Delta Conservation Framework

Section IV

Contents

IV. Delta Conservation Based in Science

Throughout the Delta, ecosystem processes are impaired by a multitude of stressors. Together, these stressors impact ecosystem processes and discourage the persistence of native species.[1,2,3,4,5,6,7,42] Science-based conservation practices will support rapid responses to crises and provide long-lasting solutions to Delta conservation.[8,9,10] Long-term monitoring and research is critical to guide conservation actions.[9] An integrative approach to conservation, which is informed by science, will help rebuild Delta ecosystem resiliency and address impacts associated with climate change and other drivers.[8,9]

Ecosystems are most resilient and functional when they are interconnected at various temporal and spatial scales.[11,12] Planning and managing conservation projects in isolation, or on very short time scales, is ineffective in restoring ecological processes. To achieve lasting resilience in the Delta, it is important to understand how ecological processes function across time and space within a mosaic of wildlife-friendly land management approaches and agriculture.[13,14] Over the coming decades, environmental extremes will make it much more difficult to sustain functional Delta ecosystem processes that adequately support native species.[2,15,40] It may, therefore, become necessary to shift focus to managing for "reconciled" or "novel" ecosystem functionality.[16,17]

> ***"Reconciliation ecology seeks to improve conditions for native species while recognizing that most ecosystems have been altered irrevocably by human use and will continue to be used to support human goals. Improving ecosystem conditions for native species must therefore happen in a context of continuing use of land and water by humans and continuing physical and biological change."***[16]

This section offers an overview of the capacity of science in the Delta, including current and upcoming scientific research and progress made toward a comprehensive adaptive management program that addresses the needs of upcoming conservation and mitigation actions through the California *EcoRestore* initiative,[18] state and federal water project operations, and California *WaterFix*.[8,19,20,21] It provides a discussion of the goals, strategies, and objectives for scientific assessment of conservation actions and for the evaluation of climate change and other stressors and drivers.

Delta Science Capacity

Several science-based programs and partnerships exist that support conservation and long-term management in the Delta, including the Delta Science Program, the Delta Independent Science Board, Interagency Ecological Program, the Collaborative Science and Adaptive Management Process, and the State and Federal Water Contractors Agency science program. In addition, research programs such as those conducted by the San Francisco Estuary Institute (SFEI) and the UC Davis Center for Watershed Sciences provide significant scientific contributions to inform conservation and land management in the Delta. The Public Policy Institute of California helps communicate science to decision-makers by using scientific research to inform public policy.

Delta Science Program

> ***The mission of the Delta Science Program is "to provide the best possible scientific information for water and environmental decision-making in the Bay-Delta system."***

The Delta Science Program was established by the Delta Reform Act of 2009 as the replacement for and successor to the CALFED Science Program. Information gathered and evaluated by the Delta Science Program must be unbiased, independently peer-reviewed, relevant, authoritative, integrated across state and federal agencies, and communicated to Bay-Delta decision-makers such as agency managers, stakeholders, the scientific community, and the public. The Delta Science Program's Lead Scientist is responsible for overseeing the implementation of the Science Program. In 2013 the Delta Science Program developed the Delta Science Plan,[20] which is a framework for conducting science that organizes and integrates Delta science activities and builds its vision of an open collaborative science community known as *One Delta, One Science*. The elements of the Delta Science Strategy are the Delta Science Plan, Science Action Agenda (SAA),[19] and The State of Bay-Delta Science (SBDS). The Delta Science Plan is the foundation that sets a shared vision for Delta science (*One Delta, One Science*). The SAA prioritizes and aligns near-term science actions to inform management actions and achieve the objectives of the Delta Science Plan. The SBDS synthesizes scientific knowledge about the Delta, including progress made on key research questions and remaining knowledge gaps. More details about the Delta Science Strategy and its components (Delta Plan, SAA, and SBDS) are presented in the subsections below.

Delta Independent Science Board

The Delta Independent Science Board (Delta ISB)[22] provides independent oversight of the scientific research, monitoring, and assessment programs that support adaptive management of the Delta through periodic program reviews. The Delta ISB is composed of nationally or internationally prominent scientists with expertise to evaluate the broad range of scientific programs that support adaptive management of the Delta.

Collaborative Science and Adaptive Management Program/Collaborative Adaptive Management Team

> ***"The CSAMP and CAMT were formed as part of a federal and state proposal to modify the court-ordered remand schedule for the salmon and delta smelt biological opinions for the water export facilities. The CSAMP is a multi-agency effort led by a Policy Group that includes the Directors of the state and federal agencies involved in the biological opinions and the Directors or top managers of the entities involved in the litigation that challenges those biological opinions."[23]***

The Collaborative Science and Adaptive Management Program (CSAMP) is a policy group comprised of state and federal agency directors, regional directors, general managers of water agencies, and executive directors of nongovernmental organizations. The CSAMP was initiated as a result of the 2013 court decisions to remand the current U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) Biological Opinions (BiOps) on the operations of the State Water Project (SWP) and Central Valley Project (CVP). The remand schedule for completing revisions to the current BiOps and completing review under the National Environmental Policy Act was subsequently extended until 2015. Thereafter, all parties agreed to continue the CSAMP to promote the collaborative development of scientific information to inform sound decision-making into the future.

The CSAMP is structured as a four-tiered organization comprised of:

1. The Policy Group, consisting of agency directors and top-level executives from the entities that created CSAMP;
2. The Collaborative Adaptive Management Team (CAMT), consisting of managers and staff scientists that serve at the direction of the Policy Group;
3. Scoping Teams, created on an as-needed basis to scope specific science studies; and
4. Investigators contracted to conduct studies.

Going forward, as it develops its Five Year Plan, the CAMT plans to revisit and increase the scope of its mission statement. Until then, the CAMT intends to remain focused on completing the studies initiated in 2014 and identify new initiatives based on the results of these studies.[24]

> ***"The Collaborative Adaptive Management Team (CAMT) will work, with a sense of urgency, to develop a robust science and adaptive management program that will inform both the implementation of the current Biological Opinions, including interim operations, and the development of revised Biological Opinions."[24]***

Current products that are being developed by the CAMT scoping teams and principal investigators include analysis and synthesis tools and reports concerning Delta smelt (*Hypomesus transpacificus*) entrainment, gear efficiency, fall habitat, and salmonid survival. Two scoping teams will produce reports that identify key findings, issues, and recommendations. CAMT members will evaluate and prioritize the next steps recommended in the two scoping teams' reports. The highest prioritized efforts will be presented to the Policy Group and will be incorporated into the Five Year Plan that CAMT is currently developing.[24]

State and Federal Contractors Water Agency Coordinated Science Program

In August of 2009, various water agencies that receive Delta water via the SWP and CVP formed the State and Federal Contractors Water Agency (SFCWA).

> ***The SFCWA's mission is to "assist its member agencies in assuring a sufficient and reliable high-quality water supply for their customers."***

The core activities in following its mission are to facilitate habitat conservation measures and research related to the restoration of the Delta ecosystem while ensuring sufficient and reliable export water supplies.[25] In order to best support management decisions, the SFCWA Coordinated Science Program (SFCWA Science) works to facilitate research and to communicate findings that improve the understanding of water quality, ecosystem processes, and habitat restoration in the Delta.[26] SFCWA Science focuses on supporting projects that are collaborative, promoting diverse integration of ideas and expertise, and that are multidisciplinary.

The 2014 SFCWA Research Plan is funded through a SFCWA specific funding program, and it outlines research needs relevant to informing important management activities. The program focuses on: contaminants, fish, habitat restoration, modernizing monitoring, nutrients, phytoplankton, and an estuaries portal (California Water Quality Monitoring Council's Estuary Portal).[26] For each program subject, the research plan lays out what is known, research needs, and how resulting information will be used. For habitat restoration, the main research questions relate to types of habitats to restore in relation to supporting native aquatic life, minimizing potential negative effects of restoration, best use of models and design features for restoration, and implementing effective performance monitoring.[26]

Interagency Ecological Program

> ***"The mission of the Interagency Ecological Program (IEP) is to provide and integrate relevant and timely ecological information for use in the management of the Bay-Delta ecosystem and the waters that flow through it."***

The IEP promotes collaborative and scientifically sound monitoring, research, modeling, and information synthesis. The IEP mission addresses high-priority management and policy needs in order to fulfill responsibilities established under various water rights decisions, the State Endangered Species Act and Federal Endangered Species Act (ESA), and the Clean Water Act. The mission directives are carried out by multidisciplinary teams composed of agency, academic, nongovernmental organizations, and private scientists. The IEP consists of nine member agencies, including the Department of Water Resources (DWR), the Department of Fish and Wildlife (CDFW), the State Water Resources Control Board, and six federal agencies (USFWS, Bureau of Reclamation [Reclamation], U.S. Geological Survey, Army Corps of Engineers, NMFS, and the Environmental Protection Agency). The IEP also partners with SFEI, the Delta Science Program, and the Central Valley Regional Water Quality Control Board (CVRWQCB).[27]

Interagency Ecological Program Science Agenda

The IEP Science Agenda guides IEP agencies as they select studies for the IEP Work Plan and employ strategies to achieve the goals of the 2014 Strategic Plan.[28] Updates and revisions are considered as priority topics are accomplished and new needs are identified. Other planning efforts, including the Delta Science Program's SAA, are taken into consideration for planning and prioritization. By institutionalizing a Science Agenda, the IEP serves evolving priority management needs, policy needs, and diverse perspectives.[21] The Science Agenda is organized into general categories through a general conceptual model (Figure 4.1). The Science Agenda's five areas of emphasis for near-term science include:

- Effects of Climate Change and Extreme Events
- Ecological Contribution of Restored Areas
- Impacts of Non-Native Species
- Understanding Estuary Food Webs
- Restoring Native Species and Communities

For each of these topic areas, the Science Agenda lays out the current knowledge base and lists priority science questions to inform management of needs for monitoring, focused studies, data synthesis, and coordination.

