smelt offer a good case study for illustrating how we could deal with scientific uncertainty in a logical and collaborative way. The longfin smelt population has declined in abundance by about 95% from the 1967 to 1983 period, according to data from CDFW's Fall Midwater Trawl Survey. This species is listed as threatened under the California Endangered Species Act. The U.S. Fish and Wildlife Service made a determination that its listing is warranted, and there is no debate that the current status of the species is unacceptable.

As with other fish species in the Delta, the decline of longfin smelt is not easily explained, and recipes for recovery are not easy to write. Nevertheless, most, if not all, of the formerly court-room-warring parties understand we must help conserve longfin smelt. Indeed, to be successful, the BDCP must actually achieve that higher standard.

Here is where science enters. We know some important things, and we don't know other important things. For example, there is a positive correlation between winter–spring outflow and the abundance of longfin smelt observed in the subsequent fall season. Emerging hypotheses suggest that spring outflow drives this relationship, but the underlying mechanisms that support an increase in longfin smelt numbers are not as well understood as we would like. It may be that other changes in longfin smelt habitat, such as increased and improved rearing areas, increased food availability, and reduced entrainment, may contribute to longfin abundance. Other hypotheses posit that an increased population response that results from restored habitat or reduced entrainment may mean that spring outflow would be less influential. All of us would benefit from further scientific work to answer these questions and explain these relationships.

Given the positive correlation between spring outflow and longfin smelt abundance, the BDCP proposes to increase spring outflow in the wetter 50% of years. Such an increase in outflow would come at the expense of water supplies available to the State Water Project and the Central Valley Project. Though the water projects represent only a portion of the diversions made from the Delta watershed, the water users operating them are subject to and participating in the BDCP.

The BDCP posits that whatever additional benefits that longfin smelt may receive through additional flows also may be obtained through habitat restoration and reduction of other stressors. Less than 3% of the Delta's original tidal marsh remains, and there is evidence from the interdisciplinary Breach III studies is that habitat restoration would improve the food supply locally, thereby potentially benefiting pelagic fish.

Now, stakeholders may disagree about how much outflow is needed or will be needed or if restoration can adequately replace outflow. But, there is no debate that a scientific question exists. The scientific question, then, becomes: Can improvements in food production generated through habitat restoration and the reduction of other stressors have a sufficiently beneficial effect, so that lower spring outflows are necessary to achieve long-term conservation of the Delta's longfin smelt species? A primary focus of the BDCP's science component will be to test this hypothesis and address the uncertainty concerning the role of tidal habitat restoration in improving foodweb support in the Delta for pelagic fish, such as the longfin smelt.

Considering the process required, how do we evaluate this question so that interested and relevant parties are involved in formulating the study—and trust the resulting science and subsequent decisions based on that science? Common sense dictates that we seek a way to reduce uncertainty. There has to be a better way than arguing about science while species continue to decline and water supply reliability is jeopardized.

This better way starts with applying state-of-the-art scientific approaches, models, and tools. The BDCP sets forth a three-step "decision tree" process to help resolve the disagreement over whether the recovery of longfin smelt requires higher spring flows. A decision tree is nothing new: In simplest terms, it is a chart that maps successive decision points over time. Any of the emerging nodes of collaborative science could use a decision tree as an analytical tool to help identify the best means to achieve a goal, whether in the Interagency Ecological Program or the Delta Science Plan.

Here are the three steps proposed in the BDCP. First, the scientific hypotheses to be tested will be clearly described, along with the underlying assumptions. Second, a science plan will be developed and implemented to collect and synthesize the data needed to test the hypotheses. The science plan would be integrated, as appropriate, with the comprehensive monitoring framework developed under the Second Draft Delta Science Plan (DSP 2013). Development of the science plan would include stakeholder input, integration with other ongoing scientific research, and independent scientific review. Third, this science would be done over a defined time period. If the BDCP is permitted, the federal and state fisheries agencies would determine operating rules for the state and federal water projects based on our current understanding.

Since it would take at least 10 years to build the new Sacramento River intakes and tunnels proposed in the plan, the plan also proposes to use this decision tree process in the interim to test the hypotheses. Depending on the results, the operating rules set in place now might change in the future within the time frames analyzed in the decision

tree. Those rules would mandate flows sufficient to meet the biological objectives for longfin smelt in light of and in combination with the other components of the BDCP, including restoration, reduced entrainment, and other changes in the Delta.

Whatever the initial operating rules become, they would not necessarily be static. Once a flow regime has been determined based upon the best available science at the time and the operation of a new water conveyance system begins, the decision tree process would end, and the adaptive management process, supported by ongoing monitoring and research, would continue. This decision tree process would function as a focused component of the larger adaptive management framework needed to ensure that the BDCP succeeds.

The BDCP's adaptive management framework was shaped by independent science advisors and closely mirrors that of the Delta Plan (DSC 2013). As currently proposed, the Adaptive Management Team would include representatives from the California Department of Water Resources, U.S. Bureau of Reclamation, California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and the National Marine Fisheries Service, as well as the Interagency Ecological Program Lead Scientist, the Delta Science Program Lead Scientist or designee (as an advisory non-voting member), the State and Federal Water Contractor Agency Science Manager, and the Director of the National Oceanic and Atmospheric Administration's Southwest Fisheries Science Center. It would operate by consensus. If consensus could not be reached, decisions would be elevated for resolution by two separate entities—the Authorized Entity Group (its members represent water project agencies) and the Permit Oversight Group (its members work for state and federal fish and wildlife agencies).

Here is where trust comes in to play—significantly. Success in the long run will require transparency, fairness, and objectivity in science and decision-making. We know that many may not trust such a process, based on their individual experiences with each other in the past on these tough issues. As the BDCP and its environmental documents go out for public review, we anticipate receiving further input on how we can best ensure a collaborative, adaptive management program that meets the trust test.

This collaborative approach is already underway. In April 2013, federal judge Lawrence J. O'Neill granted the agencies time to conduct the Collaborative Science and Adaptive Management Program. The judge gave the U.S. Fish and Wildlife Service, Bureau of Reclamation, CDWR, and NOAA Fisheries a year to establish a diverse, skilled team to formulate a new approach to develop a science program that will test and evaluate alternative operational strategies and other management actions to improve water project performance for both ecological and water supply needs. That group—the Collaborative Adaptive Management Team—is meeting to develop this program. Representatives from water agencies and environmental groups have joined representatives from federal and state fish and wildlife agencies and water project operators to form this new team. Members have the education, training, or expertise that enables them to develop and evaluate hypotheses about water project operations

and native fish populations that will be tested to provide the basis for new biological opinions for existing water project operations. This process is designed to test the kind of scientific research needed on a larger, longer scale for the BDCP.

In all, we will learn by doing, and evaluate our progress in a structured way. We will measure success by assessing how well stakeholders are meaningfully engaged and committed to the process; by generating science that all agree is sound; by making progress toward achieving the biological objectives; and, by determining how well results from the science research are used to adjust and improve management decisions. If we can achieve these measures of success, we may be able to avoid the courts and use our best available science to give ourselves a firmer footing for balancing and managing the Delta's co-equal goals.

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San Francisco Estuary & Watershed Science: Science & Policy for the Delta

It's Time for Bold New Approaches to Link Delta Science and Policymaking

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California's Sacramento–San Joaquin Delta is widely recognized as a highly damaged ecosystem. The Delta is also emblematic of a growing sense worldwide that society needs to do a better job of using scientific knowledge to guide conservation and resource management policies. Fortunately, we now have an unprecedented opportunity to get it right in building structures that support effective science–policy linkages in the Delta. By adopting bold steps to implement a "one Delta, one science" approach for a new Delta Science Plan, California can become a leading example of how to tackle the global problem of rapid ecological change and biodiversity loss.

In this essay, we first describe the current paradox—continued environmental declines despite considerable investments in science and policy actions—and the high stakes of gambling with failure. Next, we explore why it is so hard to use scientific knowledge to design and implement policies that meet society's sustainability goals. We then outline promising ways to overcome these obstacles, drawing on recent experiences. We conclude with thoughts on how to leverage this experience to develop a bold new approach to Delta science.

