ENVIRONMENTAL SCIENCE & POLICY 12 (2009) 644–652

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Collectively engaging complex socio-ecological systems: re-envisioning science, governance, and the California Delta

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ARTICLE INFO

Published on line 17 November 2008

Keywords:
Deliberative processes
Integrated environmental assessment
Water management
Environmental management
Coevolution
Collaborative policy
Adaptive management
Restoration
Governance

ABSTRACT

We address the future of science and governance for the California Delta, focusing on the CALFED Bay-Delta Program, an interagency, multi-stakeholder effort to understand and manage the Delta for multiple purposes. We portray a Delta history as a coevolutionary process between science, governance and ecosystems. Global integrated environmental assessments (IEA) provide insights into understanding complex, dynamic socio-ecological systems. Many of the discursive stakeholder and scientific activities that have arisen under CALFED are similar to IEA and remain essential to the shared learning needed to effectively interact with a dynamic Delta. More deliberately enmeshing environmental monitoring, analysis, and collective learning into Delta governance will improve outcomes.

1. Introduction

The California Delta is the largest estuarine system on the west coast of the Americas. It is an inland delta at the juncture of the Sacramento, Mokelumne, and San Joaquin rivers that connects to the Suisun Marsh and extends on to San Francisco Bay. Its waterways and wetlands provide critical habitat for fish and migratory birds. The inland delta hosts some 500,000 people and 52,000 acres of farmland. About 48% of the water that historically would have flowed through the Delta to the Bay and sea still does so, 31% has already been diverted for human use before reaching the Delta, 17% is exported from the north to the south of the Delta, and 4% is used in the inland delta (BRTF, 2008). These diversions account for about 40% of California's "plumbed" water use (Lund et al., 2007).

Unfortunately, the California Delta is "ill behaved". It never lived up to human expectations when filled to expand urban land, diked to form agricultural land, dredged for shipping, or channeled to enhance the delivery of water from north to south (Bay Institute, 1998). It now responds inexplicably to management efforts to conserve its threatened species. For the past half century – while the state's population has tripled, the economy grown by sixfold, and lifestyles and hopes for the future have changed – the role the Delta can and should play in the California landscape and economy has been politically contentious. CALFED, a multi-agency, multi-stakeholder process to balance water use and environmental objectives and manage water conveyance through the Delta emerged in 1994. What started as an experiment developed into one of the most important water and ecosystem management institutions in the world (Hundley, 2001; Taylor et al., 2003; Heikkila and Kerlak, 2005). Yet discontent with CALFED's effectiveness triggered a critical review by a team of public administration experts (LHC, 2005) and the initiation of another process of

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1462-9011/$ – see front matter
doi:10.1016/j.envsci.2008.10.004

envisioning the Delta's future and implementing governance (Executive Order S-17-06, 2006).

This paper contributes to a broad literature on science and society. A century ago, American pragmatist philosophers argued that a balance of openness and skepticism to new arguments, a willingness to listen to others, and an insistence on empirical evidence were traits essential to both good science and real democracy (John Dewey in particular, as argued in Campbell, 1995: 101–105). Kuhn (1962) documented how social processes within science are critical to the pace and course of science. Connie Ozawa (1991) illustrated the importance of consensual procedures among scientists for policymaking. Nowotny et al. (2002) provide a broad overview of how social philosophers are rethinking the role of science in society. Judith Innes and Sara Connick analyze CALFED in this tradition with attention to the difficulties of managing complex socio-ecological systems (Connick and Innes, 2003; Innes et al., 2007). Our contribution compares and contrasts CALFED science with global scale integrated environmental assessments, stressing how discursive processes help scientists cut through the epistemological difficulties of understanding complex systems and identifying how this results in new tensions between science and society.

We make three arguments. First, visions of the Delta's future must be both dynamic and open to surprise. Visions are highly problematic when they stress desired end states reached through predetermined implementation processes. We argue that the Delta will remain unruly until its "problems" are seen, interpreted, and responded to through a highly dynamic socio-ecological systems framework. Second, visions must include how Californians organize to understand and respond to human-driven environmental change and surprise, *i.e.* they must include visions of governance including the organization of science. How the system is understood and governed needs to be seen as endogenous to its processes of change. Third, both how science is undertaken and how science interacts in the policy process have been adapting, globally and for the California Delta, to this more integral, dynamic understanding of the human predicament. Advances in discursive shared learning processes, most frequently occurring under the rubric of Integrated Environmental Assessment (IEA), should be strengthened in the next phase of Delta visioning, science, and governance.