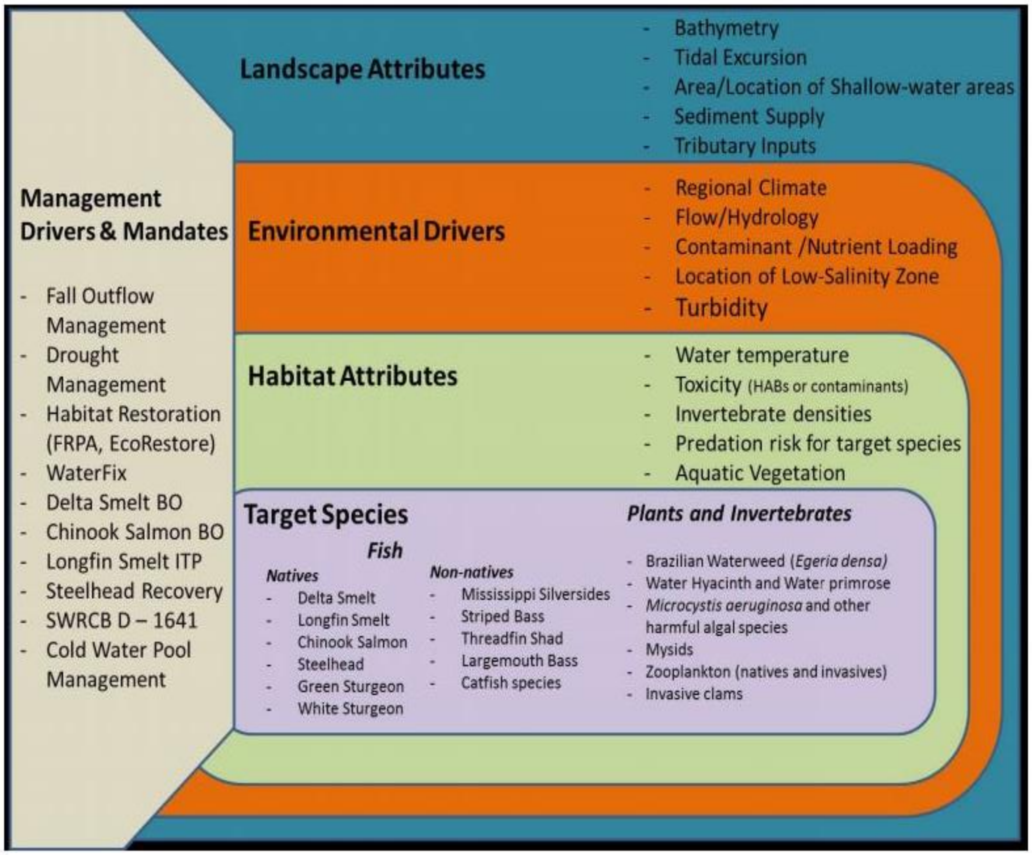


Figure 4.1: Conceptual Model diagram used to organize the IEP Science Agenda into general categories (Source: IEP 2016a)

San Francisco Estuary Institute - Delta Landscapes Project

The San Francisco Estuary Institute & Aquatic Science Center is an aquatic and ecosystem science institute with the mission to "provide independent scientific support and tools for decision-making and communication through collaborative efforts".

SFEI's Resilient Landscapes Program focuses on assessing and improving the health of the waters, wetlands, wildlife, and landscapes of the San Francisco Bay Area and the Delta, which included the completion of the *Delta Landscapes Project* in 2016. Declines in Delta ecosystem functionality are caused primarily by habitat modifications, altered flow regimes, pollution, invasive species, and direct fish management such as hatcheries and fish screens.[29] To address these declines, SFEI recently published "*A Delta Renewed: A Guide to Science-Based Ecological Restoration in the Sacramento-San Joaquin Delta*"[13] to offer tools and direction for creating and maintaining Delta landscapes that can provide desired ecological functions for decades to come. The publication is the third report of the *Delta*

Landscapes Project, supported by CDFW's Ecosystem Restoration Program, to inform landscape-scale restoration of the Sacramento-San Joaquin Delta ecosystem.[13,14,30]

Rather than attempting to recreate the Delta of the past, given the nature and scale of documented changes, the project instead highlights the services that altered Delta ecosystems currently provide and could provide in the future. Recommendations are based on extensive research that analyzes how the Sacramento-San Joaquin Delta used to function,[30] how it has changed,[14] and how it could evolve given implementation of a suite of conservation and management actions that focus on providing enhanced ecological function of Delta ecosystems into the future.[13]

Specifically, "*A Delta Renewed*" offers guidance for creating and maintaining landscapes that can provide desired ecological functions into the future by building on work that others have piloted.[13] Its recommended approaches to reestablishing or mimicking certain natural processes aim to establish an appropriate functional configuration of habitat types at the landscape scale, and they aim to use multi-benefit management strategies to create a more viable Delta ecosystem that can adapt and continue to provide valued functions as the climate and land uses change. The recommended approaches are also designed to integrate with the human landscape to provide ecosystem improvements that also benefit the agricultural economy, water infrastructure (and diversions), and urbanized areas in the Delta. The resulting strategic conservation approach builds on history and the ecology of the region, and it contributes to the establishment of co-benefits that promote a strong sense of place and provide recreational value to the Delta. The recommendations provided in "*A Delta Renewed,*" therefore, directly inform a number of Delta Conservation Framework overarching goals, strategies, and objectives (see Section III). These tools and recommendations are especially relevant in the context of expected future climate change projections and the potential impacts associated with sea-level rise, extreme weather events, and related flow alterations.

UC Davis Center for Watershed Sciences

The UC Davis Center for Watershed Sciences (Center) is dedicated to the interdisciplinary study of critical watershed challenges.[31] Geologist Jeffrey Mount and fish biologist Peter Moyle founded the Center in 1998 to develop more integrated and imaginative approaches to water science and policy. Over time, it grew in size and disciplinary breadth to stay ahead of potential water crises associated with climate change and increased water demands. It is now one of California's leading water management academic institutes. Today, the Center utilizes expertise from physical, biological, social, and engineering sciences to conduct quantitative analyses of ecological, economic, and social aspects of water management systems and to evaluate critical uncertainties in watershed, riverine, riparian, floodplain, and tidal marsh restoration efforts. Center scientists partner with agencies and conservation groups to conduct problem-solving research and data syntheses on topics such as restoration and water resource management. The Center also conducts non-partisan research supported primarily by foundations, public agencies, and conservation groups.

Public Policy Institute of California

As a nonprofit, nonpartisan think tank, the Public Policy Institute of California (PPIC) is dedicated to informing and improving public policy in California through independent, objective, and nonpartisan research. PPIC includes three policy centers that integrate science information at the policy level to inform decision makers.[32] Most relevant to the Delta is the PPIC Water Policy Center (http://www.ppic.org/water), which recommends water management solutions that support a healthy economy, environment, and society. Other PPIC capacities include the PPIC Higher Education Center, advancing practical solutions that enhance educational opportunities for all of California's students. Topics that may be relevant to the Delta include *Climate Change/Energy, Economy,* and *Political Landscape*. The PPIC Statewide Survey provides a voice for the public and likely voters on key policy issues facing the state.[32] PPIC multidisciplinary research staff include experts in economics, demography, political science, sociology, and environmental resources.[32] PPIC was established in 1994 to conduct research without partisan or ideological biases, encourage productive dialogue, and inspire the search for sustainable solutions in Sacramento and across the state.[32] A variety of Delta-relevant publications are available at: http://www.ppic.org/publications/#t1.

Delta Science Planning and Implementation Efforts

The Delta Science Program coordinates, plans, and implements science efforts through the Delta Science Strategy. Interdisciplinary science efforts, including a focus on integration of socioeconomic, biophysical, and ecological scientific findings are part of the "*One Delta, One Science*" approach. The three-part *Delta Science Strategy* includes the Delta Science Plan, the SAA, and the SBDS. These three elements support the vision of "*One Delta, One Science*," as outlined in the Delta Science Plan.[20] The SAA prioritizes and aligns near-term science actions to inform management actions and achieve the objectives of the Delta Science Plan. The SBDS synthesizes the current scientific knowledge in the Delta, including progress made on key research questions and remaining knowledge gaps. The knowledge gaps identified in the SBDS are used to guide updates to the SAA.

