THE *Baylands* AND *Climate Change*

WHAT WE CAN DO

BAYLANDS ECOSYSTEM HABITAT GOALS
SCIENCE UPDATE 2015

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SCIENCE UPDATE 2015

PREPARED BY
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FOREWORD

Climate change is altering the natural world at an accelerating pace, particularly in low-lying coastal areas like San Francisco Bay. Today management of the bay's shores must account for a future of rising sea levels and more extreme weather events while continuing to address the challenges posed by the demands of a growing urban population. Climate-change science has advanced greatly since the 1999 Baylands Ecosystem Habitat Goals were developed, spurring the need for a technical synthesis of climate-change projections and updated recommendations. The findings of this Science Update indicate clearly that restoring a vibrant and functioning baylands ecosystem will make our future shorelines more resilient to these stresses. Baylands restoration is not a luxury but an urgent necessity as ecological change accelerates.

This Science Update documents and celebrates the remarkable progress made toward achieving the 1999 Baylands Ecosystem Habitat Goals over the past decade and a half. Restoration managers have begun to reverse over a century of habitat loss in the baylands, recommitting tens of thousands of acres to the natural world through a comprehensive and adaptive restoration approach that enhances wildlife habitat, recreational opportunities, water quality, and flood protection.

The variety of uncertainties affecting the baylands requires transitioning from a static to a dynamic approach to planning, one that values flexibility and innovation. An increased commitment to long-term collaboration among diverse regional and local constituencies is essential, as is a willingness to study and learn from our inevitable missteps. This Science Update identifies strategies that are within the current experience of restoration managers but also calls for novel actions that are well beyond the scope of previous activities. Such a bold vision—along with improved monitoring, governance, and financial investment—is required for an estuary that will support a thriving economy and quality of life in the more dynamic environment that the region now faces.

Achieving such a bold vision will require great focus and long-term resolve, and the successes in restoring the estuary to date show that local managers can devise solutions, learn their strengths and

Restoration of the baylands will be increasingly important in the coming century.

weaknesses, and expand actions when policy, funding, science, and regulation align effectively. The Science Update, however, highlights many unmet needs in achieving such an effective alignment. The scope and pace of scientific experimentation and monitoring must increase, relevant policies and regulations must support innovative strategies, and efficient and cost-effective paths to implementation are critical. In addition, it is quite possible that the pace of climate change will be faster than currently projected or that efforts to effectively mitigate its impacts will lag.

Consequently, now is the time to prepare to adapt—to experiment with new ideas and learn what novel techniques can be most effectively scaled up. We must also act quickly to implement the strategies known to work, to give the baylands the best chance to take advantage of current conditions while they last. At the same time, long-term opportunities to reenvision the shoreline will take decades to realize, and planning must begin now.

This Science Update is a nonregulatory, voluntary effort to point the Bay Area toward a more resilient future, with strategies that were developed over several years by several hundred experts and practitioners in the region. It is a first step on a long journey to learning how to live, work, and play with a changing estuary, an estuary where ecological processes and ecosystems are used to best advantage.

This region has the distinct advantage of a populace that recognizes the critical importance of the San Francisco Bay estuary and baylands to its economy and quality of life. We invite you to participate in this, the journey to our future bay.

The Baylands Ecosystem Habitat Goals Steering Committee
October 2015

Baylands Goals Science Update

SCIENCE REVIEW PANEL

October 2015

The San Francisco Bay ecosystem represents habitat of national and global significance as well as providing important ecosystem services for the region. The 1999 Baylands Ecosystem Habitat Goals report was a seminal document that provided a comprehensive scientific vision for non-tidal and tidal wetland restoration in the baylands ecosystem. This update incorporates new science available since that report and addresses the challenges resulting from the present-day understanding—of climate change and other key drivers—needed to maintain a resilient bayland ecosystem through 2100. The Science Review Panel (SRP) was convened to review the science included in the updated report, identify gaps in the individual chapters, and provide feedback to the Chapter authors and the Steering Committee. The SRP met twice with the Workgroup Chairs to review initial chapter drafts and to discuss issues, concerns, and feedback about our impressions of the scientific concepts, content, and general organization of the individual chapters. The SRP provided a written report and series of recommendations for the entire draft.

The Baylands Goals Science Update includes the work of over 100 scientists who represent an outstanding cross section of expertise and experience in the San Francisco Bay area. A considerable amount of work has been invested in the Baylands Goals Science Update, which reflects the wealth of new information available since 1999. The SRP was able to engage in robust discussions with the Chapter leads about the scientific information in their chapters. We commend all the authors and contributors for their efforts in completing this report, which represents a critically important long-term vision and consensus scientific basis for guiding the development of a resilient ecosystem that can respond to the environmental challenges of the 21st century. We fully expect that as the scientific understanding of these systems and their physical drivers change through continued research and monitoring, further updates will be produced and used in an adaptive management feedback process.

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Please forgive any unintentional omissions.

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THE *Baylands* AND *Climate Change*

WHAT WE CAN DO

BAYLANDS ECOSYSTEM HABITAT GOALS
SCIENCE UPDATE 2015

OVERVIEW

Ensuring a Healthier Bay Shore

RESTORE WETLANDS TODAY, FOR THE FUTURE

The wetlands at the shore of the San Francisco Bay are an integral part of the region's iconic beauty, and they provide numerous benefits for our economy and quality of life. These baylands support abundant wildlife, clean water, open space for recreation, and flood protection. More than 100 scientists who study the bay, its wetlands, and watersheds have concluded that now is the time to ensure that these ecosystems continue to provide such benefits. Sea-level rise and climatic and other changes have brought about a critical moment. The extensive bay marshes and mudflats can be sustained for decades to come, but it will require a bold approach to restoring their natural processes. Meanwhile, we must also accelerate the concerted action of the past two decades to restore tidal habitats.

This page, from top: marshland near San Pablo Bay, a young volunteer. Facing page: endangered salt marsh harvest mouse; a stream channel wall; cities around San Francisco Bay.

Much progress has been made on restoring San Francisco Bay's tidal wetlands since the *Baylands Ecosystem Habitat Goals* report was released in 1999. This science update to that report provides guidance for sustaining a healthy and vibrant shore. Carrying out its recommendations will help meet state and federal objectives for the conservation of endangered and threatened species. And it will implement federal strategies (*Tidal Marsh Ecosystem Recovery*) and state plans (*Safeguarding California*) to withstand the impacts of climate change.

A BAY SURROUNDED BY WALLS AND CONCRETE?

Projections show that if we don't act, rising seas and greater erosion will cause the baylands to shrink. We would lose the protection these wetlands provide to our shoreline by buffering storm waves, and the cost-effectiveness of a natural infrastructure that adjusts as sea levels rise. The bay would fundamentally change, with hardened edges and little vegetation.

Eventually, this damage would be irreversible. The region would be obliged to construct and maintain more sea walls and levees, and larger ones. (In places where wetlands are not naturally sustainable, other forms of sea level rise adaptation will be required in any case.) The baylands would eventually retract to narrow strips at the base of these structures or disappear altogether. Water quality could degrade as the baylands would no longer absorb excess nutrients from wastewater or filter contaminants. The diversity and abundance of native animals and plants would be drastically reduced. Several endangered species found only in San Francisco Bay could go extinct, and millions of migratory waterbirds would lose critical feeding and wintering grounds.

"This report tells us what we need to do today to ensure a healthy San Francisco Bay into our future. If we have the courage to act now and follow scientific recommendations, we can secure much of what is most precious about living in the Bay Area, and ensure the gratitude of our grandchildren."

Sam Schuchat, Executive Officer, California Coastal Conservancy; Chair, Baylands Ecosystem Habitat Goals Update Steering Committee

HOW DID WE GET TO THIS POINT?

The forces that control the balance of land and water in San Francisco Bay are changing. The sea level is rising, weather patterns are shifting, and the sediment supply that has helped nourish the baylands since the Gold Rush appears to have been exhausted. Without enough sediment to sustain bay wetlands as sea levels rise—especially coupled with a greater frequency of extreme storms, flooding, droughts, and heat waves—most of the marshes are projected to be damaged or destroyed by 2100 unless we intervene now.

Our response to these events will be fundamental to the fate of wildlife populations. We will either choose to actively support population recovery after a disaster or exacerbate the harm with inappropriate responses. Higher average temperatures, a greater intrusion of seawater into the bay, and new invasions by exotic species will also affect natural communities.

This pivotal moment comes after nearly two centuries of habitat loss and degradation as well as the modification of key natural processes such as freshwater flows, tidal exchange, floodplain productivity, and invasion by nonnative species. Our levees, flood-control channels, roads, railways, storm drains, garbage dumps, and sewage treatment systems have all been built at the edge of the bay. This alteration of the shore has left a legacy of fragmented habitats with small and stressed native wildlife populations and fixed, inflexible systems for controlling water and sediment flows. Neither our critical human-built infrastructure nor the remaining natural habitats are expected to be resilient to coming changes without significant new investment in adaptation and resilience strategies.

"Rising sea level, more extreme weather events, and other impacts of climate change are already altering our region's ecosystems, and this will accelerate in coming decades. By using our new scientific understanding to highlight important actions for visionary management, this document provides a vital basis for sustaining the iconic beauty and valuable services of our remarkable baylands for future Bay Area residents."

Carl Wilcox, California Department of Fish and Wildlife, project co-chair and contributing author of *Baylands Ecosystem Habitat Goals* report (1999)

This page, from top: bicyclists on a levee; assessing health of baby tern. Facing page, top: volunteers put in marsh plants.

NEW APPROACHES, NEW POLICIES

To arrive at a future with functioning, dynamic baylands, we must act immediately. Resilience to sea-level rise depends on natural processes that work over years and decades. We need to adjust our policies to encourage the rapid restoration and enhancement of the natural infrastructure that cost-effectively protects people and property while also supporting native plants and animals.

STRATEGIES FOR A HEALTHY SHORE

The scientists that developed this report suggest regional strategies to maintain healthy baylands and the benefits they provide. These strategies are summarized below and listed in full in the second chapter of the report.

Restore complete baylands systems.

To achieve and maintain the Baylands Goals (100,000 acres of tidal marsh and the targets for other habitat types), we should maximize baylands resilience. This means restoring complete wetland systems with their many interconnected habitat types, along with the physical processes that sustain them. Reconnecting the baylands to nearby open lands is also crucial to provide wildlife with refuge during high-water events and for

Below: Artist's conceptual rendering shows a future Bay Area shoreline that has successfully accommodated significant sea-level rise through the restoration of baylands and the processes that sustain them. Reconnected waterways provide adequate sediment and freshwater to sustain marshes, while diverse connected marsh habitats allow wildlife to flourish and migrate near urban areas. Gradually sloping undeveloped areas also provide space for marshes to move inland as the sea level rises. These restored baylands enhance the lives of millions of people, protect built infrastructure, return wildlife to our communities, and improve water quality.

the baylands to move landward as sea levels rise. Diverse, connected baylands habitats will foster diverse wildlife populations that can survive extreme conditions, move where they need to go, and evolve with the changing environment. Management techniques can be refined to prevent further subsidence, increase organic matter accumulation, reduce greenhouse gas emissions, and sequester more carbon. Even though they are not naturally resilient systems, artificially managed ponds are a valuable component of future baylands ecosystems to support waterbirds and compensate for the extreme loss of wetlands across California.

"These updated Goals provide an urgently needed roadmap to secure the future of the San Francisco Bay region during this time of rapid change. Produced by leading scientists, managers, and decision makers, these practical, climate-smart recommendations will guide habitat restoration and management to sustain wildlife and people for decades to come."

Ellie Cohen, President and CEO, Point Blue Conservation Science; co-founder, Bay Area Ecosystems Climate Change Consortium

Accelerate restoration of complete baylands systems by 2030.

Restore tidal flows to strategic areas and manage sediment to establish tidal marsh ecosystems. Tidal marshes that are established by 2030 are more likely to flourish and provide ongoing benefits when the sea-level rise accelerates in the middle of this century. To achieve this goal, the planning, permitting, and construction of restoration projects on currently available lands must be accelerated.

This page, from top: salt ponds in the south bay; scientist prepares a native oyster restoration experiment. Facing page: volunteers plant willows; children study the bay.

Plan ahead for the dynamic future.

Create regional policies for the shore that anticipate change over time, using projections of sea-level rise and expected shifts in habitat types, locations, and connectivity. Baylands can better sustain themselves as sea levels rise if they can migrate landward. We should prepare for this migration by conserving the transition zone between the baylands and adjacent lands.

Develop and implement a comprehensive regional plan to reuse suitable dredged, excavated, or naturally occurring sediment. This sediment could come from the bay, local rivers and streams, flood control channels, reservoirs, and other sources.

Prepare for the likely increases in extreme weather events such as floods and drought. Extreme events will inevitably cause damage, but they will also provide opportunities to rebuild more-resilient shores. We can buffer wildlife populations against extreme events and prevent extinctions by monitoring them and taking protective action at strategic moments.

Increase regional coordination.

Creating a resilient and healthy shore will be more successful if the responsible agencies and interested stakeholders collaborate to build consensus, identify barriers to action, solve problems, and promote shared learning and aligned benefits from individual projects. Regionally coordinated research, monitoring, and implementation are critical for rapid innovation and large-scale, complex restoration. This approach will foster the adoption of the most promising techniques for restoration and management, build understanding for and support of necessary new policies, and establish coalitions to obtain the public funding required for a healthy future shore.

"The recommendations provided by over 100 of the region's leading scientists are invaluable for helping managers, scientists and decision-makers continue to make progress in restoring our valuable wetlands. We now know we must accelerate our restoration efforts, and adopt new watershed and in-bay management practices to ensure there is sufficient sediment for the baylands to continue to provide a multitude of beneficial functions with our rising seas."

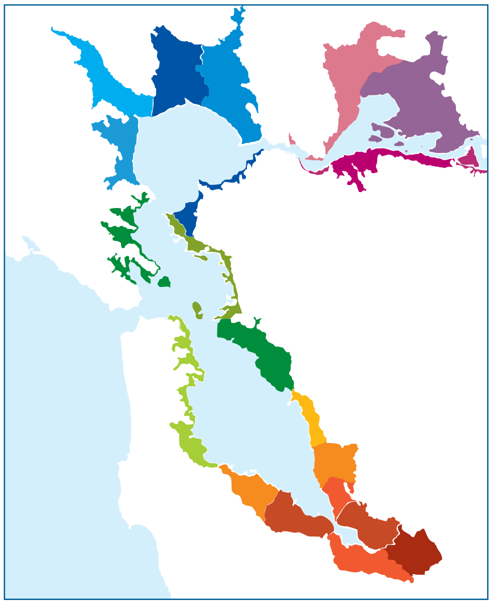
Michael Monroe, lead author and project co-chair for the *Bayland Ecosystem Habitat Goals* report (1999)

THE SUCCESS we have already achieved with baylands restoration provides us with the opportunity to continue this work. But this opportunity is available only if we act now. Restoring the baylands is a necessary part of creating a resilient and healthy shore that supports our economy and maintains the remarkable natural heritage of the Bay Area.

ABOUT THIS SCIENCE UPDATE

This report is an update to the 1999 *Baylands Ecosystem Habitat Goals* that for the first time set comprehensive restoration goals for the San Francisco Bay estuary. It synthesizes the latest science— particularly advances in the understanding of climate change and sediment supply—and incorporates projected changes through 2100 to generate new recommendations for achieving healthy baylands ecosystems.

The habitat acreage goals set in 1999 remain the same. Recommendations have been updated—and many new restoration approaches are suggested—for the region, its major subregions, and local shorelines. These actions must be integrated with civic and economic planning to arrive at appropriate implementation strategies. This report provides technical information that policy makers and others can use in deciding how to maximize ecosystem health.



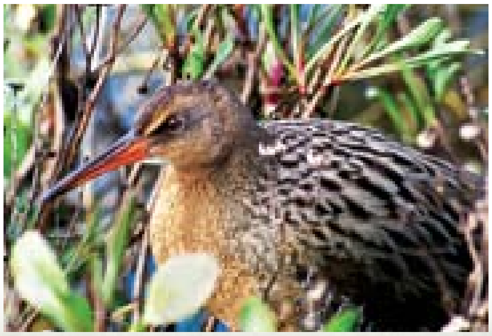
The report provides updated recommendations for the region, its major subregions, and local shorelines.

TO OBTAIN THE REPORT

Access the full Science Update at **www.baylandsgoals.org**.

Available on the website are PDFs of the full report, maps, and appendixes, as well as Science Foundation chapters that provide the technical background to the report.

For inquiries, please contact info@baylandsgoals.org.



Top: Mud Slough; above: endangered Ridgway's rail

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NEW UNDERSTANDING

The Baylands and Climate Change

NEW UNDERSTANDING

The Baylands and Climate Change

A Summary of Findings from the Science Foundation Chapters of the Baylands Goals Science Update

UPDATING OUR VISION FOR THE FUTURE

The Baylands[1] Ecosystem Habitat Goals Project ("Goals Project"), completed in 1999, spurred the restoration and enhancement of tens of thousands of acres of wetlands around the San Francisco Bay. This restoration enriched the Bay Area's economy and its quality of life. It has provided cleaner water, flood protection, more wildlife, and beautiful places to be in nature in the heart of this urban region. The original Goals Project anticipated the need for updates to account for changes in scientific understanding, the environment, and social values. This report is the first "Science Update." It advances the Goals Project by providing new science-based recommendations to address climate change and other key drivers, including sea-level rise, freshwater flows, and sediment supply, over the next century. This report describes actions that can be taken to ensure that the baylands continue to support the ecosystem functions and services that are vital to the ecological and economic health of the region. Its focus is on estuarine wetlands—namely, tidal flats and tidal marshes—because of the wealth of services they provide and the threat they face from rising sea levels and other aspects of future change.

This Science Update focuses on how to create resiliency in the baylands and their wildlife—the native plants and animals that use the baylands as habitat—so they can adapt to environmental change while retaining vital ecosystem functions. Planning for climate change creates opportunities to reenvision the baylands in the context of the estuary as a whole, including its watersheds, which are integrally connected environmental systems. When natural ecological processes are allowed to flourish across these systems, the baylands and their wildlife are inherently resilient. This natural resiliency can be enhanced, though this requires altering traditional approaches to shoreline management. Engineered shorelines do not adapt well to change; they are static and will require ever more intense and expensive solutions. Rather than

1. The baylands are all the areas upstream of the Golden Gate between minimum and maximum tide elevations, including the areas that would be flooded by the tides if not for levees or other unnatural water-control structures. This Science Update pertains only to the baylands downstream of Broad Slough, which demarcates the downstream limit of the Sacramento–San Joaquin Delta.

The future of the baylands will be defined by their ability to adapt to changing conditions.

see the baylands as fixed habitats, restoration managers need to take advantage of their ability to move and evolve by reestablishing and nurturing their natural formative processes, including nourishment by freshwater and sediment inputs from watersheds.

With significant changes in watershed and sediment management, marshes and mudflats could receive sufficient sediment and space to keep pace with, and adapt to, sea-level rise. Historical baylands that have been reclaimed for uses that are not compatible with climate change could be restored to the tides or otherwise repurposed. Ponds managed for wildlife could be reconfigured or moved. Space could be created within watersheds to accommodate the inland migration of the baylands due to sea-level rise. In this vision, the vital ecosystem services of the baylands would be maintained. Achieving this vision will require accelerating the development and implementation of new restoration approaches, investing more resources, and adjusting public policies to ensure success. With help, the baylands can evolve and migrate, continuing to give the Bay Area ongoing flood protection, wildlife, clean water, carbon sequestration, and recreation opportunities for the next hundred years and beyond.

This summary chapter synthesizes information from six Science Foundation chapters, listed below and found at www.baylandsgoals.org, which provide significantly more detail on the most recent baylands science. The recommended actions that emerged from the Science Foundation chapters are presented in the following chapter: New Opportunities: How We Can Achieve Healthy, Resilient Baylands.

Purpose

This Science Update furthers the original purpose of the Goals Project to offer a long-term vision for a healthy and sustainable baylands ecosystem. Specifically, this report identifies key scientific findings that support recommended actions to sustain diverse and healthy communities of wild plants and animals in the baylands in the face of climate change and other stresses. The Science Update provides a scientific basis to guide regional planning for public and private interests seeking to maximize the ecological integrity of the baylands as part of a shore that is resilient to the impacts of climate change.

In keeping with the guiding principles of the Goals Project, the recommendations aim to

- achieve robust, functioning ecosystems with a preference for self-maintaining systems wherever possible
- prioritize the support of native species over nonnatives
- focus on biological communities more than individual species

As the estuary (defined in the geographic scope section below) continues to change over the next century, some of the species and biological communities that are present now are likely to change. Novel communities may arise, with nonnative species arriving via anthropogenic transportation and native species arriving via range shifts. Species will also be lost in the Bay Area due to extirpation or range shifts, and species that were present historically may not be able to survive. We therefore focus the recommended actions on preserving, protecting,[2] enhancing, and restoring the ecological functions of the baylands to sustain diverse and healthy wild plants and animals while recognizing that no one can control exactly how the ecosystem will be structured or which species will be present in each community.

This report focuses on the ecological integrity of the baylands, especially the tidal marshes and mudflats, yet acknowledges that the baylands provide many critical ecosystem services to the region. In particular, estuarine wetlands reduce flooding by attenuating waves and spreading out and slowing down high water, enhance water quality by filtering out and breaking down contaminants, provide nurseries for fish and shellfish, sequester carbon, and provide important recreational opportunities. Through these services, wetlands make valuable contributions to the local economy and quality of life and can be part of multi-objective, cost-effective, low-maintenance, nature-based solutions to protect developed infrastructure from sea-level rise and flooding.

Intended Use

This report is a guide for resource managers, planners, local governments, and other decision makers who are working to integrate the protection, restoration, and enhancement of thriving baylands ecosystems with infrastructure updates, watershed management, and plans for a future shore in the context of climate change.

Developed as a technical resource based on a synthesis of the best available science, this report is not a policy document. Rather than providing a comprehensive review of all baylands science, this report focuses on the actions that resource managers can take to maintain the ecological health of the baylands. The recommendations stem from the science and are intended to guide the planning, restoration, and management of the baylands; however, they must be reviewed, vetted, and adopted by individual agencies through formal public processes if they are to result in policy or regulatory changes. They likewise reflect the technical expertise of the contributors

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2. Protect in the context of this report refers to land-use or land-tenure actions taken with willing partners and landowners to ensure the future availability of lands and waters to provide desired ecological benefits. Protection can be accomplished through management of lands acquired by fee, conservation easement, permit, lease, or cooperative agreement. Land protection may also be provided by local regulatory control through a formal public process, such as zoning, ordinance, or regulatory permit.

Box 1 The Success of the 1999 Baylands Goals

The 1999 Baylands Ecosystem Habitat Goals (Goals Project) galvanized the restoration of tidal habitats in the San Francisco Bay region. Prior to its publication, tidal wetland restoration projects were rare in the region and small in scale, with the largest around 350 acres. By providing a consensus-based scientific vision of the kinds, amounts, and distribution of baylands habitats needed to sustain healthy populations of fish and wildlife for the entire region, the Goals Project gave regulators, resource managers, environmentalists, and citizens the framework necessary to pursue large-scale restoration for baylands habitats.

In the decade after the Goals Project report was published, over 12,000 acres have been restored, and nearly 30,000 more are now under way. The report has become a cornerstone of policy, planning, coordination, and advocacy for the acquisition, protection, and restoration of the San Francisco baylands.

Policy and Strategic Planning

Many public agencies have incorporated the Goals Project into regional planning and policy documents. The San Francisco Bay Regional Water Quality Control Board referred to it as the nonregulatory component of a conceptual regional wetlands management plan. The San Francisco Bay Conservation and Development Commission amended its policies for tidal marshes and tidal flats, and for fish, wildlife, and other aquatic organisms in 2002, endorsing the Goals Project's recommendation to restore to tidal action 65,000 acres of land now diked from the bay. The California State Coastal Conservancy 2007 Strategic Plan referenced the Goals Project as the basis for the region's wetland restoration goals, and the San Francisco Bay Joint Venture incorporated the Goals Project's baylands habitat acreage goals (Habitat Goals) into its Implementation Plan, "Restoring the Estuary."

These actions have supported many restoration projects, including the Napa River Restoration Project, Cullinan Ranch, Sears Point, Bair Island, the South Bay Salt Pond Restoration Project, and many more throughout the San Francisco Bay region.


Salt marsh harvest mouse

to the report and do not necessarily reflect the positions of the agencies whose staffs participated.

Due to the nonregulatory and technical nature of the document, a formal public comment period was not undertaken; however, public engagement with the document is welcome. The document is intended as a resource in working with communities to develop regional and local strategies based on a wide range of criteria and concerns not fully addressed here, including economic constraints, landowner desires, land-use planning and regulation, and competing societal interests and priorities. It is hoped that the ecological visions, principles, and recommendations herein help inform those broader planning processes.

Public and Private Funding for Acquisition and Restoration

Funding for baylands restoration projects increased dramatically after the Goals Project was released. Environmental organizations such as Save the Bay, the Bay Institute, and the National Audubon Society successfully convinced a California State Senate Select Committee, US Senator Dianne Feinstein, and private foundations that the acquisition and restoration of the South Bay salt ponds was a keystone to implementing the Goals Project. In 2002, the Goals Project was specifically cited in the voter-approved Proposition 50, which included up to $200 million for the Wildlife Conservation Board to implement projects recommended in the report. Over the past decade, this funding, along with other state bond funds, federal appropriations, and local and private funds, has enabled ecosystem-scale acquisition, planning, and restoration actions in the baylands.

Many smaller bay restoration projects have benefited from the Goals Project, as state and federal agencies increasingly rely on credible science-based plans to identify acquisition and restoration projects that meet their habitat- and water-quality grant-program mandates.

Federal and State Legislation to Create a Regional Funding Source

The Goals Project recommendation to reestablish 100,000 acres of tidal wetlands in the bay has been the driving force in securing new funding sources. In 2008, Save the Bay successfully sponsored legislation (AB 2954, Lieber) that created the San Francisco Bay Restoration Authority, which has the capability to raise and grant regional funds to restore bay wetlands.

The Goals Project has also spurred regional entities in working with US Representative Jackie Speier and Senator Dianne Feinstein to seek a federal funding program (the San Francisco Bay Improvement Act of 2010) comparable to other nationally significant bay-restoration programs to accelerate the restoration of the bay.

Development of Regional Goals for Other Habitat Types

The Goals Project inspired the development of two other regional science-based habitat conservation visions:

- The Bay Area Open Space Council developed the Conservation Lands Network, which identifies the types, amounts, and distribution of habitats needed to sustain diverse and healthy ecosystems in upland habitats beyond the baylands. The report, the culmination of five years of work by 125 experts, serves as a guide for making conservation investments, supporting collaborative conservation planning, and helping to protect biodiversity throughout the region.
- The San Francisco Bay Subtidal Habitat Goals Project, produced by a collaboration of public agencies and a panel of scientists, marks the first time that comprehensive information about submerged areas in the bay has been compiled. It includes broad regional goals for protecting and restoring underwater habitats in the bay, with detailed objectives and actions for implementation over a 50-year planning horizon.

Thus, instead of a set prescription, this report outlines a broad suite of actions for evaluation that are intended to be implemented voluntarily, incrementally, and cautiously in the coming decades. These actions can be adapted to create regional and site-specific solutions that match the particular context and needs of communities involved.

Additionally, the report is neither an environmental impact statement nor an environmental impact report intended to meet requirements of the National Environmental Policy Act or the California Environmental Quality Act. Any project that proposes to implement recommendations within this document will need to undergo appropriate environmental impact analysis.

RELATIONSHIP TO THE 1999 BAYLANDS ECOSYSTEM HABITAT GOALS

The Goals Project developed the first comprehensive vision of how to restore the baylands ecosystem. Goals were set in the form of habitat-acreage[3] targets, general landscape configurations, and habitat elements (the "Habitat Goals"). Notably, the regional acreage goals called for tidal marsh restoration on an unprecedented scale: 60,000 acres to be restored, to reach a total of 100,000 acres. These acreage targets remain principal goals and are not revised here. This Science Update uses new scientific knowledge to revise the recommendations found in chapter 5 of the original Goals Project report and provides new recommendations to achieve the original acreage goals.

Impact of the 1999 Goals Project

The Goals Project galvanized the restoration of tidal habitats in the San Francisco Bay region. Prior to its publication, tidal wetland restoration projects were uncommon, small in scale, and mostly planned in isolation from each other and from surrounding landscapes. The Goals Project provided environmental policy makers, regulators, resource managers, and nongovernmental advocacy organizations with a scientifically based consensus vision of the kinds, amounts, and distribution of baylands habitats needed to sustain healthy populations of fish and wildlife for the entire region. The Goals Project gave birth to new, more collaborative ways to approach ecological planning across policies and programs at all levels of government.