In Section 1 we portray a coevolutionary environmental history of Delta science, governance, and ecosystem transformation. In Section 2 we describe global IEA processes as examples of the emergence of a new model of doing science to understand dynamic, complex socio-ecological systems. In Section 3 we argue that many of the discursive stakeholder and scientific activities that have arisen under CALFED are along the lines of an IEA process and remain essential to the shared learning needed to effectively interact with a dynamic Delta. At the same time, Delta science has not been organized to work as well as it could. We develop the policy implications in Section 4, concluding with an argument for strongly enmeshing collective environmental monitoring, analysis, and learning into the structure of governance in Californian's vision of the future of the Delta.

2. Historical background: the coevolution of science and governance in the California Delta

Science, governance, and transformations of the Delta occurred together, each affecting the others and to some extent selecting on features of each other in a coevolutionary process (Norgaard, 1994). Our portrayal highlights both how Delta ecological processes change and how the way scientists at different times have bounded problems and focused on some interactions out of the immense complexity of the Delta, while ignoring others, is intertwined with governance objectives and past and intended transformations of the environment. There are diverse ways of understanding, interacting with, and governing the Delta and different actors align with different ways. Over time, some ways dominate and affect mutual selection. Surprises and the continuous presence of diversity usurp path-dependencies, and new ways of seeing or acting upon the Delta gain currency.

Since the second half of the 19th century, diverse parties have intervened in the system, imposing changes with little concern for the interests of others or the public good (Bay Institute, 1998; Hundley, 2001; Lund et al., 2007). Cities filled Bay marshes and shallows for industrial development, reducing tidal flushing and transforming food webs on which Delta fisheries depended. Agricultural interests built levees inland in the Delta, transforming marsh to farmland and thereby changing the future of anadromous and other fisheries as well as the habitat and thereby abundance of migratory waterfowl. Hydraulic miners blasted Sierra Nevada hillsides, flushing vast amounts of material into streams. The silt affected fisheries immediately. The sand and gravel raised the bed of Delta channels, putting levees at increased risk, affecting tidal action and water salinity, and further threatening anadromous fisheries. Then local, state and federal agencies built dams on Sierra Nevada streams that flow into the Delta, transformed hydrologic regimes, and diverted water to farmers and urban users. Agricultural return flows brought both unnatural nutrients and toxics to the system. More recently suburbanites increasingly come to live in the reclaimed islands on the edges of the Delta near urban areas (Lund et al., 2007).

Scientific activity and governance mirrored these transformations. Specialized agencies delivered specific transformations: reclamation, flood control or water supply. Separate laws governed their activities. Experts, most of them trained as engineers, advised and implemented the transformation of the Delta from the beginning, working largely as specialists for particular agencies – local, state and federal – with specific goals serving specific interests. Until the past quarter century, each agency and discipline of scientists largely focused on narrow scientific questions that related to their mandates (Freeman and Farber, 2005).

Many of the conflicts between interests arose well after the filling, diking, withdrawing, and polluting, began. Different aspects of ecosystems respond to new forces differentially over time. A few ecosystem services are lost immediately, others after several life cycles of key species. Natural variations in climate complicate the difficulties of understanding the processes of change. The costs each interest imposed on the others and the public were lagged and blended in a manner such that causes and effects, and thereby responsibilities, were never clear. Thus the early dominant vision of the Delta as a vast, open resource that could be acted upon by separate interests with little, if any, effect on each other lasted well into the latter half of the 20th century.

By the 1960s, as the Delta became the hub of California's water system, one use of the Delta dominated and stood at the political forefront: water supply (Hundley, 2001). Reservoirs in the Sacramento and San Joaquin Rivers stored mountain snow run-off and released it to the Delta where it was lifted by huge pumps and distributed through California's two main aqueducts, the Central Valley Project and the State Water Project, to supply much of the State's agriculture and the rapidly urbanizing south. Upstream and in-delta withdrawals, levee failure risk and associated saline intrusion from the Bay, and the contamination of water limited the quantity and quality of water that could be delivered south. The Delta, now envisioned as a conduit for water supply, came to be bounded by dominant political and economic interests (Gottlieb, 1988; Hundley, 2001). Many presumed at that time that a peripheral canal that would by-pass the polluted and fragile Delta and bring water directly to the aqueduct would be constructed.

But the peripheral canal 'solution' collided with new interests. Federal and State environmental laws passed in the 1970s regulated for the protection of wetlands, endangered birds and fish, such as salmon whose numbers were plummeting, and surface water quality. State and Federal water and fisheries agencies initiated an Interagency Ecological Program in 1970 to conduct joint monitoring and analysis. Though much of this shared effort occurred because courts and regulatory bodies required the agencies to monitor and report, it began to provide data and the context for some agency scientists, as well as the larger community of scientists, to undertake serious research in the Delta. In the process, scientists begin to view the Delta as an environmental system.