Science–Policy Disconnects, Not Neglect

The symptoms of ecosystem disturbance to the Delta are well-chronicled: low primary production; replacement of native zooplankton by non-native species that have lower food value to fish; recurrence of toxic algal blooms that threaten human and ecosystem health; waterways choked by introduced plants; and—most highlighted in the policy debates—population declines of native fish, many of which are now listed as threatened or endangered under the state and federal Endangered Species Acts.

This downward spiral has occurred even though the Delta lies within one of the world's best-studied estuaries, and the overall quality of science is high (NRC 2012). Yet despite calls to use science to inform decision-making in all the major Delta policy

processes (Gray et al. 2013), the system has fallen short on using scientific knowledge to guide policy effectively. Numerous policies have been established to regulate flows, salinity, and pollutants; to limit species introductions; and to restore habitats. But fragmentation in the landscape of scientific knowledge has led to piecemeal regulatory approaches to a systemic problem. The resulting failure to stem the tide of ecosystem decline, combined with the financial costs of mitigation (typically borne by specific stakeholder groups), has heightened scientific controversy and fostered the conduct of "combat science"—where science takes center stage in courtroom battles, far outside the traditional arenas of scientific inquiry and debate.

Bridging the science–policy disconnect is an imperative in the Delta and beyond. Today's breathtaking pace of global environmental change threatens sustainability of the Earth-system processes that have allowed humanity to thrive over the past 10,000 years. Sustainability thresholds for three of these processes, including climate change and rate of biodiversity loss, have already been crossed; and others, including global freshwater use and land-use change, are approaching critical thresholds (Rockstrom et al. 2009). In the Delta, the impending loss of native biodiversity is costly in its own right, and it also threatens continued human uses of the region's land and water resources.

Why Is This So Hard?

The first barrier to more effective science–policy linkages is scientific complexity. Understanding the causes of the Delta's environmental degradation—and, even more important, the likely effects of potential mitigation actions—is a tough scientific problem. Recent surveys show that scientists and a wide range of Delta stakeholders and policymakers recognize that ecosystem disturbance is the result of many stressors (Hanak et al. 2013). But we don't fully understand how today's Delta has been shaped by the cumulative effects of historic transformations (e.g., landscape) and more recent perturbations (e.g., water management, pollution, species introductions), and we know surprisingly little about the interactive effects between perturbations such as water exports and species introductions. An additional layer of complexity arises from the need to infer the causes of species population declines, because the underlying processes of population variability (migration, reproduction, mortality) are rarely all measured. Complexity grows as we consider future conditions driven by human population growth and a changing climate (Cloern et al. 2011). As a result, there is considerable uncertainty about the likely effectiveness of many mitigation actions. This makes it especially hard to communicate scientific findings to a policy audience looking for solutions to an urgent management problem.

The second barrier is a cultural divide. Despite a broad consensus that effective policies need to be grounded in scientific knowledge, scientists and policymakers have different understandings of what this means in practice. Many policymakers expect the scientific community to deliver a prioritized list of actions to meet policy goals.

In contrast, scientists are trained to measure and understand environmental change and to project outcomes of various actions; they understand that their credibility can decline when they advocate specific policy directions. Scientists can also naïvely expect policy decisions to be based solely on the knowledge they generate, not recognizing that policymakers must also consider political constraints and the social and economic outcomes of their decisions. (The 2009 Delta Reform Act acknowledges this reality by establishing "co-equal goals" of ecosystem sustainability *and* water supply reliability for the Delta.)

The third barrier is institutional fragmentation. Scientific research on the Delta ecosystem is conducted in numerous venues: federal, state, and local agencies; universities; environmental non-profits; and private consulting firms. The past 15 years have witnessed some progress toward coordination (notably through the Interagency Ecological Program, a scientific consortium of nine federal and state agencies) and in strategic funding (notably through the Delta Science Program—formerly CALFED science—which distributes state and federal funding for research). But there is no institutional structure with the resources, responsibility, and authority to assist with applying science to guide decision-making. Despite improvements in interagency coordination, many members of the regulatory community perceive agency science as biased because they don't participate in setting the agenda. The result has been growing incentives for separate stakeholder-funded science and courtroom battles over the scientific facts. Recent surveys highlight the resulting divergence in views: for example, 62% of scientists considered reducing water diversions to be a top environmental management priority, but only 5% of those who export water from the Delta—those most likely to lose from reductions in water diversions—agreed with this priority (Hanak et al. 2013).

What Might We Do About It?

Overcoming these barriers will require more and stronger interactions between scientists and policymakers, to improve not only the process of science communication, but also the organization and conduct of science itself.

For instance, to address complexity more effectively, we need science–policy interactions that specifically target the problem of multiple stressors. Perhaps the best hope for advancing actionable knowledge is through coordinated efforts to use the rich data sets available to build holistic models of the Delta ecosystem. These models would provide new capabilities for isolating the effects of individual stressors and understanding their interactions through sensitivity analyses, and for projecting outcomes of future changes including a range of policy actions. A good starting place would be to clarify the bounds of what we know already.

More generally, narrowing the cultural divide and reducing fragmentation will require institutions that can facilitate more effective science–policy linkages. Facilitation should include processes to: (1) give scientists the incentives, communication skills,

and opportunities they need to become fully engaged with society (Smith et al. 2013); (2) reach broad agreement about the role of scientists; (3) develop syntheses of scientific knowledge tailored to meet the information needs of policymakers; (4) broker science–policy dialogues to, for example, reach common understanding of what is well-known and what is not, or how uncertainty is measured and can be used in policy development; (5) foster new partnerships in which scientists and policymakers (including regulators and representatives of the many stakeholders who use the Delta's resources) work collectively to shape, fund and implement policy-relevant research targeted to unravel the complexity of ecosystems disturbed by multiple stressors.

Fortunately, California possesses strong foundations—including knowledgeable human resources and budding institutional models—that can serve as building blocks for achieving this agenda. Useful experiences to build from include:

1. **Rapid Synthesis to Identify Research Priorities.** The Delta Science Program (DSP) is following a tradition established by the CALFED Science Program to organize workshops that aim to synthesize knowledge on controversial policy issues. A recent example is the June 2013 workshop on the effects of tidal marsh restoration on native fish populations, which brought together experts on the Delta and other ecosystems (DSP 2013). Such efforts could be intensified; they should inform near-term priorities for research as well as policy discussions (e.g., on restoration strategies of the Bay Delta).

2. **Consensus-based Synthesis for Policy.** The State Water Resources Control Board (SWRCB) has begun commissioning panels of researchers to synthesize scientific understanding for decision-making. For instance, Bennett et al. (2010) provide an overview of approaches to adopting Delta flow prescriptions to support native fish. The 11 authors—including researchers from two universities and five state and federal agencies—participated jointly in an expert panel discussion with the SWRCB. This is a welcome change from the traditional approach, where lawyers for competing interests at hearings take turns presenting their versions of the science to the SWRCB, which results in "dueling" interpretations and no effort toward synthesis or common ground. To be most effective, such efforts should not be one-shot deals, but rely upon ongoing interactions with policymakers.

3. **Policy-focused Collaborative Science.** Over the past few decades, useful models for science–policy partnerships have emerged in both Southern California (through the Southern California Coastal Water Research Program) and the Bay Area (through the San Francisco Estuary Institute [SFEI] and the Aquatic Science Center). These "common pool" approaches involve multiple parties setting the research agenda and supporting the work, where the resulting science provides a solid, less conflict-ridden basis for developing policy prescriptions (Gray et al. 2013). As an example, studies of sources and loads conducted by SFEI scientists were the foundation of the San Francisco Bay Water Board's plan to reduce mercury and PCB loads to San Francisco Bay. The commissioned studies were

specifically geared to policy-relevant issues, such as setting loading limits, and the result has been a set of environmentally protective policies that the regulated community supports.

4. **Collaborative Efforts to Move Beyond Combat Science.** Following several years of contentious litigation, water users and regulatory agencies have teamed up under the new Collaborative Science and Adaptive Management Process (CSAMP) to develop the science that will inform more protective water flow policies for Delta fish species listed under the Endangered Species Act (Maven 2013).