The Goals Project has become a cornerstone of policy, planning, coordination, and advocacy for the acquisition, protection, enhancement, and restoration of the baylands. Between the Goals Project in 1999 and the latest comprehensive baylands habitat mapping in 2009, 9,000 acres of diked baylands were restored to tidal baylands and 2,000 acres of diked baylands were created or enhanced for wildlife support. In addition, 23,000 more acres are being planned for restoration to tidal baylands, and another 8,000 acres of diked baylands will be created or enhanced for wildlife support (see box 2 for more details). The Goals Project has been incorporated into many public-agency planning and policy documents and has brought significant focus and resources to the implementation of its habitat goals. This success inspired the development of science-based habitat-conservation visions for Bay Area watersheds (*Conservation Lands Network*) and subtidal habitats (*San Francisco Bay Subtidal Habitat Goals Report*).

Migrating terns arrive at a restored wetland.

3. Because the habitat goals were set in acres, this report contains both the metric units typical of standard scientific practice and the nonmetric unit of acres when referring to habitat areas.

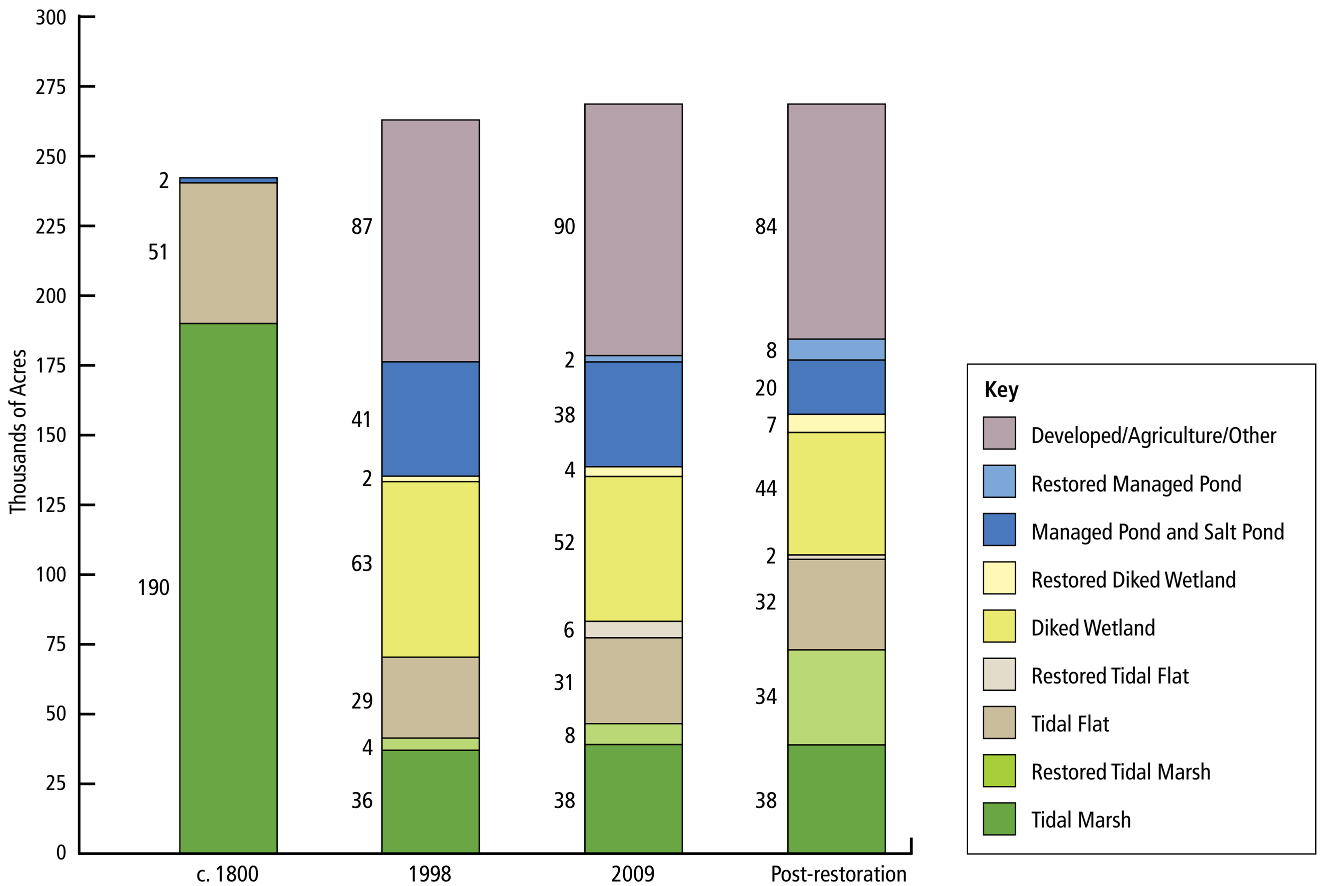


Figure 1 Change in the extent of baylands habitats over time. Numbers on bars represent thousands of acres. Acres of restored habitat in each time period are cumulative for each habitat type (e.g., restored tidal marsh in 2009 reflects all marsh restored before 2009, including marsh restored prior to 1998). To standardize the habitat types among different mapping efforts, some calculations are slightly different here from those in the 1999 Goals Project (see box 2 for more details).

Restoration managers are now poised to implement the broader concepts underlying regional restoration and to design complex multicomponent systems that incorporate dynamic processes and natural ecological variability. By doing so they will help establish resilient baylands ecosystems that can adapt over time, support native wildlife, and provide the ecosystem services upon which the region relies.

Process for Developing the Science Update

The success of the Goals Project motivated the authors of this update to follow a similar process and organizational structure. The key organizational elements were (1) a steering committee of representatives from resource management and science organizations, (2) collaborative and open participation by science contributors organized into workgroups, (3) an independent science review panel, and (4) a core administrative team, including the science coordinator.

Wetlands at sunset

Well over 100 scientists and managers contributed to the Science Foundation chapters. The chapters, each developed by a workgroup led by two co-chairs, are described below:

- **Science Foundation Chapter 1: The Dynamic Workings of the Baylands** lays out conceptual models of how drivers of change influence the evolution of baylands habitats.
- **Science Foundation Chapter 2: Projected Evolution of Baylands Habitats** details what is known about how the geomorphology of the baylands is projected to evolve under the future scenarios.
- **Science Foundation Chapter 3: Connections to the Bay** covers how changes in the bay, delta, and ocean may affect the baylands. Several case studies that furnish examples of the vulnerabilities and potential responses of key wildlife species and groups are provided.
- **Science Foundation Chapter 4: Connections to the Watersheds—The Estuarine–Terrestrial Transition Zone** describes the important area where the baylands transition to their watersheds, including information on transition zone types and ecosystem services.
- **Science Foundation Chapter 5: Risks from Future Change for Wildlife** focuses on how wildlife populations and communities may be harmed by future changes. The chapter includes several case studies that furnish examples of the vulnerabilities and potential responses of key wildlife species and groups.
- **Science Foundation Chapter 6: Carbon Sequestration and Greenhouse Gases in the Baylands** discusses carbon storage in the baylands as well as greenhouse gas emissions.

Standardization of processes and products was accomplished in several ways. First, the science contributors developed a conceptual model of the physical, chemical, and biological processes that govern the formation of baylands and the evolution of habitat types. The Dynamic Workings of the Baylands below (and Science Foundation chapter 1) summarizes this model. Other models developed by the workgroups for subsequent Science Foundation chapters link to the overarching landscape model. Second, we developed several scenarios of future change to guide the analyses of each workgroup. Finally, scientific discussions, revisions of these documents, and coordination of feedback on the many drafts were made possible by extensive communication among workgroup chairs and the science coordinator.

The content of this report reflects the guiding principles that emerged from the authors' discussions with the steering committee and workgroup chairs. Of particular importance was the use of the best available science. The guiding principles, organizational structure, timing, and funding of the effort are described in greater detail in appendix A.

The report went through several rounds of review by the science contributors, workgroup chairs, science review panel, and the steering committee. A near-final draft of the report was sent for review to more than 50 individuals, representing a range of baylands stakeholders. After each round of review, content was revised to address the feedback received.

Much of the effort contributed to the Science Update was provided in kind by the participating organizations and individuals. Major funding was provided by the California State Coastal Conservancy, the Gordon and Betty Moore Foundation, and steering committee organizations, with additional assistance from the California Landscape Conservation Cooperative and the San Francisco Bay Wildlife Society.

Marsh channels and vegetation in Salt Pond A21

Geographic Scope

This report mirrors the geographic scope and subregional breakdown of the Goals Project. It includes the portion of the San Francisco Bay–delta estuary downstream of the Sacramento–San Joaquin Delta, with the demarcation at Broad Slough (fig. 2). Within this area, the Goals Project designated four subregions: Suisun, North Bay, Central Bay, and South Bay. The baylands were further divided into 20 segments to allow a more detailed examination of restoration needs and opportunities.

Within this geographic area, the Science Update focuses on the baylands and the greater baylands ecosystem (fig. 2). The baylands are

Figure 2 Goals Project area

Suisun Bay

defined as the lands that lie between the maximum and minimum elevations of the tides over multiyear cycles, including those areas that would be covered by the tides in the absence of levees or other unnatural structures. The baylands ecosystem, as defined by the Goals Project, includes the baylands and their adjacent waters and lands, and their associated communities of plants and animals.

To the east of the baylands lies the Sacramento–San Joaquin Delta, which is part of the estuary and has important physical, chemical, and biological interactions with the bay. While addressing the delta in detail is beyond the scope of the Science Update, the important physical, chemical, and biological connections between these two parts of a single estuary are acknowledged. Major changes in the delta that could affect the bay, and vice versa, are noted.

Baylands Ecosystem

The baylands lie between the San Francisco Bay and its watersheds and rely on the energy and materials provided by these adjacent ecosystems. Tidal, fluvial, and terrestrial processes are critical to the baylands' formation and maintenance even when originating outside them. Thus, restoring resilient baylands requires looking outside as well as inside their boundaries. Moreover, within the baylands, processes and functions in one part of the ecosystem affect outcomes in other parts. The geographic relationships between the habitat types and their connections by physical, chemical, and biological processes greatly affect their functioning.

Changes imposed by the urbanization of the baylands and their watersheds have fragmented baylands habitats and disconnected or otherwise modified the processes that drive ecosystem functions. As we consider how to protect the ecological integrity of the baylands over the next century, restoring hydrologic and geomorphic processes that sustain the landforms will be critical. As a co-benefit, using natural processes to maintain ecosystems can be a low-cost, low-maintenance approach to retaining the services the baylands provide, which include flood protection, water-quality improvement, and recreational opportunities. Thus, the Science Update recommends the restoration of complete tidal wetland systems and the processes that sustain them (see chapter 2: New Opportunities).

The baylands include tidal and diked habitats (fig. 3). Tidal baylands are subject to the daily action of tides. Diked baylands are areas of historical tidal habitats that have been isolated from tidal action by the construction of levees, tide gates, or other water-control structures. The most prevalent types of tidal baylands are tidal marsh

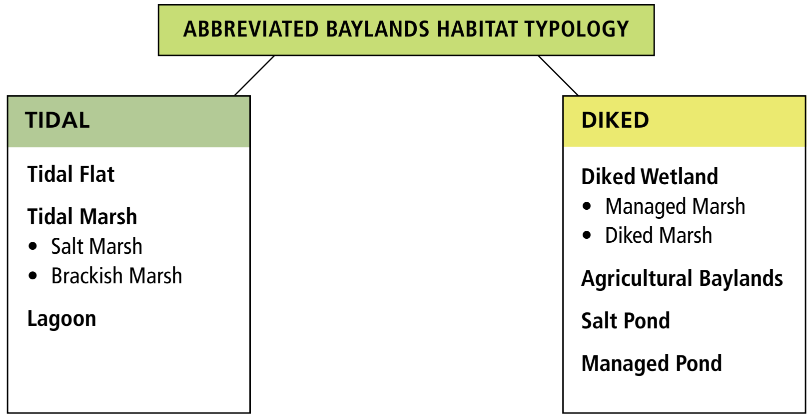


Figure 3 Major habitat types

and tidal flat (mainly mudflat). The most prevalent types of diked baylands are managed marsh (mainly duck clubs and wastewater treatment marshes), agricultural baylands, salt ponds, and managed ponds. Most of the acreage of managed ponds in the baylands is managed to enhance the habitat value for wildlife. This category includes wastewater treatment ponds and impounded waters in urban and residential areas (e.g., Lake Merritt and Bel Marin Keys). Here we will refer to *managed ponds* as those diked baylands that are physically separated from the tides by a berm or levee and have artificially controlled water levels or salinities through a weir, culvert, or flap gate. The baylands ecosystem and habitat types are described in detail in the 1999 Goals Project (see chapters 2 and 4 of that report). The habitat typology has been slightly modified for the Science Update to include managed ponds.

CHANGE IN BAYLANDS HABITATS OVER TIME

Progress toward the Habitat-Acreage Goals

Between 1800 and 1998, 79 percent of tidal marshes (150,000 acres) and 42 percent of tidal flats (21,000 acres) were lost to diking and filling (figs. 4–6).[4] In the late 1980s through the 1990s, habitat loss was slowed and then reversed through the protection of threatened parcels and early restoration activities. The Goals Project provided the first comprehensive measurement of baylands habitat extents, and estuarywide mapping was repeated using aerial imagery from 2009 as part of the development of EcoAtlas.

For this Science Update, existing information about planned and ongoing restoration projects was assembled primarily from the Wetland Project Tracker and the San Francisco Bay Joint Venture. Contributors to the Science Update reviewed the data and provided best estimates of expected habitat outcomes for particular sites.

Restoration projects completed by the year 1998 added 4,000 acres of tidal marsh and 2,000 acres of diked wetlands (figs. 5 and 6). If currently planned projects are successful, they will add around 28,000 acres of tidal marsh—including 5,000 acres of

4. These numbers differ slightly from those reported by the Goals Project due to mapping differences.

Pickleweed marsh

previously restored tidal flat that will evolve naturally into tidal marsh (fig. 7)—to the baylands habitats mapped in 2009. Although 54,000 acres of managed ponds are planned for restoration or enhancement, the overall extent of managed ponds will be reduced by 13,000 acres. Similarly, 35,000 acres of diked wetlands will be created or enhanced, but the overall diked wetland extent will decrease by 3,000 acres. This estimation of future baylands extent (fig. 7) includes restoration, enhancement, and mitigation projects that have been funded, permitted, or both and therefore have a high probability of completion within the next 20 to 30 years. See box 2 and appendix B for a detailed discussion of assumptions and data sets.

In summary, of the 60,000 acres of tidal marsh recommended for restoration by the 1999 Goals Project, over 7,000 acres of tidal marsh were restored as of 2009, and 28,000 more acres of restored tidal marsh are expected to result from future projects or habitat evolution of current projects. In addition, today's baylands include mudflats,

Box 2 Mapping the Changing Baylands: Methods and Assumptions for the Baylands Habitat Maps

Habitat maps in this report use data from the 1997 Bay Area EcoAtlas, the 2009 Bay Area Resource Inventory (BAARI), and the Wetland Project Tracker. EcoAtlas 1997 represents the most up-to-date baylands habitat-type data layer available at the time of the 1999 report publication. BAARI 2009 represents the most complete regionwide baylands habitat-type data layer currently available. It includes detailed information on all tidal and nontidal aquatic features in the region. Information on the mapping procedures and standards used are available at http://sfei.org/baari. The BAARI layer was released in 2009, but the date of the imagery used for some areas could be earlier. Wetland Project Tracker data were used to determine the status and extent of restoration or mitigation projects during each time period. Projects represented were issued a Clean Water Act Section 401 Certification and/or Waste Discharge Order from the Regional Water Quality Control Board. Additional information about wetland projects was provided by local land managers and agencies.

The 1998 and 2009 maps show projects where groundwork has been completed. The future habitat map includes projects in progress and planned projects that have been funded, permitted, or both. They therefore have a high probability of completion within the next 20 to 30 years. For the future habitat map the predominant habitat type was mapped across the full extent of each identified project area or subarea, and the maximum tidal marsh extent was assumed for projects with multiple future scenarios. Therefore, future tidal marsh extent is likely overestimated. The future habitat map does not include the projected evolution of habitats due to climate change and sea-level rise. It should be noted that much of the difference in non-restored tidal marsh, non-restored tidal flat, and urban/agriculture acreage between 1998 and 2009 is due to differences in mapping and available data layers between the two time periods.

These maps are meant to provide an overview of bayland habitat extents, and details may be incorrect or inconsistent between maps due to incomplete information in the data layers used or inconsistencies in the habitat-type definitions used for different data sets. They are not adequate for jurisdictional or regulatory purposes. Note that the 2009 map shows a greater level of detail due to the improved tools and data layers available. Given the need to create equivalent habitat-type categories among the different mapping efforts, some calculations are slightly different here than in the 1999 Goals Report. See appendices B and C for more detail on mapping methods and assumptions.

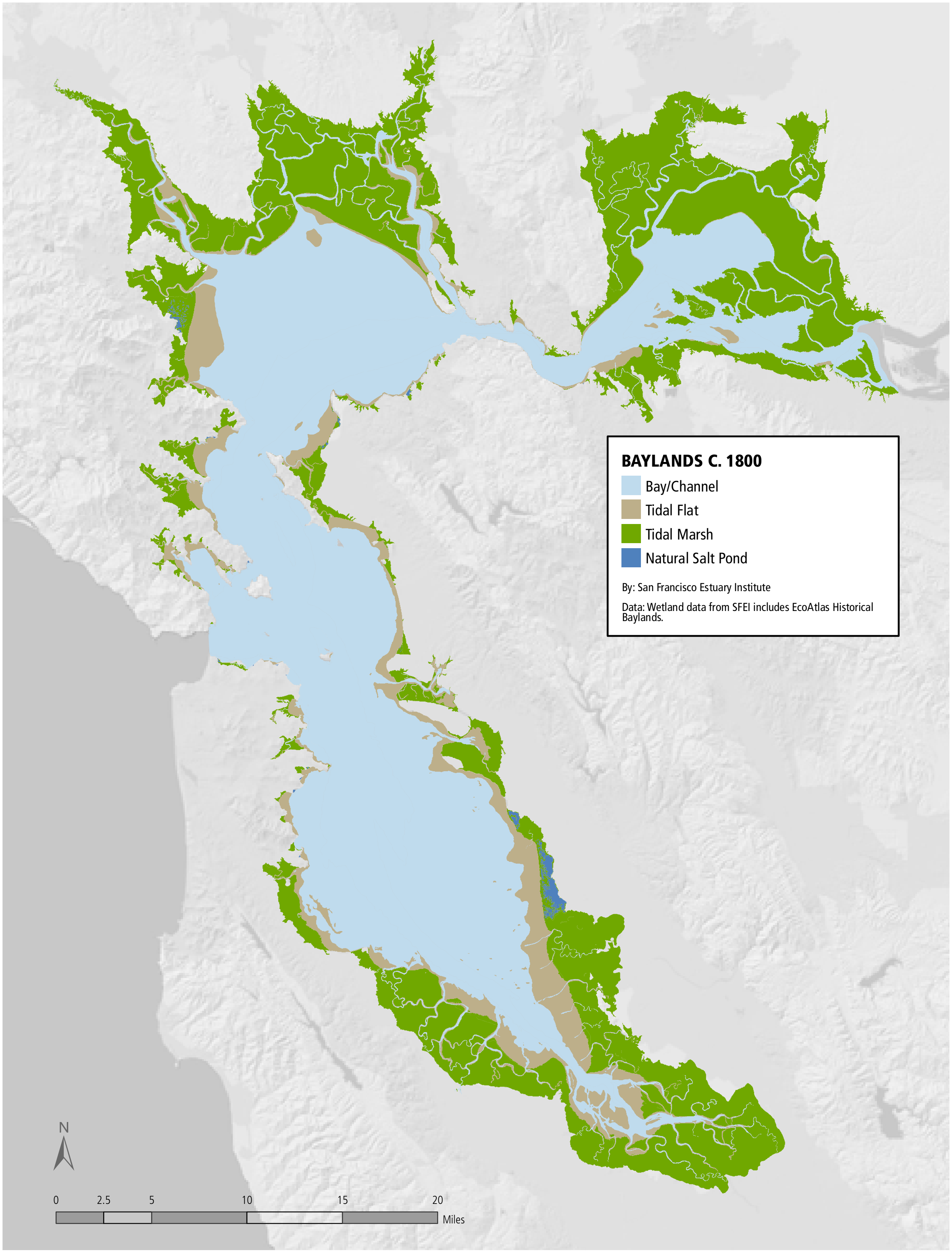


Figure 4 Baylands habitats c. 1800. See box 2 for more detail about the data and assumptions for this map.

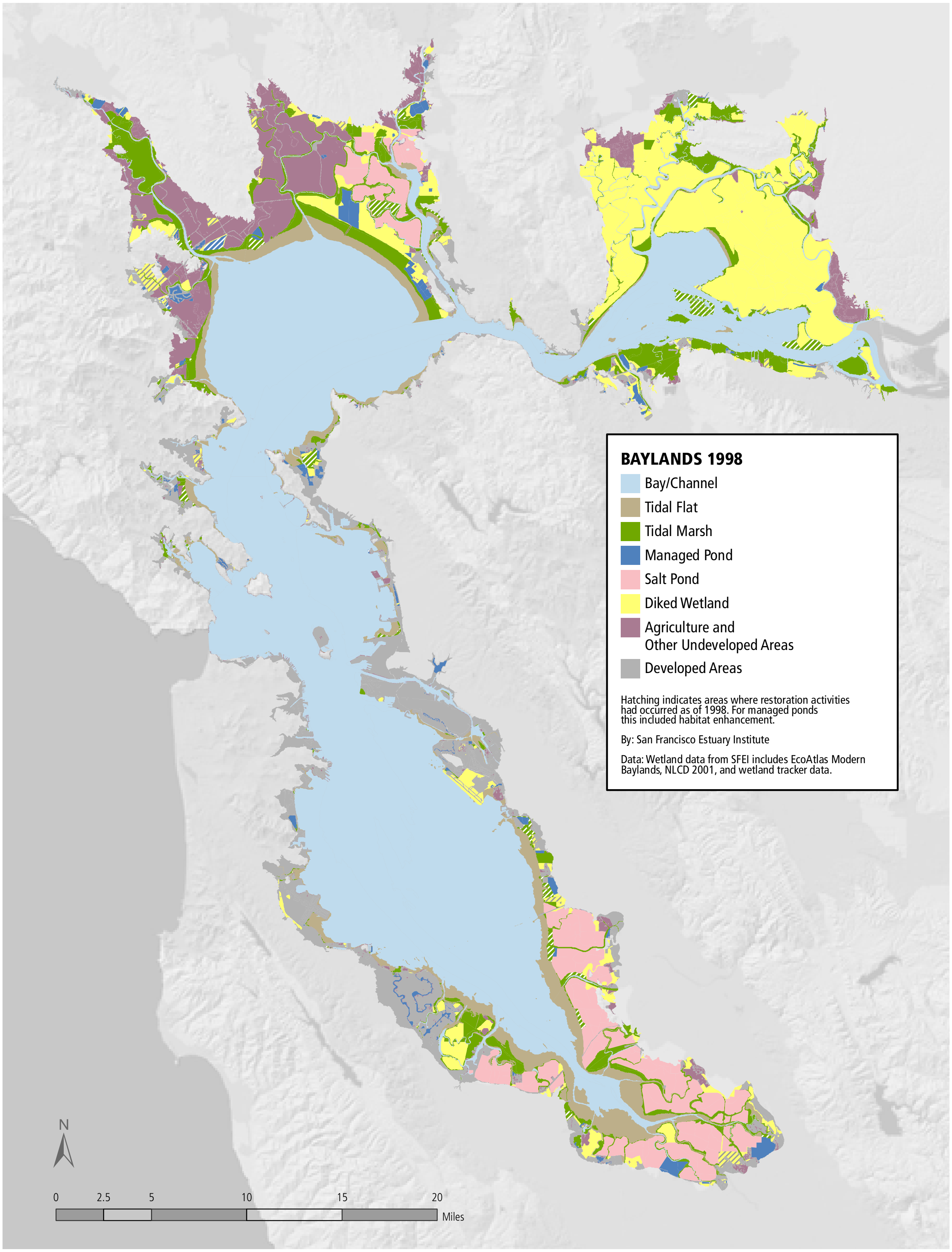


Figure 5 Baylands habitats in 1998. See box 2 for more detail about the data and assumptions for this map.

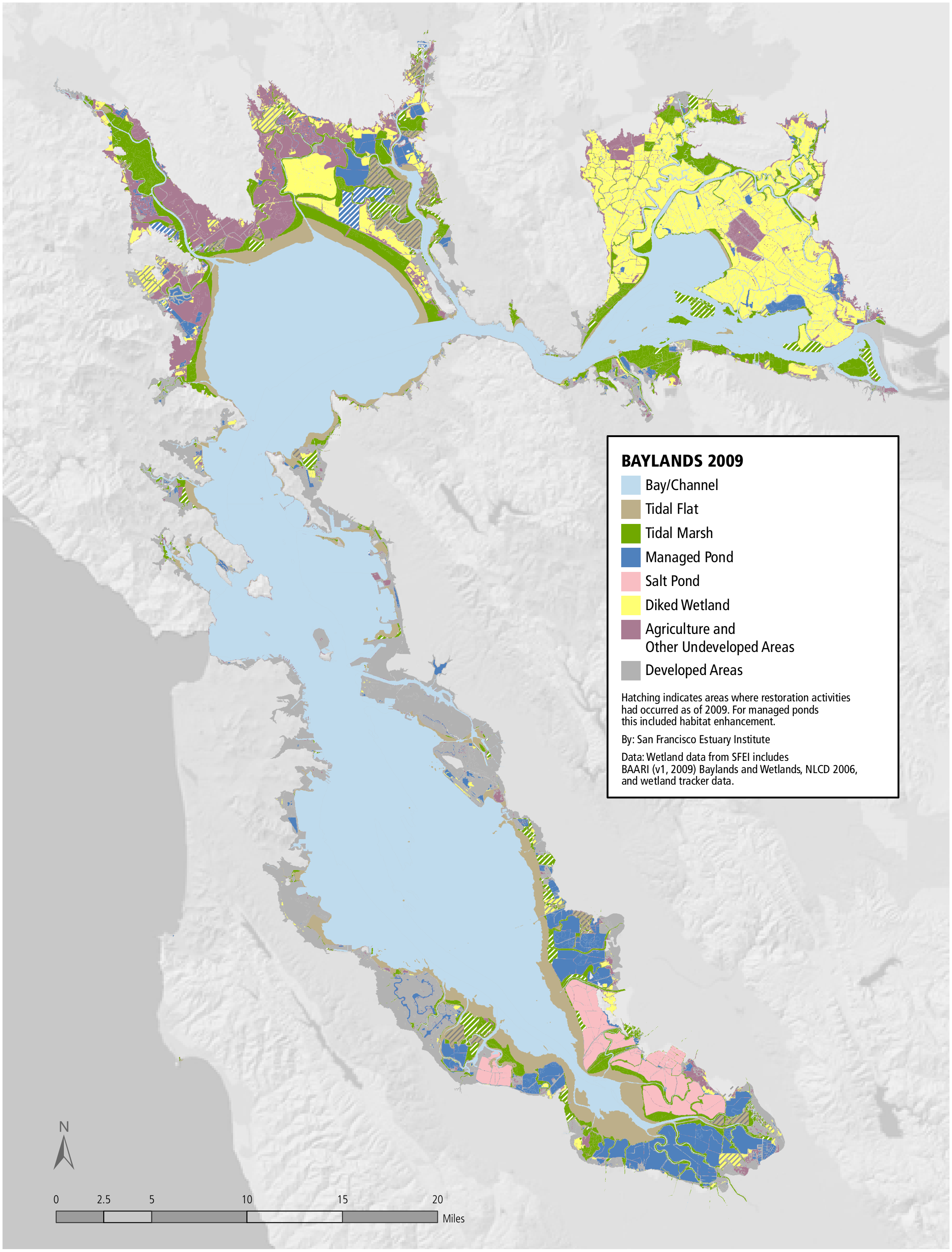


Figure 6 Baylands habitats in 2009. See box 2 for more detail about the data and assumptions for this map.