A strong environmental constituency coevolved with these governing functions and opposed the peripheral canal on environmental grounds (Gottlieb, 1988). Together with northern California interests who were afraid the canal would siphon more water south and Delta interests afraid of losing access to water and state financing for levee maintenance, they defeated a peripheral canal ballot measure in 1982 (Hundley, 2001; Gottlieb, 1988). The same interests turned to the Courts in 1986 and, by invoking the public trust doctrine, forced State and Federal agencies to put limits on water exports to protect water quality and environmental functions (Hundley, 2001). As legal and political debates focused on how much water could be exported from the Delta without damaging regulated environmental services, the Delta came to be viewed as a conveyance facility subject to environmental constraints. Scientists were engaged in a new set of questions that included how much water was needed to flush saline intrusion out of the Delta and how much and when water could be pumped south without trapping endangered fish (Connick and Innes, 2003; Freeman and Farber, 2005).

But the problems were seen as increasingly complex. Old mines and agricultural land were leaching contaminants into streams. Quantity and quality were interacting unevenly and in different ways in different parts of the Delta at different times. Levee collapses could rapidly increase saline intrusion. Saving one species here endangered another there. Agency experts began to work together, engineers began to listen to fisheries and wildlife managers, and a few ecologists were hired in agencies still dominated by engineers. With no slack in the system, declining populations of fish species causing interruptions of water exports, and new toxics to address, the perceived need to understand Delta dynamics was greater than ever.

Agencies and stakeholders joined to form an experiment in governance. Governor Wilson formed the State Water Policy Council in 1992 made up of state agencies to coordinate water management in the Delta. This was followed by a federal interagency agreement in 1993, and then CALFED arose in 1994 as an Accord and Memorandum of Understanding between federal and state agencies (Rieke, 1996; Freeman and Farber, 2005). By 1997, a chief scientist, an ecosystem restoration program with funding, and an Interim Science Board for the Ecosystem Restoration Program were in place. CALFED provided a forum for multiple federal and state agencies and stakeholders together to devise a plan that was expected to be able to satisfy the divergent interests, primarily stressing Delta ecological restoration while ensuring a reliable water supply to the South, but other issues including levee stability and water use efficiency were included (Connick and Innes, 2003; Freeman and Farber, 2005). The agreement was meant to hold off the several policy and legal processes separately affecting the Delta and reset management under a common framework.

Multiple visions blended in the CALFED process. Some saw the Delta as a water conduit (subject or not to environmental constraints), others saw it as a place to live and farm or a place where fish and birds live, and yet others emphasized the plights of low-income or indigenous communities. Interacting in multiple venues and failing to come up with any single solution that would cure all ills (a smaller and more regulated peripheral canal design failed to garner political support), stakeholders increasingly realized the complexity and dynamism of the Delta. Eventually a political and scientific consensus, a plan for action, emerged that was documented in the 2000 CALFED Record of Decision (CBDP, 2000). Acknowledging that the system was still little understood, a decision with respect to a peripheral canal would be postponed. For the next 7 years, an experimental 'adaptive' approach toward meeting environmental and water supply goals was to be tried (Hundley, 2001; Freeman and Farber, 2005; Innes et al., 2007). Agencies and stakeholders embraced each other's hopes for a compatible solution. Multiple programs gave something to each interest group, and an open process of implementation and coordination was set in place. All were expected to observe and adapt their activities according to outcomes. CALFED was expected to organize the monitoring of the progress made and evaluate it at the end of the seven years, deciding whether to revisit or not a peripheral canal-type of solution (Hundley, 2001). An awareness of uncertainty, complexity, emerging properties, and the necessity of adaptation began to coexist with a conventional, although contradictory, mandate of achieving specific goals and evaluating performance according to goal achievement.

In 2002 a new state agency, the California Bay-Delta Authority, was established to implement the CALFED program, staffed with experts largely from participating agencies. During this stage, focus shifted with varying degrees of success to ecological restoration, water use efficiency, recycling, reallocating the use of water through markets, and understanding the Delta as a system. Postponing their hopes for significant additional water supplies through State or Federal agencies, water suppliers took more responsibility for improving the efficiency as well as the resilience to drought of their individual water systems. Setting aside political discussion of a peripheral canal, however, also entailed setting aside doing science directly related to alternative conveyance facilities. CALFED science funds were directed at water quality, improving water use efficiency, ecological restoration, and upper watershed management. These issues evolved into their own self-regenerating research programs within the Delta science community while historic expert knowledge and synthetic understanding with respect to conveyance alternatives waned, even in the water development agencies. While there was now greater ecological knowledge of the Delta to draw on to inform conveyance facility design and operation, there was less thought being given to how new scientific findings related to alternative conveyance facilities. Thus when interest in a peripheral canal rekindled in 2006, policy makers were surprised to discover that scientific confidence had diminished with respect to how alternative conveyance facilities might be designed, operated and would impact Delta ecosystems compared to a decade earlier.