5. **Building Communication Skills and Opportunities.** Organizations such as COMPASS (Smith et al. 2013) are helping give natural scientists the communication skills and networking opportunities they need to become more effectively engaged with the media and policymakers. COMPASS's work with marine scientists has demonstrated the links between communication capacity and collaboration, enabling better synthesis of knowledge to guide ocean policies.

Conclusion: Going Bigger and Bolder

An unprecedented opportunity now exists for California to build on these experiences to forge effective science–policy linkages for sustainable ecosystem management. The DSP is now developing a Delta Science Plan (targeted for completion by late 2013) to support the attainment of society's broad co-equal goals for the Delta, as outlined in the newly adopted Delta Plan (DSC 2013). Early discussions of the science plan have recognized the need to reduce fragmentation and take a holistic approach, as summarized by the theme "one-Delta, one-science." To be successful, this effort needs to be bold. This means taking a common-pool approach to Delta science: (1) involve all parties in setting the agenda and funding the research; (2) foster synthesis and consensus about what is known and about scientific priorities to support management; and (3) provide new opportunities to improve the two-way communication between the scientific and policy communities to achieve their common goals for a sustainable Delta ecosystem that supports a healthy and prosperous economy and society. If we succeed here in California, the lessons may also benefit others seeking to tackle this global challenge.

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San Francisco Estuary & Watershed Science: Science & Policy for the Delta

Leading Change: The Collaborative Science and Adaptive Management Program and the Delta Science Plan

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The opinions expressed in this essay are my own and not the policies or positions of the SFCWA or CSAMP member agencies or the Delta Science Program.

In the Sacramento–San Joaquin Delta, "adaptive management" and "best available science" have become catch phrases describing how we will address the restoration of a highly altered ecosystem and improve the reliability of the water supply. The Delta Reform Act (2009) mandates the use of both as we work towards the co-equal goals. The Delta Stewardship Council has released a Delta Plan (DSC 2013) that calls for its Delta Science Program to draft a Delta Science Plan (DSP 2013) by December 2013. The Bay Delta Conservation Plan (BCDP) is nearing completion, and, as an eventual part of the Delta Plan, it too relies heavily on the two concepts. But, will adaptive management and best available science help us achieve the co-equal goals? The draft Delta Science Plan recognizes both concepts are necessary, but not sufficient. Success will require collaboration[1], integration, time, and a sustained commitment from all of us who conduct science in the Delta and all of us who rely upon it.

INTRODUCTION

This essay recognizes that success will require a conscious effort to actively "lead change" in how we approach and support scientific endeavors. The assessment of our collective ability to lead change is not a critique of scientists or science, but is critical of how scientific information for policy is generated and used. The process that resolves controversial policy decisions needs improvement. Delta scientists will need to work together in new ways, but they will only succeed if policymakers, managers, and stakeholders create the environment necessary for scientists to excel; this is the more difficult challenge. This essay suggests that for the Delta Science Plan to be successful, we must consciously lead the changes required for implementation.

1 Collaboration is a mutually beneficial and well-defined relationship entered into by two or more parties to achieve shared goals.

A recent positive step forward is the formation of the Collaborative Science and Adaptive Management Program (CSAMP) and the Collaborative Adaptive Management Team (CAMT). The CSAMP and CAMT were formed as part of a federal and state proposal to modify the court-ordered remand schedule for the salmon and delta smelt biological opinions for the water export facilities. The CSAMP is a multi-agency effort led by a Policy Group that includes the Directors of the state and federal agencies involved in the biological opinions, and the Directors or top managers of the entities involved in the litigation that challenges those biological opinions. The organizational structure of CSAMP is illustrated in Figure 1. The CAMT, a mix of scientists and managers working under the direction of the Policy Group, will use a structured process to yield defensible conclusions. Its adaptive management framework promises to integrate information from research, monitoring, and modeling to inform Delta resource management and policy (Lohoefener 2012). The CAMT could

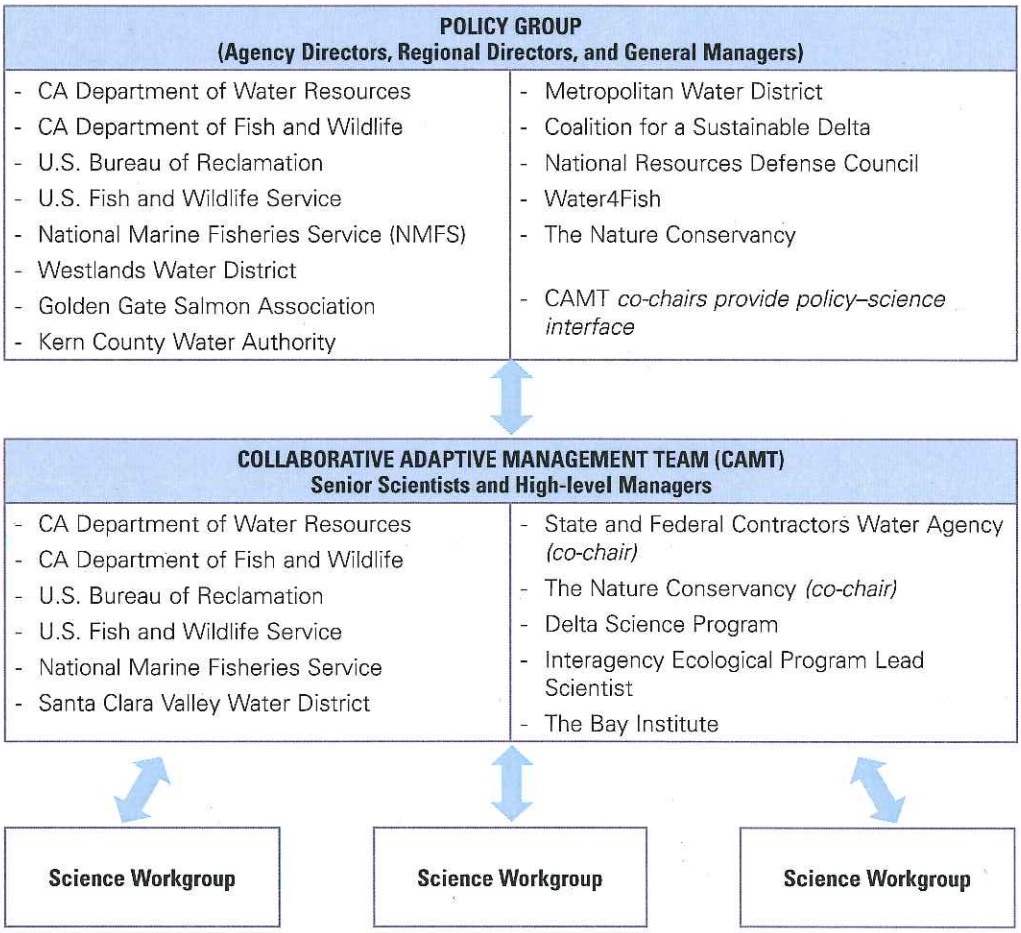

Figure 1 Organizational structure and membership of the nascent Collaborative Science and Adaptive Management Program

improve inclusivity and transparency in the development of operational strategies tied to the biological opinions. The goals are improvements in common understandings of the science, joint fact-finding, increased transparency through information sharing, and a commitment to work together. In the end, the parties hope to develop mutual trust that can overcome over-reliance on the courts to resolve disputed scientific and technical issues (USDC 2012).

The CSAMP represents an opportunity to test, on a limited scale, the type of collaborative, integrated science described in the Science Plan, by implementing proposed actions and approaches outlined in the Science Plan. The CSAMP is a potential pilot for implementing the portions of the Science Plan that include adaptive management, conflict resolution, engagement of decisionmakers in setting research and monitoring priorities, and a governance structure similar to the one in the draft plan. The CSAMP could model how new information would be used to promote a reduction in the multiple stressors of endangered fish species, optimize habitat restoration designs, and provide reliability for State Water Project and Central Valley Project operations. Table 1 summarizes the role and functions of the teams comprising the CSAMP.