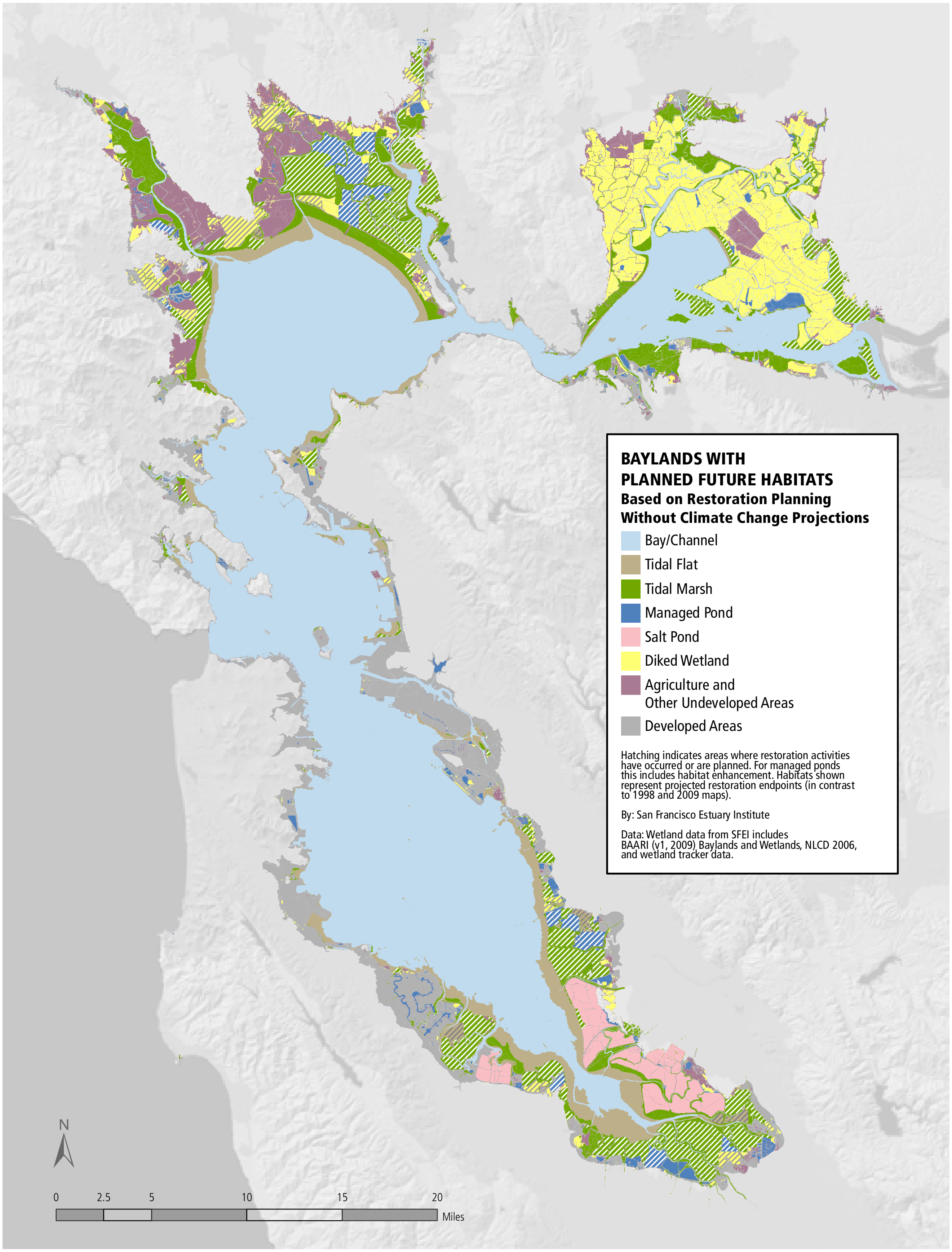


Figure 7 Baylands habitats with planned projects. See box 2 for more detail about the data and assumptions for this map.

diked wetlands and ponds, and other habitat types that provide critical support for wildlife.

Looking forward (fig. 7), the largest expanse of undeveloped baylands that are not already slated for particular restoration projects is in Suisun. Suisun has tens of thousands of acres of diked wetlands that are managed principally for duck hunting. Restoration plans for Suisun will need to be coordinated between the San Francisco Bay and delta regions, given the overlapping authorities of the Bay Conservation and Development Commission, the Delta Stewardship Council, and their respective planning documents. The Suisun Marsh Management and Restoration Plan is a key guiding document for Suisun Marsh.

Coyote Hills Regional Park

The other three subregions also provide opportunities for reaching the habitat-acreage goals. In the North Bay, much future restoration is already planned, but some large agricultural areas in the northwest area of the subregion could be considered for restoration. Less opportunity exists in the Central Bay, where the baylands are constrained by steeper slopes and extensive urbanization, so smaller projects will be the focus there. In the South Bay, remaining commercial salt ponds totaling several thousand acres could, if made available for restoration, link the Alviso and Eden Landing portions of the South Bay Salt Pond Restoration Project. In order to better visualize potential restoration opportunities, the maps depict the distribution of agriculture as well as low- to medium-density and high-density development.

Changes in Habitat Configuration

While the Goals Project quantified the loss of baylands habitat extent, it could only describe the loss of habitat quality. As changes in climate and other ecosystem and land-use drivers challenge managers' ability to maintain extensive baylands acreage, the quality of the habitats becomes ever more important. Here we describe an analysis of marsh fragmentation.

The configuration of baylands habitats has changed dramatically since 1800. Tidal marshes have become more fragmented, with much more edge relative to interior or core areas and some isolated habitat patches. These changes in habitat configuration are common in modern landscapes and are likely to reduce some support functions for resident marsh wildlife above and beyond the loss in habitat extent. Against a background of severe habitat loss, fragmentation has reduced the baylands' ability to support wildlife by decreasing the connectivity between populations and increasing edge effects that promote predation and anthropogenic stress.

FRAGMENTATION OF TIDAL MARSHES

Due to extensive fragmentation of once-large, nearly continuous marshes, the average size of tidal marsh habitat patches has declined since 1800 (figs. 4, 5, and 8). Large marsh patches in the current baylands are primarily composed of wide marsh areas connected by narrow fringing marsh. The complex shape of these patches leads to a high proportion of edge habitat, where predation and other stressors are intensified (fig. 9). For this

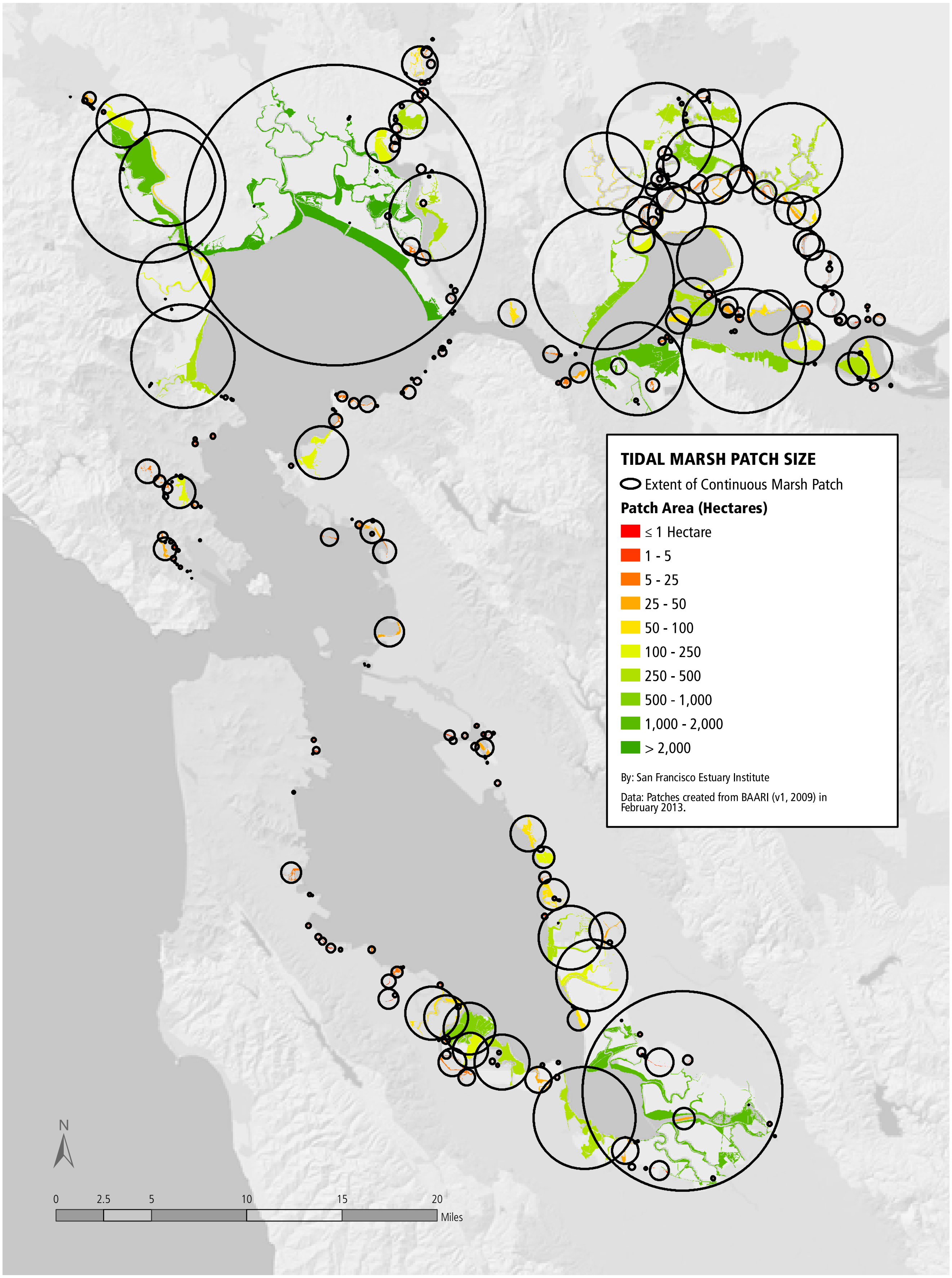


Figure 8 Tidal marsh patches by size in 2009. Each circle encompasses a patch.

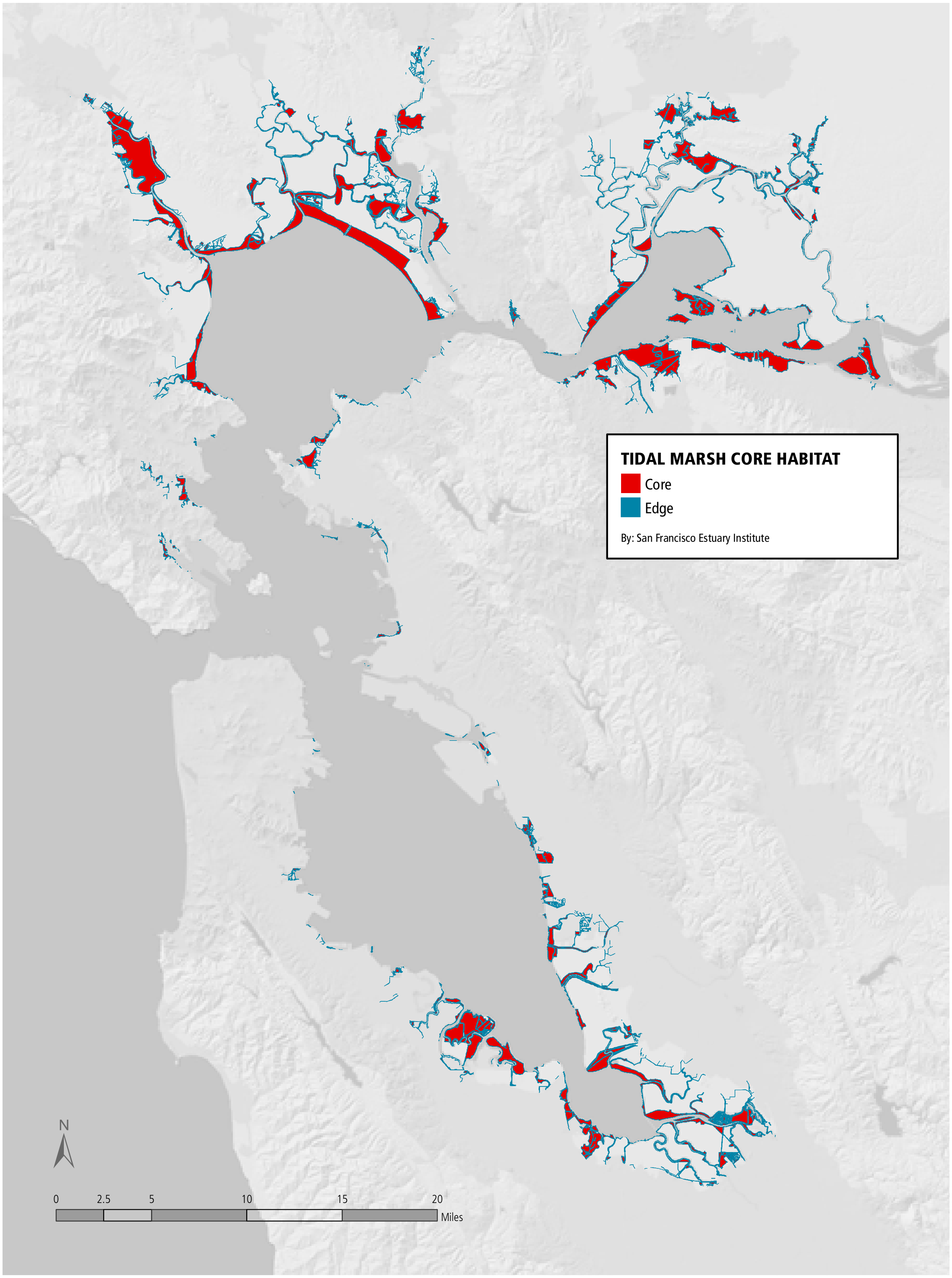


Figure 9 Core and edge tidal marsh habitat in 2009

analysis, *edge habitat* is defined as within 50 meters (164 feet) of the marsh edge, and the rest of the marsh interior is defined as *core habitat.* Also, habitat patches are considered separate if they are greater than 60 meters (197 feet) apart. For the justification behind these definitions, and for other details of this analysis, see appendix C.

Marsh fragmentation varies across the region (fig. 10). The Central Bay has the fewest, smallest, and most isolated marshes. The North Bay has the largest average marsh patch size (205 acres) and the largest marsh patch in the bay (8,518 acres; fig. 9). The South Bay has the second-biggest patch (4,655 acres) and second-largest

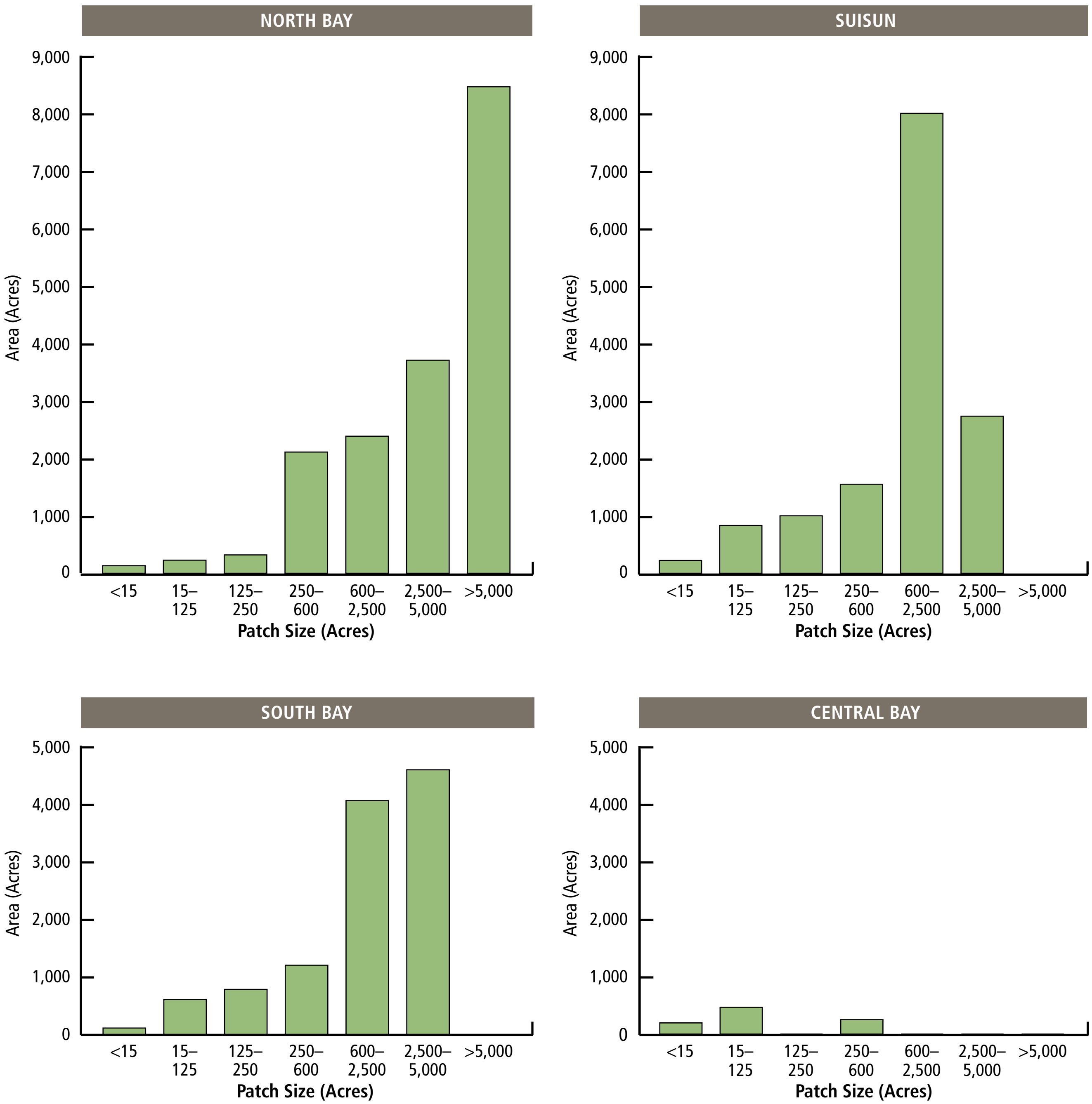


Figure 10 Total marsh area within each patch-size category for each subregion in 2009

Size, shape, and connectivity of patches are key to their habitat function.

average patch size (172 acres). The South Bay has a greater proportion of edge to core marsh habitat than either the North Bay or Suisun. The discontinuous fringing marsh in Suisun may account for the smaller average size of marsh patches in that subregion. While the tidal sloughs in North and South Bay appear to have filled in during the past 200 years, creating miles of fringing marsh, the channels in Suisun have not, for the most part.

Framing Future Change in the Baylands

Despite recent advances toward meeting the Habitat Goals, the extent of historical losses and the current level of fragmentation across the estuary remain significant vulnerabilities for the baylands' ecological functioning. At the same time there are new threats to the baylands from accelerating climate change. The climate will continue to warm, heat waves will increase in intensity and duration, sea levels will rise at least a few feet, and extreme storms and droughts are projected to become more frequent. Sea levels are projected to increase rapidly in the middle decades of this century, with the National Research Council projecting a regional sea-level rise for San Francisco Bay of 12 to 61 centimeters (about 4.5 to 24 inches) by 2050 and 42 to 166 centimeters (about 16.5 to 65 inches) by 2100. The long-term increase will include periods of both slower and more rapid change, driven by oceanic processes such as El Niño and the Pacific Decadal Oscillation (PDO). In particular, the cold phase of the PDO currently suppresses sea level. Sea levels will be enhanced when the PDO shifts to a warm phase (or when a strong El Niño occurs), exacerbating impacts on the baylands associated with higher seas.

Additionally, less precipitation will be stored as snow into the summer months, resulting in runoff that is higher in winter and lower in summer. These changes in precipitation may affect water-management practices and, consequently, a large portion of the freshwater inflows into the bay. These changes will not always be slow and steady; rather, a greater number of severe episodic events are projected to produce significant changes in the landscape on a short timescale.

The baylands are particularly vulnerable to the anticipated increase in sea-level rise, reductions in sediment availability, the stressors and limitations imposed by urbanization around the baylands, and other aspects of expected change (see The Dynamic Workings of the Baylands). Ultimately, the concern is that marshes and mudflats will drown, leaving only narrow, fragmented habitat patches along the shoreline. Such patches would be squeezed up against levees and seawalls with development behind them, exacerbating flooding and creating deleterious edge effects within the baylands. These impacts would be additive or synergistic with other stressors that may also increase, such as invasive species, contaminants, and reductions in freshwater inputs.

Future Scenarios Evaluated

Particular scenarios of change were evaluated as part of the Science Update. These scenarios represent the most current projections published in the peer-reviewed scientific literature. The scenarios were built around climate-change and marsh-accretion models, emissions scenarios, and sediment supply. The uncertainty inherent to these future projections was addressed by selecting scenarios that bracketed the low and high ends of key drivers. All workgroups assessed the same scenarios using a standardized approach. The scenarios were based on (1) the newest estimates for sea-level rise for the California coast from the National Research Council, (2) the Marsh98 accretion model applied across the full Goals Project area, and (3) two climate-change scenarios from the US Geological Survey Computational Assessments of Scenarios of Change for the Delta Ecosystem (CASCaDE) project, downscaled for this region, that were selected to roughly bookend a range of possible climate outcomes for the bay–delta ecosystem. The CASCaDE projections included extreme weather events.

To develop the scenarios, the Science Update first examined the results of the CASCaDE modeling, which project that the San Francisco Estuary will have

- an increase in air temperature
- an increase in the salt content of water
- a possible decline in precipitation (with little chance of an increase) and runoff, and a very likely decline in snowmelt contribution to runoff
- earlier runoff, as precipitation is not stored in snowpack for as long
- possibly lower suspended-sediment concentrations (very unlikely to increase)
- an increase in the frequency of extreme environmental conditions, such as higher water temperatures, higher storm surges, higher flood peaks, and possible droughts

Given these results, the workgroups considered five scenarios for conditions in the year 2110:

- Scenario 1—low sea-level rise (52 cm, 1.7 ft), low sediment
- Scenario 2—low sea-level rise (52 cm, 1.7 ft), high sediment
- Scenario 3—high sea-level rise (165 cm, 5.4 ft), low sediment
- Scenario 4—high sea-level rise (165 cm, 5.4 ft), high sediment
- Scenario 5—severe storm event

The workgroups evaluating scenarios 1 through 4 were asked to consider projected changes in tidal marsh under different sediment and sea-level rise conditions and the range of other climate-change factors bookended by the two CASCaDE scenarios.

Scenario 5 was a projected storm event taken from the long-term CASCaDE projections. The storm resembles the flood of 1986, consisting of back-to-back atmospheric river events. This scenario calls for a large storm with heavy precipitation coinciding with a high tide. It is representative of water levels that will become more frequent over time as sea levels rise.

For more details about these scenarios, see appendix D.

THE DYNAMIC WORKINGS OF THE BAYLANDS

The likely effects of the scenarios described above on the baylands and their wildlife will be mediated by the processes and drivers that form, maintain, and influence the ecological functioning of the baylands. The following discussion summarizes our current understanding of these processes and drivers, building on detailed information found in Science Foundation chapter 1. The restoration approaches presented in this report are based on these processes.

Natural Processes Conferring Resilience on the Baylands

The San Francisco Bay's evolution during the historical and late Holocene periods suggests a strong potential for resilience to climatic variation and helps identify the challenges and opportunities for human intervention that could enhance this adaptive capacity. Tidal marshes emerged around the edge of the bay 2,000 to 3,000 years ago, after rates of sea-level rise slowed to 1–2 mm/year. Marshes in south-central San Francisco Bay date from 500 to 1,500 years ago, while expansion of marshes in the southernmost bay dates from 200 to 700 years ago. The earliest stages of salt marsh development indicate instability as sea-level rise gradually slowed. Alternating layers of sediment from that time period (observed in cores taken from deep below present-day marshes) show that marshes were formed, then became mudflats or subtidal areas when the sea level rose, then re-formed again when they were able to build up faster than the rate of sea-level rise. These data indicate that tidal marshes in San Francisco Bay can withstand rates of sea-level rise greater than currently exist (2–3 mm/year), as long as sediment availability is relatively high and other factors, such as subsidence, remain relatively constant.

The estuary's tidal marshes have been responding to wide swings of climate and extreme meteorological events during their 2,000- to 3,000-year history. Analysis of carbon-stable isotopes, pollen, plant macrofossils, and other indicators of salinity in sediment cores reveals that Suisun and San Pablo Bay marshes have alternated between brackish and saline marsh vegetation over multiple-century intervals of warm and dry or cool and wet climate. The wildlife species associated with these marsh salinity gradients and habitat configurations either adapted rapidly when the climate changed or moved across whole subregions of the estuary, persisting for centuries before abruptly moving again with the next climate shift. Wildlife was able to persist through these large shifts likely due to factors that conferred resilience on the baylands ecosystems, including habitat connectivity, uninterrupted sediment supply, and adjacent transition zone migration space. This history demonstrates that the baylands and their

American avocet

Managed ponds provide diverse habitat functions.

wildlife can withstand significant environmental changes when natural landscape processes are intact.

The natural processes that confer resilience on the baylands have been interrupted, altered, and reduced by development and other human activities over the past few hundred years. Human activities have severely constricted baylands habitat extent, fragmented habitat patches, altered sediment supply, and cut off transition zone migration space with levees and development. At the same time, urbanization of the region has created many stressors to wildlife populations. These include contaminants, invasive species, nonnative predators, native predator populations augmented by human food subsidies, and direct disturbance by people and domestic animals. Meanwhile, California's climate since 1850 has been unusually stable and benign, compared to climate variations during the previous 2,000 or more years. Thus, our negative impacts to the baylands have occurred during a time when the baylands have not needed to respond to climatic shifts in order to persist.

A major climatic shift is now under way and is projected to increase in magnitude. To enable the baylands and their wildlife to persist through this shift and provide the ecosystem services the community relies upon, the natural processes that make this ecosystem resilient must be reinstated, enhanced, or replicated. The following sections describe actions that will enhance these natural processes.

Complete Tidal Wetlands

The baylands are a dynamic continuum of habitats connected by physical and biological processes; they extend from the open waters of the bay through intertidal mudflats, tidal marshes, and adjacent terrestrial areas. Less extensive habitat types, such as beaches and rocky intertidal areas, are also important parts of the baylands, and each habitat type has variation and complexity, as well as transitions between it and the adjacent habitat type.

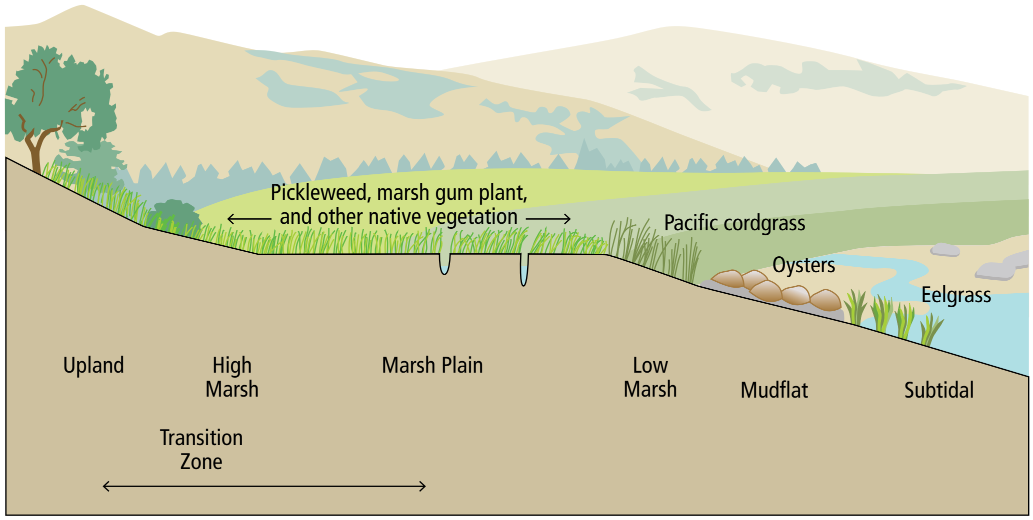


Figure 11 Schematic of the complete tidal wetland system.

Given the complexity of the tidal conditions and freshwater inputs to San Francisco Bay, drawing boundaries between the functions of the open-water bay, mudflats, tidal marshes, and estuarine–terrestrial transition zone is difficult and sometimes arbitrary. A more accurate way to consider this continuum of habitats involves the concept of a "complete tidal wetland system," which emphasizes all the aspects of the baylands ecosystem and the full gradient of ecological functions and ecosystem services (fig. 11).

Although diked baylands are not natural features, some do provide significant habitat value, particularly ponds that are managed to support wildlife. Restored and extant tidal marshes may not provide all the habitat functions currently provided by managed ponds. Therefore, these managed habitats must be included in any plans for restoring complete tidal wetlands systems.

