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Scientist and Stakeholder Views on the Delta Ecosystem

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Summary

Improving the management of the Sacramento-San Joaquin Delta's aquatic ecosystem is a major water policy challenge for California. Native fish populations have been in decline for several decades, leading to severe legal constraints on the Delta's ability to serve as a conveyance hub for statewide water supplies. While there is broad scientific recognition that a wide range of ecosystem stressors are responsible for the declines in native fish populations, significant tensions have arisen between science and policymaking regarding the relative roles of different stressors and the potential of various management actions to improve ecosystem health.

In the summer of 2012, PPIC conducted two confidential surveys to provide insights into the challenges and opportunities of managing the Delta ecosystem. The first survey sought input from scientific experts on the impacts of ecosystem stressors on native fish species and the potential of a suite of management actions to address the needs of these fish. The second survey sought answers to a subset of these questions from a group of engaged stakeholders and policymakers. The survey results serve to synthesize current scientific understanding and identify areas of consensus and divergence between the scientists and stakeholders. Key findings are as follows:

- Almost all scientists and stakeholders agree that all five categories of ecosystem stressors—discharges of pollutants, direct fish management, changes in the flow regime, invasive species, and alteration of physical habitat—have contributed to the ecosystem decline.
- For most scientists, habitat and flow alteration are the most important stressors. Stakeholders generally agree with this ranking, but individual groups tend to consider stressors that conflict with their interests less important (e.g., water exporters tend to consider flow alteration as less harmful, while Delta residents consider habitat alteration as less harmful).
- Scientists are more pessimistic than most stakeholders about the future effects of stressors under current management practices. Groups most responsible for discharges of pollutants, flow regime change, and habitat alteration consider these areas less likely to cause increasing harm in the future.
- A strong majority of scientists prioritizes habitat and flow management actions that would restore more natural processes within and upstream of the Delta.
- Stakeholders and policymakers generally agree with scientists on priority solutions. However, individual groups are more likely to prioritize actions unrelated to their own uses of Delta resources, and to shy away from actions that would be costly for them. Some common ground also exists, with many stakeholders seeming willing to consider actions to support native fish species despite potential for economic costs and disruptions to their interests.
- More research and experimentation is required on many management actions. There is low consensus among scientists about the biological potential of some actions, including many direct fish management activities (e.g., conservation hatcheries to support native fish populations in the near-term) and a proposed canal or tunnel to divert water exports underneath or around the Delta. The lack of consensus reflects high levels of uncertainty about these actions, including how the new export conveyance infrastructure would be operated. In addition, some actions that most scientists rank highly—including more variable flows, restored tidal marsh, and more suitable channel-margin habitat—are still relatively experimental and will require ongoing analysis to develop and fine-tune suitable implementation programs.

- 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 the solutions. Delta science not only must push the frontiers of knowledge on effective ecosystem management, but also must do so in ways that enhance its legitimacy and acceptance by the many interests who have a stake in the outcome.

Companion reports

This report presents results from two surveys conducted in summer 2012 regarding ecosystem management in the Sacramento-San Joaquin Delta. It is part of a wide-ranging study on the management of multiple ecosystem stressors in the Delta. For a summary of overall study findings, see *Stress Relief: Prescriptions for a Healthier Delta Ecosystem* (Hanak et al. 2013). Several companion reports address related topics in greater depth: (1) *Aquatic Ecosystem Stressors in the Sacramento-San Joaquin Delta* (Mount et al. 2012) summarizes the science of Delta ecosystem stressors for a policymaking audience; (2) *Costs of Ecosystem Management Actions for the Sacramento-San Joaquin Delta* (Medellín-Azuara et. al. 2013) provides cost estimates for a suite of management actions addressing various sources of ecosystem stress; (3) *Integrated Management of Delta Stressors: Institutional and Legal Options* (Gray et al. 2013) presents our proposals for institutional reform of science, management, and regulation; (4) *Where the Wild Things Aren't: Making the Delta a Better Place for Native Species* (Moyle et al. 2012) describes a realistic long-term vision for achieving a healthier ecosystem. All of these reports are available on PPIC's website at www.ppic.org.

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A technical appendix to this paper is available on the PPIC website:
www.ppic.org/content/pubs/other/413EHR_appendix.pdf

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Abbreviations

BDCP	Bay Delta Conservation Plan
CVP	Central Valley Project
DFG	Department of Fish and Game (former name of DFW)
DFW	Department of Fish and Wildlife
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
HCP	Habitat Conservation Plan
NMFS	National Marine Fisheries Service
SRCSD	Sacramento Regional County Sanitation District
SWP	State Water Project

Introduction

A central water policy challenge facing California is how to improve the management of the Sacramento–San Joaquin Delta's aquatic ecosystem. The Delta is a network of mostly manmade islands and channels at the confluence of the Sacramento and San Joaquin Rivers. Together with the San Francisco Bay, the Delta forms the largest estuary on the Pacific Coast of the Americas. It is the terminus of California's largest watershed and a major source of the state's water supply. It is also a valued ecological resource.

Over the past several decades, sharp declines in several types of native fish species have heightened conflicts over the management of water and land resources in this region and the ecologically-related upstream areas.[1] Native fish species that are now listed as endangered, threatened, of concern, or on a watch list under the federal and state Endangered Species Acts (ESA), include two open water (or "pelagic") species that spend their entire lives in the Delta (delta smelt and longfin smelt), three resident natives that inhabit the Delta and upstream rivers (Sacramento splittail, Sacramento perch, and river lamprey), and six anadromous species that travel through the Delta during migrations between the ocean and upstream spawning grounds (southern green sturgeon, Central Valley steelhead trout, and several runs of Chinook salmon).

These listings have prompted regulatory restrictions on water exports to agricultural and urban users located outside the basin, who have been held responsible for mitigation under the state and federal ESAs and clean water laws.[2] The declines in native fish populations have also prompted several decades of legal disputes. While environmental and fishing interests have sought to increase restrictions on export diversions, exporter interests have sought to reduce restrictions on their diversions and spread the responsibility for environmental mitigation to parties responsible for other sources of ecosystem stress.[3] Within the past few years, lawsuits have been filed to compel the state to manage predation of juvenile salmon by the non-native striped bass and to compel the Federal Emergency Management Agency (FEMA) to consider the role of levees in the destruction of riparian habitat that supports native fish.[4] Exporter interests have also promoted increasing regulation of the Sacramento Regional County Sanitation District (SRCSD), the watershed's largest urban wastewater utility, which was recently ordered to upgrade its facilities to reduce discharges of harmful ammonium.[5] These actions have, in turn, provoked objections from those who would be affected by such changes.[6]

[1] We use the term "Delta" when referring to the statutory Delta and Suisun Marsh on its western edge (Water Code § 85058), and the "Delta watershed" or "greater watershed" when referring to the Sacramento River and San Joaquin River hydrologic regions that drain into the Delta (*id.* § 85060).

[2] For a more detailed discussion of this issue, see the companion report to this study, *Integrated Management of Delta Stressors: Institutional and Legal Options* (Gray et al. 2013).

[3] In 2007, lawsuits filed by environmental and fishing organizations (*NRDC v. Kempthorne*, *Pacific Coast Federation of Fisherman's Associations v. Gutierrez*) led to the invalidation of the biological opinions that governed the operations of the Central Valley Project (CVP) and the State Water Project (SWP), and severe restrictions on exports were ordered. New biological opinions were issued in 2008 and 2009, leading to lawsuits by export contractors (*Consolidated Delta Smelt Cases* F. Supp. 2d 855) which resulted in the new biological opinions being invalidated as well.

[4] The Coalition for a Sustainable Delta filed a 2008 lawsuit against the state Department of Fish and Game (DFG), arguing that predation by non-native striped bass was a major contributor to the decline in salmon populations. In a 2012 settlement agreement, DFG agreed to reduce restrictions on striped bass fishing, but this action was not approved by the state Fish and Game Commission, which regulates hunting and fishing licenses. (The department was renamed Department of Fish and Wildlife [DFW] in January 2013). In 2010, the Coalition for a Sustainable Delta filed a lawsuit against FEMA for violating the ESA by not consulting wildlife agencies on the impacts of the construction and maintenance of levees on native fish in the Delta. The suit was settled in 2012 and resulted in a court-ordered biological assessment of flood programs in the Delta.

[5] A December 2008 op-ed in the *Sacramento Bee* by Laura King Moon, assistant general manager of State Water Contractors, responded to the newly imposed restrictions on exports by pointing out other stressors in the system, most specifically SRCSD's wastewater treatment plant and their ammonia discharges (King Moon 2008). The op-ed argued that an unfair burden was being placed on exporters to fix the Delta's problems, with insufficient attention to other stressors. In December 2010, the Central Valley Regional Water Quality Control Board issued an order requiring SRCSD to upgrade its facility to full tertiary treatment by 2022.

[6] SCRCSD responded to the order to upgrade its treatment facilities by filing suit against the state to contest the terms of compliance.

The litigation and public debates have taken place against a backdrop of increasing scientific understanding of the multiple causes of native fish species declines. There is now broad scientific recognition that a wide range of stressors—most resulting from human management of the water and land resources of the Delta and the greater watershed—are jointly responsible for the undesirable changes to the Delta ecosystem (National Research Council 2012; Delta Independent Science Board 2011). This recognition is reflected in the two most recent, high-profile efforts toward greater coordination of Delta ecosystem management: the Delta Plan and the Bay Delta Conservation Plan (BDCP). The Delta Plan is the state's foundational long-term (100-year) planning tool for meeting the "co-equal" goals of water supply reliability and ecosystem health, established by the Delta Reform Act of 2009 (Water Code § 85054); it is scheduled to be adopted in the spring of 2013.[7] The BDCP, under development since 2006 and scheduled for public review in 2013, is a habitat conservation plan for the Delta that would simultaneously provide broader environmental protections for the Delta's endangered aquatic and terrestrial species and a more reliable framework for continued water exports under the terms of both federal and state ESAs.[8] Although large—potentially involving multibillion-dollar investments in Delta habitat restoration and new water conveyance infrastructure—BDCP is more narrowly focused. If deemed sufficiently protective of native species, BDCP will be incorporated in the Delta Plan, as will other plans related to Delta management (e.g., water quality and flows, flood protection) and the conduct of Delta science.[9]

All ongoing processes advocate science as the basis of decisionmaking, but science itself has become a major source of conflict. Although scientific understanding of the ecosystem has vastly improved, the complexity of the Delta means that many uncertainties remain. Meanwhile, native fish populations have continued to decline, and regulations intended to reverse these trends have become increasingly costly for the affected parties. Scientific uncertainty, and the inability of the scientific community to address it and effectively communicate what *is* known, frustrates decisionmakers, with blame often landing on science as unreliable. Uncertainty has become a rationale for resisting inconvenient measures to address stressors,[10] and it has encouraged the use of competing scientific opinions in the courtroom. When parties engaged in coordinated planning processes are likely to meet as legal adversaries, science takes on a "combat" nature—where legal defensibility, rather than improved understanding, becomes a driver, and where all sides develop an interest in having their own sources of expertise and in selectively using facts and analyses. The resulting disagreements over causes and responsibility for native species declines and the most promising solutions have been debilitating for policy discussions and the science needed for effective solutions (National Research Council 2012).