Table 1 Responsibilities of the nascent Collaborative Science and Adaptive Management Program

Policy Group	Collaborative Adaptive Management Team	Science Workgroup
• Provide input on priority Delta science needs • Demonstrate collaboration at the leadership level • Provide the interface to the public • Quickly resolve issues • Provide guidance to the CAMT • Plan the future of the Program	• Develop a robust science and adaptive management program that will inform the biological opinions • Implement science-based framework for adaptive management • Develop key questions and problem statements • Evaluate potential management actions to protect one or more of the listed species • Develop an annual work plan, including the Science workgroups • Prepare and submit progress report to District Court • Address specific scientific issues following adaptive management framework	• Develop annual work plan • Respond to external peer review • Assess results

THE PROCESS FOR SUCCESSFULLY LEADING AND MANAGING CHANGE

Because an integrated Science Plan that guides collaborative adaptive management will require that we change the ways we conduct, support, and use science, leadership of the change process is essential. I have developed and implemented new science-based programs many times in my career. My implementation success increased after I realized that accomplishing change in an organization has its own requirements, and that I needed a successful model to do it. John Kotter from the Harvard Business School (Kotter 1996) provided that model. Kotter's eight steps are summarized below, together with an assessment of our ability as scientists and policymakers to lead that change successfully. In the final analysis, leading and managing the change required to implement collaborative adaptive management will require time and a strong commitment from policymakers, managers, scientists, and stakeholders.

Step 1: Establish a Sense of Urgency

People don't change unless there is a compelling reason to do so. Major changes in approach require that most of the individuals being asked to change feel a sense of urgency. Urgency is driven by recognition of great opportunities and great risks (Kotter 1996). Most parties involved in the Delta, including the participants in the CSAMP, all agree on the urgency of changing current Delta conditions and the current dynamics surrounding Delta policy decisions. Abundance of listed fish species remains precariously low. Water supply reliability is threatened by pumping restrictions, drought, and climate change. The disrespect and distrust among entities representing different perspectives is extreme. No one wants to continue with the status quo. The CSAMP and Science Plan are real opportunities for change, while not changing will have critical impacts on both listed fish species and all who live in California.

Step 2: Create the Powerful Guiding Coalition

Putting together the right coalition of people to lead a change initiative is critical to its success. The coalition must have enough power, the right composition, a significant level of trust, and a shared objective (Kotter 1996). Clearly the Delta Stewardship Council that oversees the Delta Science Program and the Policy Group that oversees the CSAMP (Figure 1) are powerful guiding coalitions with the abilities to lead change, but change will require a strong and constant dedication from members of both groups. They need to:

- Develop a shared vision for science-based collaborative adaptive management;
- Communicate that vision to hundreds of people;
- Eliminate key obstacles;
- Ensure short term wins;
- Lead and manage projects; and
- Anchor new approaches deep in the culture of both the guiding organization and their individual organizations.

Step 3: Develop a Change Vision

Like the Science Plan, the CSAMP envisions science as being used for new purposes, rather than serving as the basis for legal actions among the interested parties who all support a healthy and productive Delta. The CSAMP sees science as the foundation for bringing diverse interests together, reducing uncertainties and conflicts, and discovering new solutions to the complex challenges ahead of us. That new vision, the transformation of science from an adversarial weapon to a tool for increased understanding and effective adaptive management, must be a centerpiece in the change process. Kotter suggests that the creation of a clear vision simplifies decision-making, motivates people, and helps diverse stakeholders coordinate their actions. The Science Plan serves as a clear statement of this vision. The CSAMP offers an opportunity to realize this vision on a pilot scale.

To be effective, a vision must take into account not only the current realities, but also set forth goals that are truly ambitious. When a vision is supported with a strong, credible strategy, it becomes evident to participants that the vision is achievable. The vision must both inspire action and guide that action. It should be a touchstone for making relevant decisions, but not be so constricting as to reduce the possibility of empowering action. The final Science Plan must be our shared vision. The CSAMP is that vision realized as a pilot study. Our biggest challenge is the opposing need to get it "right" and the need to get it done quickly. As both are developed, we all have a responsibility to make sure the visions effectively inspire and guide action.

Step 4: Communicate the Vision for Buy-in

It is critical that all affected parties understand and accept the vision and the strategy for achieving collaborative adaptive management. The Science Plan can rely on the development and implementation of the first Action Agenda (workplan) to assist with this communication step. The CSAMP needs a communication element. Directors, managers, stakeholders, and scientists need to use every effective communication channel possible to broadcast the vision. Even more important than what is said is what is done. Leaders who transform their organizations "walk the talk," serving as living examples of the new culture toward which the vision aspires. Kotter is quite clear on the importance of this step. To be effective, the vision must be communicated constantly. With all the demands on directors, managers and scientists, this step will be a huge challenge to overcome; it is unclear that this step is occurring now.

Step 5: Empower Broad-based Action

The Delta Stewardship Council and CSAMP Policy Group have pivotal roles at this step. Each entity needs to identify ways to empower staff to champion the vision of collaborative adaptive management. Policy makers, managers, scientists and stakeholders need to identify and remove obstacles to change. This may require a change in systems, approaches, or structures. Resources and job duties may need to be redistrib-

uted. It is also important to encourage risk-taking and non-traditional ideas, activities, and actions, which is particularly difficult in large organizations.

One example of empowerment might be a change in the current working environment for agency scientists. Agency scientists could be better supported with some basic tools to maintain their skills and expertise. For example, scientists are often restricted from attending science conferences, and are not given easy access to journals. In addition, low salaries inhibit recruitment and retention of highly qualified scientists. State scientist morale is damaged by low pay relative to non-state scientists and other state employees doing equivalent work. I think we are "penny wise and dollar foolish" in shortchanging our scientists, especially considering the Reform Act, which is mandated in the Delta and requires best available science, and the estimated cost of achieving the co-equal goals.

Step 6: Generating Short-term Wins

Ensuring short-term wins is essential. The CSAMP has court-mandated deliverables that can be early successes. The CSAMP can be an early success of Science Plan implementation. Even small achievements provide early support for change efforts. Policy leaders must identify and plan for significant improvements that can happen in between 6 and 18 months. Getting these wins helps ensure an initiative's overall success. Companies that experience significant short-term wins by 14 and 26 months after a change initiative begins are much more likely to complete the transformation (Kotter 1996).

Step 7: Never Letting Up

Currently, the CSAMP is focused on the period before the release of the new Biological Opinions. But the organizational structure and technical framework for adaptive management will require ongoing focus and energy for lasting change. New behaviors and practices must be fully incorporated into our shared culture to ensure long-term success. Performance measures and target dates are valuable in assisting with this step, but only if accompanied by program reviews and responsiveness to those reviews.

Step 8: Incorporating Changes into the Culture

New practices must "grow deep roots" to remain firmly "planted" in the culture. Every individual who joins an organization is indoctrinated into its culture, generally without even realizing it. The collective group of employees maintains an organization's inertia over years and years. Changes—whether consistent or inconsistent with the old culture—are difficult to ingrain; we keep change in place by creating a new, supportive, and sufficiently strong organizational culture (Kotter 1996).

CONCLUSION

Will we be able to implement a collaborative adaptive management program to address the co-equal goals? I hope so. We have a new vision with the Delta Science Plan, and new opportunities to implement the vision through the CSAMP. We also have incredibly dedicated scientists, managers, policymakers and stakeholders who are eager to make these plans a reality.

"How science is used is as important as how it is done."

Conducting the monitoring, research, and modeling to inform policy isn't easy, but it isn't the most difficult part: The hard part is creating the new, supportive, and sufficiently strong organizational cultures necessary to succeed over the long run. That cannot happen unless the entities that generate science and the entities that rely on it are committed to using integrated science as a means to reduce uncertainty and collaborative science to reduce conflicts by building trust. How science is used is as important as how it is done. Leading this change will call on all of us to practice the lessons that John Kotter can teach us.

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Abstract:
Using science to adaptively guide management for the Sacramento-San Joaquin Delta is widely talked about as good public policy. Almost every agency, stakeholder, and planning process professes support and has its own adaptive management and science efforts. But highly fragmented adaptive management and science cannot solve such urgent complex problems. California's 2009 Delta Reform Act recognized that meeting the co-equal goals of a sustainable ecosystem and water supply reliability in the Delta required major changes in governance, planning, and management. Such changes also require major changes in how science is organized and employed in management. Here is a straw proposal for integrating the many parochial science and adaptive management programs for the Delta.