The concept of complete tidal wetlands systems is discussed more fully in Science Foundation chapter 1, and the many habitat types that make up the baylands are described in appendix E and in the 1999 Goals Project.

Natural Processes Governing the Extent of Marshes

As previously noted, tidal baylands are dynamic and evolve over time. The processes that govern the extent of tidal baylands are particularly important now, given that climate change and other drivers threaten to convert a large proportion of the baylands into subtidal areas that do not provide the same ecosystem functions and services. A number of physical processes that govern the evolution of tidal baylands are defined for this report as follows:

- *Migration* (also called transgression) is the movement of baylands upslope into their watersheds. Migration is governed by sea level, hydrology, sediment supply, plants, topography, and subsidence.
- *Erosion* is the loss of tidal baylands due to the loss of sediment from their surfaces or edges. It can be vertical or horizontal. Most horizontal erosion occurs at the boundary between tidal baylands and subtidal areas due to wave action.

- *Progradation* is the extension of new baylands into the bay when subtidal areas are converted to intertidal elevations. Progradation is governed by sediment supply, intertidal plant and animal populations, and the nature of erosive forces along the boundary between tidal and subtidal areas.
- *Drowning* is the conversion of baylands to habitats lower in the tidal frame (e.g., marsh changing to mudflat or mudflat becoming subtidal).
- *Accretion* is the vertical buildup of marshes with inorganic sediment and organic matter (mainly peat). Accretion can prevent drowning and can convert lower tidal baylands to higher tidal baylands. For example, accretion can convert subtidal areas to tidal flats, and tidal flats to tidal marsh, as observed in many restoration projects in the bay.

These processes apply to tidal wetlands systems in general. Here, they are discussed mainly in relation to tidal marsh, which was the dominant habitat in the baylands historically and is now the focus of much restoration effort. The major drivers of tidal marsh evolution are elevation, plants, inorganic sediment supply, peat accumulation, incident wave energy, migration space, and the rate of relative sea-level rise.

Diked baylands are divorced from the natural tidal processes that confer resilience on tidal baylands. Some diked baylands are subject to processes like shallow subsidence (which occurs when organic sediments dry out and oxidize) and wind erosion (which can occur when the desiccated sediments are plowed, raked, disked, or graded). See section, Diked Baylands for more on the future of diked baylands.

MIGRATION AND SQUEEZE

The topography landward of tidal baylands is a key factor in determining how far the baylands can migrate as sea levels rise. Similarly, the width of river and stream channels and the extent of their floodplains determine how far tidal baylands can migrate upstream. Steeper lands, levees, and other constructions along the landward boundary of tidal baylands constrain migration. Where migration is not so constrained, it is influenced by factors that include the relative rate of sea-level rise, suspended-sediment supply, freshwater inputs, the rate of colonization by tidal marsh vegetation, and organic matter accumulation. Terrestrial soils may not be conducive to marsh plant colonization, due to problems with soil fertility, salinity, bulk density, or permeability, which could limit the dispersal and recruitment of vegetation and, thus, the rate of marsh migration.

As the rate of sea-level rise increases, the upland topography adjacent to marshes plays an increasingly important role in allowing or preventing the landward migration of tidal baylands. Eventually the baylands could become squeezed between expanding subtidal areas and steep uplands or built environments with steep levees. The opportunities to accommodate broad areas of evolving tidal baylands due to migration are greatest in the less developed valleys around the bay. Protecting and expanding these opportunities is critical to ensure ongoing ecosystem services from the baylands.

A recent analysis of undeveloped shoreline areas across which baylands may need to migrate, given a 1.4-meter (4.6 foot) sea-level rise, shows that a little over one-third (36 percent) of this area is protected as open space, while the remaining 64 percent is privately held and subject to future residential and commercial development (fig. 12). These results highlight the importance of a holistic and directed effort to identify, plan for, and conserve baylands migration space.

EROSION AND PROGRADATION

The bayward edge of the marsh erodes or grows (progrades) horizontally depending on the energy and direction of waves produced by the wind (wind waves), sediment supply, vegetative structure, and sea-level rise. Mudflat governs many of these conditions at the bayward marsh edge, as the extent and depth of mudflat influences the size and energy of waves reaching the marsh and regulates its contribution as a local source of sediment. Thus, mudflats and marshes are interdependent parts of the complete tidal wetlands system. Mudflats dampen and regulate offshore waves, causing the waves that reach the marsh to be relatively constant in height for a given water depth.

Mudflat slope and shape thus control to some degree the balance between marsh erosion and progradation. A combination of sediment supply and wave energy determines the shape and elevation of the mudflat. If mudflat elevation does not keep up with sea-level rise, more wave energy will reach the marsh edge, leading to erosion and loss of marsh extent.

Drowning and Accretion

The sum of two interconnected processes, inorganic matter accretion and organic matter accumulation, determines the ability of a marsh to grow vertically with sea-level rise. Both processes affect and are affected by marsh elevation relative to the tide. Salinity is also a key driver of organic matter accumulation. Peat accumulates faster in freshwater marshes, and the accumulation rate decreases as salinity increases.

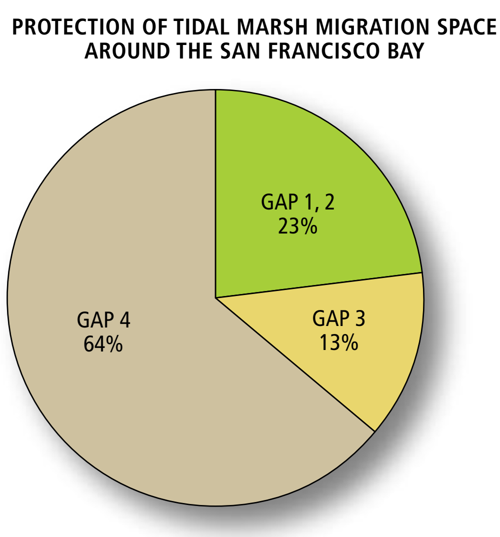


Figure 12 Analysis of GAP (National Gap Analysis Program) status of undeveloped lands within the footprint of the baylands. GAPs 1 and 2 indicate high levels of resource protection, 3 moderate levels, and 4 no protection. Adapted from Kirk Klausmeyer, The Nature Conservancy.

Box 3 Lessons Learned: The Evolution of a Big-Picture Vision of Restoration

The Goals Project advanced the region's collective ability to accomplish ecosystem-scale restoration, despite no one entity having had the resources and expertise to conduct large-scale habitat protection and restoration projects comprehensively. Projects are managed by a range of agencies and nongovernmental organizations on both public and private lands. Therefore, partnerships, coordination, and the application of lessons learned from one project to another are essential.

Restoration practitioners have now completed over 80 distinct habitat restoration and enhancement projects in the baylands. During the course of planning, designing, permitting, constructing, monitoring, and implementing adaptive management, a number of lessons have been revealed:

- Modeled impacts of habitat conversion have shown that maintaining and managing water levels and salinity in select ponds can be critical to the survival of some of the more common wildlife species.
- Techniques can be employed to make restored tidal marsh much more beneficial to waterbirds, offsetting the losses of saline pond habitat.
- In subsided areas, accurate elevation maps are essential for designing future projects and determining whether to add clean fill material.
- Sediment is an essential resource for raising elevations to marsh plain level in many projects.
- In some locations, enhancing the existing tidal marshes can be less expensive and can provide direct benefits to wildlife more quickly than can large-scale restoration.

The Goals Project's findings themselves have moved us toward the integrated vision presented in this Science Update, for example by:

- Documenting 27 miles of sandy beaches in the bay before European development and recommending that these forgotten features be an important component of baylands restoration. We are starting to reestablish beaches, not just for native plant and bird habitat, but also as dynamic, self-adjusting buffers to wave energy.
- Recommending the establishment of tidal marsh corridors along the salt-to-fresh gradient at the mouths of creeks due to their importance for the delivery of sediment and freshwater. Whether natural or artificial, these nodes are now recognized as some of the most valuable and resilient places for marsh conservation.
- Emphasizing the importance of the tidal–terrestrial transition zone; in light of sea-level rise, such transition zones are of critical importance to the future of our marshes.

Today practitioners meld these lessons to consider how a project will interact with other wetlands and infrastructure to function as part of the larger landscape.

New Chicago marsh at sunset

There is a strong feedback loop between the inundation regime (frequency, depth, and duration of tidal flooding) and plant productivity, which drives organic matter accumulation rates. Peak plant productivity occurs when the marsh plain is at or just below the marsh plain elevations of stable marshes. As a result, a slight increase in inundation may lead to an increase in plant productivity, as long as the initial marsh plain elevation is above the elevation of peak productivity. A large increase in inundation, on the other hand, would cause plant productivity to decline, leading to a further loss of relative elevation and even greater inundation, because of reduced organic matter accumulation.

This process drives, in part, the recommendation to restore marshes as early as possible, allowing them time to grow as high into the tidal frame as possible, to give them a "leg up" on the sea-level rise that will accelerate in the second half of the century. This leg up is more formally known as *elevation capital*. Elevation capital is determined in large part by comparing the absolute elevation of a marsh with the local water levels and tidal range. Most tidal marshes in the baylands are dominated by mid- to high-marsh vegetation and are at the upper elevation range for tidal marsh ecosystems. Their relatively high elevation gives them substantial elevation capital, which should help these marshes maintain their elevation in the tidal frame for a while.

While accumulation of organic matter is important, especially in the brackish parts of the estuary, inorganic sedimentation is the primary process for San Francisco Bay marshes to accrete vertically with rising sea levels. Inorganic sedimentation increases as a marsh falls lower in the tidal frame and the depth of water over the marsh increases, in contrast to accumulation of organic matter. This relationship is why sediment often accretes rapidly at newly restored sites, especially at sites that are subsided, because mineral sedimentation is much greater at lower elevations. The inorganic sediment supply, which also affects the vertical accretion rate, is a function of the suspended-sediment concentration in the water column, depth of water, and period of high water. Inorganic sediment supply depends on local conditions as much as on the supply of sediment from the delta and other baylands watersheds (particularly via local stream sediment inputs), the resuspension of sediment from adjacent mudflats, and the suspended-sediment concentration in nearby tidal waters. For inorganic sedimentation, the higher the suspended-sediment concentration and the deeper the water over the marsh, the greater the amount of sediment available in the water column to be deposited. This positive feedback loop can help maintain marshes as the sea level rises, as long as there is sufficient fine sediment.

Tidal marsh plants colonizing Mt. Eden Creek mudflat

A well-developed tidal-channel network is important for delivering sediment to all parts of a marsh.

Mineral sediment deposition is highest closer to tidal breaches and bordering tidal channels, which leads to the creation of slightly elevated natural levees along sloughs. If there is insufficient tidal prism, due to filling of the marsh or diking, then channel networks may not fully evolve, resulting in poor habitat and low accretion rates at the back of the marsh away from the channels. Lowering any bayside levee is also important for delivering sediment to tidal marsh.

Complex channel networks are critical to the resilience of tidal marshes.

Presently, tidal marshes in the bay are accreting enough sediment to keep pace with sea-level rise. Average accretion rates across the region are about the same, although accretion at individual sites varies according to local conditions. Marshes can grow vertically very rapidly, much more rapidly than the average accretion rate, when enough sediment is available and accretion is stimulated by the marsh being lower in the tidal frame—as witnessed by the ongoing need to dredge marinas around the bay. This history of keeping pace with sea-level rise has coincided with a period of relatively low rates of sea-level rise as well as high sediment supply. This period may have ended, judging from a step-change reduction in suspended-sediment concentrations that was recently observed in the estuary (see below).

Key Physical and Chemical Drivers

Several physical and chemical drivers affect both how the processes described above occur and also how the baylands function ecologically. These drivers are summarized below, leading into the analysis described in the section Projected Evolution of Baylands Habitats.

SEDIMENT SUPPLY, DEMAND, AND TRANSPORT

The processes that affect the amount of sediment available to any marsh or mudflat in the baylands are changing. Sediment supply historically increased but has since declined due to human actions in the estuary's watershed. Both the local watersheds around the bay and the delta's watershed are important in determining sediment supply to the bay.

Beginning in the early 1800s, intensive ranching and farming in local watersheds around the bay greatly increased runoff, which initiated a period of chronic erosion

Sediment rich waters enter from the bay.

of the land surface and stream channels that persisted unchecked into the 20th century. Urbanization caused additional increases in runoff and stream erosion. In the mid-1800s, extensive hydraulic mining in the Sierra Nevada mobilized large volumes of Sierran sediment to the eastern, northern, and central areas of San Francisco Bay. Areas of the bay south of the Golden Gate were less directly affected by this large pulse of Sierran sediment, but were still affected by increased local sediment supplies. During this same period, vast areas of tidal baylands were reclaimed for ranching, farming, and other uses. There was, therefore, less intertidal area for the suspended sediment carried by the tides to be deposited and stored. In response, tidal marshes and mudflats rapidly expanded, due to the abundant supply of and diminished demand for sediment. The tidal reaches of rivers and streams shoaled and narrowed, and once naturally deep harbors had to be dredged.

The supply of suspended sediment to the baylands has since greatly diminished. Today, local runoff and land surface erosion are much better managed. Channel erosion, while still a problem for many local rivers and streams, has been curtailed by bank revetment and flow regulation. Sediment entering large and small rivers and streams is often trapped behind dams and in flood-control bypasses. Many of the flood-control channels built during the last half of the past century shunt their sediment directly to subtidal areas, past the tidal baylands that need the sediment to counter sea-level rise. The massive pulse of sediment from Gold Rush mining in the Sierra Nevada has waned. Environmental laws and policies designed to protect the tidal baylands from being diked or filled, and the economics of dredging and transporting sediment, complicate its use to restore or create tidal baylands. Some subtidal areas of the bay show evidence of getting deeper, due to erosion of the bay bottom. Net erosion or drowning of the tidal baylands is not yet evident. However, one overall effect of current land-use policies and practices is that the supply of suspended sediment for tidal baylands, especially tidal marshes, is less now than anytime in the past 200 years.

The demand for sediment to protect and restore the tidal baylands is increasing. Sediment is needed not only to counter the effects of sea-level rise, but also to restore tidal marshes, which often require significant sediment volumes to achieve the right elevations for sustaining intertidal habitats, particularly in subsided areas of diked baylands. Subsided diked baylands that are accidentally breached will act as large sediment sinks that could detrimentally affect sediment supplies for nearby tidal baylands and restoration projects.

Unfortunately, this reduction in sediment supply exacerbates the problems the baylands face from sea-level rise. Increasing the sediment available to the tidal baylands is probably essential for their survival. An enhanced understanding of the balance between sediment supply and demand, and how that balance is mediated by sediment transport, is critical. A systematic program of investigation could determine where and how sediment should be managed in different subregions of the baylands. For example, a recent study found that the lower South Bay, where suspended-sediment concentrations are high, may have enough sediment to keep pace with sea-level rise if diked baylands are not restored. However, when the additional demand for sediment under various marsh restoration scenarios is factored in, sediment supply may not be able to keep pace with demand. Sediment supply and the actions that can be taken to increase the sediment available to the baylands are discussed in more detail below, in Science Foundation chapters 1 and 2, and in the recommendations chapter that follows this one.

Restoring sediment flows to the baylands.

FRESHWATER FLOWS

Freshwater flow from the delta is the predominant control of the primary salinity gradient in the bay on timescales of a week or longer. It is a critical variable for biological processes. Salinity determines the tidal marsh plant community composition and habitat quality and suitability for many aquatic animals. Delta outflow is positively correlated with the abundance of several key populations of fish and crustaceans in the northern estuary, notably longfin smelt and striped bass, a nonnative but recreationally important fish.

The vast majority of freshwater flow into the bay comes from the delta. Only about 1 percent comes from local streams and wastewater treatment plants. However, these local freshwater inputs often have important consequences for the neighboring baylands. Inflow from the delta results from a complex combination of the quantity, timing, and location of precipitation, snowpack melt, groundwater and reservoir flows, net consumption in the delta, losses to evapotranspiration, and exports from the southern delta.

Future runoff from the Sierra is projected to peak earlier in the year, owing to less precipitation falling as snow and more falling as rain that immediately runs off, along with an earlier melt of the snow that does accumulate. Increasing human population will drive greater demand for the now-reduced summer runoff, possibly leading to more upstream storage and diversion. An increase in human demand for freshwater could be offset to some degree by more efficient water use, the fallowing of lands, or changes in cropping patterns.

Local freshwater flows will have important consequences for the baylands.

TEMPERATURE

Air temperature in the Bay Area is projected to rise. Water temperature will track air temperature in the upper estuary, as it does now. Coastal ocean temperatures, however, may fall as a result of potentially greater upwelling. This contrast would result in a stronger thermal gradient across the estuary from the ocean to the delta in the summer and a weaker one in the winter. However, there is significant uncertainty in projections of upwelling. The severity and duration of extreme temperature events, such as heat waves, are projected to increase, while frost events are projected to become rare locally.

NUTRIENTS

San Francisco Bay has long been recognized as a nutrient-enriched estuary. However, excessive phytoplankton growth and accumulation appear to be controlled here largely by a combination of factors, including strong tidal mixing, light limitation due to high turbidity (muddy waters), and consumption by clams. These controls have helped keep the estuary healthy, maintaining dissolved oxygen concentrations in subtidal habitats much higher, and phytoplankton productivity and biomass substantially lower, than would be expected in an estuary with such high nutrient enrichment. In the future, these controls may be less successful, particularly as the water clears (discussion of decreasing sediment supply above) and water temperatures rise.

Tidal marshes play a role in improving water quality by cycling nutrients. How the baylands restoration will influence nutrient cycling is uncertain due to the system's variability and complexity. However, marshes are known to assimilate nitrogen, particularly in the form of nitrate. Wetlands can be highly effective at removing nutrients from wastewater. Therefore, marsh restoration can help reduce the projected impacts of anthropogenic nutrient inputs to the estuary by retaining and sequestering nutrients. Thus, restoration of marshes may enhance the resiliency of the baylands ecosystem with respect to human inputs of nitrogen.

SEA-LEVEL RISE

Sea-level rise will cause fundamental changes in the nature of the bay and baylands. As previously discussed, sea-level rise necessitates that the baylands and the transition zone migrate landward and upward into local watersheds. If sediment for accretion or space for migration is lacking, then this landward push could result in very narrow strips of baylands along the natural shoreline and levees. Sea-level rise will also move the salinity gradient up toward the delta, allowing ocean water to intrude further into the bay. This happens because deeper water increases the landward penetration of saline waters on the bottom of the bay. This tendency would be enhanced by lower freshwater flow in the dry season.

TIDES

The baylands are strongly affected by tidal waters that move sediment, nutrients, and organisms across habitats. Every few hours tides expose sessile intertidal plants and animals to strongly changing conditions, to which they are well adapted. Large changes in the geometry of the San Francisco Bay, such as would follow a levee failure

Box 4 Planning in the Face of Uncertainty: The South Bay Salt Pond Restoration Project Adaptive Management Plan

We face significant uncertainties in predicting how and when the effects of climate change will be felt along the bay's edge. Land managers, resource agencies, and regulators must develop flexible approaches to planning and permitting to support resilient baylands.

The South Bay Salt Pond Restoration Project (SBSPRP), a large-scale, long-term restoration effort, obtained all the necessary permits for implementation based on an adaptive management plan that commits the project to restoring a range of wetlands habitats. However, the exact mix of habitat types and extent will be determined by what is actually developing on the landscape over the next 40 years. By developing a preferred alternative that commits to a scientifically driven range of outcomes, the SBSPRP provides a model for a wetland restoration program that constantly takes in new information and adapts to changing conditions in the bay.

Development of the SBSPRP's Adaptive Management Plan

The SBSPRP was launched in 2003 upon the transfer of over 15,000 acres of Cargill salt ponds into public ownership. From the outset of restoration planning, the project partners understood the importance of developing a restoration plan and approach with both scientific rigor and broad public support.

The sheer size of the project required its science and consultant teams to grapple not only with the physical scale of restoration, but also with its progression over a 50-year period. The teams considered whether there was enough sediment in the bay to establish marsh in deeply subsided ponds, and whether marsh accretion could keep pace with uncertain amounts of sea-level rise. Uncertainty over how guilds of bird species would respond to large-scale habitat change similarly led the project partners to realize that the overall restoration plan had to be built on a strong foundation of science and adaptive management.

Early on, the issue of how much pond habitat to manage versus how much marsh development to encourage became foundational to the entire restoration effort. The participants issued a series of white papers on key scientific uncertainties facing this large-scale project over time and developed the concept of creating "bookend" alternatives for

A small dredge lock on Pond M12

in Suisun or the delta, would change tidal action, probably reducing it in many areas. A loss of tidal action, plus more ocean intrusion from sea-level rise and less freshwater flow, could shift parts of the bay toward a more lagoonlike system that is less directly coupled to river outflows, as currently seen in the lower South Bay.

California Environmental Quality Act (CEQA) purposes that establish ranges of restoration targets rather than specific targets. The determination of restoration targets as well as triggers for management action was predicated on this approach.

In the project's Environmental Impact Report and Statement, the high end of the projected range for tidal marsh restoration (90 percent) was set out as the preferred alternative. This was paired with a scientifically driven process to assess success along a continuum that remains at the heart of the approved adaptive-management plan.

Principles for Future Planning

The experience of developing and implementing the SBSPRP showcases four principles for Bay Area agencies and stakeholders to consider as they plan how to address sea-level rise and other drivers of change around the bay:

1. Plan for uncertainty: Allow agencies that are in the position of planning for or permitting future bay restoration or flood-management actions to use scientific and community stakeholder input to develop ranges of desired outcomes.
2. Increase tolerance for failure: One of the best successes coming out of the SBSPRP was that the project partners agreed to scientifically driven management that adapts to site conditions over time.
3. Support science and monitoring: Real adaptive management requires a commitment to learning through the funding of long-term science and monitoring. The expense and commitment of this approach may require both resource and regulatory agencies to consider innovative mechanisms for funding these efforts. The importance of monitoring needs to be made abundantly clear to funders, and barriers to funding need to be addressed.
4. Organizational transparency: The success of the SBSPRP to date is a result of the commitment of the project partners to ongoing organizational learning, active public participation, and transparency of both the planning and implementation processes. As one member of the project management team stated, it requires that a critical mass of partners be committed to continually "tend the consensus" to keep everyone on board.

Implementing these principles is easier said than done. A SBSPRP management team grapples continually with maintaining the long-term vision, funding the needed science, and tolerating unanticipated short-term outcomes on the landscape. The shared understanding of the adaptive-management approach needs to be constantly reinforced and revisited over time. Agency personnel and leadership can change, funding sources decline or change, and active community stakeholders change over time as well. Long-term adaptive management therefore requires a steady commitment on the part of all parties to recommit resources over time.

Most future wetland or coastal restoration projects in San Francisco Bay will be smaller in scale than the SBSPRP, and may not have the capacity to track large-scale climate change or population trends. This constraint will require regulators and policy makers to think creatively about how to measure and analyze trends in the bay across multiple small restoration efforts. Agencies and their stakeholders will have to cultivate flexibility and a higher tolerance for the possibility of failed experiments or ambiguous outcomes—on the promise of ending up on a more sustainable trajectory over the long term.

STORM EVENTS

An increase in the frequency of intense storms due to climate change could physically affect baylands habitats through flooding and erosion. Large storms create higher water in the bay from storm surge and freshwater outflow. Also, storm winds can cause higher waves in the bay, which reach the baylands with more energy because of the increased water depth. Thus, more intense storms could generate more powerful wind waves that increase erosion of the baylands. More erosion could occur both at the bayward edge of marshes and at the landward edge during very high tides.

The dynamic processes and key drivers that govern baylands evolution operate on multiple timescales, with some outcomes requiring decades to be fully realized. To sustain the local baylands ecosystem functions and services in the long term requires planning, preparation, and implementation in the near term. Thus, projections of what the baylands will look like after the drivers of change have influenced their evolution are necessary to guide decisions about which management actions to set into motion. This section summarizes the latest science on how the baylands are likely to evolve under different scenarios (see section Future Scenarios Evaluated, above) and details the types of actions that can be taken to influence that trajectory. It builds on detailed information found in Science Foundation chapter 2.

Tidal Baylands

The evolution of tidal baylands habitats could progress in a number of ways: through equilibration/dynamic stability, gradual evolution, or collapse.

- **Equilibration/dynamic stability.** Existing tidal marshes accommodate sea-level rise with a minor long-term conversion of tidal habitat types and a gradual landward migration. Gradual (historic) rates of sea-level rise and net-positive sediment budgets result in relative resilience. This stability is not likely to occur in a regime of rapidly increasing sea-level rise and neutral or negative sediment budgets.
- **Gradual evolution.** Tidal marsh habitats gradually submerge, with the following habitat-type conversions: high marsh transitions to mid marsh, mid marsh to low marsh, low marsh to mudflat, and mudflat to subtidal. Tidal marsh pans expand and tidal channels enlarge. The bayward marsh edge undergoes a progressive but slow erosional retreat, creating wave-cut marsh "cliffs," or scarps. The landward marsh edge experiences either levee overtopping, erosion, and breaching, or levee raising, armoring, and additional artificial bayland drainage (such as ditches). The "gradual evolution" progression is compatible with coastal climate-change adaptation through modification of the baylands.
- **Collapse.** Marshes convert abruptly to mudflats and subtidal areas. This worst case is associated with an early onset of sea-level rise at the upper end of projected rates. Sea levels would overstep marsh platforms, causing the wholesale drowning of marshes. Marsh plains initially respond by converting to low marsh but are ultimately lost as rapid marsh vegetation dieback creates extensive pans that "swallow" fragmented marshes, converting them to tidal flats. This is analogous to the contemporary tidal marsh loss in Elkhorn Slough in Monterey County, the Gulf of Mexico, and the Mississippi Delta. Rapid marsh-edge and levee erosion, increased flooding of diked baylands or undiked adjacent lowlands, and the rapid loss of critical high-marsh and transition zone habitats are likely to occur.

The next 50 years will probably see a variable mix of equilibrium/dynamic stability and gradual evolution, unless the sea-level rise rapidly increases due to abrupt changes in ocean temperature or ice-sheet collapse. Maintaining the existing marsh

Marsh and mudflat processes will experience changing equilibrium.

zones with no conversion would be an optimistic projection, because as marsh plain drainage decreases with submergence, so does marsh plant growth and vegetation height. Reduced marsh vegetation growth will mean less stem height and density for trapping and stabilizing suspended sediment and less production of organic matter in the soil.

Events like storms, droughts, and earthquakes that cause change in baylands habitats will probably punctuate any mix of equilibrium/dynamic stability and gradual evolution with more abrupt changes in particular locations. Erosion caused by more intense storms may be significant in some areas. In general, over the next century we expect climate change and other drivers to create a more dynamic landscape, with the location and nature of baylands habitats shifting more frequently than in the recent past.

RESULTS FROM MARSH-ACCRETION MODELS

The balance between sea-level rise and rates of marsh sediment accretion is critical to marsh sustainability. Several recent modeling efforts have investigated this balance, using different models, sites, and input parameters. All the results from these models are sensitive to the rate and magnitude of sea-level rise and the supply of sediment to the marsh. The future numeric values of both variables have uncertainty. The models were relatively less sensitive to the different scenarios tested for organic sediment accumulation.

Like all other models, they involve assumptions and structures that are simplifications of the complex processes in the natural world. Thus, between the uncertainty in the sea-level rise and sediment-supply input parameters, and the uncertainty inherent to the structures and assumptions, the models do not indicate what will happen. Rather, they provide a projection based on the best available science, with an output falling within a range of uncertainty.

The Marsh98 model, with the most comprehensive geographical coverage of the bay, was part of the basis of scenarios 1 through 4 (see Future Scenarios Evaluated). Across all sea-level rise and sediment-supply scenarios, the model projects an increase in mid-marsh habitat between 2010 and 2030 throughout the estuary, partly at the expense of high-marsh and upland habitat (fig. 13).

Between 2030 and 2050, the model projects an increase in low marsh and a decrease in high marsh and upland across all scenarios. For the high sea-level rise/low-sediment scenario (scenario 3), mid marsh also declines. In general, the area of tidal marsh is projected to remain relatively unchanged between 2030 and 2050, but the composition of the marshes is likely to change, with more low marsh and less mid and high marsh.

The outcomes of scenarios 1 through 4 become quite different when projected to 2110. The model projects an increase in mid marsh for low sea-level rise under either sediment assumption and for the high sea-level rise/high-sediment assumption (scenarios 1, 2, and 4). In contrast, the model projects a conversion of more than 90 percent of mid marsh and high marsh to low marsh, mudflat, or subtidal habitat in the high sea-level rise/low-sediment scenario (scenario 3). The model shows opportunities for unimpeded marsh migration, with 5,000 to 7,500 acres of currently terrestrial habitat potentially evolving to tidal marsh by 2110, depending on the scenario.