To help inform the ongoing policy process, we conducted two surveys in the summer of 2012. The first sought input from scientific experts—researchers with peer-reviewed scientific journal articles on the Delta ecosystem—on the impacts of ecosystem stressors on native fish species and on the biological potential of a suite of management actions proposed to address the ecosystem needs of these fish. The second sought answers to a subset of these questions from a group of engaged stakeholders and policymakers, identified by their participation in the Delta Plan or BDCP or by their position as senior officials of key state regulatory agencies.

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[7] The Delta Plan's development and implementation are the responsibility of the Delta Stewardship Council—a new state agency created by this same legislation. When discussing this plan, we refer to the last staff draft, issued in November 2012 (Delta Stewardship Council 2012).
[8] When discussing this program, we refer to materials that were made public in 2012 (Bay Delta Conservation Plan 2012).
[9] Technically, BDCP must meet the conservation standards of the state's Natural Communities Conservation Planning Act, which provide for recovery of listed species, and it must otherwise be deemed consistent with the Delta Plan (Gray et al. 2013). For an overview of other related planning processes, see Mount (2011) and www.aquafornia.com/wp-content/uploads/2012/07/DeltaOrganizationChart1.pdf.
[10] See Kahan (2012) for a discussion of this phenomenon as it relates to climate change policy.

We received responses from 122 scientists (41% of those contacted). Most scientists who responded were from universities or research institutes (53%) or state and federal agencies (34%), with the remainder from advocacy organizations, local agencies, and consulting firms. To check for potential bias, we ran statistical tests to determine whether responses to key survey questions differed along the dimensions on which respondents differed from nonrespondents. [11] In general, we found relatively few statistically significant differences; these are noted in footnotes where relevant.[12]

We received responses from 240 stakeholders and policymakers (31%); here we report answers from those who could be assigned to one of six groups (often referred to in shorthand below as "stakeholders"):[13]

- Delta-based interests (38 respondents): representatives of local governments, water agencies, and advocacy groups and other engaged residents;
- Environmental advocates (56 respondents): employees and members of environmental organizations;
- Export interests (22 respondents): primarily representatives of water agencies located outside of the watershed that depend on Delta exports;
- Fishing and other water-based recreation interests (14 respondents): principally representatives of recreational fishing within the watershed but also several representatives from the salmon and crab industries;
- Upstream interests (39 respondents): representatives of agricultural and urban water agencies that divert water upstream of the Delta or that discharge pollutants into the watershed; and
- Federal and state officials (56 respondents): employees of regulatory and management agencies active in the Delta.

We also present the simple average of responses by all six stakeholder groups (with each group weighted equally) as a way of summarizing the broad tendencies in the views of stakeholders and policymakers.

The survey of scientists helps synthesize scientific understanding on stressor impacts and possible mitigating actions, highlighting areas of agreement and areas where further research and experimentation are needed. Seeking expert views through such a survey is particularly valuable for the Delta, given the incomplete guidance from the literature on forward-looking, ecosystem-based management.[14]

The survey of stakeholders and policymakers enables us to identify areas of consensus and divergence between the scientists and various stakeholder groups and among stakeholders. These comparisons provide useful insights into the challenges and opportunities in Delta ecosystem planning and policymaking. The results can also help inform the design of a Delta science program that can better support the societal goal of ecosystem health.

The report is organized as follows. The next chapter begins with a brief taxonomy of the ecosystem stressor categories used in the surveys, drawing on a companion report from this study, *Aquatic Ecosystem Stressors in the Sacramento-San Joaquin Delta* (Mount et al. 2012). It then summarizes views of scientists and stakeholders

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[11] See Technical Appendix A for more details on the sampling method and sample characteristics.
[12] See Technical Appendix C for the full suite of test results.
[13] These group assignments were made by the authors based on biographical information available for all those invited to participate in the survey. Responses for a seventh "other" group (15 respondents), including a mix of groups too small to analyze separately—employees of statewide advocacy groups, tribal representatives, and private sector consultants unaffiliated with the other groups—are not included in our discussions in the body of this report but are displayed in Technical Appendix B.
[14] The use of expert elicitation is expanding in many fields to address gaps in the scientific literature, particularly where there is uncertainty about priorities for decisionmaking (See Technical Appendix A).

regarding the historical and likely future role of these stressors on the Delta's native fish populations. The third chapter looks at respondents' views regarding a suite of roughly 30 potential mitigating actions. For scientists, this includes their assessment of the potential biological impact of each action as well as their views on which five actions are top priorities for implementation as a package. For stakeholders, we only inquired about the top five priorities. We also provide rough cost estimates of these actions, drawing on another companion report, *Costs of Ecosystem Management Actions for the Sacramento-San Joaquin Delta* (Medellín-Azuara et al. 2013). A concluding chapter summarizes key findings and implications. Technical appendices provide more information on the survey methods and respondent characteristics (Technical Appendix A), survey questions and detailed answers (Technical Appendix B), and results of supplemental statistical analysis (Technical Appendix C).

Impact of Ecosystem Stressors: Past and Future

Few scientists are comfortable ranking stressors in order of their responsibility for the decline of the Delta's native species, given the significant and often complex interactions among them (National Research Council 2012). For example, levees reduce seasonal floodplain habitat from high winter and spring flows, which reduces spawning and rearing areas for many native fish species. Likewise, upstream water diversions can intensify the effects of agricultural and urban discharges, altering food webs and ecosystems in ways that promote conditions more favorable to invasive species. While the scientific community has tended to emphasize the complexity of the problem, recent public policy debates often have oversimplified it, with various stakeholder groups emphasizing the importance of individual stressors in native species' decline.

Given this disconnect between scientific and public discourse, it is useful to see how various groups viewed ecosystem stressor roles in our confidential surveys. The surveys sought the views of both scientists and stakeholders on the historical and likely future impacts of five broad categories of ecosystem stressors on the Delta's native fishes—discharges of pollutants, direct fish management activities (e.g., hatcheries, fish screens), flow regime changes (e.g., exports, diversions), invasive species, and alterations of physical habitat. For scientists, these questions were more detailed, looking separately at the three primary groups of fish species (pelagic, anadromous, and resident native). In this chapter, we provide a description of the five stressor categories and then present key survey findings.

A Simple Taxonomy of Stressors

One of the challenges for policy discussions on Delta stressors is finding a way to organize them analytically. One list highlighted 42 different categories of stressors (Delta Independent Science Board 2011)—much smaller than the actual number of individual stressors, but still too large for a broad policy-oriented evaluation. To facilitate policy discussions regarding causes of stress and options for management, we have grouped stressors into five broad categories with similar processes, causes, or consequences, listed here in alphabetical order (Mount et al. 2012):

- **Discharges.** Land and water use activities that directly alter water quality in the greater Delta watershed by discharging various contaminants that degrade habitat, disrupt food webs, or cause direct harm to populations of native species (point and nonpoint sources of conventional pollutants, nutrients, toxics, endocrine disruptors, etc.).
- **Fish management.** Policies and activities that can adversely affect populations of native species through harvest (commercial or sport), hatcheries, or other management actions such as fish screens.
- **Flow regime change.** Alterations in flow characteristics due to water management facilities and operations, including volume, timing, hydraulics, sediment load, and temperatures (including upstream dams and diversions, as well as in-Delta diversions and exports).
- **Invasive species.** Alien (non-native) species that negatively affect native species by disrupting food webs, altering ecosystem function, introducing disease, or displacing native species.
- **Physical habitat loss and alteration.** Land use activities that alter or eliminate physical habitat that supports native species, including upland, floodplain, riparian, open water/channel, and tidal marsh. This category includes levees, channelization, diking and draining of wetlands, dams, dredging for ship channels, and the narrowing or reduction of riparian zones, shallows, and tidal and fluvial marshes.

This approach simplifies a system with many complex processes, responses, and feedbacks. Yet, viewing stressors in this way allows for a broad analysis of the causes of ecosystem stress and aids strategic thinking about mitigation strategies, because each stressor group is linked to ongoing and past human activities within the Delta and the greater watershed. Two other sources of stress are climate change and ocean conditions. Climate change—warmer temperatures, accelerated sea level rise, and changing runoff patterns—will affect all five stressor categories listed here. Management actions to address any of these stressors will need to incorporate consequences of climate change—consequences that will be greater if national and international policymakers fail to address its causes. Ocean conditions directly affect native fishes that migrate through the Delta (salmon and steelhead), as well as the region's climate and weather through the El Niño-Southern Oscillation, Pacific Decadal Oscillation, and other patterns of climate variability. We excluded ocean conditions from our list because they are not readily amenable to policy interventions, although mitigation strategies will need to consider their effects.

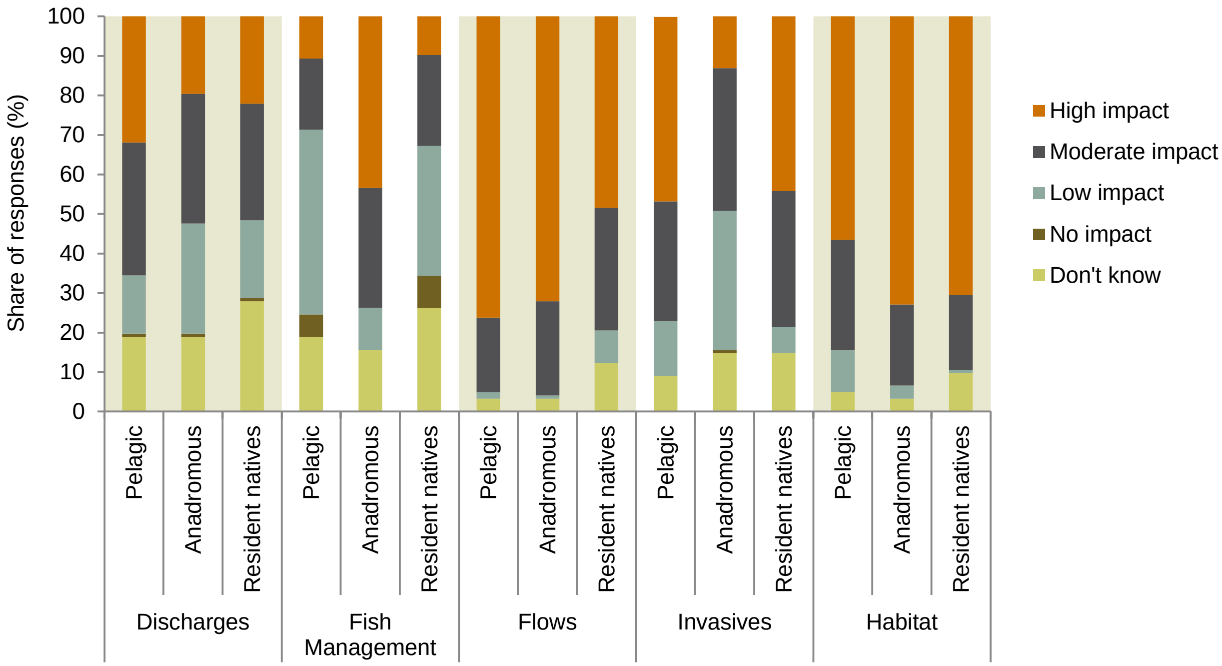
Both surveys presented these five categories of stressors to participants and sought their views on the roles of each in the decline of the Delta's native fishes. Participants had the opportunity to consider the effects of climate change, ocean conditions, and other factors (e.g., population growth) when they considered the likely future impacts of the five stressor categories.