Whereas scientific understanding had been sharpened in many ways, taking a more systemic view also opened new questions that made answers even more uncertain. Furthermore, little headway was made in formally understanding the state or dynamics of the environmental system because it kept changing so rapidly (Healey et al., 2008). This necessarily meant that measurement of the extent to which the combination of initial goals specified in CALFED's Record of Decision (CBDP, 2000) was being achieved was poor as the process adapted to ever emerging conditions. Whether CALFED succeeded depended much on eyes of the beholders and many of them thought it failed: some endangered species were at record-low levels, pollution was still high; levees collapsed, flooding islands; and droughts continued to threaten supply reliability (Freeman and Farber, 2005; LHC, 2005). The New Orleans disaster brought flooding risk and housing and infrastructure vulnerability to the political forefront, even more so given the likelihood of earthquakes in the Delta (Mount and Twiss, 2005). Climate change raised prospects of sea level rise, greater flood risks, and saline intrusion in the Delta. The disturbed ecosystem also became increasingly vulnerable to invasive species brought from far-way estuaries through growing global shipping. A successful invasion by the Asian overbite clam in Suisun Bay during the 1990s significantly affected the Delta aquatic food web as a whole a decade later. Scientists and policy makers, already overwhelmed trying to understand relationships between water inflows, exports, salinity and fish, watched complexity exploding in many directions.

In short, the environmental goals spelled out in the CALFED ROD were not being met while the quality of water supplied became less dependable. Both water users and environmentalists became disenchanted with the CALFED process, some declaring it a failure. The Little Hoover Commission (2005) reviewed the situation of CALFED and the Delta from the perspective of ''good management'' and argued:

> Policy-makers need to explicitly endorse specific objectives so that government officials have a clear mandate to pursue progress. Lawmakers need to be clear about what they expect of state agencies and then hold them accountable for outcomes (second page of cover letter by Michael Alpert, Chair).

The Commission perceived the Delta as a complicated machine that has to be understood with ''better science'' and then operated to achieve predetermined future targets. The era of (incomplete) experimentation and adaptive management seemed to be coming to an end with a retreat to the normal paradigm of positivist science and hierarchical governance. But the elusiveness of understanding the Delta in a single, unified way and of agreeing on what has to be done with it, is what had lead to the adaptive approach in the first place. History seemed to be repeating itself.

3. Collectively understanding complexity: integrated environmental assessments

Scientists argue that science is distinguished from non-science by the scientific method, frequently portrayed as a single method tied to the replicability of research findings. In fact, however, we observe scientists engaged in a variety of activities. If science stuck to the lab bench story of replicability, scientists would never be found doing less than fully controlled field experiments, bothering with statistical analysis, building computer simulation models, assessing the literature, undertaking meta analyses, or ''brainstorming.'' Looking back several centuries, we see that scientists were doing different things than they do today. And taking a closer look at recent developments in what scientists are doing, we see a new activity becoming quite important, *i.e.* integrated environmental assessment (IEA).

Sometimes referred to as ''global environmental assessments (Mitchell et al., 2006) or simply environmental assessments (Farrell and Jäger, 2006), we use the term integrated environmental assessment or IEA as increasingly used in Europe (European Environment Agency) and through the training efforts developed for UNEP's Global Environmental Outlook Reports (UNEP, 2007). There are strong parallels between the ways in which scientists are organizing to undertake IEAs around global issues and around regional issues, such as the Delta, to understand what we call complexity.

Thousands of scientists around the world are working together to collectively understand the processes of climate change (Intergovernmental Panel on Climate Change, 2007) and ecosystem transformation (Millennium Ecosystem Assessment, 2005). These IEAs combine the knowledges of scientists from multiple disciplines into a ''reasonably coherent'' whole through a discursive, shared learning process (Norgaard and Baer, 2005a). Scientists collectively review and debate the broader significance of the existing, typically narrowly focused, scientific literature, they share and collectively redesign formal models and informal frameworks of analysis, and they use existing disciplinary techniques but under new assumptions, pushing them into territory their disciplinary peers would not have considered exploring. Working together, they are able to collectively understand and make judgments about systems in ways that no individual scientist, or group of scientists with similar backgrounds, could. This collective approach has arisen and acquired importance because of the limits of understanding complexity by other means. Climate scientists appeal to their computer models for scientific credibility and their ability to explain the past as evidence that they have fit things together effectively and correctly. Formal models certainly help. Yet the big global circulation models are very incomplete while the fairly complete models are incredibly simple (Norgaard and Baer, 2005b). It is the shared learning process that is critical.