The potential impact on specific marshes can be seen in the Marsh Equilibrium Model (MEM) projections for China Camp (fig. 14). Increasing the rate of sea-level rise and decreasing the availability of sediment results in a greater loss of relative marsh elevation, with mudflat being the ultimate outcome in 2110 under the worst-case scenario.

The 2012 National Research Council report shows a projected range of sea-level rise between 40 centimeters (1.3 feet) and about 1.6 meters (5.4 feet) at 2100 for San Francisco Bay. The high and low ends of this range have very different ramifications for what happens to the marshes. Across various models, the results agree that at a low sea-level rise rate (e.g., 50 cm/century), the marshes can keep pace with the sea level, even with low sediment availability. However, with a sea-level rise greater than 100 cm/century and low sediment supply, there will be a decline in mid- and high-marsh habitat.

Diked Baylands

Many parts of the bay are not fully tidal, which limits their ability to evolve because they are isolated from the tides and the sediment the tides carry. The baylands were typically diked by constructing earthen berms along the margins of the marsh plains where they bordered mudflats or large tidal channels. The major types of diked baylands are diked wetlands (including duck clubs and other managed marshes), agricultural baylands, salt ponds, and managed ponds (which include storage and treatment ponds and ponds managed for wildlife). Salt ponds are located in the South Bay, managed ponds are largely in the North and South Bay, duck clubs in Suisun, agricultural baylands in the North Bay, and water-treatment ponds in the Central and South Bay.

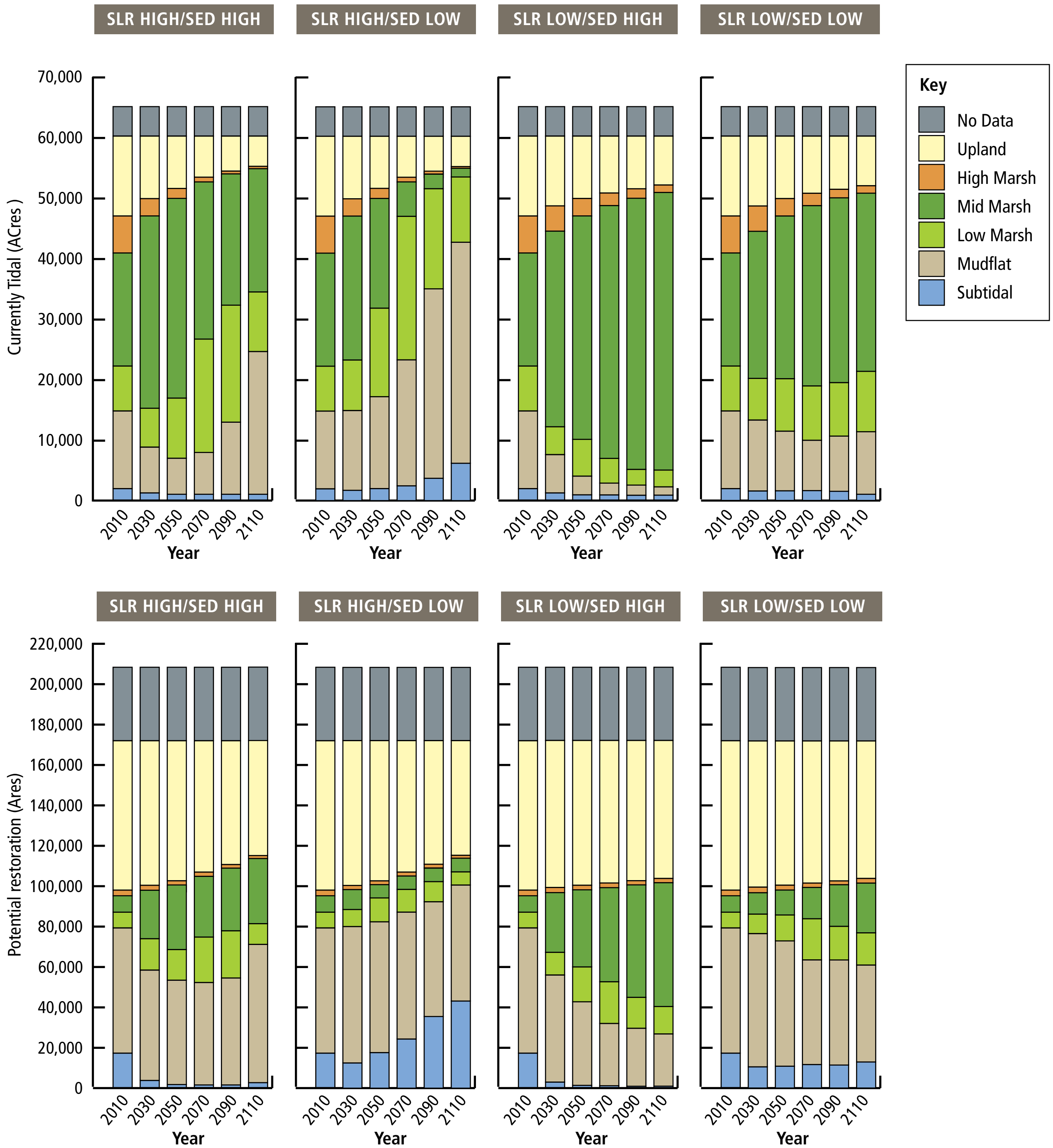


Figure 13 **Results from the Marsh98 model showing projected marsh habitat extents under different sea-level rise (*SLR*) and sediment supply (*SED*) scenarios for both current tidal areas and potential restoration areas.** Note the different *y*-axis scales. Adapted from Stralberg D et al (2011). Evaluating tidal marsh sustainability in the face of sea-level rise: a hybrid modeling approach applied to San Francisco Bay. *PLoS ONE* 6(11): e27388.

Although diked baylands are not natural features of the bay, some of them do provide significant habitat value that may not be fully replicated in tidal marshes, even if the goal of 100,000 restored acres is achieved. In addition to ponds managed for wildlife, diked baylands include duck clubs, muted tidal marshes, treatment wetlands, and mitigation wetlands. Diked habitat types and the wildlife species they support vary greatly, from large duck clubs to small mitigation projects to support endangered species such as the salt marsh harvest mouse. Diked baylands also feature significant urban areas, including airports and entire cities, and agriculture from hayfields to vineyards. These developed diked baylands weigh heavily in the planning for sea-level rise, requiring additional protections or land-use conversions that will shape opportunities for future baylands restoration and wildlife support.

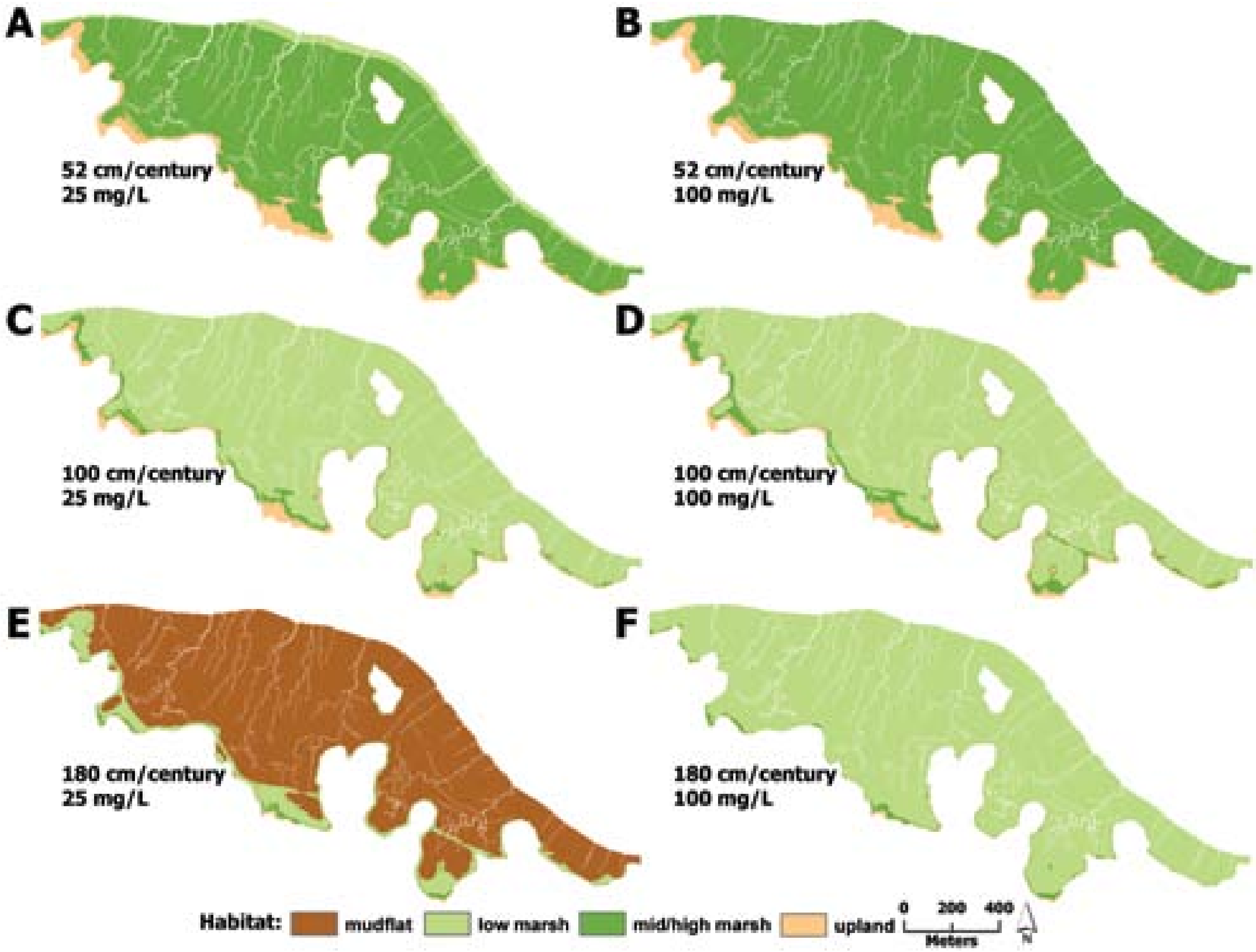


Figure 14 Distribution of modeled habitat types in 2110 from the MEM projections at China Camp marsh for various rates of sea-level rise (in centimeters per century) and suspended-sediment concentrations (in milligrams per liter). From Schile et al (2014). Modeling and marsh distribution with sea-level rise: evaluating the role of vegetation, sediment, and upland habitat in marsh resiliency. *PLoS ONE* 9(2): e88760.

The effects of climate change, particularly sea-level rise, challenge the long-term viability of managed baylands habitats. It is prudent to minimize reliance on managed systems, as these ponds are spatially fixed features in a bay that is dynamic and moving landward. Managed ponds in public ownership are already experiencing technical and financial challenges to sustain their expected performance. Even under low to moderate sea-level projections, the functionality of these managed systems will become increasingly difficult to sustain.

To control water levels and salinities inside the ponds for target species, the water-control structures and levees usually require specific elevations for water intake and outlet points. Intake water for managed baylands comes from the bay or adjacent freshwater sources, depending on the location and habitat goals of that pond. Climate-change-related stressors, such as higher water levels, a greater frequency and intensity of storm events, and regional salinity shifts, may make it difficult or even impossible in the future for managers to maintain target habitat conditions inside the ponds (fig. 15).

Considerations for Actions Related to Habitat Evolution

The following discussion details the considerations the science contributors looked at when developing recommended actions to take in response to the scientific findings summarized in the earlier parts of this section. The appropriate application of these actions will vary across the baylands depending on particular physical, chemical, and ecological settings. In each section of this science summary, we provide a brief introduction to the recommended actions relevant to that section, so that the reader can trace the scientific basis of the recommendations.

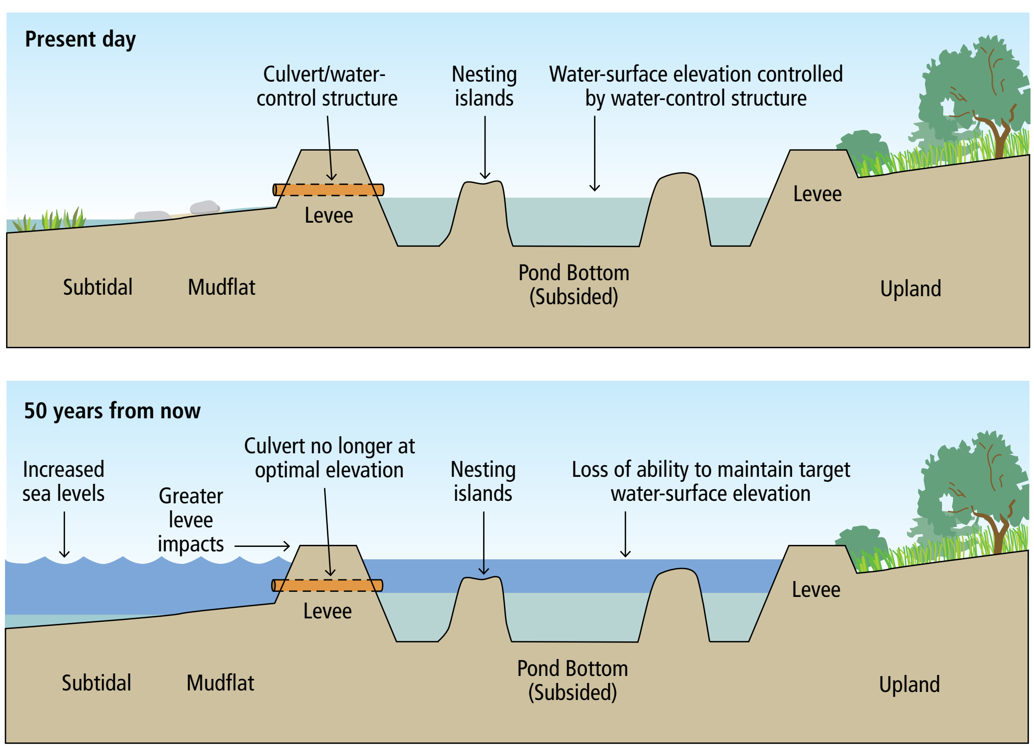


Figure 15 The impact of sea-level rise on managed ponds over time, from the present day (*T=0*) to 50 years from now (*T=50*). Water-surface elevation is controlled by the water-control structure.

TIDAL BAYLANDS

As sea levels rise, the extent of tidal marsh and mudflat can be influenced by the management of sediment supply and accretion, shoreline stabilization, space for landward migration, and the elevation capital of marshes. These are mostly relatively new variables for restoration and planning efforts, requiring a significant change in common practices.

Vertical Accretion and Elevation Capital

Management actions can increase the vertical accretion rate of marshes by increasing the supply of fine sediment, improving the pathways by which the sediment arrives to various parts of the marsh, or increasing the trapping of sediment on the marsh. Fine sediment can be introduced directly into the water column (a water-column recharge), on the marsh surface, or on the mudflat to be later resuspended by wave action and deposited onto the marsh by tidal and wave processes (a mudflat-and-marsh recharge). Direct placement of sediment in subsided areas has been done successfully in several areas of the bay, capturing 100 percent of the sediment placed. However, it is expensive to do. Recharging the water column and mudflats has considerable benefits, allowing the choice of when, where, and how much sediment to introduce into the system. However, mudflat and water-column recharges are untried in the bay and present significant permitting challenges, as they could have detrimental impacts to existing habitat and organisms.

Sediment sources from the landward side of marshes could be exploited as well. Options include placing clean fill material directly in subsided areas and changing watershed management practices to increase sediment inputs to the marshes or the bay. Significant amounts of sediment are trapped behind dams, and learning how to safely access and move those sediments and other watershed sources to the bay is worth consideration. Streams could be managed to sustain flows after a storm so that they transport silts and clays all the way to the bay. These types of changes to watershed management may require significant research into ways to increase sediment delivery to the bay without harming stream habitat or affecting management goals.

Sediment transport can be enhanced by reconnecting creeks and rivers to the landward side of marshes. Terrestrial sediment loads from local tributaries can contribute to local marsh accretion and extend natural river levees into tidal marshes (figs. 16 and 17). For example, the tidal marshes of Bolinas Lagoon persist or regenerate in confined reaches of the lagoon where sediment deltas are deposited by creeks. This pattern could be a guide for more resilient shoreline types in the bay; the alluvial fans of today are the tidal marshes of tomorrow. Sediment transport can also be enhanced by ensuring that marshes contain tidal channels of sufficient size and density to convey fine suspended sediment from the bay to the landward portions of the marsh, as well as by lowering any bayside levee. A co-benefit of complex channel networks is that they protect water quality by promoting circulation and maintaining adequate dissolved oxygen for aquatic species, while minimizing toxicity (pH and ammonia) and mercury methylation.

The trapping efficiency of fine sediment can be improved by increasing the density of vegetation through plantings, by constructing sedimentation fences or similar

Figure 16 Example of a broad natural levee extending into former tidal marsh

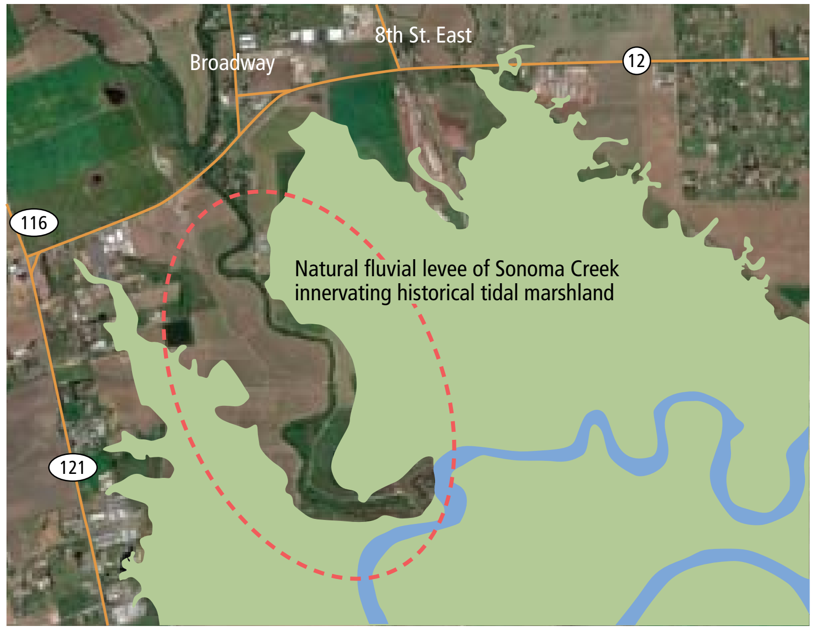


Figure 17 Example of a supratidal area caused by flood deposits of sediment on top of tidal marsh

features to emulate vegetation, and by retaining waters on the marsh surface for an extended period of time to allow more sedimentation to occur.

Restoration of tidal marsh can be timed and located to maximize elevation capital and long-term persistence. The timing is simple: the sooner the better, and ideally before 2030. Sea levels are projected to begin rising much more rapidly around midcentury. The sooner that diked baylands are restored to the tides, the sooner they can begin accreting inorganic sediment, and the sooner they can vegetate and begin accumulating organic matter. If sediment supplies are continuous, marshes established before 2030 will have 20 years to build up elevation capital while rates of sea-level rise remain moderate. Ideally, marsh plains would be a little higher than the maximum plant-productivity elevation (see Drowning and Accretion) before rising sea levels challenge them to accrete vertically as rapidly as possible. Marshes that can increase plant productivity may be able to keep pace with rising waters longer.

The siting and scale of restoration projects could include careful consideration of both long-term sediment supply and the tidal energy that influences sediment transport and deposition. Areas of the bay that have high concentrations of suspended sediment and a recent history of rapid accretion rates could be prioritized for tidal marsh restoration. Such areas include the deltas around rivers and streams with high sediment loads.

Planning for restoration actions and for the evolution of policies and regulations should also consider long-term sediment supply. Restoration managers can work with dredging projects that have both sediment availability and a regulatory requirement to reuse dredged sediment annually. Practitioners can begin accumulating and stockpiling material (either dredged material or upland fill) now for future use. Also, the innovative approaches discussed above need to be tested, monitored, perfected, and demonstrated in the local setting, which will require some changes in current policies and regulations.

Shoreline Stabilization Measures

The intent of these approaches is to slow the loss of tidal marsh due to erosion at the bayward edge, allowing the marsh to maintain its width for a longer time. Marsh erosion can be slowed through wave attenuation, which decreases wave energy on the marsh edge. Wave attenuation over the mudflat can be enhanced by elevating mudflats, increasing the bottom friction of the mudflat by planting submerged aquatic vegetation, and constructing low-crested breakwaters or berms, including living shoreline elements, such as shellfish beds. The marsh edge could be armored with a beach constructed of relatively coarse material and then stabilized with structures such as groins and headlands constructed of large woody debris or rock.

Coarse gravel beaches are a natural form of shoreline that can adjust to local wind-wave conditions and water levels even during extreme wave events. Unlike typical engineered revetment systems, such as riprap, the movement of cobble and gravel is an inherent characteristic of a coarse beach and not an indication of failure. Coarse beaches tend to erode less than fine-sand beaches, even gaining material in some cases. The sloping, porous coarse beach, once prevalent in the Central Bay, is able to dissipate wave energy by adjusting its shape in response to the prevailing wave

Enhancing channel and sedimentation dynamics will improve long-term marsh resilience.

conditions. This approach would provide the geomorphic foundation for a gradual migration and ecological transition of native vegetation and habitats associated with the bayward marsh edge.

Low-crested berms constructed from coarse gravel or oyster shell are potential alternatives to conventional armored breakwaters. These would be able to accommodate a rising sea level by naturally rolling landward, driven by wave forces. They may also enhance rather than conflict with ecological and aesthetic objectives for tidal wetland systems and provide additional recreation benefits. For typical nearshore conditions in the East Bay, such berms could reduce wave heights by 10 to 70 percent during normal tidal conditions, which could significantly reduce horizontal erosion rates. The height, width, length, and distance offshore of the berms would determine the amount of wave attenuation and the amount of marsh they would protect.

Migration-Space Measures

Future migration space for the baylands is contained in the estuarine–terrestrial transition zone. Below, Connections to the Watersheds: the Estuarine–Terrestrial Transition Zone details ways to create and restore the transition zone to foster landward migration of the baylands.

Another strategy complementary to restoring and creating a transition zone is to realign bayfront flood-risk-management levees further inland to allow marshes and mudflats to transgress landward naturally. Realignment takes advantage of the physical protection provided by marshes and mudflats to reduce the risk of flooding and

PERSPECTIVES FROM THE STEERING COMMITTEE

Box 5 Planning to Implement Recommendations for Regional and Subregional Goals

The Science Update recommends that restoration projects be coordinated at the regional and subregional scale. The 2003 acquisition of 15,500 acres of Cargill ponds enabled restoration planning to take place at a subregional scale, with the South Bay Salt Pond Restoration Project representing about 90 percent of the restoration opportunities in the South Bay.

Coordinated planning between project sites in other subregions of the estuary is more challenging, as projects are smaller in acreage, are managed and funded by a variety of land managers and restoration partners, and don't have the advantage of simultaneous timing for funding, planning, and permitting.

Where coordinated planning isn't always feasible geographically, it can be achieved programmatically. Resource managers representing more than 25 landowning and scientific partners of the San Francisco Bay Joint Venture have been using a structured decision-making process to predict and analyze implications of habitat-management decisions that implement the Goals Project recommendations, both near term (present through 2029) and longer term (2030–2100). Climate-change projections and expert elicitation informed a process that led to measurable attributes, resource allocation implications, and, for the first time, quantified predictions and trade-offs to address climate change in multiple habitats.

Such decision-support tools and models can build confidence in management decisions on a regional and subregional scale. Concurrence of measurable targets of biological integrity can inform true adaptive management and become the basis for informing trade-offs and prioritizing investments both regionally and subregionally.

erosion, allowing smaller levees to be built (fig. 18). The presence of a tidal marsh can reduce storm-wave heights at the landward edge by over 50 percent, depending on water depth and marsh width. Thus, tidal marsh with a smaller levee at the landward edge can provide the same level of flood protection as a larger levee not fronted by tidal marsh. It may be more cost effective to build a flood-risk-management system that incorporates a tidal marsh than to build only a conventional earthen levee.

DIKED BAYLANDS

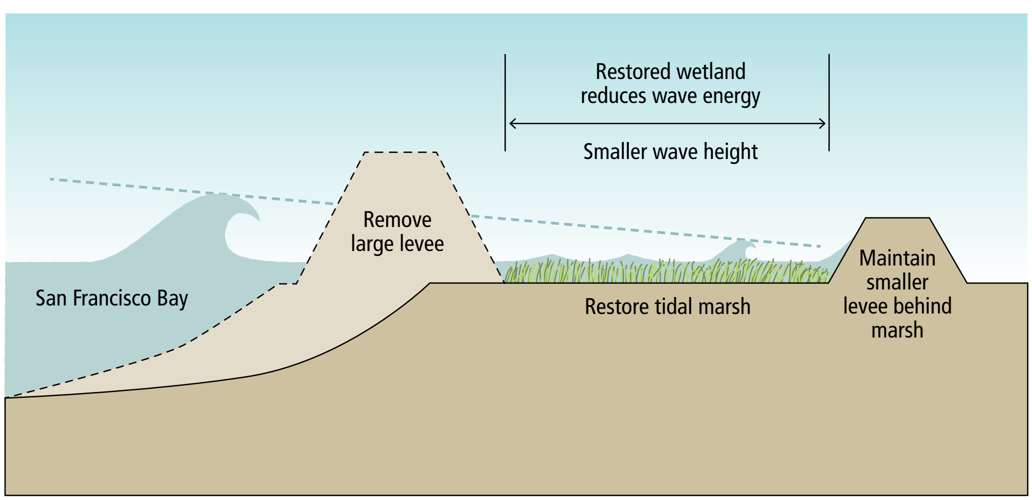
Management actions, some of them novel, will be needed to sustain target habitat conditions inside managed ponds and marshes over time. Levees will come under pressure, either due to increased overtopping of the crest or direct erosion of the levee itself. The most immediate action would be to raise or reinforce existing levees to keep unregulated tidal waters out and retain the ability to control internal water levels. Another approach would be to take advantage of outboard tidal marshes or other site-specific protection opportunities where there are opportunities to do so.

Furthermore, to sustain water-management capabilities, water-control structures would probably have to be modified, added, or replaced, and managed ponds and marshes may become more reliant on the pumping of water as opposed to more passive gravity-driven configurations. In more extreme cases, managed retreat may be appropriate for some of these areas, requiring the relocation or abandonment of diked baylands in areas of higher threat from sea-level rise. Abandoned ponds could then be converted to other (likely tidal) habitat types, after the need for additional flood protection at the specific location is evaluated.

Innovative approaches to making managed ponds and marshes more resilient could be pursued for retrofitting existing diked baylands or constructing new ones. These might include designs for more flexible water-control structures or water-management configurations that can accommodate changes in sea level. Also, there may be ways to allow the bathymetry of managed ponds and marshes to rise with sea levels by capturing sediment, which could ameliorate the need for reinforcing levees and pumping water.

Habitat types will naturally shift over time due to sea-level rise, salinity changes, and restoration. To ensure that the habitat needs of waterbirds are being met, a

Figure 18 Example of a levee realignment, coupled with tidal marsh restoration



large-scale, long-term planning and monitoring effort across the bay, delta, and Central Valley (and ideally the rest of coastal California) is needed. The reliance of Pacific Flyway waterbirds on baylands habitats is partly due to the extensive loss of wetlands in the Central Valley (particularly the delta) and other parts of coastal California. For more on this topic, see Science Foundation chapter 5.

MANAGEMENT ACTION STRATEGY

Choosing which actions to implement will require a consideration of trade-offs between competing uses, near- and long-term benefits and impacts, and which ecosystem services are protected and to what degree. Ultimately, successful implementation will involve adaptive management, defined as a rigorous process of learning by doing and using the results to improve subsequent management actions. Because our knowledge of natural and social systems is incomplete, these systems can respond in unexpected ways. Given this reality, many gaps in data can be filled only by implementing actions and monitoring their performance over the long term.

For example, as part of the restoration of former salt ponds over the past decade, salinities in the North and South Bay managed ponds were purposefully reduced, precipitating a redistribution of the shorebirds that thrive on brine flies and brine shrimp to the remaining salt ponds (which continue to have high salinity). To compensate for such changes, and in anticipation of the ongoing evolution of breached ponds toward tidal marsh, a few managed ponds were enhanced to support greater waterbird numbers in smaller areas. Two such ponds, A16 and SF2, now support very dense avian populations and are a testament to the potential for using science to carefully design restoration and management to meet the ecological needs of baylands wildlife as the landscape changes.