Scientists' Views on Stressor Impacts

Many scientists expressed some reluctance in evaluating the roles of individual stressors, given the interconnected way in which they can affect the ecosystem. Nevertheless, most provided their assessments in response to the survey questions.[15] Figure 1 summarizes their views on the role of the five stressor categories in the historical declines of the Delta's three main categories of native fishes: pelagic (delta smelt and longfin smelt), anadromous (salmon, steelhead, and sturgeon), and resident natives (splittail, blackfish, hitch, tullyhead, etc.).

[15] Only one respondent answered "don't know" to all questions regarding stressor impacts; for others, these non-responses were less frequent and typically related to specific stressor areas or fish groups (see Figure 1).

FIGURE 1
Scientists consider all five stressor categories important in the decline of the Delta's native fishes



SOURCE: Technical Appendix Table B1a–c.

NOTE: The figure depicts responses to the question: "Please indicate the level of impact you believe each stressor group has had on the historical decline of the Delta's native fishes." Sample size: 122.

A majority of scientists believe that all five stressors have had at least a moderate impact on the decline of the Delta's native fishes, with flow regime changes especially harmful ("high impact") in the case of pelagics (76%) and anadromous fish (72%), and physical habitat loss especially harmful for all three types of fish (73% for anadromous fish, 70% for resident natives, and 57% for pelagics). These responses reflect the substantial alteration of physical habitat and flows within the Delta and its upstream watershed over the past century and a half. Over 95 percent of the Delta's once abundant tidal marsh has been dredged, drained, and converted to agricultural uses (Whipple et al. 2012). Hundreds of miles of flood control levees within the Delta and upstream are now lined with rocks, creating inhospitable habitat for various native fishes (Moyle et al. 2012). Upstream dams have cut off historical spawning grounds for anadromous fish. Flow regime changes—including both upstream diversions and exports from the South Delta pumps—have also significantly altered conditions in the Delta, making it less seasonally variable in salinity (with fewer episodes of seasonal flooding) than under pre-development conditions. To keep water fresh enough for agricultural and urban uses within the Delta, flows have sometimes been pulled in reverse directions. Consequently, this aquatic habitat is now more favorable to invasive species than native fishes (Moyle and Bennett 2008; Baxter et al. 2010). The pumps are also responsible for direct entrainment of fish (Kimmerer 2008; Grimaldo et al. 2009).

As might be expected, scientists considered direct fish management activities most harmful for anadromous fish (73% responded that these activities have had a moderate or high impact on these fish). Both salmon and steelhead have been subject to intensive management efforts, including hatcheries, in an effort to mitigate the blockage of upstream habitat by dams, and recent research has highlighted the harmful effects of hatcheries on wild populations (Williams 2006). In contrast, pelagics and resident natives are considered more susceptible to harm from invasive species (rated as having a moderate or high impact by more than 75% of the scientists). Discharge of pollutants ranks in the middle, with the largest effects on pelagics (rated as moderate or high impact by 62% of the respondents), reflecting recent research emphasizing the harmful role of ammonium discharges on the food web supporting these fish (Glibert 2010; Teh et al. 2010; Miller et al. 2012).

It is also worth noting that there were much larger shares of "don't know" responses for pollutant discharges (19% or more for all three fish groups) and fish management (16% or more) than for the other stressor categories. These patterns likely reflect the relative amount of research done on the different stressor categories, as well as individual respondents' more limited professional background in these two areas: 23 and 27 percent of the sample reported no expertise on discharges and fish management, respectively.[16]

In general, scientists were also more likely to respond "don't know" with regard to stressor impacts on resident native fishes, reflecting the much more intensive research efforts on pelagic and anadromous fishes over the past two decades. Although those without background in a particular stressor area were more likely to withhold an opinion on the stressor's importance, there were few other distinguishable differences among scientists in their evaluations of the historical impact of stressor groups.[17]

We also asked scientists to pick the top two stressors, considering interactions among groups of stressors, and then to pick the single stressor that they considered most important in the decline of the Delta's overall ability to support native species (Figure 2). Consistent with their higher impact scores, flow and habitat disturbances emerged as the top stressors. Over three-quarters of the sample included at least one of these stressors in their top two choices, and nearly three-fifths (57%) chose both of them together. In the uncomfortable exercise of selecting the single most important stressor, 82 percent of all scientists picked either flow or habitat disruption, with a slight edge toward disruption of habitat.

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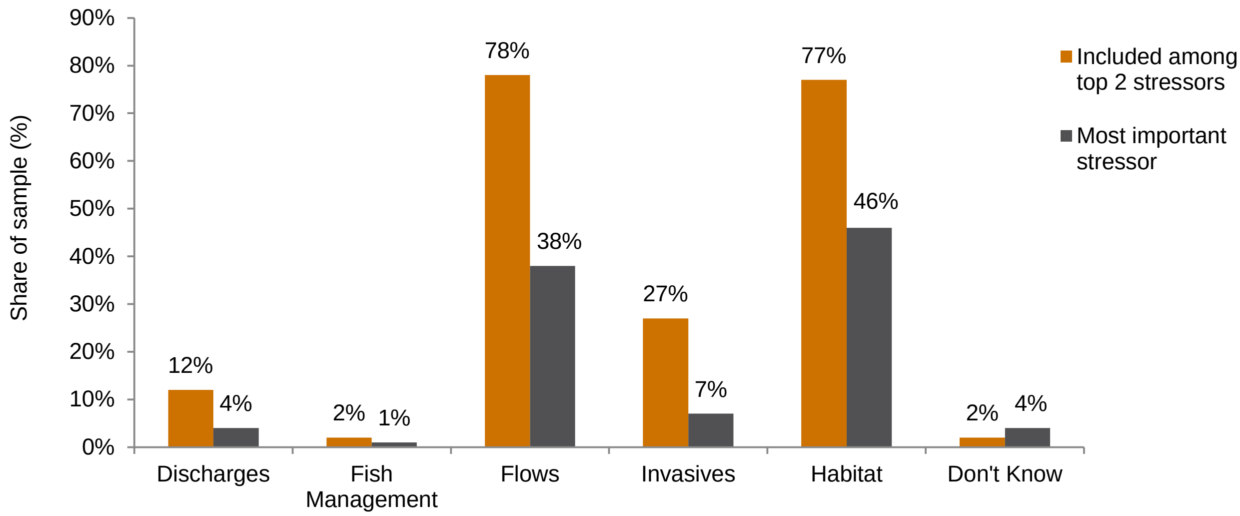
[16] See Technical Appendix Table B12. Those without background in discharges or direct fish management were significantly more likely to respond "don't know" to impact questions relating to both the historical and future role of the corresponding stressor groups, and those without background in habitat were significantly more likely to respond "don't know" to historical impact questions on habitat, but not future impact questions. Those without experience in fish management were more likely to favor developing new conservation hatcheries to support native fish (Technical Appendix Table C4b). The few without experience in habitat were less likely to favor improving upstream habitat and increasing sub-tidal habitat (Technical Appendix Table C4e). In contrast, experience with discharges was not associated with views about potential impacts of management activities in this area (Technical Appendix Table C4a).

[17] Those with broader expertise on stressors (measured by the number of stressor groups on which they had published articles or scientific reports) were less likely to consider discharges as a major stressor. This was also true for "leading experts"—a group designated by survey respondents as the most exceptional in their ability to understand the complexities of the Delta's aquatic ecosystem. Scientists affiliated at some point in their careers with the Moyle fish lab at the University of California, Davis, were less likely to consider discharges important for native resident fish and more likely to consider physical habitat important for anadromous fish. Scientists with fewer years of Delta experience were most likely to emphasize invasive species impacts for pelagic fish (Technical Appendix Table C2a).

FIGURE 2
Most scientists consider changes in flow and habitat to be the top overall causes of ecosystem stress in the Delta

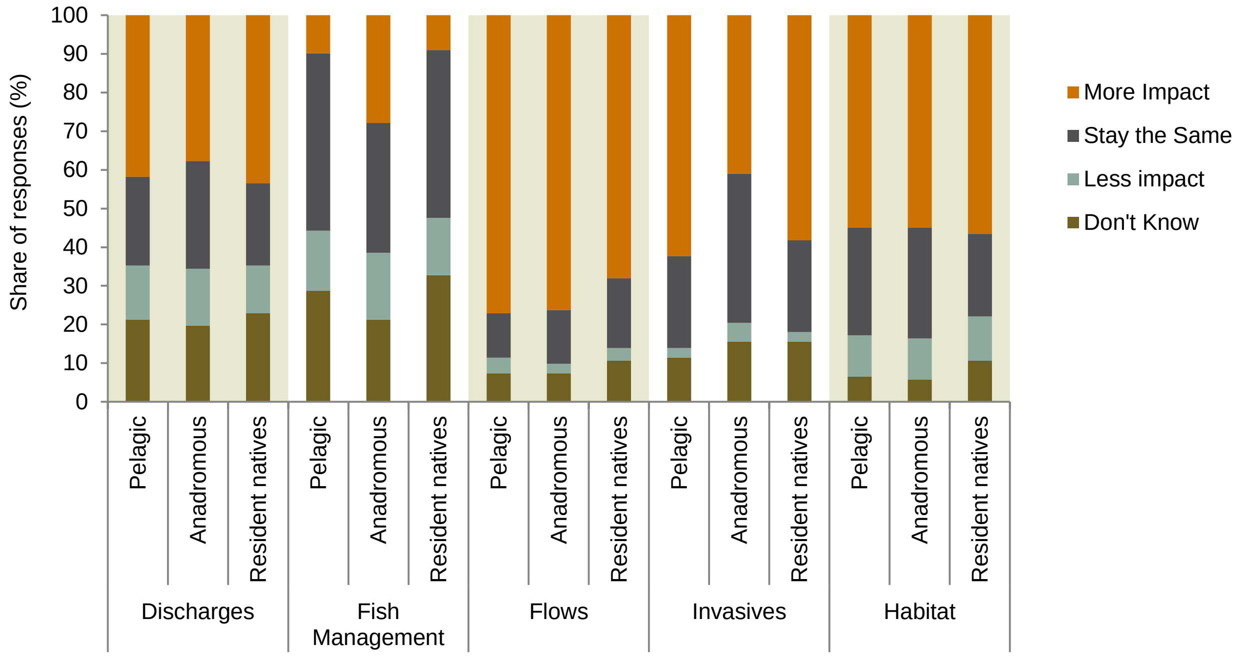


SOURCE: Technical Appendix tables B2 and B3.