Delta Science Plan

The Delta Science Plan offers a cooperative science-oriented approach that extends across multiple agency and program authorities and is based on a culture of cooperation and stewardship among Delta scientists, policymakers, managers, stakeholders, and the interested public to advance *One Delta-One Science* to inform decisions.[20] Science that is responsive to, and integrated with, management and policy processes is a key component to finding conservation solutions in the Delta. The Delta Science Plan offers a vision, principles, and approaches for expanding existing Delta science efforts and for the development of new efforts. The Delta Science Plan is intended to provide an approach for the integration of Delta-oriented science programs and conservation efforts, such as the Delta Science Program, IEP, SFCWA Science, CSAMP, California *WaterFix*, California *EcoRestore*, and the CVRWQCB's Delta Regional Monitoring Program. The Delta Science Plan can also be used to guide implementation of other scientific efforts to support the Delta Plan adaptive management requirements.

The State of Bay-Delta Science

In 2016, the Delta Science Program published the SBDS to provide a synthesis of current scientific understanding in the Delta learned since SBDS 2008.[22] Updated every four years, the SBDS compiles chapters on scientific topics that emphasize progress made on key research questions during the past decade and identifies remaining knowledge gaps. The 2016 papers covered an array of topics including the status and population dynamics of endangered and threatened fish species, the Delta as a changing landscape, food web dynamics, climate change impacts, agricultural and urban water supply reliability, dynamics of water contaminants and their transportation, multi-dimensional models on distribution and movement of fish and food organisms, levee system vulnerability, nutrient dynamics, and contaminant effects in the Delta. The papers are available in the July, October, and December 2016 issues of the online journal, *San Francisco Estuary and Watershed Science*. Two of the papers published in this technical series were targeted at a general audience. They described the challenges of managing Delta water and ecosystems and the implications of recent scientific findings to policy.

Interim Science Action Agenda and 2017-2021 Draft Science Action Agenda

In 2014, the Delta Science Program developed the Interim Science Action Agenda (ISAA), as a tool to assist in the implementation of the Delta Science Plan.[33] The draft 2017-2021 SAA identifies priority areas that are organized into scientific actions that address knowledge gaps and that build scientific infrastructure and capacity on a three-year implementation cycle. The draft 2017-2021 SAA identifies priority science actions for the Delta and is founded on SBDS 2016 and completed interim SAA efforts (i.e., the 2014 ISAA and High-Impact Science Actions).[19] It establishes 12 broad priority science actions that are organized into five action areas (see SAA Figure 4.2 below). The 12 science actions are broad in nature and span a wide range of scientific approaches to achieve key management needs.

Integrating a Socioeconomic Research Focus

The human uses of Delta landscapes directly influence current and future conservation opportunities. As a result, understanding the needs and opinions of landowners and the public is essential to long lasting conservation success.[34] When designing and adaptively planning for future Delta landscapes, it is important to consider local cultures, economic realities, and human interactions with restored landscapes through socioeconomic research. This should help ensure that conservation projects fit within a broader cultural context that supports the *Delta as an evolving place*.[34] The SAA highlights the importance of considering the human impacts of natural resource management decisions and the big picture effects of changing land use in the Delta when planning for conservation (Action Area 1; Figure 4.2). In order to integrate these factors into conservation planning and decision-making, a variety of tools and processes are available. These tools include scenario planning,[35] the Open Standards for the Practice of Conservation (Open Standards),[36] and Structured Decision Making (SDM).[37] Short overviews of these methods are presented in Section VI.

PROPOSED FINAL DRAFT 2017-2021 SCIENCE ACTION AGENDA 07/18/2017

Summary of Priority Science Actions

Table I: A summary of the 13 priority science actions organized into five action areas.

Action Area 1: Invest in assessing the human dimensions of natural resource management decisions
A. Investigate the most cost-effective methods to improve species' habitat on working lands.
B. Develop tools to assist adaptive management in the Delta.
C. Initiate a research program on the Delta as an evolving place that integrates the physical and natural sciences with the social sciences.
Action Area 2: Capitalize on existing data through increasing science synthesis
A. Strategically build the capacity to do collaborative science and science synthesis through implementing the science synthesis mechanisms outlined in the Delta Science Plan.
B. Identify and prioritize important data sources that should be interconnected to promote collaboration and provide the technology necessary to allow this information to be easily accessed.
Action Area 3: Develop tools and methods to support and evaluate habitat restoration
A. Develop methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve.
B. Estimate and assess the system-wide effects of location and sequence of tidal marsh habitat restoration projects in regions where sea-level is rising and climate is changing.
Action Area 4: Improve understanding of interactions between stressors and managed species and their communities
A. Implement studies to better understand the ecosystem response before, during, and after major changes in the amount and type of effluent from large point sources in the Delta including water treatment facilities.
B. Identify areas that act as refugia for species of concern during extreme conditions, particularly drought and flood, to inform management decisions and priorities during extreme climate events.
C. Understand mechanisms for observed relationships between flows and aquatic species.
D. Evaluate the effects of toxicity (e.g., contaminant mixtures, pharmaceutical products, HABs) on aquatic species' survival including possible effects on predation.
Action Area 5: Modernize monitoring, data management, and modeling
A. Advance integrated modeling through efforts such as an open Delta Collaboratory (physical or virtual) that promotes the use of models in guiding policy.
B. Explore innovative technologies and cost-effective methods for scientific monitoring and analysis of flow, water quality, and ecosystem characteristics (e.g., improved tools for fish monitoring, LiDAR, high-resolution bathymetry technology, new measurements for Delta levee hazards, and citizen scientist monitoring programs).

Figure 4.2: Summary of priority SAA science actions [Note: insert final version when ready]

Example Questions for Priority Research Needs (for full list of questions please reference: Delta Science Program 2017,[19] IEP 2016a[21]):

- How do native species (including ESA-listed) and nonnative species use restored habitats?
- How do tidal wetland projects impact physical (e.g., tidal dynamics) and ecological (e.g., food web dynamics) characteristics of the Delta?
- What are the most effective designs for tidal restoration sites while achieving tidal flow velocities that preclude establishment of invasive aquatic vegetation?
- How do different channel morphologies and channel margin habitats affect native fish species and communities?
- To what extent do invasive species influence the suitability of restored habitats for target species or native communities?
- How do large-scale tidal wetland restoration actions affect tidal excursion, hydrodynamics, bathymetry, the low salinity zone, and sediment dynamics in the estuary?
- How can we best manage flows and salinity over the long term in the face of continuing SLR?
- Are financial subsidies effective in increasing wildlife-friendly agriculture on private lands?
- How will physical, chemical, and biological conditions in the estuary change as climate change occurs?
- Is the Bay-Delta water and fish management system resilient to climate change?
- Habitat: What is the contribution of different habitat types (open water, floodplain, tidal marsh, benthic, floating aquatic vegetation, submerged aquatic vegetation, etc.) to the food web in the estuary?
- How does large-scale tidal wetland and floodplain restoration affect the range of tidal excursion, bathymetry, X2, and sediment dynamics in the estuary?
- At a local scale, how do tidal wetland and floodplain restoration affect tidal dynamics?

Assessing Conservation Progress and Informing Effective Management

Insights from new scientific research clearly indicate that a combination of multiple stressors impact the continuing existence and resilience of native species; these stressors include 1) habitat loss; 2) the increasing frequency of extreme weather conditions linked to climate change; 3) sea level rise (SLR); 4) anthropogenic changes in flow regimes; and 5) a heightened importance of nutrients in Delta waterways that can simultaneously promote the spread of floating aquatic invasive plants (such as water hyacinth) and influence the growth of phytoplankton at the base of the food web;[8,38,39] and 6) an ever-changing mixture of contaminants derived from agricultural, urban, and industrial discharges.[2,15,40] Nutrient loads have a direct relationship with cyanobacteria, particularly *Microcystis* sp. bloom frequency,[8,38,41] which could have negative effects on fish. Nutrients are also directly linked to other ecosystem stressors, including irreversible changes in the Delta food web that prohibit the continuing existence of native vertebrate communities in areas where they once occurred.[1,3,16,42] Taken together, the persistent pressures of multiple stressors suggest continued severe population declines for native species, particularly species of special concern and listed species.[2,15,40]

By outlining priority science actions, the 2016 IEP Science Agenda and the SAA guide science activities for multiple agencies and science programs in the Delta. These science actions will help elicit competitive and informed grant solicitations, agency budget change proposals, coordinated multi-agency efforts, and updates to individual science program strategic planning efforts within federal and state governments. These agendas should also guide existing nongovernmental science organizations in a common direction to advance scientific understanding and ensure a strong science-based infrastructure that supports conservation, management, and policy decisions. This will be especially useful, for example, in light of upcoming challenges related to climate change, where there is rising public recognition and support. Goal E (Table 4.1) highlights the need to evaluate conservation progress and to address climate change stressors and other drivers of change. It calls for implementing the Delta Science Plan and IEP science strategies, the adaptive management program for BiOps related to state and federal water project operations (AMP), and the California *EcoRestore* adaptive management program.

Table 4.1: Goal E and related strategies and objectives for implementation.

GOAL E: To evaluate conservation progress and to address climate change stressors and other drivers of change, implement the DSP and IEP science strategies, the adaptive management program for Biological Opinions related to state and federal water project operations (AMP), and the California *EcoRestore* Adaptive Management Program.