A management-action strategy will need to be developed for each stretch of the shoreline, at the scale of the segments described in the following chapter or even smaller reaches. The strategies will likely consist of multiple actions to be implemented in a number of phases dependent on the amount of sea-level rise (fig. 19). The first phase provides immediate ecological benefits that will enhance the existing baylands and maximize their resilience through years 2050 to 2070, when sea-level rise rates will still be relatively low. The second phase prepares the baylands for the increasing rates of sea-level rise expected after 2070 that may outpace vertical accretion. This is when marshes will need to migrate landward to survive. The recommended actions for each baylands segment in the following chapter initiate this planning process by providing near- and long-term visions and the accompanying actions to take. Action plans for each marsh can then be built out from the more general segment plans.

In the near term, the priorities should be to (1) enhance the resilience of existing marshes by increasing sediment accretion and reducing erosion, (2) expedite the restoration of marshes, and (3) creatively retain or enhance the ecological functions of the other baylands habitats, including the estuarine–terrestrial transition zone, subtidal–intertidal transition, and managed ponds. Pilot studies are crucial to understanding and optimizing the efficacy of various innovative techniques, so that future implementation actions can more readily achieve project goals.

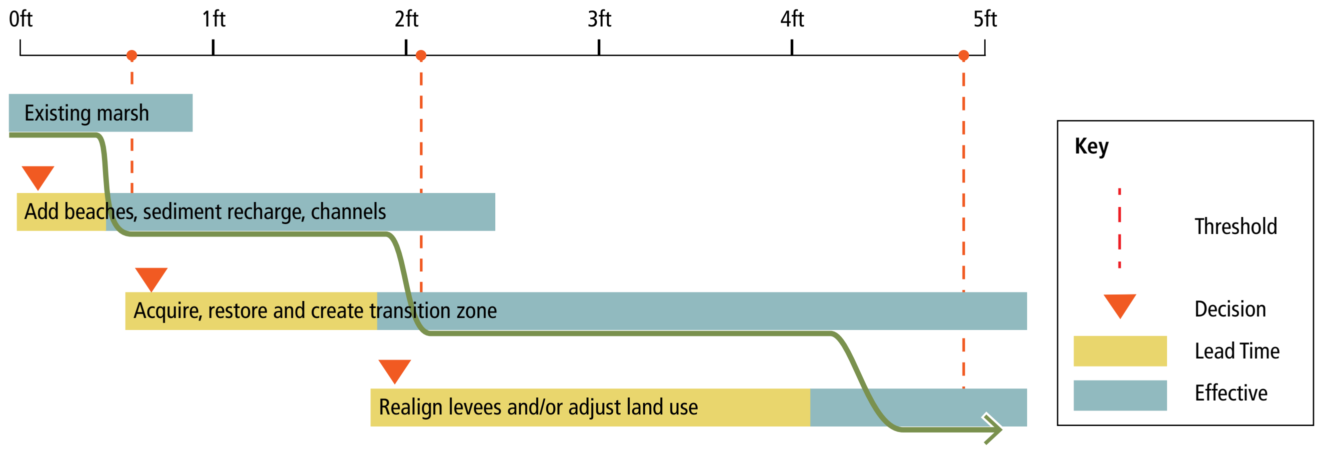


Figure 19 Conceptual phasing of adaptation measures triggered by changes in sea level, rather than a chronological timeline. Because many of the management actions have long lead times for planning, permitting, and construction, decisions about how and when to implement them will have to be made well in advance of when they are needed.

In the longer term, it will be necessary to focus even more on restoring and creating transition zones as well as realigning levees. Coordination with other nonecological shoreline adaptation activities with a potential to affect the baylands will be critical. Successful pilot studies performed in the near term should be scaled up as appropriate, and regional coordination on multipurpose projects and appropriate habitat trade-offs should be explored.

Successful implementation of a management-action strategy will require working closely with the regulatory community to find ways to allow for new and creative solutions when project objectives are to restore or sustain baylands habitat extent and function. Implementation will also require addressing technical factors while also pursuing detailed analyses of costs and benefits, ecosystem service co-benefits (improved water quality, flood protection, recreation opportunities, etc.), the impacts to land use, flood-protection requirements, available and required funds, the policy and regulatory context, and other considerations.

CONNECTIONS TO THE SAN FRANCISCO BAY

The open waters of the bay link the baylands to each other, to the major rivers through the Sacramento–San Joaquin Delta, and to the Pacific Ocean. We refer to these links collectively as the Bay Connection. The following discussion summarizes our current understanding of this connection, building on detailed information found in Science Foundation chapter 3.

The Bay Connection brings the effects of remote changes in the watershed and the ocean to the baylands. The bay and baylands are linked dynamically through the movement of water, sediments, and nutrients (see discussion above in The Dynamic Workings of the Baylands), as well as organic matter and organisms. These links provide mechanisms by which changes in the atmosphere, ocean, and watershed can influence the bay and thereby the baylands.

Infrastructure decisions can be made in the context of a phased approach to adaptation.

The movement and net flux of organic matter and organisms between the bay and the baylands is a complex relationship that varies by location and over time. The exact details of the exchange processes depend on the physical configuration of the marsh, including the residence time of water and the kinds and abundance of producers and consumers within the marsh, especially of transient organisms. Few of these aspects have been examined thoroughly in marshes of the San Francisco Estuary.

Long-term studies of the channels of Suisun Marsh have revealed much about fish assemblages, jellyfish, and some zooplankton. A general conclusion from this work is that the channels of Suisun Marsh are largely isolated from the rest of the estuary and that, presumably because of long residence times here, the assemblages of species are somewhat distinct from those of the nearby open waters. On the other hand, the South Bay Salt Pond Restoration Project has documented large numbers of juvenile fish in managed ponds restored to the tides just a few years after breaching, as well as very high productivity of invertebrates such as shrimp as soon as one year after breaching. This high productivity is apparently exported to the open waters through the consumption of small fish and invertebrate prey by predators with larger home ranges in South Bay.

Under present conditions, the delta supplies freshwater that opposes the upstream movement of ocean salt intrusion, nutrients largely from wastewater treatment plants, phytoplankton that subsidizes the low-productivity brackish region of the northern estuary, and zooplankton from freshwater into the brackish region. The Gulf of the Farallones is likewise connected to, and not particularly distinct from, the marine-influenced Central Bay in terms of biota and physical processes. Exchanges between the Central Bay and the Gulf of the Farallones export low-salinity water, sediment, and estuarine organic matter and organisms from the estuary while importing coastal sediment, nutrients, organic matter, and organisms into the estuary.

The Bay Connection links open waters to the baylands.

Future Change in the Bay Connection

Habitat types, their extent, and their quality, as well as the wildlife populations and communities of the Bay Connection, are likely to change under future scenarios. This section draws on several case studies of estuarine organisms and biological communities that consider the effects on each group (see table 1, which summarizes all the case studies used in the Science Update).

EFFECTS OF OCEAN CHANGE

The pH of ocean water is decreasing (commonly referred to as ocean acidification) as a consequence of a greater flux of carbon dioxide from the atmosphere and the subsequent formation of carbonic acid. Relatively acidic ocean water will flow into the estuary, but it is not clear whether the overall range of pH will shift enough to affect biota. The effect of acidification will be complicated by high short-term and small-scale variability. Any persistent decrease in pH is likely to impair calcifying organisms, notably native oysters, which may be particularly sensitive in the larval stages (see oyster beds case study—and all other Bay Connection case studies mentioned below—in Science Foundation chapter 3, appendix 3.1).

Upwelling brings cool, nutrient-rich, low-oxygen, low-pH water to the surface and promotes phytoplankton blooms in the coastal ocean. Estimates of recent climate-related trends in upwelling and projections of future upwelling have been equivocal, but the past several decades have seen an upward trend. Increased upwelling could increase the nutrient supply for plants and algae in the estuary. It could also bring in large numbers of diatoms and other plankton that thrive in upwelled waters. Low-oxygen events associated with pulses of upwelled water have been observed in South San Francisco Bay since 2006, possibly linked to the observed expansion of the oxygen minimum zone (OMZ) off the Pacific Coast.

EFFECTS OF CHANGES IN SEA LEVEL, SALINITY, AND EXTREME EVENTS

Beds of submerged aquatic vegetation (SAV) interact with sediment supply. Their maximum depth is limited by light penetration and therefore turbidity, but they also trap and stabilize sediments. Like marshes, SAV beds can presumably migrate upslope as sea levels rise, but that depends on local bathymetry and wave energy. The seaward limit of SAV beds is generally set by light availability, although a decrease in turbidity may favor more extensive SAV beds in the future (see case study).

Rocky intertidal organisms will experience effects from both the bay and the baylands.

In the latter half of this century, salinity could penetrate farther and more persistently into the estuary during the dry season, depending on several factors: how much the spring–summer runoff declines; whether and how structures and operations of Central Valley water projects are altered to supply sufficient water for human use in summer; whether tidal areas expand due to restoration and levee failures; and how much the sea level rises. Higher average salinity could allow eelgrass, native oysters, and other salt-tolerant benthic or marsh organisms to colonize farther up the estuary.

Winter salinity patterns may be more variable between and within years if storms become more intense, but such changes are difficult to project and would be altered by levee failures in the delta. In years of high outflow, or during a storm event such as that described in scenario 5, eelgrass and possibly other saline-dwelling organisms may undergo temporary diebacks during winter. The resulting shifts in distribution would affect the baylands' sediment-trapping capacity. Such storm events might also set up conditions favorable to invasive species, as may have been the case with the overbite clam (see the plankton case study).

A winter flood or an earthquake could also have lasting consequences if many levees fail in the delta or Suisun Marsh and are not repaired. This situation seems likely only if repairs take considerable time and are not feasible for all levees. Over a century, these events have a high probability of occurring, but the probability and nature of a permanent response in estuarine organisms is highly uncertain.

EFFECTS OF WARMER WATER

Rising water temperature may have a number of effects on estuarine organisms. Warmer water may stimulate a greater incidence of disease and parasite attacks. Blooms of the freshwater microalga *Microcystis* occur in the delta during warm, dry summers and may persist longer with warming. High summer air temperatures, stronger winds, and a greater tidal range may increase the risk of desiccation in intertidal areas (see the rocky intertidal organisms case study). Temperature changes may put organisms out of phase seasonally with their food or predators.

A few species may already be near their upper thermal limits, and higher temperatures are likely to prove harmful. In particular, high summer temperatures in the delta will add to the problems already besetting delta smelt. High water temperatures in Central Valley streams, particularly in combination with low flows in the dry season and a limited cold-water pool in the reservoirs, are likely to limit the viability of some salmon runs, notably winter-run Chinook (see the salmon case study). The loss, or reduction in abundance, of salmon in the estuary during the outmigration period may have ecological effects on the Bay Connection, but these cannot be predicted.

EFFECTS OF CHANGES IN SPECIES COMPOSITION

The particular species present in the bay and their relative abundance (or species composition) are likely to change in ways that influence the Bay Connection (see all case studies), but the effect of such changes is unpredictable. These changes can arise through new introductions, range expansions or contractions, habitat changes, and ecological interactions.

Changes in temperature, chemistry, and species within the open bay will affect the baylands.

Examples from the past indicate that the effects of these changes, though unpredictable, can be significant. The introduction of the overbite clam precipitated a series of events that severely altered food webs in the estuary, including a decrease in phytoplankton production and a substantial contraction of the salinity range of the northern anchovy, which had been the most abundant fish as far up-estuary as Suisun Bay (see the plankton and anchovy case studies). The resulting decreases in the spring–summer abundance of several species of copepod and mysid vastly reduced their availability as food for fish, which probably caused a decline in abundance of longfin smelt and striped bass. The Brazilian waterweed, which spread through the delta in the 1990s, provided cover for a host of nonnative fishes, while excluding native fish and native SAV, also significantly affecting the estuarine food web.

Future introductions are likely to have effects of similar magnitude. It is difficult to anticipate what species might arrive in the estuary, although the arrival of quagga and zebra mussels appears inevitable. While these freshwater mussels are unlikely to become very abundant in the bay, their grazing on delta phytoplankton could have substantial effects. Under present conditions the delta subsidizes phytoplankton in Suisun Bay, so a loss of productivity in the delta could affect that bay (see the plankton case study).

SUMMARY OF CONSEQUENCES FOR THE BAY CONNECTION

Overall some species will be extirpated, some will decrease in abundance, others will increase, others will change seasonal patterns, and still others will extend their ranges into the estuary and become established. The outcome will be an unpredictable shift in the composition of, and interactions among, estuarine organisms, which will change the suite of open-water species available for interactions within marshes.

Presumably, some marine species will be able to penetrate farther into the estuary and become significant members of the marsh fauna and flora in areas where they are not now abundant.

Considerations for Actions Related to the Bay Connection

The complexity of interactions in the Bay Connection makes planning for future change difficult. Addressing some critical unknowns would help reduce the amount of uncertainty around how the Bay Connection will change and what management actions should be taken. Specific characteristics of the exchange between marshes and open waters are key to understanding the Bay Connection but are poorly understood. Many aspects of the estuarine food web are not monitored, particularly the benthic communities in the Central and South Bays, as well as metrics pertaining to jellyfish and plankton. Wetlands managers can and should plan for invasions by new species. It is critical to establish a program to anticipate and prepare for the consequences of the impending invasion by quagga and zebra mussels. Another important preparation action is to finalize and implement the draft rapid-response plan in the California Department of Fish and Wildlife's Aquatic Invasive Species Management Plan from 2008 and expand it to include more estuarine species.

INTEGRATED SUBTIDAL HABITAT RESTORATION

The Bay Connection offers opportunities to adapt habitats using new configurations of subtidal and low intertidal elements. As discussed above, restoring complete tidal wetland systems, including subtidal habitats like eelgrass and oyster beds, is important for promoting resilience, given the strong links among the physical and biological processes relating to the exchange of water, sediment, organic matter, and organisms. Such integrated restoration projects provide ecological benefits, physical protection for the more landward habitats and infrastructure, and probable cost savings over equivalent isolated restoration projects.

Living shorelines restoration techniques hold promise for helping restore complete tidal wetland systems.

Native oysters provide important water quality, shoreline protection, and habitat benefits.

Subtidal habitats that increase bottom friction, mainly oyster reefs and eelgrass beds, could be placed to attenuate wind waves and thereby buffer tidal wetlands and creek mouths from erosion. Eelgrass beds offshore from a marsh may also provide food resources for waterbirds, substrate for herring eggs, and habitat corridors for fish moving between the bay and the baylands. The combination of marsh restoration and nearby subtidal habitat restoration could create local zones of sediment retention, minimizing the need for ongoing intervention. Local concentrations of oysters on constructed reefs may increase water clarity, thereby increasing the amount of light available to nearby eelgrass beds. Integrated restoration also reduces the effects of habitat fragmentation.

Restoration techniques for subtidal habitats are less understood than those for baylands, creating a need for pilot projects that address key science questions and generate data on restoration outcomes. Integrated experimental projects incorporating baylands and subtidal restoration with both constructed and natural elements should be implemented soon to generate knowledge about these new techniques as early as possible. Integrated physical and biological goals can be better incorporated into innovative designs that enhance and reinforce the ecosystem functions and services in the Bay Connection. Integrated designs can be more cost effective by providing habitat restoration benefits while testing new approaches to climate-change adaptation.

CONNECTIONS TO THE WATERSHEDS: THE ESTUARINE–TERRESTRIAL TRANSITION ZONE

Life in the Bay Area is concentrated along the bay shore. The edge of the bay is packed with ecological, economic, and cultural values. In the most urbanized areas, almost nothing is left of the natural shore, which has been fitted with major infrastructure for communications and power transmission, and for moving people, commercial goods, water, fuel, and wastes. This infrastructure rings the bay, crossing through current and former tidal marshes, crossing over and channelizing its rivers and streams, and restricting connections between the bay and its local watersheds. Much of the wildlife, water, and sediment from the surrounding hills and valleys now moves along unnatural channels and pathways through built environments to reach the bay.

Efforts to address the ecological and economic threats imposed by sea-level rise and other aspects of climate change have begun to focus on the estuarine–terrestrial transition zone (between the baylands and local watersheds), hereafter called the transition zone. Transition zone design and management can help mitigate these threats. The transition zone can provide space for the bay to expand without creating unacceptable flood hazards and without losing the ecosystem services of the baylands. Many historical and cultural resources are associated with the transition zone, and it affords important recreational opportunities. The transition zone provides critical support for wildlife throughout the region, while also supporting its own unique plant and animal communities.

Interest in the transition zone has intensified since the Goals Project was completed in 1999. While the need to restore and conserve the transition zone was generally appreciated in the Goals Project, the broad range of transition zone services was not as well understood, and the need for a transition zone to mitigate the threats of a rising bay did not seem urgent. This Science Update presents an opportunity to address more fully the need to restore and protect the transition zone now and into the future. Hence, this report includes a definition and detailed description of the transition zone and its ecosystem services, information that was provided for the other baylands habitat types in the Goals Project. The following discussion builds on detailed information found in Science Foundation chapter 4.

Definition and Description of the Transition Zone

The transition zone is defined as the area of existing and predicted future interactions among tidal and terrestrial or fluvial processes that result in mosaics of habitat types, assemblages of plant and animal species, and sets of ecosystem services that are distinct from those of adjoining estuarine, riverine, or terrestrial ecosystems.

Mudflat at sunset

Transition zones extend along the tidal reaches of streams.

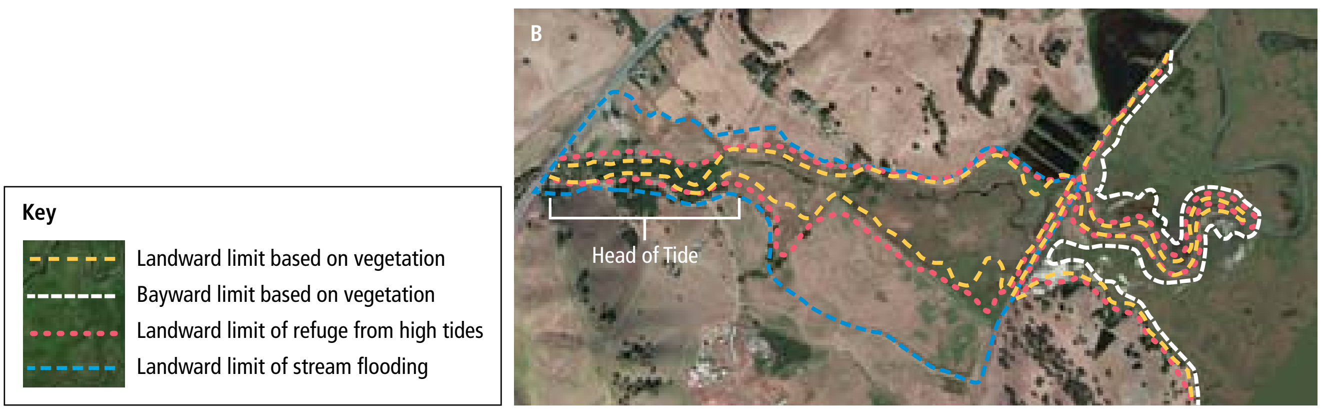
The transition zone is an integral part of a complete tidal wetlands system, but the transition zone as defined here does not include all the baylands. It does not include all of the tidal marshlands. The transition zone includes the areas of intertidal vegetation that are measurably influenced by terrestrial runoff and other freshwater discharges. It includes diked baylands that serve to store terrestrial floodwaters or that represent future space for baylands migration, since these are transition zone services, but it does not necessarily include other diked baylands.

The transition zone has often been visualized as the area of transition between tidal marsh vegetation and terrestrial vegetation. Such transitions are certainly part of the transition zone (see Science Foundation appendix 4.3). However, the full suite of transition zone ecosystem services indicates that the transition zone can be much broader in some settings. The relationships among topography, land use, runoff, transition zone services, and transition zone width can be represented by a simple transition zone classification system (see Types of Transition Zones). There is also a relationship between transition zone type and approaches to transition zone planning and management. These and other relationships are explained in this section to support the recommended transition zone conservation actions.

The transition zone provides a physical and ecological connection between the baylands and local watersheds. It connects the bay to both its developed and its undeveloped margins. It extends all along the bayshore and along the tidal reaches of rivers and streams. The transition zone extends landward (across wetlands and uplands, and along streams and rivers) to the limits of tidal effects on terrestrial and fluvial conditions. It extends bayward (across marshes and sloughs) to the limits of the effects of terrestrial runoff and other freshwater discharges on conditions of the baylands.

The transition zone varies in width from place to place and over time. In the landward direction, its width is affected by the vertical range of the tide, the slope of the land, and the locations of built structures that control the upstream or landward movement of tidal water. In the bayward direction, its width depends

Figure 20 **Transition zone boundaries corresponding to different ecosystem services, showing (A) the upper and lower boundaries based on plant species assemblages indicative of the landward marsh edge, plus the landward boundary of the high-tide refuge service for the transition zone associated with a levee (Richmond, Contra Costa County); and (B) these same kinds of boundaries plus the range in head of tide and the landward limit of the flood-control service for the transition zone associated with a perennial stream (San Antonio Creek, Sonoma County).** The area of stream flooding in (B) relates to a railroad grade that constricts the connection between the fluvial and intertidal portions of the floodplain. (Note: The boundaries in this figure are provided as examples for the purpose of illustration and are not based on field measurement or quantitative modeling.)



on the volume of terrestrial runoff entering the baylands. In general, for any given volume of runoff, the transition zone is wider where the tidal range is greater and where the land slopes gently to the bayshore. It is narrower where the tidal range is smaller and the land is steeper.

The required width of the transition zone also varies depending on the desired ecosystem services (fig. 20). For example, a broader transition zone is needed to provide refuge from high tide for marsh wildlife than if such refuge is not provided, and a broader zone is needed to accommodate sea-level rise for the next century than for the next half-century. Field and map indicators can be used to estimate the maximum width of the transition zone present or needed at any location around the bay.

The principal indicators of the landward extent of the transition zone are

- the upper extent of tidal marsh vegetation
- the area of high-water refuge for marsh wildlife (from both tidal and fluvial flooding)
- the head of tide, which is the upstream limit of the influences of tidal waters on channel geomorphology and hydraulics

- specific, complex habitat mosaics created by large-scale interactions among tidal, fluvial, and terrestrial processes
- migration space for sea-level rise
- ecological connectivity for wildlife, including fish and invertebrates, that use baylands and adjacent terrestrial or fluvial habitats

The principal indicators of the bayward extent of the transition zone are:

- the bayward extent of processes originating at the back of the marsh
- the extent of influence from freshwater discharge

Examples of the first indicator include seasonal freshwater seeps and shallow pans from natural drainage processes (or a lack thereof), the wrack line, and the extent to which pets and people venture into the marsh from levees and paths. For the second indicator, freshwater discharge includes terrestrial runoff that reaches the transition zone through rivers, streams, canals, ditches, and effluent from water treatment facilities. The effects of freshwater discharge can be assessed as the bayward extent of tidal marsh plant species that are indicative of fresh or brackish water conditions, and the bayward extent of fluvial bedload (the sediment transported along the bed of a stream rather than suspended in the water column). The bayward effects

PERSPECTIVES FROM THE STEERING COMMITTEE

Box 6 The Future Shoreline

The bay shoreline is a desirable address. Homes, businesses, institutions, airports, seaports, and myriad others all derive some benefit from their shoreline location, and some must be there. Airports can reduce noise impacts to their neighbors and increase public safety by conducting flight operations over the bay. Restaurant patrons, homeowners, office workers, and others enjoy fantastic bay views and often have ready access to the Bay Trail, waterfront parks, or other recreational opportunities. Marinas, seaports, fishing piers, and other water-dependent facilities require a bayside address. Shoreline development contributes significantly to the character of the region, providing places for memorable events that help make the Bay Area such a special place.

Some developed landforms slope up steeply from the shoreline, others meet the shoreline with hardened structures, and some are level or gently sloping. Riprap revetments, sea walls, and levees provide structural protection from flooding or erosion, sometimes in conjunction with shoreline wetlands. Where shorelines are steep, like those in parts of Marin County, San Francisco, or the Carquinez Strait, wetlands will not be able to form or migrate as the sea level rises. Where land slopes gently up from the shoreline, wetlands can migrate inland, though in many places only if barriers are removed to allow wetland formation, or if adjacent land uses are changed.

As the Bay Area develops strategies to adapt to sea-level rise, it will face hard choices in selecting the developed areas it will protect, areas where the public benefits of allowing the bay to migrate inland outweigh the cost of protecting the current shoreline, and areas where wetlands can be restored or managed in place. The transition zone research and analysis recommended by this Science Update can inform the complex process of adapting to a changing bay in an ecologically sound and forward-thinking manner.

Above: Transitions are evident even in urbanized baylands.

Right: Black-necked stilt at restored wetland

of freshwater discharge can include the extension of fluvial levees into tidal marshes (fig. 16), the deposition of sediments on marshes that adjoin streams (fig. 17), and the existence of brackish marsh vegetation.

Transition Zone Ecosystem Services

The ecosystem services of the transition zone relate strongly to its role in linking the baylands to local watershed processes. Inorganic sediment derived from local watersheds helps form and sustain tidal marshes. Freshwater runoff from local watersheds creates salinity gradients through the baylands that greatly increase the biodiversity of the region. Many wildlife species, including birds of prey and salmon, move between the bay and local watersheds through the baylands. The bay and its local watersheds are linked together by the baylands, and the mechanisms of this linkage are the workings of the transition zone.

The transition zone delivers the following major ecosystem services:

- buffering for the landward effects of tidal processes and the bayward effects of fluvial and terrestrial processes, which helps control pollution, biological invasions, and erosion
- flood protection where channels, floodplains, and floodwater storage areas exist
- sea-level rise migration space for the baylands, especially for tidal marsh and the tidal reaches of rivers and streams
- nutrient processing in transition zone wetlands
- groundwater recharge during floods in riverine floodplains and stormwater retention basins that are part of the transition zone
- support of diverse native wildlife (including fish) through the provision of
    - habitat for transition zone species, including important pollinators for marsh plants and invertebrate prey for marsh fauna
    - refuge from predators and physical stressors like high water
    - foraging areas

- movement corridors along the shore or up into watersheds (especially important for allowing certain species to find the right salinity in variable conditions)
- landscape complexity by increasing the number of habitats and combinations of adjacent habitats
- a wide range of conditions that promote the physiological, behavioral, and other adaptations necessary for population persistence

- cultural amenities, including recreation and educational activities
- carbon sequestration

More details on these services and the species of management concern that the transition zone supports are given in Science Foundation chapter 4.

Types of Transition Zones

The transition zone typology has two parts. One part organizes the transition zone into types based on formative processes and physical structures (fig. 21). The second part organizes the transition zone into subzones based on the spatial limits of their ecosystem services. Seven types of transition zones represent the full range of historical and existing transition zone conditions for the bay (fig. 21 and 22). Each type of transition zone consists of two to four subzones that provide different suites of services. Subzone 2 has been the focus of recent marsh–upland transition zone restoration efforts and is highlighted in Science Foundation appendix 4.3.

The stratification of the transition zone into a number of contiguous subzones based on the "footprints" of its various services has precedent in riparian buffers. Many public agencies responsible for riparian buffers subdivide them into three or more component zones that correspond to different kinds or levels of buffering. From the perspective of riparian science, the transition zone as defined here is essentially the riparian zone of the bay.

Transition zone subzones extend varying distances inland.

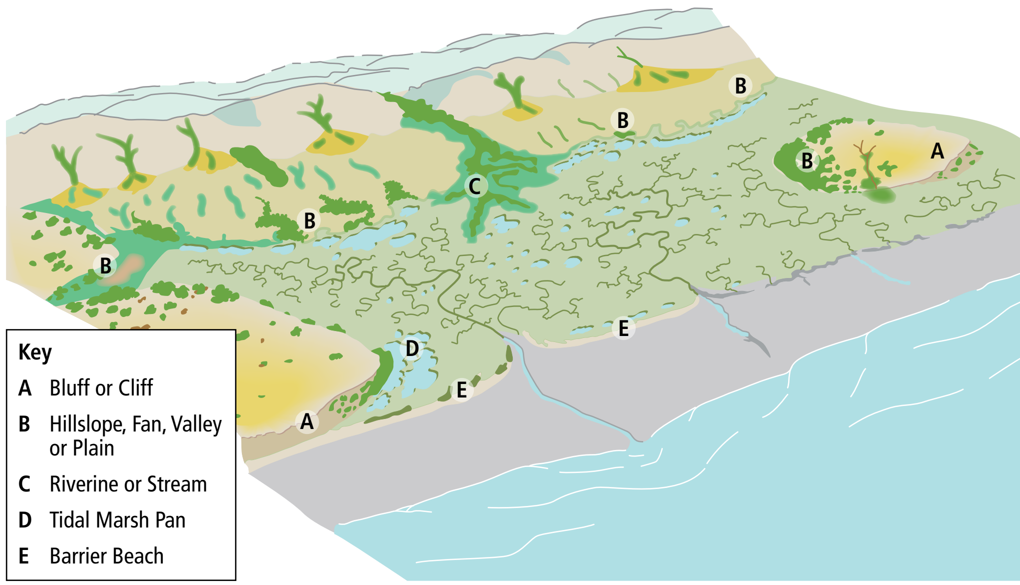


Figure 21 A typical arrangement of the natural transition zone types in a virtual San Francisco Bay landscape. The tidal salinity regime can be brackish or saline. Natural salt pond and artificial levee transition zone types are not included in this figure.