NOTE: The figure reports responses to the questions: "Considering interactions among different types of stressors, which two stressor groups have contributed most to the decline in the Delta ecosystem's overall ability to support native species?" and "In your opinion, which single stressor group has contributed the most to the decline in the Delta ecosystem's overall ability to support native species?" Sample size: 122.

Scientists were also asked to assess the likely future trends in stressor impacts, considering natural and physical changes in the ecosystem from climate change, ocean conditions, and other factors. They were asked to think about conditions toward the middle of this century and to assume management of the stressors continued as it is today. Figure 3 summarizes these results. Although the share answering "don't know" is generally somewhat higher than for historical stressors (Figure 1), a strong majority of respondents (68% or more) express concern that problems with flow management will continue to aggravate conditions for all three groups of native fishes, given the anticipated effects of climate change (warmer temperatures, more frequent droughts) and the increasing demands of population growth. A majority of scientists also thought habitat and invasive species conditions would create greater problems in the future, while some noted that much of the habitat damage had already been done.

FIGURE 3
Scientists are most concerned about flow management as a future source of stress



SOURCE: Technical Appendix Tables B4a–c.

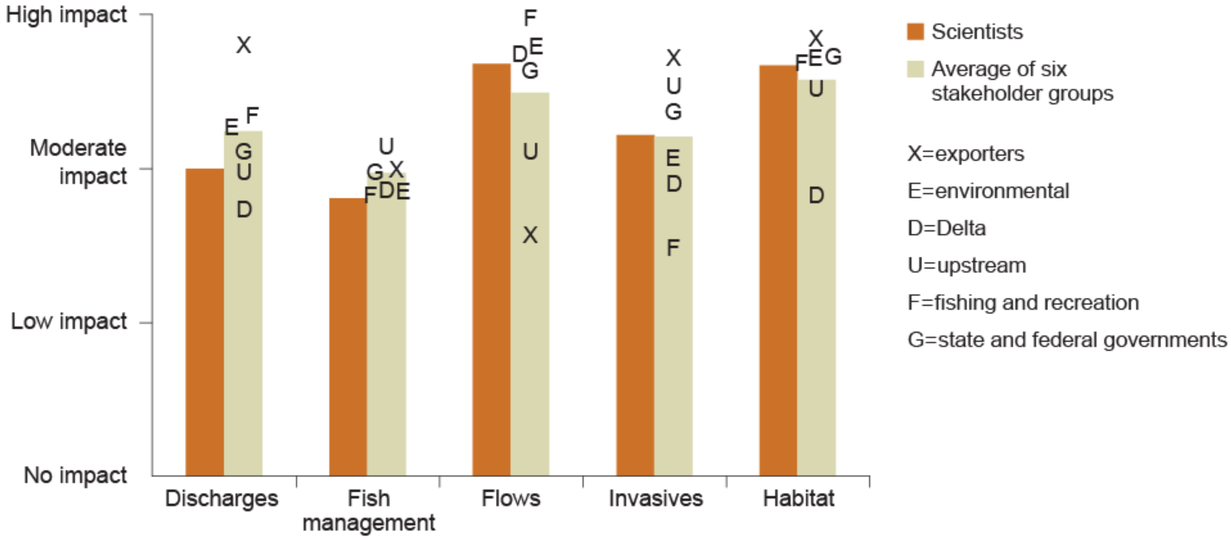
NOTES: The figure reports responses to the question: "For the three fish categories, please indicate how the impact of each stressor group will likely change in the future (e.g., by 2050) as a result of climate change and other factors. Assume management of each stressor group continues as it is today." Sample size: 122.

Comparing Scientist and Stakeholder Views

Figure 4 compares the views of scientists and the various stakeholder groups regarding the historical importance of each of the five categories of stressors in the decline of the Delta's native fish species. The two bars compare the views of scientists (orange) and the average across all six stakeholder groups, with each group weighted equally (beige); the letters show the average responses for individual stakeholder groups. Because stakeholders were asked to gauge the impact of stressors on the Delta's native fish overall, the figure presents the average responses for scientists across all three types of fish examined above (pelagic, anadromous, and resident natives).

Despite often-heated public exchanges on this issue, representatives of various stakeholder groups generally agree with scientists that all five stressor categories have contributed to the decline of the Delta's native fish species. Most respondents believe that all stressor categories have had at least a moderately negative influence, and almost no one considers any category completely unimportant. This broad acceptance suggests the potential for a more constructive public discourse on Delta policy.

Figure 4
Scientists and stakeholders generally agree that native fish have been harmed by all five types of stressors



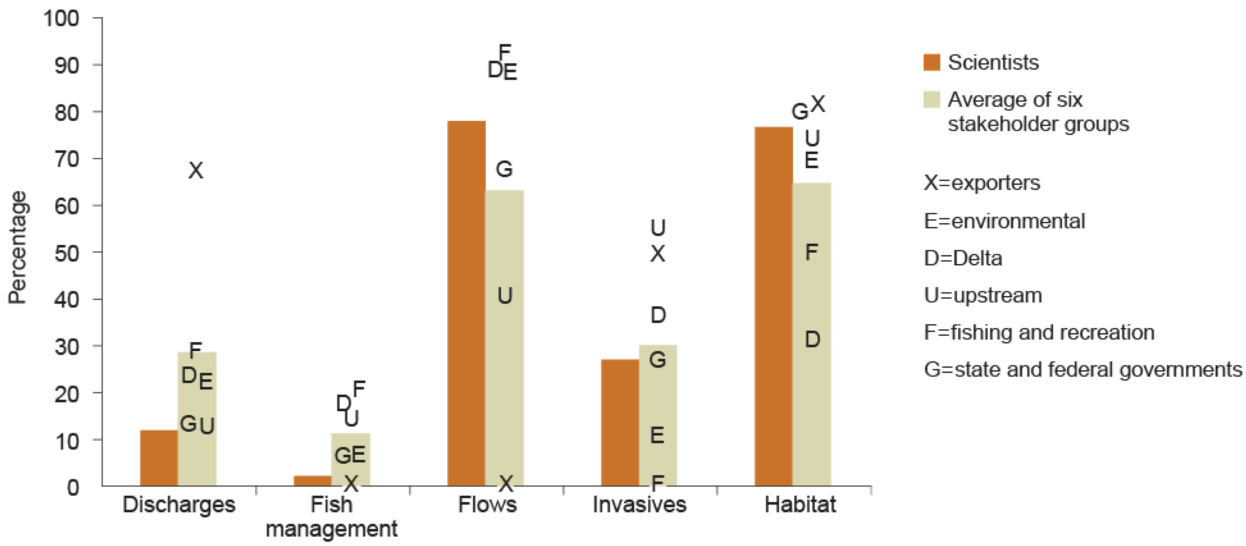
SOURCE: Technical Appendix Tables B1d and B14a–e.

NOTES: The figure depicts mean responses to the instruction: “Please indicate the level of impact you believe each stressor group has had on the historical decline of the Delta’s native fishes.” Mean responses were obtained by coding categorical responses: “no impact” (0), “low impact” (1), “moderate impact” (2), and “high impact” (3). For the scientists, the figure shows the average of responses to separate questions for three types of Delta fishes (pelagic, anadromous, and native resident). “Don’t know” responses are not included in the averages. Among scientists, “don’t know” rates (calculated as the share of scientists who answered “don’t know” for all three types of fish) were highest for discharges of pollutants (15%) and fish management (12%), followed by invasive species (5%), disruption in habitat (2%), and disruption in flows (1%). For stakeholders, the average “don’t know” rates were lower: fish management (9%), discharges of pollutants (3%), invasive species (3%), disruption in habitat (1%), and disruption in flows (0%).

However, the groups diverged somewhat in their emphasis. For example, a strong majority of scientists considered disruptions in habitat and flows to be high-impact stressors, and most stakeholders agreed. The exceptions were the groups benefiting most from the activities causing ecosystem stress. Delta residents, who live and work in the highly altered landscape of today’s Delta, were least likely to rank habitat alteration as a serious problem. Similarly, exporters and upstream diverters, who benefit daily from the altered water management within this watershed, were least likely to view flow regime in a negative light. Scientists generally considered the three other stressor groups to have a more moderate influence. This was also true for stakeholders, on average, but patterns for individual groups again reflected their economic interests. Delta and upstream interests, who discharge pollutants into the watershed, were the least concerned about discharges, whereas exporters, located outside the watershed, were the most concerned about this practice. And representatives of the fishing sector, much of which relies upon alien fish species in the Delta, were the least likely to view invasive species in a negative light.

These divergences in views became even starker when respondents were asked to identify the two most significant categories of stress (Figure 5). The gap is widest on the contentious question of flows: whereas no members of the exporter group named flows among the top-two stressors, a strong majority of scientists and nearly all representatives of Delta, fishing, and environmental interests did.

FIGURE 5
Views differ widely on which two stressors are most important



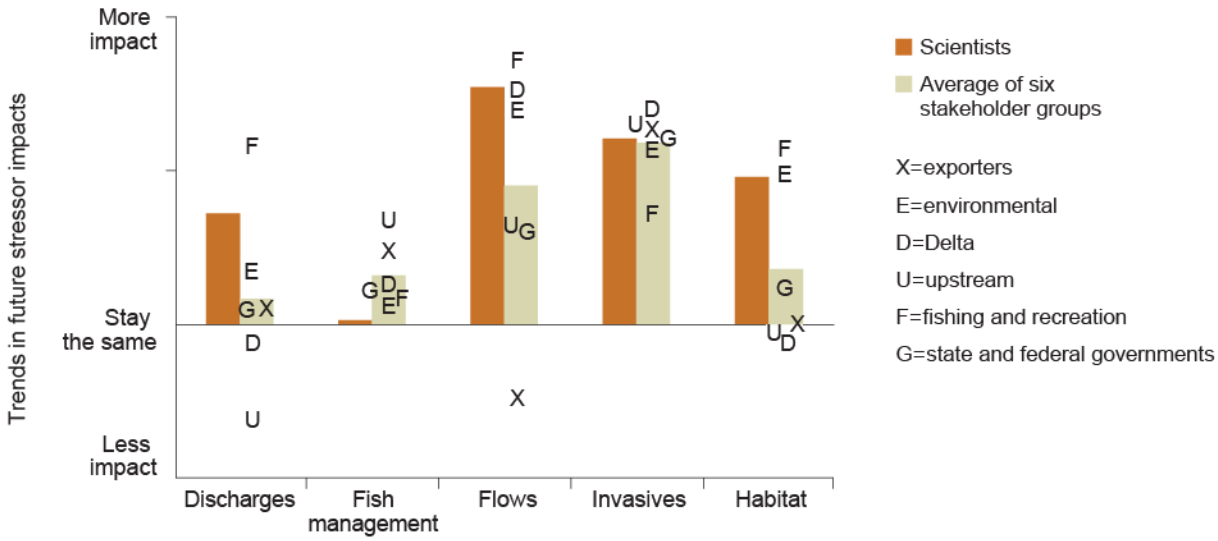
SOURCE: Technical Appendix Tables B2 and B15.