Strategy E1: Implement the priority research science actions and needs outlined in the Delta Science Strategy, the IEP science agenda, and Delta smelt and salmonid Resiliency Strategies.

- OBJECTIVE E1-1: By 2021, implement the 2017-2021 SAA and 2016 IEP science agenda priority actions pertinent to ecosystem conservation and evaluate progress through the AMP and California *EcoRestore* Adaptive Management Program to inform planning and management decisions and evaluate conservation progress in the Delta.
- OBJECTIVE E1-2: By 2021, implement and evaluate progress of the Delta Smelt Resiliency Strategy and Sacramento Valley Salmon Resiliency Strategy.
- OBJECTIVE E1-3: Advance integrated modeling tools to support research efforts and science-based decision making.
- OBJECTIVE E1-4: By 2021, implement research aimed at assessing the human dimensions of natural resource management decisions.

Strategy E2: Utilize adaptive management, including coordinated, area-wide monitoring programs, as an integrated part of Delta conservation to assess progress and status and trends of resources of interest.

- OBJECTIVE E2-1: By 2018, implement actions outlined by the AMP and California *EcoRestore* Adaptive Management Program, and coordinated monitoring programs such as the Tidal Wetland Monitoring Framework.[43]

Strategy E3: Develop resources and recommended best practices to maintain or increase ecosystem and wildlife resiliency to projected climate change effects.

- OBJECTIVE E3-1: By 2019, develop a suite of recommended best practices to maintain or increase ecosystem and wildlife resiliency to projected climate change effects in the Delta.
- OBJECTIVE E3-2: Identify practices that will achieve, and maximize, both climate adaptation and carbon sequestration benefits in tidal wetlands and managed wetlands in the Delta.
- OBJECTIVE E3-3: By 2022, implement and evaluate the effectiveness of best practices to maintain or increase ecosystem and wildlife resiliency to projected climate change effects, including sea-level rise, salinity intrusion, precipitation and temperature changes, and extreme weather events.

Addressing Priority Science Actions and Needs to Inform Delta Conservation

Efforts to restore ecological processes and recover ecosystem functions in the Delta are accelerating in response to declining native species populations and reduced ecosystem health.[18,44] Improving habitat conditions for threatened and endangered species and native wildlife communities also provides beneficial ecosystem services to humans.[45] Advanced scientific tools and methods are needed to plan and implement projects in an integrated, consistent, and systematic way and to improve implementation of adaptive management over the long term.

Delta Smelt and Sacramento Valley Salmon Resiliency Strategies

The CSAMP will coordinate a research program to investigate to what extent increased Delta outflow can positively affect environmental drivers and habitat attributes important to Delta smelt resiliency.[46] The CSAMP will determine the appropriate research method relative to the management actions in the Delta Smelt Resiliency Strategy (details in Section III) individually and synergistically, and will also oversee implementation and synthesis of results to inform subsequent management actions. The Sacramento Valley Salmon Resiliency Strategy implementing entities will consult with and report to CSAMP regarding designs for research, monitoring, and evaluation to assess action performance, review of proposed research or monitoring proposed by others, and progress reporting.[47]

The management needs outlined in the SAA are focused on landscape-scale practices to evaluate the functionality of restored areas, conduct effective planning, and assess potential cumulative effects. Priority science actions to address these management needs include: 1) developing methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve; and 2) estimating and assessing the system-wide effects of location and sequence of tidal marsh habitat restoration projects in regions where the sea level is rising and climate is changing. In addition to developing tools, a suite of existing tools can be used to address science needs.[21] In an emerging effort, the Resource Management Associates (RMA) Bay-Delta model is currently being applied by DWR to assess various implementation scenarios for planned tidal restoration sites in the Delta, to assess how each may affect system-wide salinity distribution (see text box, page IV-17). This modeling effort has the potential to evaluate cumulative effects of projects on system-wide function and the interactions between projects, as well as which projects to implement, potential design modifications, mitigation options, and best phasing of projects.[48,49]

EXISTING TOOLS include:

DSM2—a modeling package for analysis of complex hydrodynamic, water quality, and ecological conditions in riverine and estuarine systems[50,51]

RMA Bay Delta Model developed by Resource Management Associates[51]

Pilot study results from the Fish Restoration Program Monitoring Team[52,53]

LANDSCAPE SCALE SALINITY MODELING

To ensure consistency with other restoration goals within the Bay-Delta, the DWR Fish Restoration Program has funded a modeling effort to assess cumulative salinity changes in the Delta and Suisun Marsh attributable to planned restoration projects. Additionally, this modeling effort aims to assess changes in tidal prism throughout the Delta and Suisun Marsh as restoration projects are implemented. DWR intends to work collaboratively with other tidal restoration practitioners throughout the Delta and Suisun Marsh in utilizing this common modeling framework in order to better understand how collective restoration efforts are impacting salinity and the tidal prism on a system-wide scale. Initial work on model calibration has been completed, and scenario development is ongoing, with a study report expected in 2018. As this modeling effort develops, further information will be available at http://www.water.ca.gov/environmentalservices/frpa.cfm and http://resources.ca.gov/ecorestore/.

[Source: E. Loboschefsky, DWR]

RMA BAY-DELTA MODEL

The RMA Bay-Delta model is a well-established tool for analysis of the hydrodynamic and water quality impacts of proposed projects in the San Francisco Bay and Sacramento-San Joaquin Delta.[48]

The RMA Bay-Delta Model was one of the primary tools used for the Bay Delta Conservation Plan evaluation of tidal marsh restoration and has been used extensively in the development of the Suisun Marsh Programmatic Environmental Impact Report/Environmental Impact Statement.

Since 1996, the model has been used for analysis of:

- Wastewater discharges, including dilution, dissolved copper and nickel, coliform, pathogens, and nutrients
- Levee failures (from single breaches to seismically induced Delta-wide failures), their impact on water quality and Delta operations, and the effectiveness of emergency response measures
- Tidal marsh restoration projects and their impact on hydrodynamics, tidal mixing, and water quality in the Delta
- Hydrodynamic and water quality impacts of Delta Cross Channel reoperation and installation of various gates and barriers throughout the Delta
- Fish behavior based on flow, salinity, and turbidity conditions
- Flood events
- Drought conditions
- Nutrients and temperature
- SLR

Measuring Conservation Status and Progress

In order to evaluate progress of conservation projects or programs it is necessary to determine baseline ecosystem conditions, quantify the efficacy of conservation actions, and assess progress towards landscape-scale goals and objectives. Adaptive management allows for the accumulation and incorporation of knowledge in order to reduce uncertainty and to provide a structured approach to management and decision-making.[54] Adaptive management is well suited for situations where there is potential to learn; costs, benefits, and risks can be balanced quantitatively; it is possible to incorporate learned information into management practices without causing irreversible effects on the system; and there is sufficient buy-in from stakeholders.[9] Adaptive management is necessary in complex, nonlinear systems, or systems that change rapidly, where there is considerable uncertainty about the outcomes of conservation or management actions.[9] As a science-based, flexible approach to resource management decision-making, adaptive management programs, when properly designed and executed, provide the capability to make and implement decisions while simultaneously conducting research to reduce the ecological uncertainty of a decision's outcome (see Strategy E2, Table 4.1).[55] This approach also facilitates resource management that is transparent, collaborative, and responsive to changes in scientific understanding.

Adaptive management involves a series of cyclical steps that include: defining the problem; establishing measurable goals and objectives; modeling linkages between objectives and proposed actions; selecting actions and related performance measures; designing and implementing actions and developing an associated monitoring plan; analyzing, synthesizing, and evaluating new data; disseminating learned information; and adapting practices to incorporate what was learned.[9] Adaptive management should be directly integrated into goals and objectives of conservation planning efforts and program/project budgets, as appropriate, given the high level of uncertainty of desired outcomes in the Delta.

Adaptive Management Program for California WaterFix *and Current Biological Opinions on the Coordinated Operations of the Central Valley and State Water Projects*

The Delta Reform Act of 2009 identified adaptive management as the desired approach to reduce ecological uncertainty related to the management of the Sacramento-San Joaquin Delta ecosystems. The federal and state water operations agencies (Reclamation and DWR) and the state and federal fisheries agencies (USFWS, NMFS, and CDFW) (collectively, the Five Agencies) are in agreement that adaptive management is the tactic best suited to advance the management of the Delta and its resources.[55] Under the AMP, the Five Agencies commit to ongoing adaptive management under the current BiOps of the combined operations of the CVP and SWP, as well as the effects of future operations under California *WaterFix*.[55] The aim is to decrease uncertainty and improve the performance of CVP and SWP water operations in protecting listed species. To do this, significant new investments in related research, monitoring, and modeling are needed, with the understanding that all efforts (existing and new) will build on each other. A new Interagency Implementation and Coordination Group (IICG) will be formed to coordinate recommendations and the making of decisions on those recommendations.