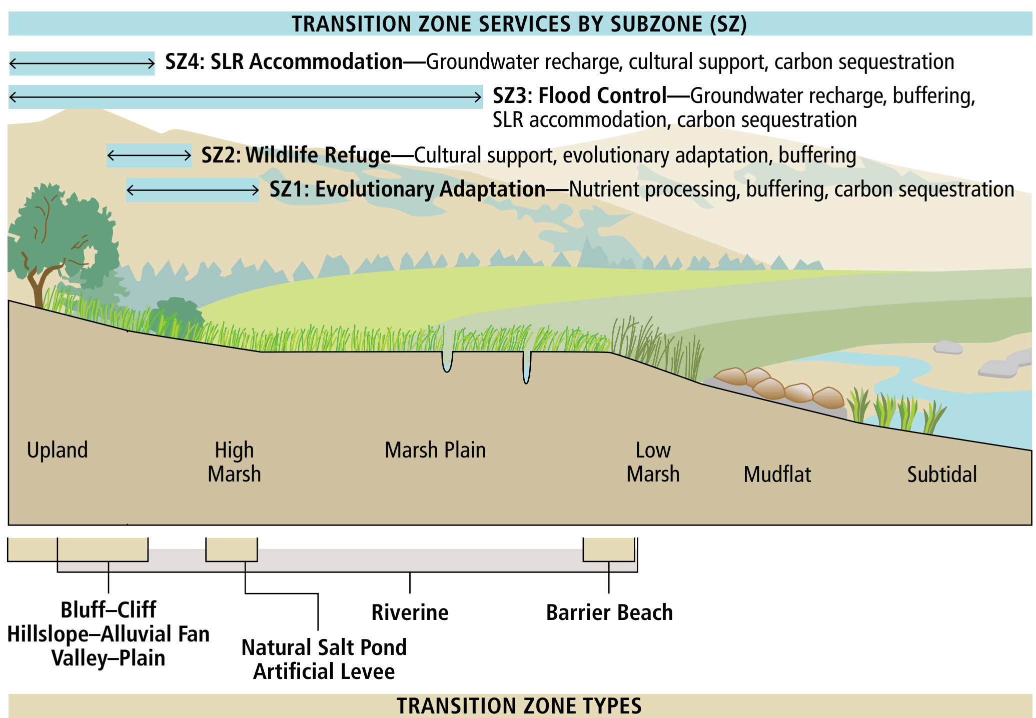


Figure 22 Spatial relationships among transition zone types and subzones. Subzones 3 and 4 extend landward of the upland extent shown in this figure. The riverine type extends bayward to the limits of the effects of freshwater discharge on intertidal vegetation. The primary services of each subzone are shown in bold. Services common to all transition zone types, such as wildlife movement and landscape complexity, are not shown.

One type of transition zone, the *barrier beach*, often occurs at the bayward margin of tidal marsh. It is identified as a type of transition zone because it provides many of the ecosystem services as the other transition zone types. For example, barrier beaches can serve as a high-tide refuge, and they support the evolutionary adaptation and movement of intertidal plants and animals.

The typology can serve to guide transition zone restoration and management. For example, successful restoration will require knowing what type of transition zone is best suited for a given restoration site, based on the local controlling factors and processes. Mismatches between transition zone types and settings may cause restoration efforts to fail. The kinds and levels of service provided by the transition zone can be controlled to some degree through the design and management of subzones.

Considerations for Actions Related to the Transition Zone

FUTURE CHANGES IN THE TRANSITION ZONE

The transition zone will be affected by the impacts of climate change on local watersheds as well as sea-level rise. The projected increase in the intensity of rainstorms could result in more erosion of hillsides and streams, which in turn could increase the volumes of sediment delivered to the hillslope–alluvial fan, bluff, and riverine transition zone types. The projected rise in dry-season air temperatures and the possibility of longer droughts could result in more frequent disturbance by fires in the undeveloped landward subzones of each transition zone type. It's very difficult to predict how the terrestrial vegetation of the transition zone will be affected by climate change, but invasions of nonnative plant species are likely to increase, given that these species tend to exploit disturbed environments. Changes in the plant community of the transition zone will in turn lead to changes in how the transition zone supports wildlife.

The basic effects of a rising bay on transition zone conditions are perhaps more predictable. As the bay rises, the transition zone will tend to migrate landward if there is adequate migration space. In many areas, providing adequate space would

Development backs many of the region's existing marshes, limiting transition zone services and opportunities.

Waterways will provide opportunities for transition zones to move inland, where constrictions allow.

require relinquishing some human activities located landward of existing marshes or transition zones. Otherwise the transition zone will be increasingly compressed or will drown. Since the diversity of services of the transition zone increases with the number of intact subzones, and since the levels of service of any subzone tend to increase with its width, compression of the transition zone will likely result in a loss of both the diversity and levels of its services. This highlights the importance of a broad subzone 4 that can accommodate the landward migration of all the subzones.

Extreme weather events can significantly affect conditions of the transition zone. Extreme storm events that cause water to overtop roads, levees, tide gates, and other structures can suddenly alter the transition zone by changing soil and moisture conditions, which will affect plant and animal distributions and survival. As the head of tide migrates upstream with sea-level rise, the likelihood increases that wind-generated waves, boat wakes, and extreme high tides, including "king tides," will overtop levees and berms. Such extreme high events are likely to affect conditions in the transition zone as much as, or more than, the increase in the average bay height.

Under natural conditions, the transition zone can be resilient to climate change and extreme weather. For example, estuarine barrier beaches can naturally gain height with the deposition of materials during a storm wave run-up, and alluvial fan vegetation buried by episodic riverine flood sedimentation can regenerate after a few years. This does not mean that the ecosystem services of the transition zone will

Many native species depend on transition zone services.

withstand climate change and sea-level rise without human intervention, but rather that understanding transition zone processes allows careful intervention to sustain appreciable levels of services.

If nothing is done to protect and restore the transition zone, the diversity and magnitude of the ecosystem services it provides will decline. The primary reasons for this are the lack of migration space, the transition zone's greater vulnerability to erosion and disturbance as the adjoining tidal marsh erodes, a greater vulnerability to biological invasion due to increased frequency and magnitudes of disturbance, and fragmentation along the bayshore due to its extreme compression against the built environment.

The response to future change will vary by the type of transition zone. Management plans need to take into account both the type of transition zone and the desired ecosystem services. Detailed discussions for each transition zone type are provided in chapter 4. Key points that relate to management actions for particular types of transition zone are summarized here.

For steep transition zones on constructed levees, the "horizontal levee" is a recent concept for building habitat resilience and enhancing ecosystem services. The traditional levee is augmented with carefully graded fill that extends the transition zone bayward to create a wide, low-gradient terrestrial slope. Diked wetlands can be designed into the horizontal levee. For example, reclaimed wastewater effluent could be used to irrigate the slope to create freshwater for brackish wetlands. The concept is most applicable to urbanized areas that lack migration space. Implementation might require partially filling diked baylands or shallow subtidal areas adjacent to the existing transition zone. A complementary strategy is to realign the flood-risk-management levee to a new location further inland (as described in Projected Evolution of Baylands Habitats and fig. 18).

For alluvial fan and valley plain transition zones, the projected increase in rainstorm intensity and riverine flooding could be used to increase the supply of sediment through the fans and valleys and to the marsh, pushing the transition zone bayward and enlarging baylands migration space, as well helping the marsh keep pace with sea-level rise. This approach would be effective where fluvial fans and valleys have not been developed. At the same time, the projected increase in air temperatures during the dry season and increased intensity of droughts could decrease surface and groundwater flow through the alluvial fans and valleys. This decrease in flows could reduce or eliminate the slope and depressional wetlands, along with the brackish marsh, which are naturally associated with this transition zone type. Creative ways to improve safe yields of sediment and to assure adequate flows of clean water through the fans and valleys that adjoin the bay are needed to protect and restore the valley–fan transition zone. In short, wide and gently sloping transition zones will last longer if connected to active estuarine and terrestrial processes.

To prevent increased riverine and tidal flooding associated with more intense storm events and higher sea level, levees in many places will need to be raised and extended upstream, or development moved back, to make room for riverine and tidal influences. Alternatives to longer and higher levees should be considered where possible. For example, the restoration or construction of terrestrial floodplains should be considered, as should the ability to shunt floodwaters across tidal marsh plains during low tide and into diked baylands during high tide. In some areas, it might be possible to move riverine levees farther apart, to make room for floodplains between the levees. Flood control designs can be integrated with the realignment of infrastructure

Alternatives to longer and higher levees should be considered where possible.

and a planned retreat of land uses at the landscape scale to create migration spaces with abundant riverine ecosystem services. These concepts and others could be integral elements of landscape designs that reconnect the bay to its local watersheds in ways that restore the ecosystem services of the baylands as a whole.

Future policies concerning watershed-based sediment management and flood control will largely determine whether flooding is used to nurture the transition zone and the rest of the baylands. Watershed-based sediment management, as envisioned for rivers and streams impaired by fine sediment, should consider the effects of sediment management on the riverine transition zone and other components of the baylands.

TRANSITION ZONE DESIGN AND MANAGEMENT

Managing the transition zone presents difficult challenges because of the need to balance demands for ecosystem services against existing development. Meeting these challenges requires ongoing coordination among agencies at all levels of government. However, the conflicts among transition zone management objectives can be mitigated through transition zone design. At this early stage of transition zone restoration science and engineering, pilot projects are needed to test various design concepts. In general, each restoration project should set ecosystem service goals for the transition zone type that best fits the restoration site. These goals should be based on an operational understanding of the formative processes, local constraints, and future opportunities for further restoration.

Currently, there is no regional map of the transition zone as defined here. A regional transition zone mapping effort is needed to identify and track restoration opportunities, to assess the relative effects of restoration and ambient climate change, and to evaluate the efficacy of state and federal policies for protecting the zone. Local maps are needed to inform restoration design. The optimal mapping approach will probably involve estimating the extent of each type of transition zone and the width of the subzones, such that the map can inform the restoration and management of specific ecosystem services.

RISKS FROM FUTURE CHANGE FOR WILDLIFE

Wildlife, here defined to include both animals and plants, has evolved in the San Francisco Estuary to accommodate environmental change. Local extinction and colonization of new habitat have occurred repeatedly. In the present day, however, wildlife faces the cumulative anthropogenic impacts of (1) habitat loss, fragmentation, and degradation; (2) barriers to dispersal, such as freeways and cities; (3) contaminants; and (4) the alteration of habitat and food webs by nonnative species. Moreover, the unprecedented rate of climate change anticipated in the coming decades will exacerbate these stressors. The combination of higher rates of change, more intense extreme events, and additional stressors poses a high risk to wildlife.

These risks to wildlife can affect long-term population trends and the population viability or sustainability of baylands plants and animals. Population trends depend on the rates of survival, reproductive success, recruitment, and dispersal. Population viability depends in good part on population resilience, or how well species tolerate or recover from changes in the environment.

The exact consequences of climate change for wild plants and animals cannot be predicted with certainty. Nevertheless, there is enough information about changes in habitat and climate to foresee the likely general trends and provide recommendations for management actions to prepare for and alter those trends. Here we consider the short- and long-term impacts of the five future scenarios (see section Future Scenarios Evaluated) on wildlife, building on detailed information found in Science Foundation chapter 5.

Case Studies

The Science Foundation chapter on wildlife (chapter 5) and this summary of it are based on 32 case studies covering a wide variety of plants and animals (table 1). These case studies are located in Science Foundation appendices 3.1 and 5.1 and describe the effects of drivers on populations, guilds, or communities. The wildlife workgroup used five criteria to select focal groups for case studies. Primary criteria for the focal taxa were

- well-understood ecological processes and population status
- high conservation concern or the group's marked vulnerability to climate change
- qualities representative of other species

Secondary criteria were

- a particular association with baylands habitat
- the group's important ecological role (for example, as a key player in the food web)

Using patterns of impacts apparent from the case studies, we recommend management actions to enhance population resilience and thereby maintain or restore the health of wildlife populations. These case studies update the Species and Community Profiles published for the Goals Project by considering (1) the likely impacts of future change, (2) other new information learned since 1999, and (3) specific management recommendations relevant to (1) and (2).

American white pelicans rest on a protected island within a managed pond.

Table 1 List of case studies (available online in Science Foundation appendices 3.1 and 5.1)

Species	Indicator for	Habitat	Status in Baylands
Mammals			
salt marsh harvest mouse	marsh (tidal and non-tidal) small mammal	tidal marsh; diked bayland	resident in baylands
Suisun shrew, salt marsh wandering shrew	marsh (tidal and non-tidal) small mammal	tidal marsh; diked bayland	resident in baylands
river otter	aquatic mammal (creeks and rivers)	creeks and rivers	mostly terrestrial–bayland interface
harbor seal	aquatic mammal, using bay and mudflat	open bay, mudflat, sand-bar, rocky intertidal	resident in baylands
Marsh Birds			
Ridgway's rail	tidal-marsh-dependent birds	tidal marsh	resident in baylands
song sparrow	tidal-marsh-dependent birds	tidal marsh	resident in baylands
black rail	tidal-marsh-dependent birds	tidal marsh	resident in baylands
northern harrier	marsh predator	multihabitat	resident, multihabitat
Waterbirds			
American avocet, western sandpiper	avocet: large shorebirds sandpiper: small shorebirds	marsh; mudflats; managed pond	avocet: breeder in baylands sandpiper: migrant
least tern and Forster's tern	fish-eating birds	beaches, marshes, sloughs, islands	breeder in baylands
dabbling ducks: northern shoveler, northern pintail, American wigeon, gadwall, mallard, green-winged teal	six species of dabbling ducks	diked bayland and tidal marsh; managed ponds	both resident and migratory species
diving ducks: scaup (lesser and greater), surf scoter, bufflehead, canvasback, ruddy duck	bay ducks; sea ducks; stiff-tailed ducks	diked bayland; open water; managed ponds	predominantly migrant

Least sandpiper

Amphibians			
California toad	wetland amphibians	wetlands	resident
California red-legged frog	wetland amphibians	wetlands	resident
Fish			
Pacific herring	subtidal	shallow aquatic	migrant
delta smelt	upstream part of estuary	open water	migrant
longfin smelt	pelagic throughout estuary	open water	migrant
longjaw mudsucker	marsh fish	pickleweed marsh	migrant
tidewater goby	small estuaries	estuarine lagoon	breeder
grunion	recovered native	sandy beach	breeder
chinook salmon and steelhead	migratory fish	vegetated marsh edge	migrant
Invertebrates			
macroinvertebrate: Dungeness crab	aquatic: nursery value of baylands	shallow aquatic, eelgrass	migrant
terrestrial marsh inverte-brates	multiple species	tidal marsh	resident
Vernal Pool Community			
plants, crustaceans, other invertebrates, plants	multiple taxa	freshwater, ephemeral pools	resident
Plants			
invasive and native Spartina	invasive and native Spartina	tidal marsh	resident
submersed aquatic vegetation	multiple species	open water	resident
low tidal marsh grami-noids	multiple species	tidal marsh	resident
high tidal marsh annual forbs and graminoids	multiple species	tidal marsh	resident
high tidal marsh sub-shrubs and perennial forbs	spring high-tide zone	tidal marsh	resident
high tidal marsh peren-nial graminoids	spring high-tide zone	tidal marsh	resident
terrestrial ecotone/high-marsh graminoids	multiple species	terrestrial transition zone	resident
terrestrial ecotone psam-mophyte	multiple species	terrestrial transition zone	resident

Impacts on Wildlife

Two types of impacts from future change will affect wildlife: long-term trends and episodic events, each of which relates to particular drivers (see Science Foundation chapter 5 for the particulars of this conceptual model). Long-term trends will affect the average population sizes through changes in habitat quantity and other habitat characteristics, especially structure and salinity. However, the average population size through time is not the best indicator of population viability or sustainability, as extinction risk is particularly exacerbated by extreme events, floods, droughts, and storms. Such risk is amplified in smaller, isolated populations that result from habitat loss and fragmentation, so the two types of impacts interact.

IMPACTS ON SURVIVAL AND GROWTH

From Inundation and Salinity

Northern harrier

Increased inundation and higher salinity will change the distribution of plant communities with far-reaching effects for wild animals and the plants themselves. As the sea level rises, the distribution and abundance of submerged aquatic vegetation adapted to deeper flooding is expected to increase. Inundation and salinity limit the populations of many brackish plants. For example, the effects of salinity and inundation stress due to sea-level rise will reduce the first-order tidal-channel habitat supporting the rare Suisun thistle and thus limit its distribution and abundance throughout Suisun Marsh.

Marshes that are now brackish will shift to salt marsh vegetation, and brackish marsh communities will extend into formerly freshwater marsh areas. Tidal marsh bird communities will probably shift in keeping with the plant assemblages. Change in the distribution of brackish bulrush and tule will likely cause change in the distribution and possibly the population size of birds, such as marsh wrens and common yellowthroats, that rely on these plants for cover and breeding sites. Storm events causing a onetime deposition of seawater to high elevations can leave a legacy of saline soil, and heavy deposits of wrack can smother vegetation.

Fish communities will also shift with salinity and inundation changes. Freshwater fish that are currently found in Suisun Marsh will become rare. On the other hand marine fish, including halibut, flounders, and white seabass, are likely to become more reliable components of the fish community of the Central Bay. With longer inundation periods, aquatic species associated with higher salinity marshes, like longjaw mudsuckers and Dungeness crabs, may have less exposure to avian predators and longer foraging times. However, higher temperatures during the periods of exposure may override the benefits of increased inundation.

Tidal marsh birds and mammals are particularly susceptible to the effects of inundation from storm events. Flooding of the marsh has energetic consequences, because terrestrial animals cannot access marsh foods. In one example, black rails were unable to forage for many hours over several days during a winter storm. The stress on this species was not just due to the inundation, but also to its duration. The rails had to expend energy to stay warm but could not replenish themselves with food. Marsh residents, including salt marsh harvest mice, can perish during such extended flooding.

Perhaps most importantly, inundation leads to a greater risk of predation. During high-water events, terrestrial wildlife in the marsh is forced into the landward edge of the marsh or must cling to tall vegetation, concentrating it in small areas where predators can more easily take it. Thus, marsh inundation interacts with predation to affect terrestrial marsh vertebrates. This mortality pressure is well demonstrated by the Ridgway's rail, whose survival rates are lower when tides are higher.

The loss of mudflats, or a general lowering of mudflats relative to mean sea level, could lead to the decline of several waterbird groups. Deeper water in mudflats or managed ponds would reduce the foraging habitats of wading birds, shorebirds, and dabbling ducks. Shorebirds are already energetically limited during the winter and migration, so they rely on good foraging in the estuary to complete their energy budgets. Changes in salinity may also affect shorebirds by altering the distribution and abundance of their prey.

From Temperature

Warming temperatures will also affect the survival and growth of wild animals and plants. Higher temperatures may result in an energetic imbalance for some species, due to fewer foraging hours or a need to spend extra energy to maintain physiological processes. However, lower freshwater flows and higher salinities may improve the growth of salmon in the baylands. Of much greater concern are thermal stress and dewatering upstream, particularly for steelhead. Higher temperatures and CO_2 levels will affect plant growth, survival, recruitment, dispersal, and competition, as well as altering ecosystem processes, such as decomposition, nutrient cycling, primary productivity, and organic-matter accretion. The outcomes of these changes may be significant, but the complexity of the systems and the uncertainty of the changes make them impossible to predict accurately.

From Drought

Drought and the associated increases in salinity cause significant mortality in amphibians and plants. The combined effects of drought and hypersalinity will harm mid- to high-marsh plants, such as the Suisun thistle and gum plant that are adapted to brackish rather than saline conditions. The gum plant is an important resource for marsh wildlife. Drought will likely cause a mass dieback and smaller plants, which will reduce the cover and nest sites for marsh animals.

IMPACTS ON REPRODUCTIVE SUCCESS

From Inundation and Salinity

Many mid- to high-marsh plants may fail to reproduce in the absence of a low-salinity period for germination during the winter and spring. This is of greatest concern for uncommon local endemic species, such as the Suisun thistle and water hemlock, but applies to other plant species as well.

The nests of Ridgway's rails, black rails, and tidal marsh song sparrows are likely to be flooded more often from sea-level rise and extreme storms. More frequent storms could cause the failure of renesting attempts after an initial failure, resulting in complete reproductive loss for the year. Reproductive failure of this kind can rapidly lead to severe reductions in population size of these relatively short-lived species. Salt marsh harvest mice, baylands shrews, shorebirds, and other breeding waterbirds are probably also at risk for reduced reproductive success or lower offspring survival due to flooding.

Harbor seals require tidal flats and other habitat types with particular characteristics to haul out and birth pups. The loss of adequate haul-outs (as a result of erosion or drowning) is a concern, resulting in reduced reproductive success. Similarly, shorebirds require suitable breeding locations, including beaches and mudflats, which may be lost due to sea-level rise.

From Freshwater Outflow

If reduced or earlier delta outflows occur later this century, they may reduce the reproductive success of aquatic wildlife. Many aquatic species have shown better survival or reproduction in years of higher delta outflow. Restriction of outflow events to early in the water year could restrict the spawning success of both longfin smelt and delta smelt. Prolonged summertime conditions could reduce the survival and fecundity of delta smelt in particular, if the salinities they occupy in the summer and fall were to move upstream into less productive portions of the delta. The ability of longfin smelt to use more oceanic waters should allow them to be more resilient to increasing salinity than the delta smelt. Pacific herring require a combination of solid substrates and appropriate salinity that is likely to become spatially disconnected during future climate conditions. Suitable salinities will move upstream into San Pablo Bay, where the appropriate solid substrates are rarer. Thus, herring eggs will be deposited on inappropriate substrates or in even greater densities on the limited patches of appropriate substrate, leading to less successful reproduction.

Amphibians, including the California toad and California red-legged frog, require freshwater ponds of sufficient depth and appropriate temperature. Breeding ponds need to maintain appropriate conditions long enough for offspring to mature. Climate change may result in ponds that are too salty or that dry out too quickly.

IMPACTS ON MOVEMENT AND DISPERSAL

As habitat configurations change, especially if the baylands become more fragmented, dispersal limitations that already affect many baylands species will become more important. Annual forbs of concern in the high tidal marsh include several rare or endangered species (e.g., *Chloropyron maritimum, C. molle, Castilleja ambigua*). These species have limited ability to spread or recolonize, or even maintain their number, and recruitment is also limited due to competition with nonnative species. Thus, for the native marsh species of concern to establish populations in new areas, active translocation may be required. A similar situation exists for several rare native plants from vernal pool habitats.

IMPACTS OF PREDATION

Current levels of predation are already straining the resilience of many baylands wildlife populations, especially because predators from adjoining uplands (including developed areas) can easily access the baylands via built structures like levees and utility towers. Predation may increase for a number of reasons. Nonnative and human-associated predators may gain easier access or experience a rise in population; the edge effects of baylands becoming squeezed against the shoreline may increase; or refuge may be inadequate at times of stress, such as high-water events.

Predators that are already affecting baylands wildlife populations, such as California gulls and other human-associated predators, must not become more prevalent. Increased inundation and higher sea levels are likely to enhance mosquito production, and any resultant stocking of mosquito fish into temporary ponds could severely reduce the reproduction of California red-legged frogs and California toads. Levee enhancement and other efforts to buffer human infrastructure from the impacts of climate change are likely to improve access for predators, especially human-associated predators like raccoons, cats, dogs, and rats.

Stress to tidal marsh wildlife from high-water events is often coupled with intense predation during the flooding. Also, river otters require dense vegetation for refuge during high flows. Designing habitats that function as refugia under such extreme conditions will be an important part of planning for the impacts of climate change.

IMPACTS OF DISEASE

Risks to wildlife populations due to disease are expected to rise with climate warming. Shorter, milder winters are expected to increase the spread of disease. For both plants and animals, pathogens may evolve faster in response to climate change than host populations, thus spreading more quickly with more virulent results. Plant disease effects will likely increase from climate change. Strong plant–microbial linkages, including that of mycorrhizae, may help reduce disease, but climate-change predictions for microbes are not available. Amphibian chytridiomycosis (caused by *Batrachochytrium dendrobatis*) is of great concern for the California toad. Some warming may cause *B. dendrobatis* to spread or increase, but substantially higher temperatures may actually reduce the pathogen. Avian cholera infecting waterfowl is a concern in the estuary now, but future incidence of the disease has not been projected. River otters are currently subject to disease, and a reduced prey base from climate change may affect the susceptibility of otters to disease. Harbor seals may be subject to pathogen shifts through greater proximity to terrestrial carriers of morbillivirus (dogs, cats, raccoons, skunks), *Leptospira* (rats), *Toxoplasma* (felines), and *Sarcocystis* (opossums).

IMPACTS ON COMMUNITY COMPOSITION

Altered climate will likely produce new assemblages of species, thus changing the nature of interactions among species, such as competition. Climate change may cause both nonnative species to invade the baylands, and species native to California to

Pickleweed

Box 7 Regulatory Challenges and Opportunities

Given the need to proceed rapidly with baylands restoration to create resiliency to climate change, project proponents and regulatory agencies must better align their practices and reform the lengthy and complicated permit process that is required for restoration to proceed. Agencies likely to have a role in the permitting process of Bay Area wetlands projects include the US Army Corps of Engineers, the National Marine Fisheries Service, the US Fish and Wildlife Service, and the US Environmental Protection Agency at the federal level, and the San Francisco Bay Regional Water Quality Control Board, the California Department of Fish and Wildlife, the San Francisco Bay Conservation and Development Commission, and potentially the California State Lands Commission at the state and regional levels. In addition, wetlands restoration projects may need local authorization from cities or counties, and those that cross paths with railroad tracks, pipelines, highways, and utilities will need additional permissions in order to successfully protect the infrastructure. All these agencies can and often do require changes to designs or monitoring plans to ensure that the project is in compliance with their respective laws and policies.

Current Constraints

All applicants, whether their projects are large or small, must navigate the same process, providing much of the same detailed information to the various permitting agencies, repackaged each time into agency-specific formats. Illustrating the difficulties of moving forward with restoration quickly, the South Bay Salt Pond Restoration Project began planning its permitting approach shortly after property acquisition was completed in 2003. It received permits from most of the agencies listed above between August 2008 and January 2009.

Some agencies rely on another agency to proceed with permitting actions (e.g., a federal nexus is determined through an Army Corps of Engineers 404 permit, which triggers resource agency consultations under the Endangered Species Act) or require other environmental clearances, such as those mandated by the California Environmental Quality Act. A single application (the Joint Aquatic Resources Permit Application, or JARPA) is accepted by all the agencies listed above; however, due to its multiuse nature, it is cumbersome to complete.

On the regulatory side, agency staffing has been increasingly underfunded, leading to less-than-optimal conditions for processing permits. Lengthy permit processes have resulted in some project managers losing funding because the regulatory process extends beyond the life of some grants.

Opportunities

Monitoring is typically required by the regulatory agencies to ensure that each project is meeting its goals and the agencies' requirements. These agency monitoring requirements do not always directly address the scientific uncertainties facing a specific project. A coordinated, regional monitoring program should be created that uses this required data gathering to (1) support the establishment of streamlined permitting mechanisms for restoration projects (e.g., through regional general permits), (2) ensure that the project is not having a negative impact on resources, and (3)

move into the estuary. Conversely, current species may be extirpated from the estuary. The consequences of these new assemblages are not known, but the population viability of native wildlife may be reduced. For example, warmer temperatures and reduced circulation combine to produce lower dissolved oxygen levels, which promote the spread of predatory snails that can decimate native oysters. As another example, the introduction of various Asian gobies that prey upon and compete with tidewater gobies may preclude the reestablishment of tidewater gobies into their former areas. More studies are needed to identify the pathways by which a change in community inform restoration design and management practices regionwide.