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SF E&W San Francisco Estuary & Watershed Science: Science & Policy for the Delta

Adaptive Management and Science for the Delta Ecosystem

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Using science to guide management adaptively for the Sacramento–San Joaquin Delta is widely talked about as good public policy. Almost every agency, stakeholder, and planning process professes support and has its own adaptive management and science efforts. But highly fragmented adaptive management and science cannot solve such urgent complex problems. California's 2009 Delta Reform Act recognized that meeting the co-equal goals of a sustainable ecosystem and water supply reliability in the Delta required major changes in governance, planning, and management. Such changes also require major changes in how science is organized and employed in management. Here is a straw proposal for integrating the many separate science and adaptive management programs for the Delta.

Problems

"In California, we hate government so much that we have thousands of them."

–Anonymous

Adaptive management and science for the Delta suffer from three major problems (Lund et al. 2011):

A. Fragmentation of Management and Science. Decentralized finance and management can support local accountability and incremental innovations, but fragmentation that is incoherent can reduce the overall effectiveness of management and science. As the controversy over the Bay–Delta Conservation Plan (BDCP) shows, it is difficult for dozens of agencies to agree on strategy for complex systems such as the Delta (Madani and Lund 2012). This problem applies to both regulation and project management. Without strong state and federal leadership, strategic decisions can become mired in interagency and intra–agency conflicts.

B. Disorganized Public Science Leads to Combat Science. Instead of developing strong, strategically oriented public science, agencies and stakeholders have typically developed science programs focused on their individual missions. This science is often developed, deployed, or curtailed based on advocacy needs of stakeholders

and public agencies alike. Syntheses, organized information and forums to explore realistic solutions are rarely the emphasis in such an environment.

C. **Poor Development and Use of Science for Policy and Management.** Public decision-making processes have not used science as well in their deliberations as they could, and have inadequately supported development of scientific insights and syntheses. Policy forums should cultivate the use of science in their deliberations to provide independent insights for both long-term and short-term problems. Few agencies have long-term science plans or explicitly integrate science into policy discussions.

A Proposal

"The secret of getting ahead is getting started. The secret of getting started is breaking your complex, overwhelming tasks into small, manageable tasks, and then starting on the first one."

–attributed to Mark Twain

While fragmented management and science programs will not be effective for the Delta, a monolithic program is likely to be too cumbersome. An integrated approach is needed to organize scientific and adaptive management activities, so each activity is focused enough to be effective. Below is a proposal for organizing science and adaptive management for the Delta across project sites, local areas, and Delta-wide scales. The BDCP, State Water Resources Control Board (SWRCB), and other planning, management, and regulatory efforts might benefit from participating in or requiring such a common organization of scientific and adaptive management activities for the Delta.

Some Principles for Science and Adaptive Management for the Delta

1. **Adaptive management is mostly having management evolve with evolving science.** Science and adaptive management programs should be separated to buffer scientific work against political interests, but these programs must be related so the science can provide timely and relevant information. Science and adaptive management structures should be parallel and separate, but interact. Efforts that separate adaptive management from management usually are adaptive in name only (Walters 2007).

2. **Management of different areas of the Delta should reflect their different ecological conditions and objectives.** Historically, the Delta consisted of several regions that were distinct in their ecology and physical structure (Whipple et al. 2012). Today, these same regions still have very different ecological conditions (Figure 1; Moyle et al. 2012). The northwestern Delta and lower Yolo Bypass areas have elevation and flow characteristics most suitable for native fish species. The central Delta supports a world-class fishery for non-native bass but has habitats unsuitable for native fishes; management efforts here might focus on the fishery or on ways to speed passage of native fishes through the region. The southern Delta has unfavorable inflows and lacks mixing tidal energy for native fishes, but could be suitable for waterfowl and recreational fisheries. The northeastern Delta has tributary inflows that support native fishes, although in less abundance than in the northwestern Delta.

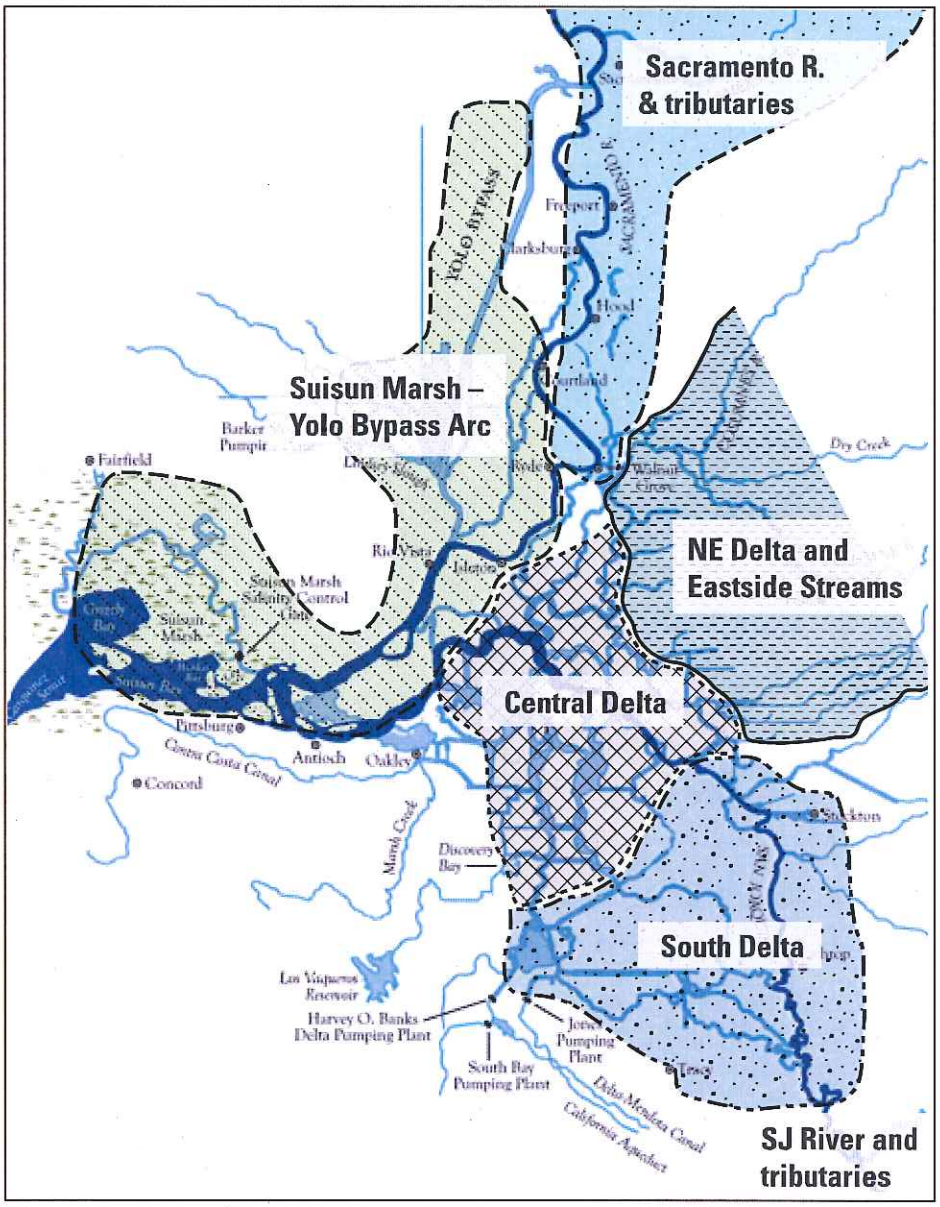

Figure 1 Ecologically specialized parts of the Delta (Sources: Moyle et al. 2012; Whipple et al. 2012)

3. **One coherent program of Delta science with geographic sub-programs will be more effective for long-term management.** Each Delta sub-area should have a research program focusing on desired ecosystem functions within the area. Sub-area programs would include science and monitoring for local restoration, water facilities, and concerns, with dedicated interagency teams and outreach involving area governments. An overall Delta program would address connections among areas, and overall water operations, research findings, overall oversight, and synthesis.