Together, the IICG and Five Agencies are referred to as the Implementing Entities for the AMP. For all adaptive management changes affecting Delta operations and other adaptive management changes outside the Delta otherwise agreed upon by the IICG, the IICG will make its recommendations to the Five Agencies for a decision by the agency or agencies with final decision-making authority. Except those addressed by the IICG, adaptive management changes that do not affect operations in the Delta will generally be implemented by the Five Agencies. The Five Agencies are developing the AMP to evaluate and inform decisions about Delta water operations and the implementation of the California *WaterFix* initiative.[55] This AMP will also integrate with existing adaptive management plans or programs that are more focused on specific conservation goals or regions within the Delta. The gaps between the few existing adaptive management programs, and inefficiencies associated with having multiple, distinct adaptive management programs, will be addressed by the AMP with the ultimate aim to effectively manage Delta ecosystems on a landscape scale (as recommended in the Delta Plan).[56]

California EcoRestore Adaptive Management Program

Concurrent with the AMP effort, the Interagency Adaptive Management Integration Team formed in 2016 to provide technical and scientific recommendations on how a habitat restoration adaptive management program for the Delta and Suisun Marsh can be developed and implemented, with an initial focus on providing support to the current suite of California *EcoRestore* projects.[57] Once implemented, the California *EcoRestore* Adaptive Management Program will also align with the AMP and will further advance system-wide monitoring to inform conservation progress and decision-making.

The Delta Conservation Framework goals, strategies, and objectives are intended to guide the initiation of projects beyond the current *EcoRestore* projects[18] that are supported by the *WaterFix* AMP and the California *EcoRestore* Adaptive Management Program. New projects will go beyond mitigation-related aquatic habitat concerns and will include the Delta's transitional and terrestrial ecosystems and the human dimension of conservation issues. These new projects should incorporate hydrologic and ecological connections to a larger, landscape-scale conservation network (e.g., projects situated upstream or downstream of current *EcoRestore* projects).

To continue effective adaptive management over the long term, adaptive management actions must inform and integrate into the planning and implementation of *Regional Conservation Strategies,* or similar bottom-up collaborative partnership approaches. *Regional Conservation Partnerships* should use adaptive management to test best management practices for projects designed to benefit Delta ecosystems and for multi-benefit projects linked to Delta agriculture and communities. This means that adaptive management will also evaluate objectives focused on evaluating best management practices and multi-benefit outcomes of individual or suites of projects. In addition, the *Review of Research on the Sacramento-San Joaquin Delta as an Evolving Place* by the Delta Independent Science Board[58] and the Delta Science Program Science Action Agenda[19] acknowledged that more research and interdisciplinary science is needed to inform decisions on when, where, and how adaptive management can be integrated into larger planning, design, and management frameworks.

IEP Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary

The IEP's Tidal Wetlands Monitoring Project Work Team developed a 2016 Tidal Wetland Monitoring Framework (TWMF) for the Upper San Francisco Estuary.[43] This monitoring framework will be used to develop scientifically sound, project-specific plans to monitor the effectiveness of tidal wetland restoration in providing benefits to at-risk Delta fish species.[43] The TWMF contains hypotheses, conceptual models, metrics, and sampling methods that have been developed and vetted by a multi-disciplinary team of scientists.

The TWMF is specifically focused on evaluating benefits to special status fish species from the restoration of tidal wetlands, and it serves as a model for preparing similar frameworks for the assessment of other conservation actions in the Delta. It includes recommendations for data management, analysis, quality assurance, and reporting protocols in order to complete the requisite monitoring plan sections. The TWMF also provides templates and links to data and resources while allowing flexibility in individual monitoring programs, based on project-level objectives and new developments in the best available science, to support adaptive management decision-making.

Resources and Actions to Address Projected Climate Change Effects

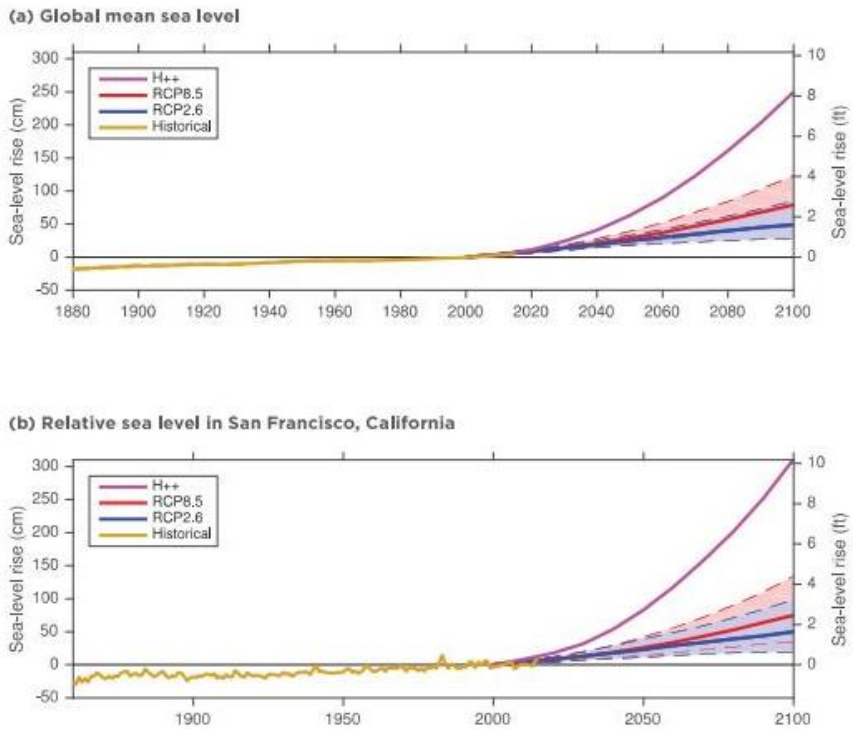
Climate change is already affecting California ecosystems, biodiversity, and agricultural land throughout the state.[59,60,61] Case studies have shown that climate change has caused temperature increases, altered hydrology, changed precipitation levels, increased drought-induced water stress and adverse effects on wildlife habitats, and impacted agricultural food production in the Sacramento-San Joaquin Delta (Delta) and Central Valley watersheds.[60] Resources and best practices are needed to maintain or increase ecosystem and wildlife resiliency to projected climate change effects (see Strategy E3, Table 4.1)

> ***A "Representative Concentration Pathway" (RCP) represents a greenhouse gas (GHG) concentration trajectory, adopted by the Intergovernmental Panel on Climate Change (IPCC). The IPCC recognizes four RPCs, or projected scenarios, for climate change. They are: RCP 2.6 (global annual GHG emissions peak between 2010 and 2020 then decline); RCP 4.5 (emissions peak around 2040 then decline); RCP 6 (emissions peak around 2080 then decline); and RCP 8.5 (emissions continue to rise throughout the 21st Century). RCP 8.5 is the scenario with the highest amount of human-generated emissions.[62]***

Climate change impacts will continue to increase over time in coastal and estuarine systems, including the Delta.[15,63] During the next century, California winters will likely become wetter and warmer, with more extreme weather events earlier or later in the season, reduced snow packs in the Sierra Nevada, earlier snowmelt with most precipitation falling as winter rain, and increases in run-off quantity and velocity during storm events.[15,63,64] Accordingly, summers will be longer, hotter, and drier. When combined with reduced river flows, this will likely result in warmer summer water temperatures, water-quality changes, and considerable increases in water demand by people and wildlife.[63,64] The Delta region is expected to experience more intense winter flooding and storm events, causing greater erosion of riparian areas and increased sedimentation in wetlands.[15,65,66,67] In the summer, lower river flows will increase the likelihood of saltwater intrusion farther upstream in the Delta, disrupting ecosystem processes, food webs, agriculture, and local water supplies.[15,63]

SLR is projected to increase between 0.22-1.5 meters (0.72-5 feet) in the 20th century, or even to as high as three meters (10 feet) in this century.[15, 67,68] SLR combined with more extreme storm events and tidal action will put additional pressures on Delta levees.[69] Assuming a 1.5-meter SLR by 2050 under the RCP 8.5 scenario (consistent with a future in which there are no significant global efforts to limit or reduce emissions),[68,70] it is anticipated that the acreage of flood prone land (during a 100-year flood event) in Solano County will increase from 15,241 to 69,877 acres. In Contra Costa County, flood-prone land is expected to increase from 847 to 8,607 acres;[67,71,72] and in Sacramento County, it is estimated to increase from 171.4 to 411 acres ("Bathtub Model").[67] An additional climate scenario (H++; see Figure below), that incorporates the likelihood of extreme SLR of up to 10 feet in San Francisco by 2100 (see Figure 4.3), should be considered alongside the probability distributions for RCPs 2.6, 4.5, and 8.5.[68,70] At this point, however, it is scientifically premature to estimate the probability that the H++ scenario will come to pass and, if so, when the world will move onto the H++ trajectory.[68]

Figure 4.3: Projections of (a) Global mean sea level, and (b) Relative sea level in San Francisco, CA. Source: Griggs et al 2017[68]



Climate change is anticipated to influence a wide variety of factors in the Delta, including:

Distribution of Delta Ecosystems: The location, extent, and composition of Delta ecosystems currently at or below sea level will change as a result of increased water elevation, increased saltwater intrusion, and shifts in the tidal hydrologic system. Tidal wetland ecosystems at the water's edge will become more deeply inundated, unless they have the capacity to keep up through accretion (accumulating additional layers of sediment) and "migrate" upslope if there are adjacent uplands. Those wetlands protected by levees will be submerged if levees are overtopped unless strategies are implemented to raise the elevations. Salt marsh and freshwater marsh are among the natural communities most highly exposed and vulnerable to climate change.[73] The Delta also supports many species that have been identified as climate vulnerable such as the Alameda song sparrow (*Melospiza melodia pusillula*), California Ridgway's rail (*Rallus longirostris obsoletus)*, salt marsh harvest mouse (*Reithrodontomys raviventris*), Delta smelt, and more.[74,75,76,77] Wildlife population level fluctuations will occur at different rates, because individual species will respond to changes in ecosystems differently. While some species will adapt in place, others will move to more suitable areas or become extirpated (locally extinct).[78]

Flood risk: SLR, increased tides and winter river flows, and more intense winter storms will significantly increase the hydraulic pressure on levees in areas where current farming practices continue and subsidence increases over time. If key levees collapse during a storm or seismic event, it could lead to catastrophic seawater intrusions and flooding throughout the Delta.[3] Portions of the Suisun Marsh are particularly vulnerable to these anticipated stressors and tidal marsh drowning.[67]

"X2" is the point identified by the distance from the Golden Gate Bridge where salinity at the river's bottom is about 2 parts per thousand, which serves as the basis of protection standards for aquatic organisms.[79]

Water quality: Changes in the timing and volume of flows and increased sea-level projections make it possible the Delta will experience higher salinities if X2 moves more into the central Delta, and seepage of saline water could occur into subsided areas .[80] Similarly, due to climate change, stream temperatures throughout the region could increase.[64] For example, projections for estuarine inflows in October through February are expected to be 20 percent higher on average and decrease about 20 percent from March through September.[64]

Average temperature and precipitation: The Delta region (including portions of Contra Costa, Sacramento, San Joaquin, Solano, and Yolo counties) is expected to experience increases in average temperatures. January average temperatures are expected to increase by 4.5-4.9 °F by 2070; average July temperatures are projected to increase by 6.6-6.9 °F by 2070.[67] Annual mean precipitation is expected to increase in Solano County (from 19.4 to 25.4 inches), Contra Costa County (from 18.4 to 23.1 inches), Yolo County (from 19.4 to 25.1 inches), Sacramento County (from 18.4 to 22.2 inches), and San Joaquin County (from 13.8 to 16.8 inches) by 2100 (RCP 8.5 emission scenario).[67] Upland areas of the Delta, including portions of Contra Costa, San Joaquin, and Sacramento counties, are also projected to experience limited increases in wildfire.[67]

Ecosystem services: The phenology of animal migration, plant budding, or insect emergence is expected to shift in response to increased temperatures. For example, shifts in phenology that cause plants and pollinators to be out of sync could disrupt the timing of pollination and drastically affect the production of natural and agricultural plants. The ecological functionality of transition zones and upland ecosystems are also likely to be disrupted.

Looking ahead, it is critical to incorporate projected long-term changes into Delta conservation planning by developing actions that integrate Delta climate change adaptation into ongoing management practices and identify the resources needed. By improving resiliency within the Delta landscape, conservation can provide insurance to sustaining wildlife and ecosystems in the form of redundancy, interconnectivity, diversity and complexity of landscape features, appropriate spatial and temporal scales, and human stewardship.[78]

The ongoing need to maintain water supply reliability for human use, and impending climate change impacts, will continue to put pressures on Delta ecosystems, levee systems, and agricultural operations.[40] To adapt to global climate change at the regional scale, novel practices affecting regionally integrated management of water, energy, food, and related ecosystem processes over the long term will be essential.[60] Science and policy support for interdisciplinary research, development of databases, tools, addressing ecosystem service complexity, and the coordination of related natural resource investments and integrated planning needs will be critical to successfully build integrated model applications that help to evaluate multiple benefits and trade-offs across ecosystem service types.[60] Due to the inherent uncertainties associated with climate change, it is important to examine a range of scenarios that considers various tradeoffs and triage when planning for conservation and long-term sustainability. This type of scenario evaluation will be essential for science-based decision-making that informs coordinated management strategies over the long term.

The **Landscape Resiliency Framework** *developed by SFEI describes seven principles for developing landscape resiliency to climate change and other stressors. Of these,* ***Connectivity*** *provides linkages between habitats, processes, and populations that enable movement of material and organisms;* ***Diversity and Complexity*** *of landscape features—such as variety, distribution, and spatial characteristics—provide a range of options for species adaptations;* ***Redundancy*** *provides multiple habitat elements or functions that provide insurance against some loss; and* ***Scale*** *considers the spatial extent and time frame at which landscapes operate to provide persistence of species, biological processes, and ecological functions. Landscape resiliency is dependent upon the biophysical, biological, and cultural* ***Setting*** *of the landscape; the physical, biological, and chemical* ***Processes*** *that create and sustain landscapes over time; as well as the shaping or stewardship of the landscape by* ***People***[78].

Endnotes

[1] Brown, L. R., W. Kimmerer, J. L. Conrad, S. Lesmeister, and A. Mueller–Solger (2016). Food webs of the Delta, Suisun Bay, and Suisun Marsh: An update on current understanding and possibilities for management. San Francisco Estuary and Watershed Science, 14(3). Available: http://escholarship.org/uc/item/4mk5326r.

[2] Brown, L. R., W. A. Bennett, R. W. Wagner, T. Morgan-King, N. Knowles, F. Feyrer, D. H. Schoellhamer, M. T. Stacey and M. Dettinger (2013). Implications for future survival of Delta smelt from four climate change scenarios for the Sacramento-San Joaquin Delta, California. Estuaries and Coasts 36: 754–774.

[3] Luoma, S. N., C. N. Dahm, M. Healey, J. M. Moore (2015). Challenges facing the Sacramento-San Joaquin Delta: Complex, chaotic or simply cantankerous? Delta Stewardship Council, Delta Science Program, Sacramento, CA.

[4] USFWS (1999). Draft recovery plan for the giant garter snake (*Thamnophis gigas*). U.S. Fish and Wildlife Service, Region 1 (USFWS), Portland, OR.

[5] USFWS (2004). 5-Year review: Delta smelt (*Hypomesus transpacificus*). U.S. Fish and Wildlife Service (USFWS), Sacramento, CA.

[6] USFWS (2008). Formal Endangered Species Act consultation and biological opinion: proposed coordinated operations of the Central Valley Project (CVP) and State Water Project (SWP). Memorandum 81420-2008-F-1418-5. U.S. Fish and Wildlife Service, California and Nevada Region (USFWS), Sacramento, CA.

[7] USFWS (2013). Recovery plan for tidal marsh ecosystems of northern and central California. U.S. Fish and Wildlife Service, Region 8 (USFWS), Sacramento, CA.

[8] Delta Science Program (2016). The Delta on fast forward – Thinking beyond the next crisis - perspectives of the state of the Bay-Delta science. Delta Stewardship Council, Sacramento, CA. Available: http://deltacouncil.ca.gov/docs/delta-fast-forward-thinking-beyond-next-crisis. Accessed: April 2017.

[9] Lund, J. E., S. Brandt, T. Collier, B. Atwater, E. Canuel, H. J. S. Fernando, R. Noorgard, V. Resh, J. Wiens, and J. Zedler (2016). Improving adaptive management in the Sacramento-San Joaquin Delta - A review by the Delta Independent Science Board. Delta Stewardship Council, Sacramento, CA. Available: http://deltacouncil.ca.gov/docs/final-delta-isb-adaptive-management-review-report. Accessed: April 2017.

[10] Davenport, J. (2014). Restoring habitat with science and society in mind – Issue paper. Delta Stewardship Council, Sacramento, CA. Available: http://deltacouncil.ca.gov/sites/default/files/documents/files/14-0923%20Ecosystem%20issue%20paper%20Final.pdf. Accessed: April 2017.

[11] Auffret, A. G., J. Plue, and S. A. O. Cousins (2015). The spatial and temporal components of functional connectivity in fragmented landscapes. Ambio 44: 51-59. Available: https://link.springer.com/article/10.1007%2Fs13280-014-0588-6. Accessed: September 15, 2017.

[12] Crooks K. R., M. Sanjayan (2006). Connectivity conservation. Cambridge University Press, Cambridge, U.K.

[13] Robinson, A., S. Safran, J. Beagle, L. Grenier, R. Grossinger, E. Spotswood, S. Dusterhoff, and A. Richey (2016). A Delta Renewed: A guide to science-based ecological restoration in the Sacramento-San Joaquin Delta, a report for the Delta Landscapes Project: Management tools for landscape-scale restoration of ecological functions. Prepared for California Department of Fish and Wildlife, Sacramento, CA. San Francisco Estuary Institute (SFEI) Aquatic Science Center, Richmond, CA. Available: http://www.sfei.org/sites/default/files/project/SFEI_DeltaRenewed_102616_lowres.pdf. Accessed: January 25, 2017.