NOTE: The figure reports the share of each group that selected stressor categories in response to the question: "Considering interactions among different types of stressors, which two stressor groups have contributed most to the decline in the Delta ecosystem's overall ability to support native species?" "Don't know" response rates were as follows: state and federal officials (4%), scientists (2%), and no one in the other groups shown.

Some of the same contrasts in views are also apparent regarding the likely future impacts of stressors (Figure 6). Particularly striking is the optimism of those groups whose actions are most closely linked to stressors that the impacts will not get worse over time if management continues to operate as it does today. Thus, upstream and Delta interests are the most optimistic about the future impacts of both discharges and habitat alterations—two areas for which they bear primary responsibility. Similarly, exporters have the most optimistic view about flows. In all three cases, the stakeholders' optimism is not shared by scientists. In fact, scientists are generally more pessimistic than most stakeholders about the future impacts of stressors under current management practices.[18]

[18] See Technical Appendix Table B18 for summary scores of the historical and projected impacts of stressors averaged across all five stressor groups. Overall, scientists are significantly less optimistic than exporters, upstream interests, and state and federal officials about future impacts. Delta interests are the least pessimistic about the average historical impact of stressors compared to all other groups except fishing-recreation interests.

FIGURE 6
The stakeholders most closely linked to stressors are the least likely to believe the impacts will get worse



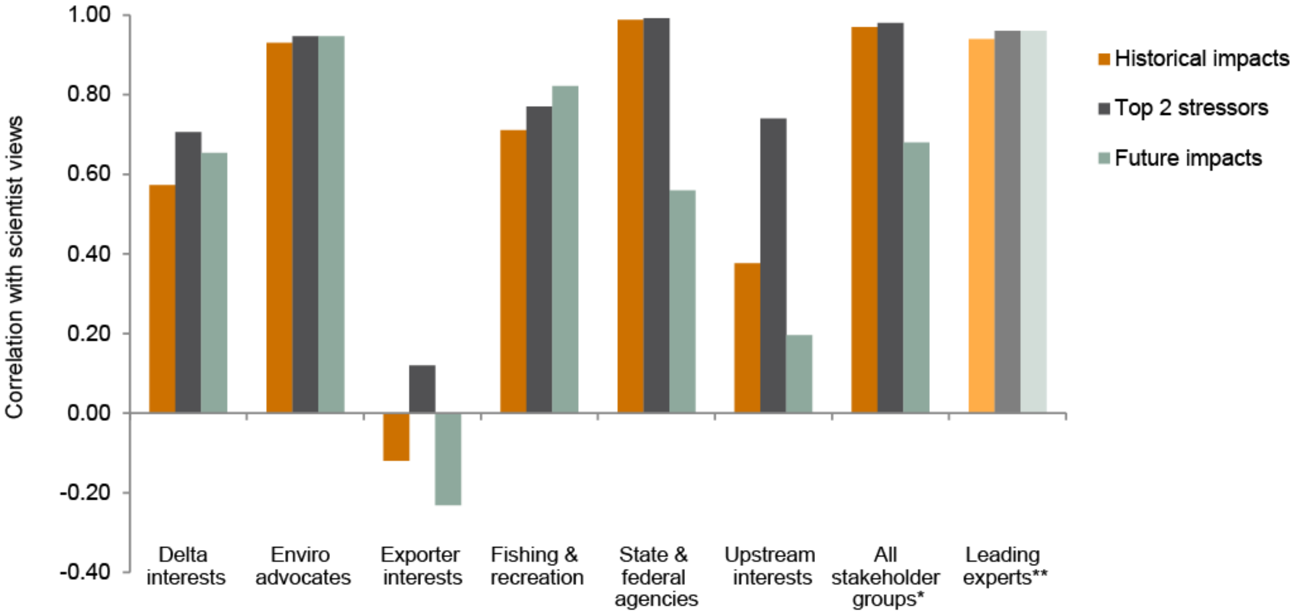
SOURCE: Technical Appendix Tables B4d and B17a–e.

NOTE: The figure reports the average responses of each group to the instruction, "Please consider how the impact of each stressor group will likely change in the future (e.g., by 2050), as a result of changes in water demand, population growth, climate change, and other non-managerial factors. Assume management of each stressor group continues as it is today." Answers are coded as: "lower impact" (-1), "stay the same" (0), "more impact" (1). For the scientists, the figure shows the average of responses to separate questions for three types of Delta fishes (pelagic, anadromous, and native resident). "Don't know" responses are not included in the averages.

Figure 7 summarizes the correlations between the views of scientists and stakeholders on historical stressor impacts, top-two historical stressors, and future stressor impacts. The last column in the figure also shows the strong correlation between the views of "leading experts" and the rest of the scientists surveyed.[19] In the case of historical impacts of each stressor group and the top two stressors, the average responses across the six stakeholder groups correspond closely with the views of the scientists. Although each stakeholder group shares commonalities with the scientists in some of their individual stressor rankings, the overall congruity is greatest between scientists and environmental advocates and government officials. (Government officials are the closest to scientists on historical impacts and top two stressors, but they are more optimistic about the future.) The largest differences in views occur between scientists and water exporters. The divergent views illustrated in this figure point to the difficulties in using science to help guide policymaking for the Delta ecosystem, and they also help explain the rise in parallel scientific efforts undertaken by some stakeholder groups.

[19] More generally, we did not find many significant differences among scientists in their views of future stressor impacts (Technical Appendix Tables C3a–b).

FIGURE 7
Environmental advocates and government officials are the most closely aligned with scientists in their views on stressor impacts



SOURCE: Author calculations.

NOTE: This figure reports the correlation between average responses of scientists and other groups for historical stressor impacts (Figure 4), top two stressors (Figure 5) and future stressor impacts (Figure 6).

* "All stakeholder groups" shows the correlation with the average score for all six groups (beige bars in Figures 4-6).

** "Leading experts" shows the correlation between the 26 scientists mentioned at least five times by their peers as having exceptional understanding of the aquatic ecosystem versus the remaining sample of scientists. "Don't know" responses are not included in the averages.

The following correlations were significant at the 90 percent level or greater: environmental advocates and leading experts for all three categories of stressor views, fishing and recreation for the future impact of stressors, government officials and the stakeholder group average for historical impacts and top two stressors.

Ecosystem Management

In choosing a portfolio of actions to support a reconciled Delta ecosystem, two considerations are key: the biological potential to support desirable species and the cost to those using the Delta's lands and waters. Ideally, the highest potential for biological payoff would come at the lowest cost. In practice, high-potential actions may have high costs, which means that negotiating tradeoffs is a major challenge for Delta policymaking.

Our surveys provide insights on promising actions—from both scientific and societal perspectives—for supporting the Delta's native fish species. For views on the biological potential of various actions, we draw on our survey of scientists. Although scientific understanding of "what will work" in this ecosystem is still uncertain and subject to change, science will need to inform ecosystem management on an ongoing basis. The survey gauges current views of the scientific community about the likely success and relative importance of a broad suite of actions.

Our survey of stakeholders and policymakers provides useful input on societal considerations. As was the case with the scientists, these respondents selected their top five actions for improving conditions for the Delta's native fishes. Although ecosystem policy must be informed by science, policy is ultimately made by society. When stakeholder views diverge from those of scientists, strategies are needed to develop a common understanding.

We also provide rough estimates of the costs of implementing various actions, based on a companion study, *Costs of Ecosystem Management Actions for the Sacramento-San Joaquin Delta* (Medellín-Azuara et al. 2013).

What Actions Do Scientists Consider Most Promising?

Table 1 presents the actions we asked scientists to evaluate. The list includes interventions addressing each stressor area, sorted by level of implementation experience within the Delta watershed and likely costs. Over half of these actions (denoted as "under way") are already employed to some extent within the Delta watershed, with additional implementation planned or being considered.[20] The other measures have not yet been tried here. Two actions—farm fertilizer discharge control (#5) and tidal marsh restoration (#29)—are planned for near-term implementation ("planned"). Several others are being considered based on modeling or experience outside the basin ("considered"). For example, BDCP negotiators are studying construction of a canal or tunnel to divert exports around or underneath the Delta (#21). And finally, some actions are still at the conceptual stage ("conceptual") and not yet sufficiently developed for active consideration—for example, ideas about controlling invasive clams, which compete with native species for food (#24), and increasing sediment available to the Delta, which could help support tidal marsh restoration (#32).

[20] As noted earlier, the Sacramento Regional County Sanitation District—the Delta's main urban point source of ammonium—has been ordered to upgrade its treatment facilities by 2022. Efforts also are under way to reduce farm pesticide discharges, to improve flow regimes upstream of the Delta, and to expand seasonal floodplain habitat in the Yolo Bypass. The National Marine Fisheries Service (NMFS) has proposed removing two dams on the Yuba River to improve salmon access to upstream habitat. (Some smaller dams have already been removed in upstream tributaries, including Butte Creek, Battle Creek, and Clear Creek.)

TABLE 1
Many actions might help improve conditions for the Delta's native fishes

	Action	Implementation stage [a]	Annualized costs [b]
Discharges	1. Reduce urban nonpoint discharges (e.g., stormwater, landscaping runoff)	Under way	$–$$
	2. Reduce farm pesticide discharges	Under way	$$–$$$
	3. Reduce toxic substance discharges (e.g., emerging contaminants)	Under way	$$–$$$
	4. Reduce urban point discharges (e.g., wastewater treatment plants, industry)	Under way	$$–$$$
	5. Reduce farm fertilizer discharges	Planned	$$$
	6. Dilute pollutant loads with increased freshwater flows	Considered	$$–$$$
Direct fish management	7. Truck juvenile salmonids around the Delta	Under way	$
	8. Increase enforcement to prevent poaching	Under way	$
	9. Increase screening of water diversions	Under way	$–$$
	10. Develop new conservation hatcheries to support native fish (e.g., delta smelt hatchery)	Under way	$$
	11. Reduce harvest of anadromous fish (salmon, steelhead, sturgeon)	Under way	$$
	12. Trap and truck fish around dams	Considered	$
	13. Allow unrestricted fishing on nonnative predatory fish (e.g., striped bass, largemouth bass)	Considered	$$
	14. Manage hatcheries to separate hatchery fish from wild populations (e.g., change hatchery locations, mark hatchery fish)	Considered	$$
Flow regime	15. Add gated structures within the Delta to improve fish passage	Under way	$–$$
	16. Reduce entrainment at export pumps	Under way	$$
	17. Reduce Delta exports	Under way	$$–$$$
	18. Increase net Delta outflows	Under way	$$–$$$
	19. Improve flow regime upstream of the Delta	Under way	$$–$$$
	20. Pattern Delta flow variability to support native species	Considered	$$–$$$
	21. Divert Delta exports through a canal or tunnel	Considered	$$$
Invasive species	22. Directly control invasive aquatic vegetation	Under way	$–$$
	23. Increase actions to prevent new invasions (e.g., ballast water, trailered boats, aquarium trade)	Under way	$$
	24. Directly control invasive clams	Conceptual	$–$$
	25. Increase salinity variability in the Delta	Conceptual	$$$
Physical habitat	26. Expand seasonal floodplains	Under way	$–$$
	27. Improve or increase upstream spawning and rearing habitat	Under way	$$
	28. Remove selected dams	Under way	$$–$$$
	29. Restore tidal marsh and shallow water habitat (e.g., Liberty Island, Suisun Marsh)	Planned	$$
	30. Improve in-Delta channel margin habitat (e.g., setback levees)	Considered	$$
	31. Increase deep-water habitat (e.g., Franks Tract, Mildred Island)	Conceptual	$$
	32. Increase sediment loads flowing into Delta	Conceptual	?