4. **One adaptive management program, with geographic sub-programs and site-specific projects will more effectively achieve reasonable results.** The different areas of the Delta would have separate programs, in parallel, to manage adaptively for area ecological goals and local objectives. A Delta-wide adaptive management program, organized under an interagency implementation committee, would balance and integrate area programs, with substantial authority and funding. The nature of adaptive management is likely to differ between site, area, and Delta-wide scales. Site-scale experimental management actions are likely to be less expensive, less controversial, and more reversible than management experiments for larger areas of the Delta. For larger and Delta-wide scales, computer modeling, supplemented by field data, will be needed to explore and evaluate management experiments. Lead agencies supported by inter-agency teams should run each area program and the overall program.

5. **A Delta-wide regulatory framework will reduce conflicts between regulators and managers.** Diverse and fragmented regulatory decisions and structures often make regulators the *de facto* managers, though they have much less ability or desire to manage adaptively. The state and federal governments should jointly sponsor serious discussions among regulators to develop a regulatory framework to better guide Delta management (Gray et al. 2013).

Using these principles, Delta management and science programs would have parallel interacting structures, organized geographically (Figure 1). Site-specific research and management projects could be organized in each area, contributing to the regional effectiveness of each site. For both programs, a Delta-wide management level provides high-level synthesis and balances resources and efforts among geographic areas and across topical areas of broad concern.

Leadership and Management

Adaptive Management. Ideally, Delta-wide adaptive management should be overseen by a Delta Director and a small interagency committee, with each specialized geographic area having a similar structure. Area entities would seek advice from local governments and people, and focus on local success in a Delta-wide context. Such simplification of lines of authority might be politically unlikely, but could serve as a model for thinking about how to improve management.

Science. The science effort must have sufficient independence to be broadly credible, enough focus to be useful, and nimble business and contracting capabilities. Such a program would be organized under a Joint Powers Authority (JPA) affiliated with the Delta Stewardship Council's (DSC) science program. Today's Southern California Coastal Water Research Project (SCCWRP) and San Francisco Estuary Institute/ Aquatic Science Center (SFEI) perform this science function and resolve technical controversies for regional wastewater discharges. Each specialized geographic area would have a lead scientist, reporting to an overall Delta lead scientist, who would assume the combined authority of the lead scientists from the Interagency Ecological Program and DSP and be advised by scientists from stakeholder groups. The lead scientist would set the science agenda, direct funding, and lead efforts in information synthesis.

Annual Operation and Implementation Plans. Annual operation and implementation plans would be developed for each sub-area and Delta-wide, in the context of longer term plans and under DSC authority. The plans would be developed in consultation with local sub-area and Delta-wide interests. An annual implementation plan process would make integration routine and in-depth, rather than rare and rhetorical.

External Review. External scientific review should be expected in Delta science, using the online open-access journal *San Francisco Estuary and Watershed Science* and other means, such as regular posting of reports with external scientific comments. The existing Delta Independent Science Board (DISB) would provide periodic overall review of Delta science and management programs, including specialized area programs and major programmatic efforts. Some reviews could be done by panels managed by the DISB. A National Research Council review of the overall scientific and ecosystem management enterprise should be considered every 4 to 10 years.

Raising New Science and Management Leaders. Most science, management, and regulatory agencies involved in the Delta face a shortage of new energetic leaders for long-term science and management. Creative new leaders seem more likely to emerge from efforts that accomplish forward-looking objectives than from continuation of entrenched conflicts in a deteriorating system. We need a program to actively encourage development of new leaders.

Funding. Long-term science requires long-term, predictable funding, which can be achieved through various means. For example, one way is to assess all agency expenditures and revenues related to the Delta (levees, tunnels, restoration, channel dredging, water sales, etc.) to fund Delta science (at 4%) and adaptive management (at 10%). Whatever the other sources, state and federal agencies that currently fund Delta science would continue to be responsible for at least 60% of science budgets in the overall Delta science program. Most Delta science efforts would be funded under the common program.

Conclusion: Adaptive Management and Muddling Through

In the literature on managing difficult ("wicked") problems, the art and science of "muddling through" is often cited (Lindblom 1979). Effective adaptive management will have similarities to effective forms of muddling through. These problems are inherently messy, so an organized approach to near-term management with an eye to long-term objectives is likely to be most effective. Using a strategic framework like the one proposed here should help California muddle through the Delta's problems more effectively.

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SF E&W S
San Francisco
Estuary & Watershed Science:
A Broad Perspective

The Econocene and the California Delta

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Considering the 50-fold increase and the globalization of economic activity during the 20th century, we are now in the Econocene: an era where our economy has become the major driver of rapid global change. Managing the California Delta will require policies that facilitate looking ahead and continually working with change rather than looking back and trying to secure a static past. Simply making modest adjustments in the current science–policy interface will be insufficient. Impractical changes—that is, those well beyond existing practice—are called for across the public, private, and non-governmental sectors.

Dealing with the variability of nature has been central to human survival, indeed to all species. Being social and smart, people have organized collective strategies to live with nature's capriciousness. Water management, in particular, has long been central to the cultures and structures of many successful societies around the world. With the rise of modern nations in the 19th century, being social and smart took the form of progressive, or scientific, governance of land and water.

Central to science a century and a half ago was the premise that nature varies in knowable ways around an invariable mean. Those concerned with the big questions of geological history and the evolution of life saw dynamics, but hydrologists and ecologists at the time saw stability. For water science, this led to classifications such as a 100-year flood and 10-year drought, as well as management concepts such as reservoir operating rules. For fish and wildlife, the concepts of sustained yield and critical thresholds were developed through an understanding of nature having set properties. Similarly, water rights—indeed our concepts of property in general—are rooted in a known nature that varies around a mean. Importantly, this allowed nature to be divided up, owned, and exchanged. Equally important for this essay, our understanding of responsible environmental management and accountability, whether in the private or

public sectors, is tied to laws and regulations that are premised on a known, or soon to be known, natural world. The role of science has been to articulate the known and push back the unknown wherever it is most important for environmental governance, both public and private.

The mechanical view of nature with statistically definable variation, complemented by increasingly market economic organization facilitated a 3-fold rise in human population and a 50-fold expansion in market activity during the 20th century. This incredible expansion in human activity is transforming the earth. Some scientists are proclaiming that the earth has moved from the Holocene into the Anthropocene, where people are the predominant marker of global change. Given the expansion of economic activity, it would be more appropriate to call it the Econocene to focus our attention on the primary driver of socio-environmental change: the global and increasingly market-based economy.

This expansion has led to numerous unforeseen environmental consequences. Learning from bad experiences, we imposed a series of environmental restraints, modifying private rights and public responsibilities accordingly, throughout the 20th century. As a part of this correction, the politics of conservation and preservation transformed during the late 1960s into a scientifically and legally driven environmental movement based on a new ecological systems understanding of nature. This shift accelerated and compounded the complexity of rooting our understanding of private property and responsible public action in a knowable world. The deterministic scientific worldview behind the idea of property and responsibility did not change, yet we discovered the world changed and evolved, and entirely new phenomena could emerge. While the public as a whole is by no means fully in tune with this systems view—indeed there is a counter rebellion to this shift in understanding—environmental scientists themselves realize that we are now in yet another new phase.

Central to the new phase of understanding is a rejection of the idea that nature varies in knowable ways around a knowable mean. Nature is constantly changing in unforeseeable ways—always has been—though now human activity appears to be accelerating this rate of change and, hence, uncertainty. Second, we can no longer think of a nature that is an "external nature" that is "out there," separate from us, for us to know. The world we live in today is driven by the ways we have known and organized—and by the technologies we have brought to bear on—nature. Our past interventions help explain the world we are in and are a major part of the driving force affecting the dynamics of the world we are trying to stay on top of today. Environmental science is becoming recursive. The California Delta we are trying to understand and the directions in which it is heading are a product of how we understood, governed ourselves, and thereby acted in the past.