Scientists select and design models, determine the most important variables for analysis, choose appropriate data and prior work to calibrate the models, and lastly judge whether the results are reasonable, or not. Similar judgments are commonly made within disciplines almost subconsciously. They are simply part of the discipline's culture learned through coursework and reinforced in the early stages of doing research within a discipline. For problems that span the disciplines, choosing models, selecting data, and judging results requires a collective ability among scientists across the disciplines to make judgments. This collective ability comes through talking together, overcoming philosophical challenges, and coming to a new, shared understanding. For individual participants, coming together across disciplines entails consciously facing new philosophical challenges and accepting incongruities with judgments accepted within one's own disciplinary culture (Lélé and Norgaard, 2005; Eigenbrode et al., 2007). Alternatively, cross-disciplinary analyses of more broadly defined systems have to encompass the breadth of assumptions made within the disciplines, making them inherently less certain than the certainty that is presumed to exist for analyses within disciplines. Becoming conscious of disciplinary cultures and their embedded assumptions and presumed certainties and much more consciously choosing new assumptions, or ranges of assumptions, is a difficult form of culture shock. Many scientists refuse to go through the process and retreat back to disciplinary comforts.

A second, and closely related, realization is that scientists frequently have no choice but to use multiple, different patterns of thinking that lead to multiple, different insights (Norgaard, 1989). This lesson was especially strong for the Millennium Ecosystem Assessment (MA). Physical scientists and economists with mathematically compatible formal models dominate climate science. The MA, however, addresses all types of ecosystem change and hence is more applicable to the challenges of understanding the Delta. Ecologists have many different, irreconcilable ways of thinking about different aspects of ecosystems: population biology, energetics, food webs, evolutionary ecology, biogeochemical cycles, community and landscape ecology, behavioral ecology, etc. Some frameworks are used more effectively at particular spatial and temporal scales, and frequently ecologists find themselves changing their frame of analysis as they shift across scales. The MA also addressed questions for which the multiple ways economists, indeed social scientists as a whole, understand economic and social systems were important (Norgaard, 2008). This is the state of our knowledge of socio-ecological systems, and it ought to induce a whole lot more humility when it comes to grand designs for the future, including the overall modern project of economic ''development'' without end.

A third important realization garnered through IEAs is that the different judgments made by different disciplines can entail strikingly different values about what is important. Values go unnoticed when individuals in a group hold pretty much the same values. Bringing scientists from different disciplines together, one quickly sees that economists and engineers both espouse efficiency but have different conceptions of the term while evolutionary understandings of biological systems intrinsically value diversity. Scientists who stay within their disciplines never discover this, those who wander a little think of it as a curiosity, and those who actually work across disciplines learn to deal with it. With the rise of interdisciplinary work in general and global environmental assessments in particular, a significant community of scholars is now very conscious of how different patterns of thinking emphasize different values. The idea of value free science is appealing, but it never existed. A new community of scholars seriously working across the disciplines is value conscious in a sophisticated way.

A fourth important realization of IEAs is the recognition that how the future unfolds very much depends on how effectively people respond to the knowledge being generated by the assessment and the unfolding of undesirable changes. Should a ''business as usual'' climate scenario assume complete ignorance and no response, not even adaptation, to climate change? Surely prices will start reflecting the realities of climate change and people will respond, and this is implicit in the IPCC scenarios (Pielke et al., 2008). Yet, alternatively, people may simply try to subsidize those things whose prices are going up because of climate change. Clearly, future scenarios in IEAs need to include how we know of environmental change, what new things we choose to learn as conditions change, and how we structure environmental governance.

4. CALFED science as an integrated environmental assessment process

The CALFED 'Science Program' (SP) plays an important coordinating, funding, and synthesizing role in Delta science. The SP is a subdivision of the California Bay-Delta Authority coordinated by a lead scientist and staffed with CALFED personnel and external consultants hired on a project basis. An Independent Science Board (ISB) composed of broad-based scientists with roots in multiple disciplines provides guidance to the SP, and ISB members participate in particular projects. Under California's 'Sunshine Laws' the Board's meetings are open and stakeholders and individual members of the public attend them, occasionally making statements at their conclusion. While there is no direct stakeholder involvement in the SP, the SP is accountable to the CALFED Public Advisory Committee where stakeholders participate. The SP solicits research proposals within broadly defined areas and funds proposals through a peer-review process to promote understanding of the dynamics of the Delta. It conducts specific 'Science agendas for core questions' such as mercury pollution or the decline of the Delta Smelt. These include open conferences, targeted workshops, consultant reports and independent panels of experts that peer review evidence. CALFED science is not confined to the 'Science Program.' Diverse agency or interagency/stakeholder scientific subgroups work on specific issues, stakeholder scientists bring their research and knowledge into the CALFED process, and academic researchers join with agency scientists to untangle particular problems.