[a] "Under way" denotes actions that are currently being implemented in the Delta watershed to some extent; "planned" denotes actions not yet implemented but planned for near-term implementation; "considered" denotes actions being considered based on modeling or experience outside the basin; "conceptual" denotes actions still at the conceptual stage, not likely to be implemented in the near term.

[b] $, < $10 million; $$, $10 million to $99 million; $$$, $100 million to $700 million. Investment costs are annualized at 5 percent for perpetuity (so, a $1 billion investment costs $50 million per year). Cost estimates do not include economic spillover (multiplier) effects—e.g., additional revenue losses in other sectors from reductions in crop output or increased revenues from new investments (Medellín-Azuara et al. 2013).

Gauging Potential Impact

We asked scientists to consider the potential impact of each action relative to current conditions. Table 2 summarizes their responses along several dimensions: the columns group the actions into three groups according to the mean impact score, and the rows group them according to the level of consensus on these scores, as measured by the standard deviation of responses. Asterisks designate actions about which a high share of respondents (10% or more) answered "don't know"—another measure of uncertainty. And the actions are grouped by annual cost (lower cost is under $100 million per year and higher cost is over this amount).

TABLE 2
Scientists agree more about the potential impacts of some actions than others

	High potential impact	Medium potential impact	Low potential impact
High scientific consensus	**Lower-cost actions** #26 Expand seasonal floodplains (U) #27 Improve upstream habitat (U) #29 Restore tidal marsh (IP) **Higher-cost actions** #28 Remove selected dams (U) #20 Introduce more variable flows (IC) #17 Reduce exports (U)	**Lower-cost actions** #2 Reduce farm pesticides (U) #3 Reduce toxic discharges (U) #1 Reduce urban nonpoint discharges (U) #22 Control invasive vegetation (U)* **Higher-cost actions** #4 Reduce urban point discharges (U)	**Lower-cost actions** #9 Screen more diversions (U) #8 Prevent poaching (U)*
Medium scientific consensus	**Lower-cost actions** #29 Improve channel habitat (IC)* #23 Prevent new invasions (U) **Higher-cost actions** #18 Increase net outflow (U) #19 Improve upstream flows (U)	**Lower-cost actions** #16 Reduce entrainment (U) #14 Separate hatchery/wild fish (IC)** #11 Reduce salmon harvest (U) **Higher-cost actions** #25 Increase salinity variability (CO)* #5 Reduce fertilizer discharges (IP)	
Low scientific consensus		**Lower-cost actions** #24 Control invasive clams (CO)* **Higher-cost actions** #6 Dilute pollutant loads (IC)*	**Lower-cost actions** #32 Increase sediment loads (CO)** #15 Add gates for fish passage (U)** #13 More fishing of predators (IC)* #10 Conservation hatcheries (U)* #12 Truck fish around dams (U)* #31 Increase deep-water habitat (CO) #7 Truck salmon around Delta (U)* **Higher-cost actions** #21 Divert exports via tunnel (IC)**

SOURCE: Table 1 and Technical Appendix Table B5.

NOTES: For a more detailed list of actions, see Table 1. Actions are split into thirds based on two survey scores. "Impact" measures the sample average impact score, in answer to the question: "In your opinion, what is the potential impact of each of the following actions on the Delta ecosystem's ability to support native fishes?" with "strongly positive" = 3, "moderately positive" = 2, "weakly positive" = 1, "neutral" = 0, and "negative" = – 2. "Consensus" is measured as the standard deviation of these impact scores, where a low standard deviation indicates high consensus. Actions within each section are ranked by impact scores (highest to lowest). Implementation stage: "U" = already under way to some extent, "IP" = implementation planned in the near-term, "IC" = implementation under consideration, and "CO" = conceptual only. Costs: Lower-cost actions are likely to cost under $100 million per year, and higher-cost actions are likely to cost more than this amount.

*10 percent to 16 percent of respondents answered "don't know."

**21 percent to 25 percent responded "don't know."

Scientists were most likely to rank habitat- and flow-related actions as having a strong potential for positive impact. Consensus was highest (Table 2, top left corner) regarding two flow actions (introducing more variable flows and reducing exports), two Delta habitat actions (expanding seasonal floodplains and tidal marshes), and two actions addressing habitat upstream of the Delta (improving upstream spawning and rearing habitat and removing selected dams). "Don't know" response rates were also low for these actions.

The scientific consensus on the strong potential of seasonal floodplain expansion is not surprising; field experience shows that several native fish species benefit from spawning and rearing in floodplain environments (Sommer et al. 2001; Moyle et al. 2004; Jeffres, Opperman, and Moyle 2008). The consensus over tidal marsh restoration is more surprising, because some public discussions have tended to highlight perceived difficulties in regenerating the type of tidal marsh habitat that was once abundant in the Delta.[21]

The top two flow management options are quite distinct. Reducing exports is a familiar option that can simultaneously freshen water outflow (helping to get fish to the productive "mixing" zone in the west Delta near Suisun Marsh) and reduce entrainment of fish and larvae in the export pumps in the south Delta. Reducing exports is also a "knob" that can be turned quickly to affect Delta ecosystem conditions. In contrast, patterning flow variability to better support native fish species has been much discussed in recent years but is not yet well defined, and its potential consequences have yet to be fully explored.[22]

In the middle of the pack—with medium impact scores and high-to-medium levels of consensus—are actions designed to reduce discharges (#1–#5) and control invasive species (#22, #25), as well as efforts to support wild salmon populations by reducing their harvest (#11) and changing hatchery management policies (#14). Most of these actions are already employed within the Delta watershed. The idea of separating hatchery and wild populations of salmon is new for California, but has been successful in the Pacific Northwest (Fraser 2008).[23]

Average impact scores were lowest for most direct fish management actions and two engineering solutions to alter flows—adding new gates to improve fish passage (#15) and diverting exports through a new canal or tunnel (#21). Scientists agreed that neither screening of diversions (#9) nor greater enforcement of antipoaching laws (#8) is likely to offer significant ecosystem benefits (Table 2, top-right corner).[24] For other actions, the low impact scores reflect wide divergences in views (Table 2, bottom-right corner). This group of actions also had the highest shares of "don't know" responses; nearly a quarter of those surveyed stated that they could not assess the potential of the two flow-engineering actions.

The lack of consensus and high share of nonresponses on the canal or tunnel—which has been under active consideration in BDCP negotiations and much discussed within the scientific community—reflect uncertainty regarding the project's size and operation. Whereas most of the other actions focus primarily on ecosystem enhancement, this project has been conceived to both improve water export reliability and reduce the harmful effects of south Delta pumping on native fish. If managed for conservation objectives, a tunnel

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[21] This type of habitat has been shown to be a net producer of phytoplankton, an important food source (Lehman et al. 2010). However, much of the Delta is so deeply subsided that re-creation of tidal marsh is impossible in many areas. Restoration opportunities do exist in parts of the North Delta, centered on the Cache-Lindsey Slough region and perhaps a few other areas such as McCormack-Williamson Tract, and within Suisun Marsh, now managed as non-tidal freshwater or brackish marsh. This marsh is likely to become increasingly saline as sea level rises, so it will bear only superficial resemblance to former Delta marshes, which were principally freshwater (Moyle, Manfree, and Feidler in press).

[22] This action would likely include increased seasonal flood flows and perhaps reduced flows in the fall to more closely mimic seasonal flow variability that existed before human development of the Delta. However, the alteration of habitat and increasing pressures on the system from a warming climate could also make some "unnatural" flow patterns desirable (Moyle et al. 2012). The cost in terms of reduced water diversions for human uses would depend on the specific timing and the ability to recapture these flows after they serve environmental purposes (Medellín-Azuara et al. 2013).

[23] This would involve such measures as marking all hatchery fish and changing hatchery locations to reduce commingling of hatchery fish and wild populations during spawning. This strategy might be less successful in California, given the challenges of siting replacement hatcheries.

[24] Poaching is regarded worldwide as a major problem for sturgeon conservation (Pires and Moreto 2011), and reducing poaching on green and white sturgeon within the Delta could be effective because these fish are slow to reach maturity, live a long time, and have high fecundity. The low impact score for this action likely reflects the view that poaching is not a major issue for other native Delta fishes such as salmon and steelhead.

could facilitate more variable flow patterns (#20) and reduce entrainment (#16)—two actions scientists consider quite promising. At the time of the survey (and as of this writing in February 2013), information about operations was not sufficient to allow most scientists to weigh in on this with confidence.[25]

Although scientists did not always agree on the potential impacts of actions, there were few distinguishing characteristics of scientists ranking actions one way or the other.[26]

Choosing Priority Packages

Because actions to mitigate Delta stressors are likely to work best in combination, we also sought scientists' views on the five actions that together would most benefit the Delta's native fish species. To isolate the priorities from a biological perspective, scientists were instructed to consider *only* impacts on native fish, not the economic costs of the actions. Although the actions were presented by stressor group (as in Table 1), the participants were instructed to pick whatever combination of actions they considered most promising as a package, without regard to stressor category. This question elicits *top* priorities only; respondents might consider actions not chosen to be worthwhile. (Indeed, some scientists noted that they would have liked to choose more than five.)

To better see the patterns among these top choices, we grouped together actions with similar functions or focus into nine areas:

- Delta habitat
- Delta flow variability
- Reduced diversions
- Upstream management
- Reduced discharges
- Hatchery management
- Diversion engineering
- Invasive species control
- Harvest management

Table 3 reports the share of scientists who picked at least one action in each of these nine areas—ranked by their popularity—along with the share of the scientists picking each individual action.