[14] Robinson, A., S. Safran, J. Beagle, R. Grossinger, L. Grenier, and R. Askevold (2014). A Delta transformed: ecological functions, spatial metrics, and landscape change in the Sacramento-San Joaquin Delta. Prepared for California Department of Fish and Wildlife, Ecosystem Restoration Program, Sacramento, CA. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. Available: http://www.sfei.org/documents/delta-transformed-ecological-functions-spatial-metrics-and-landscape-change-sacramento-san. Accessed: January 26, 2017.

[15] Dettinger, M., J. Anderson, M. Anderson, L. R. Brown, D. Cayan, and E. Maurer (2016). Climate Change and the Delta. San Francisco Estuary and Watershed Science, 14(3). Available: http://escholarship.org/uc/item/2r71j15r.

[16] Moyle, P., W. Bennett, J. Durand, W. Fleenor, B. Gray, E. Hanak, J. Lund, J. Mount (2012). Where the wild things aren't – Making the Delta a better place for native species. Public Policy Institute of California. Available: http://www.ppic.org/content/pubs/report/R_612PMR.pdf. Accessed April 2017.

[17] Hobbs, R. J., S. Arico, J. Aronson, J. S. Baron, P. Bridgewater, V. A. Cramer, P. R. Epstein, J. Ewel, C. A. Klink, A. E. Lugo, D. Norton, D. Ojima, D. M. Richardson, Eric W. Sanderson, F. Valladares, M. Vilà, R. Zamora, and M. Zobel (2006). Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography 15: 1–7.

[18] Natural Resources Agency (2017). What is California EcoRestore? California Natural Resources Agency, Sacramento, CA. Available: http://resources.ca.gov/ecorestore/what-is-california-ecorestore/. Accessed: January 26, 2017.

[19] Delta Science Program (2017). Draft Delta Science Action Agenda. Available: http://deltacouncil.ca.gov/science-program/2017-2021-science-action-agenda. Accessed: April 2017.

[20] Delta Science Program (2013). Delta Science Plan. Available: http://deltacouncil.ca.gov/science-program/delta-science-plan-0. Accessed: April 2017.

[21] IEP (2016). Interagency Ecological Program Science Agenda – Needs for near-term science in five areas of emphasis. Interagency Ecological Program (IEP), California Department of Water Resources. Available: http://www.water.ca.gov/iep/docs/2016_IEP_Science_Agenda_FINAL.pdf. Accessed: May 2017.

[22] Delta Stewardship Council (2017). State of Bay-Delta Science 2016. Delta Stewardship Council, Sacramento, CA. Available: http://deltacouncil.ca.gov/science-program/state-bay-delta-science-2016. Accessed: July 19, 2017.

[23] Connor, Valerie (2013). Leading Change: The Collaborative Science and Adaptive Management Program. *San Francisco Estuary and Watershed Science*, 11(3). Available: http://escholarship.org/uc/item/0b90d3p8. Accessed: May 2017.

[24] CAMT (2016). Calendar Year 2015 Annual Progress Report to the Collaborative Science Policy Group. The Collaborative Adaptive Management Team (CAMT), California Department of Water Resources, Sacramento, CA. Available: http://www.water.ca.gov/environmentalservices/csamp/docs/camt_2015_annual_progress_report_final_3-15-16.pdf. Accessed: May 2017.

[25] SFCWA (2012). Home. State and Federal Contractors Water Agency (SFCWA). Sacramento, CA. Available: http://www.sfcwa.org/. Accessed: May 2017.

[26] SFCWA (2014). Science Research Plan. State and Federal Contractors Water Agency (SFCWA). Sacramento, CA. Available: http://www.sfcwa.org/wp-content/uploads/Feb-2014-Final-SFCWA-Science-Research-Plan.pdf. Accessed: May 2017.

[27] IEP (2017). Interagency Ecological Program – About the IEP. Interagency Ecological Program (IEP), California Department of Water Resources. Available: http://www.water.ca.gov/iep/about/aboutiep.cfm. Accessed: April 2017.

[28] IEP (2014). Interagency Ecological Program Strategic Plan. Interagency Ecological Program (IEP). Available: http://www.water.ca.gov/iep/docs/IEP_Strategic_Plan102214.pdf. Accessed: May 2017.

[29] Hanak, E., C. Phillips, J. Lund, J. Durand, J. Mount, and P. Moyle (2013). Scientist and stakeholder views on the Delta ecosystem. Public Policy Institute of California. Available: http://www.ppic.org/content/pubs/report/R_413EHR.pdf. Accessed: July 19, 2017

[30] Whipple, A., R. Grossinger, D. Rankin, B. Stanford, and R. Askevold (2012). Sacramento-San Joaquin Delta historical ecology investigation: Exploring pattern and process. Prepared for the California Department of Fish and Game Ecosystem Restoration Program, Sacramento, CA. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

[31] UC Davis (2017). Welcome to the Center for Watershed Sciences. University of California, Davis, Center for Watershed Sciences, Davis, CA. Available: https://watershed.ucdavis.edu/. Accessed: July 19, 2017

[32] PPIC (2017). About PPIC. Public Policy Institute of California. Sacramento, CA. Available: http://www.ppic.org/about-ppic/. Accessed: April 2017.

[33] Delta Science Program (2017). Interim Science Action Agenda. Available: http://deltacouncil.ca.gov/interim-science-action-agenda. Accessed: September 18, 2017.

[34] Milligan, B. and A. Kraus-Polk (2016). Human use of restored and naturalized delta landscapes. Department of Human Ecology, Landscape Architecture Unit, University of California, Davis. Available:

https://watershed.ucdavis.edu/files/biblio/Human%20Use%20Report_for%20screen%20viewing%20%28spreads%29.compressed.pdf.

[35] Schoemaker, P. J. H. (1995). Scenario planning: A tool for strategic thinking - MIT Sloan management review Available: http://sloanreview.mit.edu/article/scenario-planning-a-tool-for-strategic-thinking/. Accessed: April 2017.

[36] Conservation Measures Partnership (2017). Open standards for the practice of conservation – Guidance. Available: http://cmp-openstandards.org/using-os/guidance/. Accessed: Janaury 28, 2017.

[37] USFWS (2008). Structured Decision Making fact sheet. In CSP3171 Introduction to Structured Decision Making. Available: https://www.fws.gov/science/doc/structured_decision_making_factsheet.pdf. Accessed: September 18, 2017.

[38] Berg M. and M. Sutula (2015). Factors affecting the growth of cyanobacteria with special emphasis on the Sacramento-San Joaquin Delta. Technical Report 869. Southern California Coastal Water Research Project, Costa Mesa, CA. Available: http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/869_FactorsAffectGrowthOfCyanobacteria-1.pdf. Accessed: April 2017.

[39] Andersen, T. (2014). Water hyacinth thrives in drought stricken Delta. Bay Nature. Available: https://baynature.org/article/water-hyacinth-thrives-drought-stricken-delta/. Accessed: April 2017.

[40] Cloern, J. E., N. Knowles, L. R. Brown, D. Cayan, M. D. Dettinger, T. L. Morgan, D. H. Schoellhamer, M. T. Stacey, M. van der Wegen, R. W. Wagner, and A. D. Jassby (2011). Projected evolution of California's San Francisco Bay-Delta river system in a century of climate change. Plos One. 6: 1-13.

[41] Lehman, P. W., T. Kurobe, S. Lesmeister, D. Baxa, A. Tung, and S. J. Teh (2017). Impacts of the 2014 severe drought on the *Microcystis* bloom in San Francisco Estuary. Harmful Algae 63:94-108.

[42] Cloern, J. E., A. Robinson, A. Richey, L. Grenier, R. Grossinger, K. E. Boyer, J. Burau, E. A. Canuel, J. F. DeGeorge, J. Z. Drexler, C. Enright, E. R. Howe, R. Kneib, A. Mueller-Solger, R. J. Naiman, J. L. Pinckney, S. M. Safran, D. Schoellhamer, and C. Simenstad (2016). Primary Production in the Delta: Then and now. San Francisco Estuary and Watershed Science, 14(3). Available: http://escholarship.org/uc/item/8fq0n5gx. Accessed: September 18, 2017.

[43] IEP (2017). Tidal Wetland Monitoring Framework for the upper San Francisco Estuary – Volume I: Monitoring plan guidance – Version 1.0. Interagency Ecological Program, Tidal Wetland Monitoring Project Work Team (IEP), Sacramento, CA. Available: http://www.water.ca.gov/iep/docs/tidal_wetland_monitoring_framework_upper_sfe_v1.pdf. Accessed: September 18, 2017.

[44] Natural Resources Agency (2015). Restoring the Sacramento-San Joaquin Delta Ecosystem. California Natural Resources Agency, Sacramento, CA. Available: http://resources.ca.gov/docs/ecorestore/ECO_FS_Overview.pdf. Accessed June 10, 2016.

[45] Daily, G. C., S. Alexander, P. R. Ehrlich, L. Goulder, J. Lubchenco, P. A. Matson, H. A. Mooney, S. Postel, S. H. Schneider, D. Tilman, G. M. Woodwell (1997). Ecosystem services: Benefits supplied to human societies by natural ecosystems. Issues in Ecology (2). Available: https://www.esa.org/esa/wp-content/uploads/2013/03/issue2.pdf. Accessed: April 2017.