The CALFED Science Program has not organized Delta scientists around a coordinated environmental assessment process in a manner comparable to scientists in the IPCC and MA processes. Delta scientists have not been trying to integrate their efforts around a general model. There is little effort to standardize measures and use words consistently as in the global assessments. The global IEAs look a century ahead, something Delta scientists only rarely do. Still, the Delta science community, like that of the global IEAs, is organized around policy questions. The CALFED Science Program has not formally established discursive processes as a method of coming to judgment about the state of the Delta, priorities for science, and possible futures of the Delta. Nevertheless, facilitating dialogue between scientists, policymakers, and stakeholders was a main reason for the CALFED process, and discursive processes, even if not explicitly recognized as such, can be found throughout the Science Program The numerous conferences, formal workshops, informal panel meetings, and discussions of commissioned papers on diverse Delta topics sponsored by the SP are very inclusive processes. Scientists and managers with different expertise and perspectives come together and learn from each other. Like the global assessments, CALFED Science has been encouraging stronger external review processes to assure the quality of findings. And the findings have been made widely available through CALFED SP publications, a journal, and the Internet. CALFED's ISB reaches collective wisdom through discussion. It makes scientific judgments in the process of giving advice to ongoing research efforts, participating in the review of research findings, and advising the policy process (Connick and Innes, 2003; Freeman and Farber, 2005; Innes et al., 2007).

In many respects, the Delta science community has had several important successes that are not even dreamed of by the IPCC and MA.

First, in the global assessments, policy makers and scientists from agencies participate much more as individual scientists, partly because the meetings are held around the world and the agencies from which they come are not expected to actually change what they do based on these "far away" meetings. This frees the participants to see the problem as a whole and work toward the common good, but the separation between thinking and the commitment by agencies to act is great. Much less separation exists in the case of the Delta scientific community. While the CALFED SP strives to provide a neutral environment for objective science, many of the participants are closely tied to agencies, only a block or two away, with historic agendas. Compared to a decade ago, however, scientists and the agencies and interests with whom they work have come much closer to a shared understanding of the problem that also feeds back into agency change and action (Freeman and Farber, 2005; Connick and Innes, 2003). Even the strains of opposing each other in legal testimony have not kept scientists from learning together. This is an extremely important accomplishment that needs to be sustained and nurtured even further.

Second, in CALFED processes, lines are not sharply drawn between the knowledge of scientists and that of policymakers, managers, and those with field experience. Similarly, lines between the knowledge of government scientists and stakeholders and the public are not sharp. This is partly because people with advanced scientific training frequently represent stakeholders and the public in CALFED processes. It is also partly because scientists and non-scientists can more easily mix together around a regional issue. The global assessments work with thousands of scientists; expanding the process to non-scientists with experiential knowledge would be increasingly difficult and costly. Though the boundaries of the Delta, let alone the forces contributing to change in the Delta, are large and fuzzy, the scale of the Delta is clearly more amenable to bridging barriers between theorists, practitioners, and the public than the globe as a whole. Indeed, a significant group of participants in the MA found thinking at a global scale in sharp contrast with most ecological and cultural knowledge and broke off to conduct sub-regional or multi-scalar assessments. Regional scale assessments of socio-ecological change appear to be gaining favor now worldwide (see, for example, European Environment Agency, 2008).

Third, Delta scientists and the CALFED SP work with highly distributed governance (Innes et al., 2007). Complex problems are difficult because they are the product of multiple forces through many actions of thousands of actors making decisions under multiple governance structures. The policy volume of the Millennium Ecosystem Assessment is vague and frustrating to read because general policy prescriptions do not exist for complex problems affected by decisions made under the governance of diverse sectors at multiple levels and places. Though this presents a major challenge for Delta science, policy, and governance, it is relatively manageable at this scale compared to thinking about the globe as a whole.

Fourth, politicians still appeal to Delta scientists to provide them with the "right" answers, policymakers still ask them for just the objective facts, but Delta scientists tend to be quite aware of how different scientific perspectives focus on different good and bad things. In part because of CALFED interactions, most scientists realize that no one of them speaks to the whole and that values are difficult to weigh. While economic valuation of non-market goods and services is often touted as the key to objectively resolving public choices, many Delta scientists accept economics as simply one of many ways of clarifying public choices. In one of the most developed market economies of the world with some of the world's best environmental and ecological economists, market valuations of environmental services provide insights, not answers, to difficult public choices.