In some cases, these functional areas combine actions associated with more than one of the five stressor groups presented in Table 1 (discharge of pollutants, direct fish management, flow regime change, invasive species, and physical habitat alteration). For example, "upstream management" includes both flow and habitat management actions that would be implemented upstream of the Delta, and "diversion engineering" includes an assortment of technological approaches to managing fish and flows that make diversions less harmful for native fish. "Hatchery management" and "harvest management" distinguish between two quite different approaches for direct fish management.

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[25] Twenty-three percent of the scientists responded "don't know" with regard to the potential impacts of a canal or tunnel on the Delta's native fish, and only 36 percent said they thought this measure would have a strongly or moderately positive impact (Technical Appendix Table B5c).

[26] Leading scientists, those with broader publishing experience across stressor groups, and those with past or present affiliation with the Moyle fish laboratory at the University of California, Davis tended to rank most actions as having lower potential (Technical Appendix Tables C4a-e). However, these characteristics were not associated with choices of priority actions, discussed below (Technical Appendix Table C7).

TABLE 3
Scientists’ top priorities include better management of habitat and flows

Action area	Individual actions
Delta habitat (82%)	**Habitat actions within the Delta** #26 expanding seasonal floodplain (61%) #29 restoring tidal marsh (48%) #30 improving channel-margin habitat (15%) #32 increasing sediment loads (8%) #31 increasing deep-water habitat (3%)
Delta flow variability (65%)	**Flow manipulations focusing on variability (not average water diversions)** #20 patterning Delta flow variability to support native species (59%) #25 increasing salinity variability to control invasive species (24%)
Reduced diversions (62%)	**Increasing the volume of instream flows** #17 reducing exports (39%) #18 increasing net Delta outflows (35%) #6 diluting pollutant loads with increased freshwater flows (4%)
Upstream management (61%)	**Habitat and flow actions upstream of the Delta** #19 improving upstream flow regime (30%) #27 increasing upstream spawning and rearing habitat (25%) #28 removing selected dams (21%)
Reduced discharges (30%)	**Reducing discharges directly (rather than by dilution)** #4 urban point sources (13%) #3 toxic substances (11%) #2 farm pesticides (7%) #5 farm fertilizers (6%) #1 urban nonpoint sources (4%)
Hatchery management (22%)	**Improving the role of hatcheries** #14 separating hatchery and wild fish (16%) #10 developing conservation hatcheries for native fish (5%) #12 trapping and trucking fish around dams (1%) #7 trucking juvenile salmon around the Delta (1%)
Diversion engineering (20%)[a]	**Using technology to make diversions less harmful for native fish** #16 reducing entrainment at the export pumps (11%) #21 building a canal or tunnel for exports (7%) #9 increasing screening of diversions (2%) #15 adding gated structures to improve fish passage (0%)
Invasive species control (20%)	**Managing invasive species directly (rather than with flows)** #23 preventing new invasions (11%) #22 directly controlling existing invasive plants (7%) #24 directly controlling existing invasive clams (5%)
Harvest management (12%)	**Directly managing recreational and commercial fishing** #11 reducing harvest of anadromous fish (7%) #13 allowing unrestricted fishing of nonnative predatory fish (6%) #8 preventing poaching (1%)

SOURCE: Technical Appendix Tables B7, B8.

NOTES: This table reports the shares of scientists that picked each individual action (right-hand column) and at least one action in each of the nine action areas (left-hand column), in answer to the question: “Considering interactions, what are the five actions that would result in the most beneficial impact on the Delta’s native fish species?” Table 1 lists individual actions.

[a] We included reducing entrainment (action #16) in diversion engineering even though one way to achieve this is to reduce export diversions. Other options involve technological methods, such as changing the timing of diversions and using barriers and fish screens.

For scientific experts on the Delta ecosystem, the most promising ways to improve conditions for native fish combine habitat and flow management, both within the Delta and upstream. At least three-fifths of all scientists surveyed picked Delta habitat (82%), Delta flow variability (65%), reduced diversions (62%), and upstream management (61%). There is tremendous agreement on these choices: 63 percent of those surveyed picked actions in at least three of these areas; 93 percent chose at least two; and only one scientist selected none. These choices reflect the prevalence of high-impact actions in all four areas (Table 2, left-hand column), particularly expanding seasonal floodplains (chosen by 61%) and the more experimental tools of patterning flow variability to support native species (59%) and restoring tidal marsh (48%).[27]

Although most scientists also picked at least one action outside these four areas, there were no strong patterns in the other combinations selected.[28] Some familiar actions, such as reducing discharges, had moderate support, as did some more experimental actions, such as separating hatchery and wild populations of salmon and steelhead. Few scientists chose other experimental actions, such as expanding conservation hatcheries and using gated structures to improve fish passage. And few selected harvest management actions, even though some of these—most notably, increased harvesting of predators—have been promoted in recent public debates.[29]

The survey provided the opportunity for respondents to write in additional actions they believed would help native fish and that they would rank in their top five priorities. Only a handful of the scientists (8%) wrote in additional priorities, and most of these were variations on the actions listed in the survey.

Scientists were also asked to provide their perspective on which actions would work as complements (where stronger implementation of one action would greatly improve the effectiveness of another) or substitutes (where stronger implementation of one action could enable less intensive implementation of another, while preserving a similar effect on the Delta's native fishes). Responses reflected the view that many stressors, and hence the actions to manage them, are interconnected in various ways. Flow management actions were commonly cited as complements that improve the effectiveness of other actions. For example, flow variability and increased outflows would increase the effectiveness of seasonal floodplains and tidal marsh. When reflecting on possible substitutes among the actions, scientists had fewer suggestions and even expressed some uncertainty about making those kinds of tradeoffs. Several respondents did indicate that greater outflows might allow fewer restrictions on pollutant discharges.[30]

Based upon the open-ended comments at the end of the survey, it is clear that many scientists consider a large number of the management actions worthy of attention, and also that they believe many of the actions will need to be implemented jointly to improve the ecosystem's ability to support native fish. Some expressed a preference for actions that in the long run require less continuous human intervention and that return the system to a more natural state. For instance, fish management actions such as conservation

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[27] More generally, the correlation between mean impact scores and the share of scientists who picked each action in their top five priorities was very high (0.73). The correlation was even higher (0.85) between mean impact assessment scores and the top five actions ranked by the share of scientists who picked them.

[28] Clustering exercises in which action choices were weighted by their ranks produced one very large cluster favoring the habitat-flow combinations described above (102 scientists) and four very small clusters, generally emphasizing one or more of the less popular areas. No systematic differences appeared in the characteristics of these scientists relative to those in the larger group (Technical Appendix Table C8). In addition, there were few significant differences in the characteristics of scientists choosing the nine action areas: Leading scientists were less likely to choose diversion engineering options and more likely to choose flow variability, Moyle lab affiliates were less likely to choose upstream management actions, those with publications on invasive species were more likely to choose actions in that area, and those with publications on fish management were more likely to favor hatchery management actions (Technical Appendix Table C7a).

[29] In 2008, a group of exporter interests sued the state Department of Fish and Game (DFG) (now the Department of Fish and Wildlife), arguing that predation by nonnative striped bass was a major contributor to the decline in salmon populations. In a 2012 settlement, DFG agreed to reduce restrictions on striped bass fishing, but this action was not approved by the state Fish and Game Commission, which regulates hunting and fishing licenses. Most scientists consider that the heavy predation of juvenile salmon moving through the Delta is a symptom of other problems and that increased fishing of predators is unlikely to be very effective in restoring salmon populations (Moyle 2011).

[30] Such tradeoffs are currently under consideration in the State Water Resources Control Board's draft plan for flows in the San Joaquin River system (State Water Resources Control Board 2012, Appendix K).

hatcheries and trucking salmon around the Delta require ongoing human intervention, whereas actions such as habitat restoration can eventually become productive without continued maintenance.

Comparing Scientist and Stakeholder Views

We asked stakeholders the same question as scientists about top five priorities for improving conditions for the Delta's native fish.[31] On average, stakeholder groups and scientists had broadly similar rankings of priority areas (compare the orange and beige bars in Figure 8). They agreed on four out of five top areas—all but upstream management (which ranked sixth for stakeholders) and diversion engineering (which ranked seventh for scientists). However, as with the stressor rankings, there were some significant differences between scientists and individual stakeholder groups.[32] Scientists were more likely to prioritize Delta habitat than all groups except exporters and government officials. Scientists were also more likely than most to prioritize Delta flow variability and upstream management, and they were in the middle regarding reduced diversions—higher than exporters (almost none of whom chose this alternative)—and lower than Delta and fishing interests (almost all of whom did). They were less likely than many other groups to prioritize reduced discharges, diversion engineering, and harvest management.

State and federal officials overlapped most with the scientists on management priorities, just as they did on the relative importance of different stressor categories, and this agreement was even stronger when considering how respondents *ranked* the priorities (Figure 9).[33] Environmental advocates' views were also fairly similar to those of the scientists, though environmental respondents were more likely to concentrate on flow-related actions and less on habitat or other complementary actions, and they were more likely to rank these flow actions as their highest priorities.[34]

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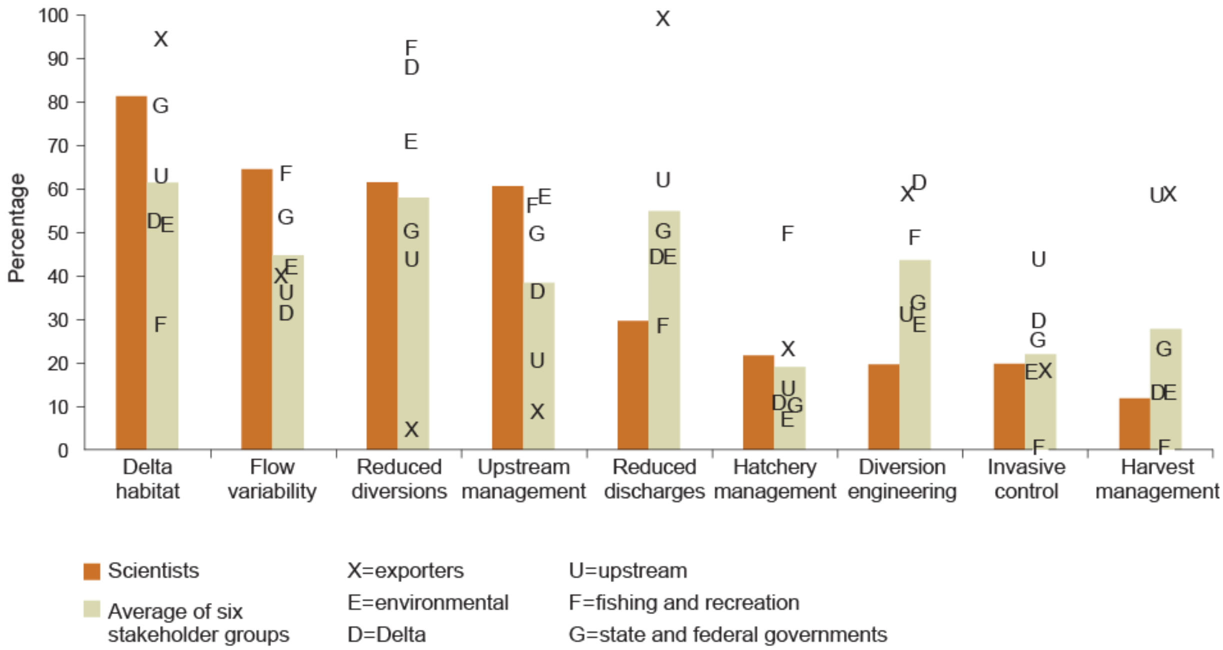
[31] Stakeholders were also given the opportunity to write in additional actions they would prioritize in their top five choices. Nearly a quarter (23%) wrote in at least one additional action. But as with the scientists, most of the suggestions were variations on the actions listed in the survey. New write-in options included suggestions such as adding surface storage to the system, reforming environmental laws such as the Endangered Species Act, and reducing overall demand for water from the system.