[46] Natural Resources Agency (2016). Delta Smelt Resiliency Strategy. Natural Resources Agency, Sacramento, CA. Available: http://resources.ca.gov/docs/Delta-Smelt-Resiliency-Strategy-FINAL070816.pdf. Accessed: April 2017.

[47] Natural Resources Agency (2017). Sacramento Valley Salmon Resiliency Strategy. California Natural Resources Agency, Sacramento, CA. Available: http://resources.ca.gov/docs/Salmon-Resiliency-Strategy.pdf. Accessed: June 2017.

[48] RMA (2017). RMA Bay-Delta Model. Resource Management Associates, Davis, CA. Available: http://www.rmanet.com/services/numerical-modeling/rma-bay-delta-model/. Accessed May 2017.

[49] RMA (2017). Featured projects - Modeling. Resource Management Associates, Davis, CA. Available: http://www.rmanet.com/projects/modeling/suisun-marsh-levee-breach/. Accessed May 2017.

[50] DWR (2017). Delta Simulation Model II - DSM2. California Department of Water Resources (DWR), Sacramento, CA. Available: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm. Accessed: May 2017.

[51] CALFED (2007). Conceptual Model for Salinity in the Central Valley and Sacramento-San Joaquin Delta. CALFED Bay-Delta Program, Sacramento, CA. Available: http://www.waterboards.ca.gov/centralvalley/water_issues/drinking_water_policy/salinity_conceptual_model/pgs39_55.pdf. Accessed: May 2017.

[52] FRP (2017). Pilot Study Phase II: Results from 2016 gear evaluation in the north Delta. Fish Restoration Program (FRP) Monitoring Team, California Department of Fish and Wildlife (CDFW), Stockton, CA. Available: http://www.water.ca.gov/environmentalservices/docs/frpa/pilot_phase_II_report_FINAL_3MAY2017.pdf. Accessed: May 2017.

[53] FRP (2016). Annual Report (January – December 2015). Fish Restoration Program (FRP). California Department of Fish and Wildlife and California Department of Water Resources, Sacramento, CA. Available: http://www.dwr.water.ca.gov/environmentalservices/docs/frpa/frp_annual_report_2015_final_2016_0427.pdf. Accessed: December 6, 2016.

[54] Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, D. Ohlson (2012). Structured decision making: A practical guide to environmental management Choices. Wiley Online Library. Available: http://onlinelibrary.wiley.com/book/10.1002/9781444398557. Accessed: April 2017.

[55] Natural Resources Agency (2016). Adaptive Management Program for the California Water Fix and Current Biological Opinions on the coordinated operations of the Central Valley and State Water Projects. Available: http://cms.capitoltechsolutions.com/ClientData/CaliforniaWaterFix/uploads/CWF_BOs_AM_Framework__072116.pdf. Accessed: April 2017.

[56] Delta Stewardship Council (2013). The Delta Plan: Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value. Delta Stewardship Council, Sacramento, CA. Available: http://deltacouncil.ca.gov/delta-plan-0. Accessed: June 23, 2016.

[57] IAMIT (2017). EcoRestore Adaptive Management Program white paper. Interagency Adaptive Management Team (IAMIT). Available: http://resources.ca.gov/ecorestore/wp-content/uploads/2017/04/2017-3-8-EcoRestore-Adaptive-Management-Program-White-Paper-v3-7-2017.pdf. Accessed April 2017.

[58] DISB (2017). Review of research on the Sacramento-San Joaquin Delta as an evolving place – A review by the Delta Independent Science Board. Delta Independent Science Board. Available: http://deltacouncil.ca.gov/sites/default/files/2017/05/17-0509_Delta_as_a_Place_Final1.pdf. Accessed: September 18, 2017.

[59] IPCC (2014). Climate change 2014: Synthesis report. Intergovernmental Panel on Climate Change (IPCC). Available: http://www.globalchange.gov/browse/reports/ipcc-climate-change-2014-synthesis-report. Accessed: April 2017

[60] Liu, Qinqin (2016). Interlinking climate change with water energy-food nexus and related ecosystem processes in California case studies. Ecological Processes 5:1-14.

[61] OEHHA (2013). Indicators of climate change in California. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA), Sacramento, CA. Available: https://oehha.ca.gov/media/downloads/risk-assessment/document/climatechangeindicatorsreport2013.pdf. Accessed: September 18, 2017.

[62] Meinshausen, M., S. J. Smith, K. Calvin, J. S. Daniel, M. L. T. Kainuma, J-F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. Thomson, G. J. M. Velders, and D. P. P. van Vuuren. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climate Change 109:213-241.

[63] Natural Resources Agency (2014). Safeguarding California: Reducing climate risk. An update to the 2009 California Climate Change Adaptation Strategy. California Natural Resources Agency, Sacramento, CA. Available: http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf. Accessed: April 2017.

[64] PRBO (2011). Projected effects of climate change in California: Ecoregional summaries emphasizing consequences for wildlife. Point Blue Conservation Science, Petaluma, CA. Available: http://data.prbo.org/apps/bssc/uploads/Ecoregional021011.pdf. Accessed: April 2017.

[65] Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville (2004). Emissions pathways, climate change, and impacts on California. PNAS 101: 12422–12427. Available: http://www.pnas.org/content/101/34/12422.full.pdf. Accessed: April 2017.

[66] Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe (2007). Climate change scenarios for the California region. Climate Change. Available: http://meteora.ucsd.edu/cap/pdffiles/Cayan_calif_scen_jan2008.pdf. Accessed: April 2017.

[67] Cal-Adapt (2017). Exploring California's climate change research. Cal-Adapt, Berkeley, CA. Available: http://beta.cal-adapt.org/. Accessed: April 2017.

[68] Griggs, G., J. Árvai, D. Cayan, R. DeConto, J. Fox, H. A .Fricker, R. E. Kopp, C. Tebaldi, and E. A. Whiteman (2017). Rising seas in California: An update on sea-level rise science. California Ocean Science Trust, California Ocean Protection Council, Science Advisory Team Working Group. Available: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf. Accessed: April 2017.

[69] DWR (2016). Central Valley Flood Protection Plan Conservation Strategy. California Department of Water Resources (DWR), Sacramento, CA. Available: http://www.water.ca.gov/conservationstrategy/docs/cs_draft.pdf. Accessed January 25, 2017.

[70] Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future 2: 383–406.

[71] USGS (2015). CoSMoS 2.1: San Francisco Bay. U.S. Geological Survey, Pacific Coastal and Marine Science Center (USGS), Santa Cruz, CA. Available: https://walrus.wr.usgs.gov/coastal_processes/cosmos/sfbay/index.html. Accessed: April 2017.

[72] OCOF (2017). Interactive Flood Map. Our Coast Our Future (OCOF). Available: http://data.pointblue.org/apps/ocof/cms/index.php?page=flood-map. Accessed: April 2017

[73] Thorne, J. H., R. M. Boynton, A. J. Holguin, J. A. E. Stewart, and J. Bjorkman (2016). A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife, Sacramento, CA. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=116208&inline.

[74] CDFW (2015). California State Wildlife Action Plan, 2015 update: A conservation legacy for Californians. California Department of Fish and Wildlife (CDFW) and Ascent Environmental, Inc., Sacramento, CA. A. Gonzales and J. Hoshi, editors.

[75] Stewart J. A. E., J. H. Thorne, M. Gogol-Prokurat, and S. D. Osborn (2016). A climate change vulnerability assessment for twenty California mammal taxa. Prepared for California Department of Fish and Wildlife, Sacramento, CA. University of California, Davis, Information Center for the Environment, Davis, CA. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=135825&inline. Accessed: September 18, 2017.

[76] Moyle, P. B., J. D. Kiernan, P. K. Crain, and M. Quiñones (2012). Projected effects of future climates on freshwater fishes of California. Prepared for the California Energy Commission, Sacramento, CA. University of California, Davis. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=141384&inline. Accessed: September 18, 2017.

[77] Gardali T., N. E. Seavy, R. T. DiGaudio, L. A. Comrack (2012). A climate change vulnerability assessment of California's at-risk birds. PLoS ONE 7(3): e29507. Available: https://doi.org/10.1371/journal.pone.0029507. Accessed: September 18, 2017.

[78] Beller, E., A. Robinson, R. Grossinger and L. Grenier (2015). Landscape resilience framework: Operationalizing ecological resilience at the landscape scale. SFEI publication #752. Prepared for Google Ecology Program, Mountain View, CA. San Francisco Estuary Institute (SFEI), Richmond, CA. Available: http://resilientsv.sfei.org/sites/default/files/general_content/SFEI_2015_Landscape%20Resilience%20Framework.pdf. Accessed: June 29, 2016.

[79] Bowles, J. (2014). Finding the right balance: Managing Delta salinity in drought. In Western Water. Water Education Foundation, Sacramento, CA. Available: http://www.watereducation.org/western-water-excerpt/finding-right-balance-managing-delta-salinity-drought. Accessed: July 19, 2017.

[80] USGS (2000). Delta Subsidence in California - The sinking heart of the State. U.S. Geological Survey (USGS). Available: https://pubs.usgs.gov/fs/2000/fs00500/pdf/fs00500.pdf. Accessed: April 2017.