While the rapidly expanding market economy has been a central driver of change, it is extremely important to stress that the mistaken incorporation of a predictable and divisible nature into our concept of private property and the market economy does not

A bureaucracy, whether public or private, is a hierarchy of wastebaskets.

mean collective ownership and central planning are the answer. The problem is deeper than the "socialism *v.* capitalism," "top-down *v.* bottom-up," or right mix of government and market debates of the last century and a half. First, we need to acknowledge that top-down hierarchical social organization has boomed in the age of markets. Corporations are hierarchies, and they are bigger and more important than ever before in human history. It is a fundamental contradiction that modern peoples worship individual choice and markets in an age of corporate bureaucratic organization. Second, and equally important to both governmental and corporate organization, the myth of a predictable and divisible nature proved instrumental to hierarchical structuring, to the very nature of bureaucratic pyramids with many people at the bottom and only a few at the top. It is not a coincidence that California's Natural Resources Agency is divided into departments, boards, and commissions that are distinguished by the particular parts of nature they separately try to oversee and that the departments are further divided yet again. Corporations are similarly structured.

A bureaucracy, whether public or private, is a hierarchy of wastebaskets. At each level, managers simplify the information they have about the complexity of the system in which they are working as they communicate to the next level up. If information were not filtered and thrown out, the person at the top would need to try to know everything that all the people at the bottom know. The organizational structure of the pyramid, undertaken along preconceived notions of nature's divisibility, strongly influences how the filtering, or synthesis process, is done. When problems arise because they were not identified in prior syntheses, and they are perceived as passing problems, we assemble special task forces of scientists and managers but generally do not change the organizational structure. Sometimes we change the structure, as in the 1970s energy crisis when we assembled diverse energy units from multiple federal agencies into the Department of Energy to integrate energy and strengthen energy planning. Of course, we have subsequently realized that the early links between energy and land, energy and water, and energy and the nuclear fuel cycle have been weakened through this new centralization that intends to emphasize the importance of energy. Hierarchical organization is advantageous only to the extent that systems can really be decoupled. If systems cannot be decoupled so as to facilitate hierarchical organization, a great deal more coordination and communication is a necessary cost.

Over the past century, Californians have struggled to address complex socio-environmental system changes, those in the California Delta being prime examples. We are now being called upon to address greater complexity; in effect the realization that what we had considered to be separable subsystems for our own organizational purposes are, in fact, more tightly coupled than we had thought. Along with this realization, we face more frequent surprises. Furthermore, the solid ground on which natural science has informed governance in the past, that ultimate underlying nature of nature, even if it is only statistical, is now in motion and taking sweeping random turns.

All parties engaged in environmental governance processes—politically active citizens, private landowners, public resource managers, environmental scientists, and politicians—now must "face forward" to effectively ride the wave of socio-environmental change during the Econocene. What will "facing forward" entail? Since the problems go back a good century and a half, a lot of serious change will be needed. For saying this, of course, smart and knowledgeable people, especially those deeply entrapped in existing science and management practice, will label me as being impractical. And what I am saying is impractical because small changes to current practice will not be sufficient. Big changes are always impractical for those deeply embedded in existing practices that are failing us.

Big changes are always impractical for those deeply embedded in existing practices that are failing us.

First, and most importantly, whether we are engaged primarily in scientific, political, judicial, or managerial processes, we will all need to change in ways that benefit each other. It is not simply a question of what kind of science is now needed in this new era. We all need to be social and smart together in new ways. Science has to be supported, understood, incorporated into institutions, and acted upon by all. Indeed, acting upon science is the only real test of its usefulness and validity.

Second, we will all have to be more responsive. Both private interests and the common good will change more rapidly. Working together politically will be easier because old battles will become environmentally and economically obsolete sooner. On the other hand, grasping the most significant emerging battles will be more difficult, leading us to cling to the old. As scientists, we will need to spend less time perfecting our understanding of decade-old questions, let alone century-old, and shift monitoring and analysis to incipient issues. Managers will find priorities a moving target. Responsive policymakers will need to keep them moving.

Third, to speed the scientific process and incorporate new knowledge, the lines among science, policy, and management need to blur; policymakers and managers need to participate more in science processes, scientists more in the policy and management processes. Universities, for example, could encourage scientists to take 3-year positions in policy and management and then return to academe. Universities also could welcome government scientists who work in policy and management to 3-year stints in research and teaching.

Fourth, knowledge will not accumulate in a march of progress. Rather, as the socio-environmental system changes, some of what we have known will become obsolete while new questions, now recognizably driven more by socio-environmental system change than by the progress of science, will arise. Surfing in front of the wave of change provides a glorious metaphor; the drudgery of being on a treadmill is equally applicable. The flood of new questions for environmental science in the Econocene is obvious already, but the idea of progress still knocks about in our minds, the language of progress still spills off our tongues and into our texts. In the Econocene, we need to work hard to stay in place.

Fifth, "facing forward" will entail envisioning and implementing preferred *transitory* futures. We will need to drop old battles more quickly and look ahead to what the future holds for our environment and how it fosters our economy and well being. Restoration ecology carries with it the vision of a static past nature that never was realistic and is even less so in the Econocene. We need a rapid philosophical and practical shift toward what I term "futuration" ecology: toward looking ahead to where habitats are headed and then trying to influence their direction toward more desirable outcomes rather than trying to return to the past. Given the great uncertainties ahead, encouraging a diversity of habitats will offer more options for species to find suitable habitats under global change.

"Facing forward" will entail envisioning and implementing preferred transitory futures.

We will need to drop old battles more quickly and look ahead to what the future holds for our environment and how it fosters our economy and well being.

Sixth, we will need to be much more trusting of each other's knowledge and intentions while at the same time less accepting of those who are not working toward the common good. We must learn to understand complex problems together and seek the common good. Looking out excessively for one's own interests was not a virtue among the participants of a wagon train heading west or among farmers settling the frontier. Indeed, individual greed was not likely a virtue in any civilizations heretofore.

The level of the sea may steadily rise, though its rate is in considerable dispute, and there are possibilities of very rapid rise. The frequency of invasive species and severity of devastating droughts and floods will, probably, be more uncertain. The mutable stresses of the rapidly changing global economy and the demand for California's agricultural crops will add to the socio-environmental system's uncertainties. Stakeholders' stakes will move; the public will repurpose. As someone who sees the change we face in rapid evolutionary terms, I cannot be more specific than this. We will surely need to combine the human animals best traits: being smart and social–but just *how* we will need to do this is unclear. I can only hope that we can all be open to discovering, and rediscovering repeatedly, the very difficult situation we have gotten ourselves into, develop more trust among us, and work our way through it smartly, together.

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Suisun Marsh is the largest tidal wetland in the San Francisco Estuary that has been subject to 6000 years of constant change, which is accelerating. Decisions made today will have maajor effects on its value as habitat for native biota in the future

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SF E&W S
San Francisco
Estuary & Watershed Science:
Case Study

The Future of Suisun Marsh: Balancing Policy with Change

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The San Francisco Estuary, from the Sacramento–San Joaquin Delta to South Bay, is a mosaic of highly altered habitats, often dominated by alien plants and animals. It is also a center of native biodiversity, supporting endemic and charismatic species, from rare plants to vast flocks of waterfowl. Many of these species are in severe decline as result of conflicts between their ecological requirements and the human uses of the estuary and its watershed. At the same time, major forces of change are operating on the estuarine landscape, among them climate change, urbanization, and increased human demand for water. These conflicts in an ever-changing environment present major challenges to policy makers: how do you balance human and ecosystem demands, especially during periods of extreme conditions, such as droughts and floods?

A good place to explore these conflicts, with an eye towards resolving them before they become too severe, is Suisun Marsh. The marsh is already a focus of mitigation habitat creation because it is centrally located in the estuary and is conspicuously large, open, and filled with wetlands and meandering channels. Of particular interest is the future of Suisun Marsh as habitat for native biota (Moyle et al. in press). Here we discuss the marsh as novel ecosystem, emphasizing how policy decisions made today will influence its future and how predicted changes to the marsh should affect these policy decisions.

The Importance of Suisun Marsh

Suisun Marsh is important as habitat because of its size, position, history, and native biota (Moyle et al. in press). Taken together, these intrinsic characteristics merge to create a vital wetland ecosystem.