Fifth, the Delta science community works quite frequently in real time as problems arise and decisions must be made. Much of CALFED's early history unfolded around the identification, monitoring, and management of saline intrusion from the Bay and selenium being released from newly irrigated agricultural lands. Scientists played central roles in the effort to understand the relations between water quality and wildlife. Week-to-week water delivery decisions are now closely tied to the scientific monitoring and analysis of the population levels and conditions of endangered species. The Delta science community works in time frames that the IPCC and MA assessments do not even contemplate.

For these reasons, in terms of crossing boundaries and forming interfaces between science, policy and society, CALFED can be thought of as a more advanced experiment than either the IPCC or MA. But this reduced separation also provides the conditions for issues to arise that global assessments, with their relatively confined 'scientific space', can safely ignore.

First, the multiple roles that some scientists assumed as consultants, sponsored researchers, independent experts, State-appointed officers, provocateurs, stakeholder representatives – sometimes simultaneously – clashes with expectations of science being independent and raises concerns about conflicts of interest.

Second, CALFED science was subject to state and national politics and related bureaucratic constraints. Whereas the SP started with support and generous funding from state and federal administrations, its ambitious agenda had to be downscaled when the second Bush administration stopped federal support of the SP (LHC, 2005). The State under the Schwarzenegger administration further reduced staffing. Yet a single science 'core question' process, such as that for the collapse of delta smelt, would need three years, six workshops, two consultants, three science board members and $500,000 to 'complete'. And there were dozens of core questions to be addressed. Furthermore, whereas issues rotate in terms of political importance, ecological research requires 10–15 years of persistent, on-going effort and investment to address one broad question. Policy-makers expected quick answers to questions of political salience at the time.

Third, scientific research reveals more and more the complexity of Delta dynamics. Policy-makers instead work with pre-framed questions tied to specific regulatory missions or wholly new questions arising with emerging public concerns. Whereas for example, CALFED science revealed the multiple place and time-specific factors that might affect fish populations, policy-makers wanted specific answers on the effects of pumps on salmon and Delta smelt (when maximum uptake is superseded, pumps have to be stopped). There was a continuous tension between the tendency of academic scientists to see more complexity, reframe questions, and reveal uncertainties that called for more research and policymakers and agency scientists demanding yes-or-no responses to specific applied questions. Panels set up for some controversial questions ended up pointing to data uncertainties and conceptual problems with the methodologies the agencies were using, instead of giving 'answers on the basis of the state of the art' that agencies demanded. While the Delta is clearly more amenable to integrating science, policy, and management than the globe as a whole, complexity is not only a function of scale but also of purpose and expectations from science.

Fourth, opening science to the public, with stakeholder participation and an extended public peer review process, is much easier said than done. The Public Advisory Committee belatedly invited staff from the SP and members of ISB to report on their activities. Some stakeholders have felt excluded from the SP and that they have had little influence over its research agenda. Meanwhile, opening ISB meetings to the public made scientists much more careful in exploring ideas that they could not fully support since these could be (mis)used by media and stakeholders. To some extent, ISB meetings ended up being sterile reviews of on-going programs rather than serious discussions about critical uncertainties in Delta science. A separate Ecosystem Restoration Science Board and a Water Management Board were temporarily established where independent scientists could interact more creatively away from public light, but this took place at the expense of accountability and participation.

Fifth, adaptive management, a central premise of CALFED's approach to the Delta environment, requires an assessment framework within which monitoring, evaluation, and adaptation occurs. But this is an incredibly complicated task. Outcome indicators such as populations of endangered species in representative sites do not help ecologists foresee the next problem that might emerge or even overall Delta health. Indicators more fundamental to ecologists are numerous while monitoring budgets must be directed to regulatory obligations. Furthermore, the multiplicity of ecosystem perspectives confounds interpretation, scaling, and aggregation in any set of indicators. It is also extremely difficult to link changes in specific indicators to policy actions given that many other factors (e.g. climate change, natural temporal variations) come to play. Thus a list of indicators to assess the state and trajectory of the Delta environment and CALFED's environmental performance was never instituted. Adaptive management faces an inherent tension between its acknowledgment of complexity, uncertainty, and emergence and its presumption that goals and system metrics can be established to evaluate and adapt interventions.