[32] For detailed results of significance tests comparing group choices of action areas, see the notes to Technical Appendix Table B20.

[33] We focus primarily on the unranked top-five priorities, given the views expressed by many scientists that it is important to consider a large number of actions in combination. Some scientists expressed discomfort with ranking these priorities. The rankings are, nevertheless, interesting in identifying the intensity of stakeholder preferences.

[34] See Technical Appendix Table B19 for rankings of individual actions used to examine ranked action correlations presented in Figure 9. Exporters had the most diverse portfolio of priority action areas (with 73% picking actions in four or five areas, out of a potential of five), and environmental advocates had the least diverse (with only 43% picking as many as four or five action areas).

FIGURE 8
Some stakeholders diverge from scientists on top priority actions



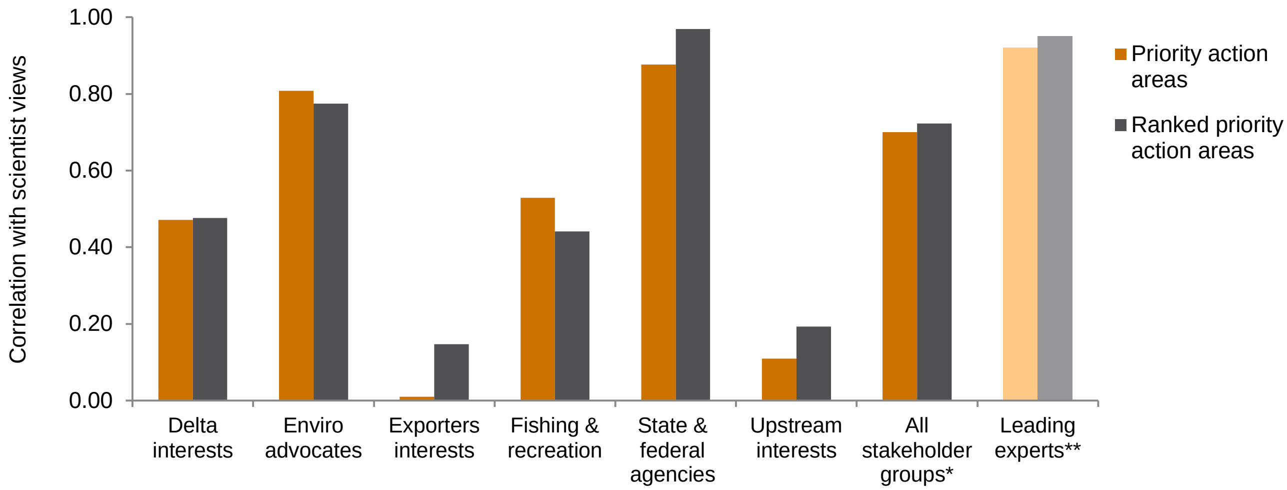
SOURCE: Technical Appendix Tables B8, B20.

NOTE: The figure reports the share of each group picking at least one action in each of the nine action areas. See Table 3 for a mapping of individual actions into action areas.

Although all survey respondents were instructed to focus only on the ecological potential of the actions (i.e., to ignore costs), groups with economic interests tended to steer away from actions likely to impose additional costs or other social or economic disruptions on themselves. Instead, each group tended to choose actions more likely to shift the financial burden elsewhere. Thus, exporters avoided measures that would reduce their diversions (either directly or through changes in upstream management), while prioritizing "non-flow" stressors including discharges, Delta habitat, harvest management, and diversion engineering such as a canal or tunnel. (Exporters have pledged to pay for a canal or tunnel—the diversion engineering tool favored by many of them—but negotiations to date have assumed that this new facility would pay for itself by improving water supply reliability and quality.) Likewise, fishery interests did not support harvest management—a direct hit on their livelihood—but strongly endorsed reducing diversions and improving upstream management to benefit fish populations. Upstream interests did not support upstream management measures that might cost them land or water. And they only supported reducing diversions if those came at the expense of exporters, not themselves. (Forty-one percent of upstream stakeholders selected reducing Delta exports as a priority action, versus only 3 percent who chose increasing net Delta outflows—a more general action that could reduce upstream diversions.)[35] Delta interests were more enthusiastic about reducing other water users' diversions and less enthusiastic about measures to develop more Delta habitat, which might harm the local economy, even if landowners are compensated for converted lands.[36]

[35] See Technical Appendix Table B19c.
[36] Delta interests' high score for diversion engineering reflected a preference for reducing entrainment at the export pumps (chosen by 32% of these respondents) and screening diversions (18%), not for building a canal or tunnel (5%). See Technical Appendix Table B19b and B19c.

FIGURE 9
Government officials and environmental advocates are most closely aligned with scientists in their views on priority actions



SOURCE: Author calculations.

NOTES: The figure reports the correlation between scientists and other groups on share of each group that picked at least one action in the nine priority action areas (Figure 8) as well as the correlation on the average ranked action area value (Technical Appendix Table B20). "Don't know" responses are not included in the averages.

*"All stakeholder groups" shows the correlation with the average score for the six groups (beige bars in Figure 8).

** "Leading experts" shows the correlation between the 26 scientists mentioned at least five times by their peers as having exceptional understanding of the aquatic ecosystem versus the remaining sample of scientists.

The following correlations were significant at the 90 percent level or greater: environmental advocates, government officials, and all stakeholder groups with scientists, and leading experts with the other scientists.

Stakeholders can find support for these disparate views in the information they consult on the Delta. Most stakeholders responding to the survey are very actively engaged, consulting traditional and non-traditional media on this topic daily, and government and scientific materials at least weekly (Technical Appendix Table B21). In recent years, some groups—notably exporter interests—have expanded their own scientific efforts on multiple stressor topics. Some of this research has supported the idea that discharges (and consequent reduced food supplies), rather than diversions, are the key culprit (and hence key solution) to native fish declines (Glibert 2010, Teh et al. 2010, Miller et al. 2012). In contrast, environmental advocates and fishery interests are most likely to rely on advocacy group publications, which often emphasize the importance of reducing diversions.[37]

Given these differences, it is heartening that stakeholders often seem willing to consider actions that might be costly to them but beneficial to native species. For instance, more than half of Delta-based respondents chose at least one Delta habitat action, and more than 60 percent of upstream interests and nearly half of Delta-based interests selected at least one discharge-related action. Over 40 percent of exporters chose flow variability actions, which could reduce diversions. And many more environmental advocates picked nonflow actions than might have been expected, given the public positions taken by many environmental groups.

[37] Examples of environmental advocacy publications include Natural Resources Defense Council (2008) and Friends of The River (n.d.). Examples of fishing industry positions include Grader (2013) (salmon industry) and Jennings (2011) (sports fishing more generally).

Costs of Ecosystem Solutions

The patterns of stakeholder priorities highlight an important social consideration in ecosystem management for the Delta: many individual management actions will be costly. Our cost estimates suggest that any comprehensive reconciliation package will cost at least several hundred million dollars per year on an ongoing basis. Some highly ranked flow- and discharge-related actions are likely to be particularly expensive (over $100 million per year each), and the combined costs of habitat improvements could easily exceed this amount as well. In many cases, there has been an expectation that individual groups would bear the costs directly (especially for discharges and flows). Even in areas that are expected to receive some taxpayer support (e.g., habitat, proposed to be covered at least in part by state bond funds), fiscal and social realities will require implementing ecosystem management cost effectively.

Pulling It All Together

Taken together, this review of scientist and stakeholder views on stressors and mitigation actions, and our rough assessment of mitigation costs, suggest the following conclusions:

1. **Scientists and stakeholders agree that all five categories of stressors have harmed the Delta's native fishes.** However, whereas scientists consider changes in flows and alteration of physical habitat to be the most significant causes of harm, groups that benefit most directly from those stressor categories are less inclined to consider them harmful.
2. **Scientists are more pessimistic than most stakeholders about the future role of stressors under current management.** Groups most responsible for discharges of pollutants, changes in flow regime, and habitat alteration consider these areas less likely to cause increasing harm in the future.
3. **Scientists largely agree upon which actions are likely to be most effective in improving conditions for the Delta's native fishes.** Habitat and flow management combinations, within and upstream of the Delta, are endorsed as top priorities by large majorities of scientific researchers who study the Delta.
4. **Stakeholders and policymakers generally agree with scientists on priority solutions.** However, individual groups were more likely to prioritize actions unrelated to their own uses of Delta resources, and to shy away from actions that would be costly for them. Some common ground also exists, with many stakeholders seeming willing to consider actions to support native fish species despite potential for economic costs and disruptions to their interests.
5. **A comprehensive ecosystem approach will be expensive.** Successful management will require packages of actions, at likely costs of several hundred million dollars per year. Fiscal and social realities will require ways to implement mitigation actions cost-effectively.
6. **More research and experimentation is required for many management actions.** There is a low degree of consensus among scientists about the biological potential of some actions, including many direct fish management actions (e.g., conservation hatcheries to support native fish populations in the near-term) and a proposed canal or tunnel to divert water exports underneath or around the Delta. The lack of consensus reflects high levels of uncertainty about these actions, including how new export conveyance infrastructure would be operated. In addition, some actions that most scientists rank highly—including more variable flows, restored tidal marsh, and more suitable channel-margin habitat—are still relatively experimental and will require ongoing analysis to develop and fine-tune suitable implementation programs.
7. **The lack of a shared understanding of Delta science is a major obstacle to effective ecosystem management.** Most engaged stakeholders consult scientific and government reports regularly, but key groups that would be most affected by potential changes arrive at different conclusions than scientists on the nature of both the problem and the solutions. Delta science not only must push the frontiers of knowledge on effective ecosystem management, but must also do so in ways that enhance its legitimacy and acceptance by the many interests who have a stake in the outcomes.[38]

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[38] In a companion report, *Stress Relief: Prescriptions for a Healthier Delta Ecosystem* (Hanak et al. 2013), we propose ways to restructure Delta science to help develop a stronger, more integrated science program that could bring greater unity of purpose to the system's primary regulators and its regulated entities.

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