Size and Location

Suisun Marsh is the largest expanse of marsh in the San Francisco Estuary. It covers about 470 km^2 and is located roughly in the middle, adjacent to Suisun Bay. This position means it is strongly influenced both by the tides that surge through the Golden Gate and by freshwater flows from upstream. The marsh is proximate to Fairfield and Suisun City, and so receives urban as well as regional run-off. It also serves as open space for recreation. In addition, it is connected to nearby natural areas, including the Potrero Hills and the vernal-pool prairies adjacent to the North Delta and Yolo Bypass. It is a major stopping place for migratory birds on the Pacific Flyway, and for migrating fishes such as Sacramento splittail and Chinook salmon.

History

Suisun Marsh is about 6,000 years old; therefore, it has never been without a human presence. While agriculture briefly thrived in the marsh from the late 1800s through the mid-1900s, since the late 19th century marsh management has focused on attracting waterfowl. Hunters, largely from the Bay Area, purchased marshlands to create duck hunting clubs, and vigorously defended the marsh against development and activities that threatened wetland habitat. The State of California also acquired large areas as wildlife reserves and public hunting grounds. Marshlands were diked off from tidal excursions and then managed as freshwater habitat for ducks and their favored food plants. At present, 158 duck clubs manage 75% of the marsh for waterfowl. In short, during the past 150 years, Suisun Marsh has been transformed from a tidal marsh that supported native peoples and wildlife, to farmland and pasture, and to a collection of waterfowl hunting areas with over 300 km of gated dikes that separate marshlands from intervening sloughs.

"[Suisun Marsh] is thus an excellent example of how our growing understanding of an ecosystem can be the basis for management."

Native Biota

Despite its history, Suisun Marsh supports 200+ plant, 180+ bird, 45 mammal, 50+ fish, and 60 butterfly species. Some species are endemic to the marsh, e.g., Suisun song sparrow and Suisun thistle. Many species, however, are not native; a constant problem for managers is keeping alien invaders from dominating habitats crucial for native species. On the other hand, the marsh still supports populations of charismatic species such as tule elk, river otter, white pelicans, and numerous waterfowl. The marsh is also important as a research site because of its accessibility and biotic diversity. It is thus an excellent example of how our growing understanding of an ecosystem can be the basis for management.

Suisun Marsh as a Site for Tidal Habitat Restoration

There is widespread agreement that tidal habitats, from salt marshes to mud flats, are important for native species, especially birds and plants (e.g., Palaima 2012). However, there is less agreement on the idea that tidal habitats export nutrients and food organisms that fuel food webs in channels where fish feed, especially native pelagic species. Nevertheless, restoration of tidal habitat is a driving force in planning in the marsh. For example, the *Suisun Marsh Protection Plan* establishes a goal of restoration of 5,000 to 7,000 acres of tidal habitat, in unspecified locations, within the marsh. Likewise the draft *Bay Delta Conservation Plan* recommends restoring thousands of acres of tidal habitat in the Delta and Suisun Marsh as mitigation for the effects of water export facilities. Planners gravitate toward Suisun Marsh because it seems to have an abundance of available places to breach levees, allowing the water flow in and out with the tides (Lund et al. 2010). It is already marsh, so this logic goes, such that all it needs is different management regime. Indeed, small-scale habitat restoration sites that target imperiled species already exist—for instance, Blacklock Island, Peytonia Slough Ecological Preserve, Hill Slough, Rush Ranch—although their restoration success is not well documented. This restoration view ignores the fact that while duck clubs are primarily managed for waterfowl, they also support a diversity of fish and wildlife including species such as river otters that do especially well in the managed wetlands.

"Today, policymakers face four main challenges to the physical environment that are driving the marsh towards becoming a very different ecosystem: sea level rise, land subsidence, reduced sediment supply, and reduced tidal energy."

Sea Level Rise and Other Stressors of Suisun Marsh

Suisun Marsh is constantly changing, despite considerable efforts by waterfowl managers to maintain the freshwater (or nearly freshwater) system for the ducks that hunters prefer. These efforts have included the installation of large salinity control gates at the head of Montezuma Slough in 1988 to keep fresh water in the marsh, as partial mitigation for the diversion of water upstream by the State Water Project. But other changes have made waterfowl management more challenging. For example, flocks of migratory ducks and geese are now attracted to flooded rice fields and wildlife areas in the Sacramento Valley, rather than to the marsh. The listing of endangered species from plants to mice to fish has constrained management options. Thus, dredging of sloughs to maintain levees is restricted, as is release of anoxic water from duck ponds into sloughs, where it can kill fish.

Today, policymakers face four main challenges to the physical environment that are driving the marsh towards becoming a very different ecosystem: sea level rise, land subsidence, reduced sediment supply, and reduced tidal energy.

Sea level rise will, conservatively, reach 1 to 2 m by 2100. Sea level has been rising for several decades and the rate of rise is accelerating. As sea level rises, overtopping and erosion of levees will become more frequent, especially during extreme high tides and major flood events. Floods also are expected to occur more often as the result of climate change.

The mixture of native and alien species from all over the world living together in highly altered habitats makes Suisun Marsh a novel ecosystem—unlike any other that exists.

Subsidence of land inside dikes is the result of the way most duck clubs are managed today. Already, about half of all land in the marsh is below sea level. Subsidence increases the likelihood of large-scale dike failures and marshland flooding. The best way to reverse subsidence is to build up organic matter by encouraging dense growth of native marsh vegetation, which may not be favorable to waterfowl in the short term.

Reduced sediment supply from upstream sources makes it more difficult to reverse subsidence through sediment deposition. Unfortunately, the whole estuary is now a sediment-starved system, in part because sediment is retained behind dams upstream.

Reduced tidal energy occurs as the tidal water is spread over larger areas as the result of submergence of Delta islands, tidal restoration projects, and similar actions. Reduced tidal energy results in less ability for the tides to transport sediment and nutrients to places where they are needed. Essentially, tidal energy in the estuary exists as a fixed quantity, so the larger the total area inundated by tides, the more this energy is dissipated. As a result, tidal currents will be greatly reduced in many channels.

What all this means is that much of Suisun Marsh will become increasingly intertidal and saline, unless enormous sums are spent maintaining ever-sinking dikes. Much of it will become tidal marsh and open water no matter what we do; it is more a matter of 'when' than 'if' this will occur. Our basic understanding of these processes means policymakers can either actively guide the future of the marsh or, by ignoring our collective knowledge, continue to respond to crises as they emerge (Moyle et al. in press).

The Future of Suisun Marsh

Ultimately, given the inevitable changes outlined above, most of the marsh cannot be maintained as diked and managed wetlands (Moyle et al. in press). The marsh will become increasingly tidal with limited space for upslope marsh expansion into new areas. If it continues to be managed as fragmented, diked wetlands until the dikes can no longer be sustained, the end result will probably be large expanses of open, salty water, pushed around by the winds, with low tidal energy to move organisms, nutrients, and sediment in and out of the system. Alternatively, controlled tidal flooding could be allowed in large areas of diked wetlands in the near future. This choice would keep many areas indefinitely as marsh—albeit as brackish marsh less favored by ducks—by allowing marsh plants to deposit organic matter in sufficient quantities to keep soil levels up with sea level rise.

Policies made today about how Suisun Marsh is managed will determine which plants and animals are abundant there in the future. The mixture of native and alien species from all over the world living together in highly altered habitats makes Suisun Marsh a novel ecosystem, unlike any other that exists. This novel ecosystem will continue to change in the future, providing opportunities for creative management.

Because a mixture of policies and changing natural processes will determine what species inhabit the marsh and what the marsh will look like, policies that work with inevitable, predicted environmental change, rather than against it, offer the best opportunity to conserve the high ecological and aesthetic values of this special place. Most policy decisions will allow Suisun Marsh to continue to function as a mixture of tidal and non-tidal habitat, as open space, and as protection for urban areas against sea level rise and flooding. These functions can also be very compatible with management options that favor native species, from plants to fish to birds. Such management, however, may necessitate new forms of science–policy collaboration, political compromise, and some consternation. But a deliberative approach to management, with clear goals for both the near and distant future, is the best way to proceed. Actions we take today will determine the marsh ecosystem of tomorrow—and the diversity of life it will support.

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