CALFED adaptive management focused at the smaller scale of specific interventions and projects. But here a different problem emerges: local success means little when the system is changing at larger spatial and temporal scales. Ecological restoration directed to particular parts of the Delta does not necessarily improve fish populations when conditions elsewhere are becoming worse. The contributions of local projects to overall Delta goals are difficult to assess, especially without an overall yardstick to evaluate overall Delta conditions. Projects ended up being evaluated in terms of their own goals (e.g. size of area restored), but this was far from an adaptive management ideal.

Some critics argue that on-going crises, events like the sudden pelagic organism decline, should have been avoided through scientific prediction, early detection, and appropriate management responses. Some see the proliferation of multiple, conflicting explanations of complex phenomena as a lack of scientific progress. Scientists' objectivity and research framings are also attacked because of conflicts of interest. These critical interpretations hide the important successes of the CALFED SP in reframing key questions, enhancing understandings about the complexity of Delta dynamics and exposing individual scientists, policy-makers and stakeholders to each others' knowledge and the limitations of any single framing or simple explanation.

The CALFED SP works with fundamental tensions that any scientific process that aspires to integrate science with policy and management is destined to face. These tensions are seriously aggravated by the complex dynamics of the Delta. The CALFED SP, along with Delta science as a whole, may have been less vulnerable to naïve criticism, along with CALFED as a whole, if the SP had been more conscious that it was working within a complex, dynamic socio-ecological system and deliberate about how scientists come to deeper, shared understandings of such systems. For these reasons, and in light of the emerging science of IEAs, we argue that CALFED science is not a partial failure (LHC, 2005), but a very interesting, incomplete experiment.

5. Conclusions: science and governance for the Delta's future

The Delta and the globe as a whole are responding to past and current human actions undertaken in the context of scientific knowledge, available technology, and social and economic organization. Science, technology, social organization, and values can be seen as directly influencing the environment while also coevolving with each other and the environment over time. The dominance of reductionist science, and modern worldview more broadly, facilitated technologies and social organization, and ultimately levels of population and economic activity that have led to rapid rates of environmental transformation. Continued heavy demands on now stressed, rapidly changing, and seemingly less stable environmental systems have led to the need to understand systems at larger scales and in greater depth than ever before. By design and by selection with respect to what seems to work, environmental scientists and practitioners are increasingly combining their disciplinary expertise and field experience into usable knowledge for governance through collective, interdisciplinary, discursive processes.

How the environment "out there" is changing is interactive with how Californians "internally" perceive, analyze, and respond to change. Science is a key part of this. Science can only describe those aspects of the environment on which it focuses, and the focus of science reflects prevailing values and concerns. Thus there is no environmental reality over time, or the possibility of one in the future, that is independent of how people both understand and affect the environment through governance, or its absence.

Retreating to earlier visions of science as objective descriptions of reality safely separated from values and governance (LHC, 2005) is unsupportable given the dynamics and complexity of the Delta. Calls for clear goals, scientific neutrality, and the reestablishment of boundaries between science and the political process, *i.e.* a CALFED SP model that would resemble that of the spacecraft's industry problem-oriented R&D is not applicable to complex socio-ecological systems where there are multiple, irreducible human values and no single 'problem to be solved.'

Instead we argue for a deepening of the interactive, integrated and adaptive processes of the CALFED Science Program. Many more scientists can be included in the discursive processes of coming to collective understandings, as in global integrated environmental assessments. Initiating the next round of the State of Bay-Delta Science (CALFED Science Program, 2008) provides an excellent opportunity to systematically shift in this direction. Instead of applying outdated templates of science and policy, we call for experimentation with new interfaces for interaction between scientists, policy-makers, stakeholders and the public. The CALFED SP should engage more consciously and deeply with the integrated and adaptive approaches that it has by necessity used. Our analysis and conclusions are relevant for other areas that experiment with new forms of adaptive science and governance of complex socio-ecological systems. On the one hand, we point to some fundamental difficulties in understanding and controlling complex socio-ecological systems and identify tensions between the rationality of adaptive, discursive processes and the rationality of modern reductionist science and decision-making. On the other hand, we argue that these difficulties should not be a reason to shy away from discursive scientific processes, but a motivation to experiment with new ways of confronting the fundamental epistemological problems in policy-oriented science for managing complex socio-ecological systems.

Acknowledgments

Many of our arguments and judgments are based on our personal knowledge acquired through being able to work within and/or discuss CALFED extensively with key participants. Richard Norgaard serves as a member of the Independent Science Board, participated in the Delta Vision Assessment Team, and was on the editorial board of the State of Bay—Delta Science, 2008 report. Giorgos Kallis attended various CALFED meetings and interviewed numerous CALFED scientists, stakeholders, and observers during 2006 and 2007. Michael Kiparsky was a CALFED consultant working with the Science Program. He was partially supported by an NSF Graduate Research Fellowship.

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