Regional mapping efforts pursued at a scale and with detail sufficient for an analysis of existing aquatic resources (quantity and quality) and of potential restoration sites could provide regulatory agencies with a more solid foundation for priority-based decision making. A plan for regional monitoring is incorporated in the state's Wetland and Riparian Monitoring Program (WRAMP), which produces regular reports on trends in wetland extent and condition and relates these trends to management actions, climate change, and other natural and anthropogenic factors in a way that informs future decisions and recognizes habitat differences in the bay's various sub-embayments.

A revised permit process should therefore include the production of a coordinated monitoring data set to inform future projects, along with built-in flexibility with regard to the number of sites that would require monitoring. Under such a permitting scheme, regulatory agencies would be able to establish a stratified sampling protocol such that each site would not necessarily need to be monitored every year. Additional flexibility could be written into the program to allow the adaptive management of sites and to give permittees the ability to truly experiment, so that a failure to meet performance standards will not necessarily entail habitat replacement where valuable learning has occurred. This flexibility may require a greater tolerance for risk from short-term impacts in the interest of testing restoration concepts intended to provide more resilient systems in the long term.

Upcoming Challenges

Managing sediment on a watershed scale is an emerging challenge. Innovations and varied approaches to the existing restoration process and regulatory frameworks will likely be necessary in order to facilitate the availability of sediment where it is needed to sustain tidal marshes. A high-priority example of this is the redesign of flood-control channels to allow for natural processes to move sediment from channels (where it impedes capacity) to the baylands (where it is needed). How we take full advantage of other sources of sediment in the system, such as navigational dredging projects, will be critical to address as well.

Another example of an emerging challenge is potential reliance on baylands restoration projects to mitigate greenhouse-gas emissions. Baylands restoration projects that are designed to maximize carbon sequestration may not fully meet other habitat objectives that regulatory agencies are charged with advancing.

Projects will increasingly need to meet multiple objectives, including climate mitigation, flood control, shoreline protection, and habitat enhancement. Addressing such challenges will require a comprehensive analysis of the specific challenges paired with an understanding of the distinctions among agency historical practices (cultural norms), internal agency guidelines, enforceable policies, and laws and regulations. Certain regulatory challenges may be resolved on a shorter time frame through modifications within the existing regulatory frameworks. Other challenges may require a longer-term process that includes revisions to laws and enforceable policies. Ongoing regional coordination among regulatory agencies and the scientific community is critical to both identify challenges and to develop a broad consensus for solutions that can lead to these refinements in policy and permitting.

composition affects target species. Because the risks are not yet identified, establishing a surveillance-monitoring program is recommended.

IMPACTS FROM INVASIVE *SPARTINA*

In recent decades, the San Francisco Bay tidal marsh has been invaded by an introduced cordgrass (*Spartina alterniflora*) from the eastern coast of the United States and subsequently by more invasive hybrids formed between the Pacific and Atlantic species. As an ecosystem engineer, invasive hybrid *Spartina* (referred to

Invasive *Spartina*

interchangeably below) can affect tidal wetland functions, such as succession, productivity, and habitat structure. On the lower end of its tidal elevation range, invasive *Spartina* has grown down into mudflat elevations, converting mudflat into hybrid meadows. On the higher end of its elevation range, invasive *Spartina* has displaced the dominant marsh plain species—perennial pickleweed, gum plant, and saltgrass—to become dominant in some marshes. In restoration sites, hybrid *Spartina* has formed dense monocultures absent of the channel complexity and diverse mid-marsh zonation typical of native-dominated marshes.

The effects from invasive *Spartina* can be beneficial in certain ways. The ability of tall, dense hybrid *Spartina* to trap sediment and cause rapid vertical accretion not typical of native marshes could help marshes endure in the face of sea-level rise. A co-benefit of using hybrid *Spartina* to hasten accretion is the provision of increased cover and foraging substrate for the endangered Ridgway's rail. The population of Ridgway's rails grew when invasive *Spartina* expanded and declined when the cordgrass was aggressively controlled. However, the association between Ridgway's rail and hybrid *Spartina* was not ubiquitous; rather, the rails appeared to take advantage of the invasive plant mainly in places where cover and high-tide refuge were lacking to begin with.

On the other hand, studies of the effect of hybrid *Spartina* on wildlife communities show the potential for significantly harmful effects. First, native cordgrass (*Spartina foliosa*), which also facilitates marsh accretion, could be at risk of extinction due to the loss of low marsh from sea-level rise and genetic assimilation by the invasive hybrids. Furthermore, conversion of mudflat to hybrid *Spartina* meadows would equate to the loss of foraging habitat for more than 500,000 shorebirds that rely on the mudflats of the bay for refueling during migration. The altered marsh plain plant structure of invaded marshes causes a loss of habitat for the endangered salt marsh harvest mouse. Invaded marshes have also altered benthic invertebrate communities in terms of biomass, diversity, and functional group identity. The shift is most marked in converted tidal mudflat, where the invertebrate community shifts from surface feeders that primarily consume microalgae to belowground feeders that primarily consume plant detritus. Finally, hybrid *Spartina* propagules could spread directly from the San Francisco Estuary to as far as Oregon, and indirectly over generations to British Columbia and Alaska.

Because of concerns about the negative effects of invasive *Spartina*, the California State Coastal Conservancy and the US Fish and Wildlife Service's Don Edwards San Francisco Bay National Wildlife Refuge prioritized the eradication of invasive *Spartina* from the San Francisco Estuary through the formation of the Invasive *Spartina* Project (ISP). Since 2005, persistent control efforts by a region-wide coalition of ISP partners have reduced the footprint of the hybrid from over 800 acres to 29 net acres as of the 2013 treatment. Complete genetic eradication of *Spartina* is notoriously difficult, as evidenced by similar situations elsewhere in the world. Monitoring for and removing invasive phenotypes (those plants that act in the environment like an invasive hybrid) is a critical aspect of the later phases of the eradication plan, given that the removal of every *Spartina alterniflora* gene may be impossible. The possibility of using invasive *Spartina* to stimulate marsh accretion in the future is acknowledged as a tool that could be used if the loss of marshes becomes dire as sea levels rise. For now, innovative approaches to adding high-tide refuge (such as marsh mounds and floating islands) and aggressive revegetation of treated marshes are under way to provide important additional cover for Ridgway's rail and other wildlife in previously invaded marshes.

Summary of Consequences for Wildlife

Tidal marsh birds and mammals are particularly susceptible to climate change. Concerns include the loss of habitat due to sea-level rise; the inundation of habitat during winter extreme tides and storms and during the breeding season, coupled with a lack of refugia; and elevated predation due to human-associated predators (including crows, ravens, and cats) as well as to increased access to tidal marsh by predators. Impacts to the transition zone may further imperil marsh wildlife, as well as transition zone species. During major flood events, tidal marsh wildlife tends to be concentrated in the transition zone, which can therefore serve as an important foraging area for many species of predators. The transition zone supports the migration and dispersal of plant and animal species. It enables them to move along the bayshore between patches of preferred baylands habitat.

Migratory and far-ranging species using the baylands, such as shorebirds, waterfowl, and other waterbirds, will be affected by changes in the bay as well as by conditions elsewhere. Similarly, anadromous fish will be affected by changes in the bay as well as by upstream and downstream conditions. San Francisco Bay may become more important to these species if their ranges shrink due to inhospitable conditions at the extremes of the ranges, or if they arrive in poorer condition during migration. Managed ponds, which support large populations of waterfowl and shorebirds, will require intensive management to persist in the face of sea-level rise.

Changes in water quality, temperature, and bathymetry are expected to affect aquatic species, though in many cases the consequences of these changes are unclear.

Considerations for Actions Related to Wildlife

Habitat restoration and conservation on a landscape scale is critical to meeting the needs of wildlife in this ecosystem, which has experienced severe habitat loss and degradation over the past two centuries. Equally important is the management of the wildlife populations themselves in the face of increasing frequency and severity of extreme climatic conditions. Thus, management actions must address long-term trends in climate and habitat as well as sudden catastrophic events. Ensuring resilience means reducing the mortality of adults and juveniles, increasing reproductive success, promoting successful dispersal, and maintaining phenotypic and genetic diversity of both plants and animals.

Changing conditions and limited resources will likely lead to further conflicts and trade-offs in managing for different species and natural communities. There is a strong need for scientists, managers, and regulators to work together on approaches to scale up from species management to wildlife conservation at the community and landscape level.

The following strategies are critical to conferring resilience upon baylands wildlife:

1. ENSURE SUFFICIENT HABITAT EXTENT INTO THE FUTURE.

All baylands habitat types are important for wildlife, including tidal marsh, tidal flats, managed ponds, managed marshes, beaches, and transition zones. Sufficient habitat extent is the first step, but not the last, in ensuring the persistence of baylands wildlife.

2. PROVIDE HETEROGENEOUS HABITATS WITH ALL NECESSARY HABITAT FEATURES, LOCALLY AND ACROSS THE LANDSCAPE.

A healthy baylands ecosystem is characterized by heterogeneity at multiple scales. A mosaic of habitat patches allows an array of species to persist, but only if the components of the mosaic are functionally connected. Plants and animals must be able to move from one patch to another, at short (daily) or long (annual, decadal) time scales. Thus, heterogeneity is a desired condition that results from dynamic ecological processes operating within a changing landscape. The management goal is dynamic heterogeneity rather than static heterogeneity; the desired landscape is heterogeneous and changes with time.

Habitat heterogeneity encourages the survival of local populations of plants and animals by promoting genotypic and phenotypic diversity. This diversity allows for adaptive evolution in response to changes in habitat conditions. Adaptation is known to occur at the margins of habitats, including ecotones, where individuals encounter the limits of their physiological tolerance to environmental factors. Maintaining heterogeneous and connected habitats can help baylands wildlife respond adaptively to changing conditions on different time scales.

One important habitat feature that contributes to heterogeneity is the width, extent, and vegetation structure of the marsh–terrestrial transition zone (see Connections to the Watersheds: The Estuarine–Terrestrial Transition Zone above). It is equally important to focus on the nature of the terrestrial habitat that borders the baylands, because predators and invasive species often enter the transition zone from the terrestrial side. Upland areas that will accommodate wide transition zones and marsh migration space are likely to become rare, so all opportunities should be considered.

Refuge habitat from predation and extreme water levels is already of high importance and will become more so. Refugia may also be needed from drought, which leads to the drying of ponds and hypersalinity.

Design considerations can allow smaller areas to do more for their dependent wildlife populations. For example, topographic relief and a highly dendritic, sinuous network of tidal channels are of great value to marsh wildlife. Enhancing topographic complexity through the creation of marsh mounds and berms can enhance marsh heterogeneity, increase plant species diversity, and provide barriers to water flow and refuge from high-water events. Similarly, designing restored marshes so they have complex channel systems will increase their habitat value.

Similarly, management considerations can improve habitat quality and support denser wildlife populations. For example, salinities have generally been lowered in managed ponds in both the North and South Bay, as part of a long-term management strategy to manage some ponds for wildlife and ultimately convert other former salt ponds into tidal marsh. The result has been a substantial increase in diving and dabbling ducks, but such change has not necessarily been as favorable for shorebirds, some of which rely on the high densities of invertebrates found in hypersaline ponds. To counterbalance such a change, reducing the water depth in managed ponds can increase the accessibility of foraging habitat for shorebirds. Recent reductions in water depth in some managed ponds have led to increases in shorebird numbers. Thus, pond management can be optimized to maintain a desired balance of salinity and water depth to support diverse waterbird species. In this way, a reduction in acreage of managed ponds can still result in a greater abundance of shorebirds and diving ducks, provided the habitats can be carefully designed and closely managed according to key parameters.

3. ADDRESS OTHER STRESSORS.

A resilient population is better able to tolerate the effects of change, especially extreme events such as droughts and floods. A reduction of known stressors will help a population withstand new stressors, even if the effects of the new stressors cannot be precisely predicted. A resilient population has sufficient reproductive success and survival to offset mortality, including occasional catastrophic mortality, with some amount of buffer.

Hence, knowing reproductive and survival rates is important to assessing whether a species is in trouble. Where abundance has declined over time, research and management teams need to respond quickly to reverse that trend. Tidal marsh song sparrows have exhibited recent declines throughout the San Francisco Estuary due to low nest survival. Ridgway's rails have increased in number relative to the 1990s, but have decreased from 2007 to 2013, with low first-year and adult survival the prime contributors. Such studies indicate which life-history stage that management should focus on to augment resilience.

The following stressors should be reduced, independent of climate change, to increase population health and resilience.

- *Predation.* Predation affects adults, juveniles, and reproductive success (through the loss of eggs, seeds, etc.). See earlier discussion.
- *Contaminants*. These include methylmercury exposure for birds and mammals, pyrethroids for aquatic species, and emerging contaminants.
- *Invasive and nuisance species.* Management that targets invasive and nuisance species is often less controversial than other actions.
- *Human disturbance*. Disturbance by humans (often due to incompatible recreational use) can be reduced. Shorebirds and waterfowl benefit from reduced disturbance, as do harbor seals.
- *Disease susceptibility.* Susceptibility can be reduced through the improvement of a species' physical condition, which in some cases reflects prey availability.

4. INCREASE RECRUITMENT AND DISPERSAL SUCCESS THROUGH HABITAT CONNECTIVITY.

For wildlife populations to be robust and resilient, successful dispersal is critical. Small, isolated populations are vulnerable to extinction, while meta-populations connected by dispersal are much more likely to persist. Baylands habitats are already fragmented, and future change is likely to exacerbate the problem. For these reasons, habitat connectivity will become even more important in the future.

Furthermore, current baylands habitat configurations are expected to change substantially. Habitat patches that are currently suitable will no longer be suitable, but other areas will become more suitable. As a result, wildlife populations will need to be able to move in order to persist, and that will require connectivity of existing and future suitable habitat.

Unfortunately, dispersal ability is limited for many baylands species of concern. This is especially so for a suite of endangered or rare marsh plant species. In addition, vernal pool plants and invertebrates, longjaw mudsucker, tidewater goby, salt marsh harvest mouse, and the baylands shrews appear to have limited dispersal abilities. Black rails and Ridgway's rails demonstrate low dispersal rates, even when such movement would be adaptive.

Restoration designs can address habitat fragmentation by targeting functional connections that allow movement and dispersal between patches. Habitat corridors should be planned and restored, taking into account likely changes in habitat configurations. Habitats do not necessarily need to be contiguous, but target wildlife species do need to be able to move between patches successfully. Highways, levees, and other structures can be designed or retrofitted to allow successful wildlife dispersal.

For some species of limited dispersal ability, or for which current barriers are too high, the active translocation of individuals will be required as currently occupied habitats are lost or degraded and new habitat is produced in other areas.

5. MANAGE FOR DYNAMIC LANDSCAPES.

The changing and unpredictable nature of future habitat configurations will require greater planning and monitoring in order to ensure successful wildlife outcomes. Restoration designs should improve on the present landscape by providing more high-quality, connected, sustainable habitat patches. In addition, restoration projects should anticipate where mudflats or tidal marsh may migrate in the future, and design accordingly. Management actions should fit into a regional vision of a landscape of diverse, heterogeneous, connected, sustainable habitat patches both now and into the future.

Changing landscapes will also require wildlife populations that can adapt to new conditions. Many species of concern in the baylands are composed of genetically distinct populations or subspecies, including tidal marsh song sparrows, California red-legged frogs, salt marsh harvest mice, baylands shrews, black rails, and salmon. This valuable genetic diversity reflects an adaptation to local conditions. These genetically differentiated populations need management to maintain their resilience and facilitate the recolonization of suitable habitat following catastrophes. Recolonization may occur by a different subspecies or population than was originally present. This may be a natural aspect of rapid evolution brought on by the impacts of climate change. Maintaining spatially distributed and connected habitat

Complex landscapes help drive population diversity and resilience.

for these species is important for preserving genetic diversity as the foundation of future adaptation.

Isolated populations, such as those of some rare marsh plants and vernal pool invertebrates, represent unique products of adaptation and genetic drift. These isolated populations have very little crossbreeding. Thus, the loss of a population due to catastrophe may represent a complete loss of some genetic diversity and must be avoided.

6. MANAGE FOR UNCERTAINTY.

One approach to addressing the uncertainty regarding the timing of changes is to develop triggers for management action: when thresholds are crossed, management action is triggered. Thresholds of concern for wildlife include

- the recurrent overtopping or breaching of levees
- a clear need for new hydraulics or significant reconstruction or armoring
- low-marsh vegetation dominating the marsh plain
- large-scale conversions of brackish marsh to saline marsh

Another approach is to address knowledge gaps, of which there are many. Baylands managers suffer from a widespread lack of basic information for many species of concern. This is the case not only for rare species, such as the baylands shrews, but also for common species, such as river otters. River otters are becoming much more common in the baylands, but whether that is the sign of a burgeoning population or of movement downstream from more disturbed areas upstream is unknown. For many species, scientists don't know if populations are currently stable, declining, or increasing. For wintering species and migrants, even if information is available about current trends for the San Francisco Estuary, it may be missing for other areas, such as breeding grounds. Population models that incorporate environmental variability can begin to fill these knowledge gaps. Such models can be used to evaluate resilience, explore how resilience can be increased, and identify thresholds of concern.

CARBON SEQUESTRATION AND GREENHOUSE GASES IN THE BAYLANDS

Many of the most fundamental actions recommended in this report offer a co-benefit of sequestering carbon or reducing the emissions of greenhouse gases that contribute to global warming and climate change. Managing carbon and these gases more explicitly as a part of baylands conservation may allow restoration and management practices to mitigate climate change at the same time as adapting to it. The following discussion summarizes our current understanding of carbon dynamics in the tidal marshes of the Bay, building on detailed information found in Science Foundation chapter 6.

Wetlands are important in the global carbon cycle. They serve as major carbon sinks, due to their fast rates of primary productivity, large standing biomass, and their tendency to retain carbon as peat. While most urbanized estuaries are net consumers of organic matter and, therefore, sources of carbon dioxide (CO_2) to the atmosphere, net metabolism in the San Francisco Estuary overall appears to be nearly balanced.

Thoughtful management of San Francisco Estuary's baylands can play a part in global climate regulation. As conditions evolve, baylands management is increasingly being understood to play a role in carbon storage and fluxes of greenhouse gases. California has established a state cap-and-trade system in order to reduce emissions. Though further behind than forestry projects, the management of organic soils on drained coastal wetlands and the restoration of these wetlands are being eyed as potential future offset projects. Knowledge gained here, where planning activities have greater support and the capacity to be more forward-looking, can be transferred to other parts of the country and the world.

At the current price of a carbon credit under the California market (approximately \$12 per ton of CO_2), carbon financing would not underwrite the cost of a wetlands restoration project. However, those funds might enable existing staff to maintain a science program to provide the monitoring, reporting, and verification of carbon credits. It has yet to be seen what the price of carbon will be in coming years, but given the need for greenhouse gas reductions, the price is likely to rise.

Carbon Sequestration

Carbon cycling through plant growth, decomposition, sequestration, and greenhouse gas emissions directly affects the sustainability of tidal wetlands. Tidal wetlands remove CO_2 from the atmosphere as they accumulate organic matter, which helps them grow vertically in the tidal frame. In this sense, carbon sequestration in tidal wetlands integrates across both adaptation and mitigation for climate change. Within the baylands, carbon sequestration is of particular management interest, because of the possibility of reversing the loss of elevation due to subsidence (see section Drowning and Accretion above). Peat accumulation is most rapid in freshwater marshes and declines as salinity increases, creating more organic matter in the soils from the less saline parts of the estuary (fig. 23). If tidal marshes in the bay can grow vertically and migrate laterally with sea-level rise, then they will sequester more carbon. However, if marshes drown and become unvegetated mudflats, they largely lose the ability to produce and store carbon.

Significant stocks of carbon have accumulated gradually within baylands soils over time. Carbon sequestration in existing tidal wetlands averaged about 80 g C/ m^2/yr (grams of carbon per square meter per year) over the last century. Although sequestration data are available for mature wetlands within the estuary, no data exist for recently restored wetlands. Given the high rates of sediment accretion in recently restored areas, sequestration rates in these wetlands could be higher than in natural tidal wetlands over the short term. Based on projected restoration plans across the bay, a total of 0.28 to 0.30 million metric tons of carbon could be sequestered in restored tidal wetlands across the San Francisco Estuary.

Research on wetland greenhouse gas biogeochemistry in the San Francisco Estuary has been advanced primarily in the delta, where the majority of former wetland acreage now exists as drained subsided organic soils. Drained organic-rich soils continue to release CO_2 over long periods, and prolonged emissions are evident in drained areas of the delta. Conversely, emissions from more mineral-rich soils typically decline or halt over time, and wetland restoration can reinitiate the slow process of carbon sequestration once vegetation is reestablished.

Management of carbon in the baylands can be integrated with habitat objectives.

Approaches to grow wetlands in order to accumulate peat and reverse subsidence have been tested in the delta for over 10 years, but not in the bay. Opportunities to apply these approaches should be examined for the baylands, even though peat accumulation is somewhat slower in brackish and salt marshes. One of our greatest challenges is filling the subsided areas of drained baylands behind levees. Subsidence-reversal techniques may fill some of that volume. In locations where natural water supplies would be too saline for reed growth, freshwater could be derived from redirected wastewater outflow.

Greenhouse Gas Emissions

In addition to emissions of CO_2, some wetland soils can release nitrous oxide (N_2O), a greenhouse gas 310 times as potent as CO_2, and methane (CH_4), a greenhouse gas 34 times as potent as CO_2. Given these substantial greenhouse effects, both N_2O and CH_4 must be incorporated into any evaluations of overall carbon dynamics and greenhouse gas emissions. Nitrous oxide emissions are greatest in wetlands affected by high fertilizer loads. Methane emissions occur in wetlands with standing water, as well as in drainage ditches and duck ponds, and are more likely to occur at salinities below 18 parts per thousand (ppt), or about half the salinity of seawater.

In addition to carbon dioxide emissions, methane is probably being released from drainage ditches and areas of standing, low-salinity, and brackish waters on drained baylands. Nitrous oxide is likely being emitted from diked baylands with cattle or where nitrogen fertilizer is used. Suisun Marsh is very likely an important source of ongoing CO_2 emissions. The diked areas of Suisun Marsh are also likely producing methane from beneath standing water in ditches and duck ponds. Reducing ongoing emissions may have greater greenhouse gas benefits than the rebuilding of peat through restoration projects.

Considerations for Actions Related to Carbon Management

The restoration of duck clubs to tidal marsh would provide multiple benefits by sequestering carbon, reversing subsidence, and simultaneously reducing net greenhouse gas emissions. Current duck club management involves standing water over organic soils, which may reduce CO_2 emissions and protect soil carbon stocks in comparison to diked areas. However, this management could also increase CH_4 emissions. Further quantification of emission benefits under different land uses is needed.

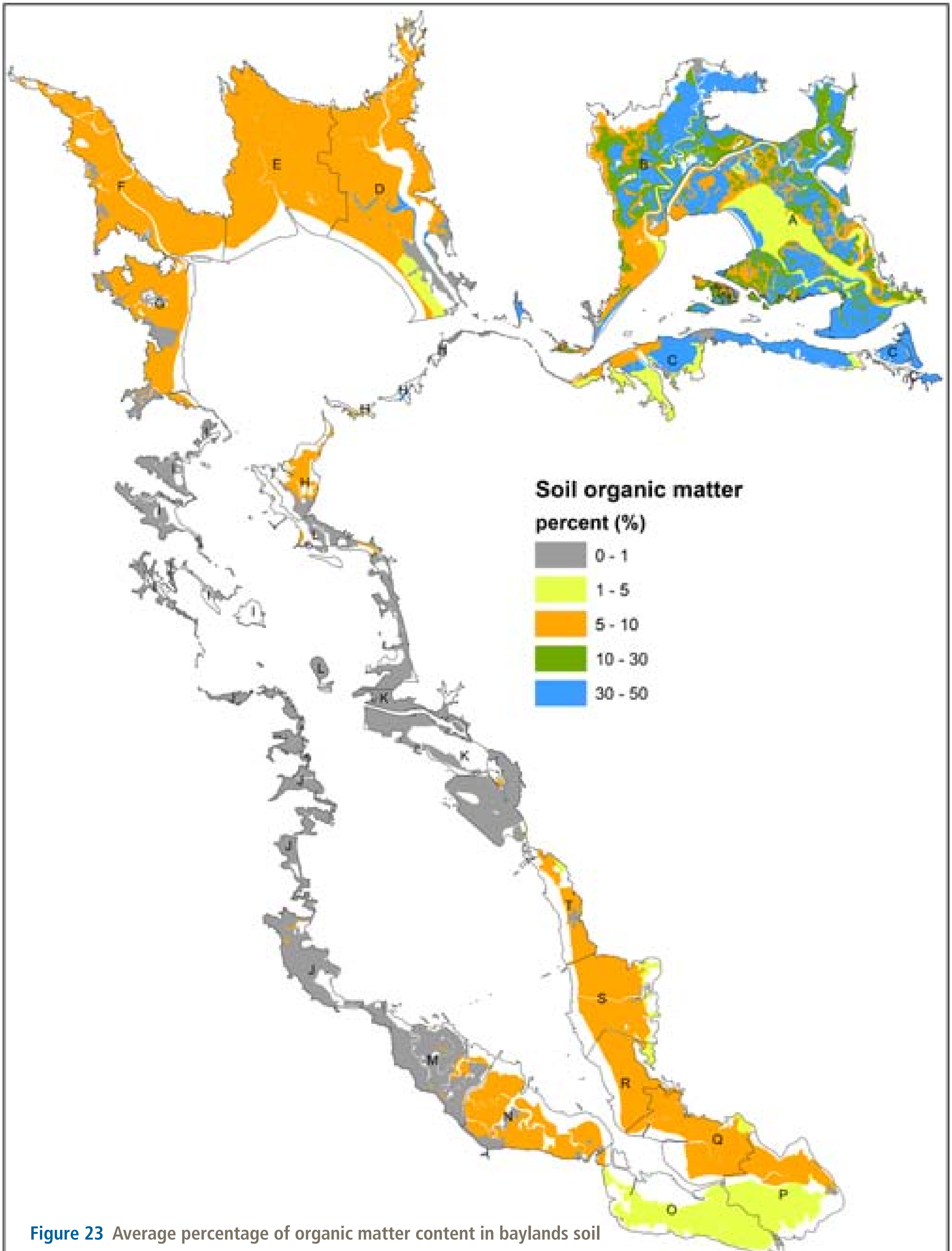


Figure 23 Average percentage of organic matter content in baylands soil

Box 8 Challenges to Funding Restoration and Long-Term Monitoring, Maintenance, and Management

Despite the recent support for, and the success of, restoration efforts, long-term funding for baylands management is uncertain. Securing funding for scientific initiatives and monitoring to guide restoration management has been an ongoing challenge.

Several traditional public funding sources for wetland acquisition and restoration are on the decline. State bonds, one of the key sources of funding over the past decade, have become less reliable, and their short-term cycles and capital focus have left gaps in the ability to assess the success of innovative approaches through consistent monitoring. San Francisco Bay, unlike other major estuaries, receives no federal programmatic funding; thus federal funds must be congressionally appropriated through the annual budget process, allocated by agencies, or won through nationally competitive grant programs. Private sources to fund restoration of the baylands remain limited.

As a result, project funding is often restricted to construction, planning, and permitting. Funder guidelines may not allow for all aspects of project planning, design, monitoring, and data sharing; so in general, project managers do not build long-term monitoring funding into a construction budget. For example, large Corps of Engineers restoration projects provide federal funding for monitoring and adaptive management for a limited period of time geared toward establishing a project's "success"; subsequent monitoring is assigned to the nonfederal sponsor.

This situation fragments evaluation processes that increasingly demand continuity for success. Restoration depends on consistent and interpretable monitoring data, yet data sets vary, as do protocols and monitoring term lengths. The lack of baseline inventories or long-term data sets complicates the ability of managers to use information for management purposes. Most monitoring is done to meet permit requirements that can be punitive if not met, and they can vary from project to project or permitter to permitter. Therefore, regulatory monitoring data that are used to satisfy permit requirements are often less useful than they could be to guide management and future restoration.

Monitoring and evaluating a project should guide adaptive management in practice, not just in theory. Dedicated funding is necessary to integrate existing programs, fill data gaps, and manage data in a way that managers can use. Monitoring programs, both regulatory and nonregulatory, should be designed to address efficacy. Are conservation efforts having the desired effects? If not, why not? What types of management actions would be necessary to bring about desired changes?

Effective monitoring will remain necessarily diverse but can be aligned. Ambient monitoring is longer term and important for answering questions about climate change. Static monitoring is needed to provide a full assessment for management purposes, and outcome monitoring on targets also needs to be conducted.

The San Francisco Bay Joint Venture Monitoring and Evaluation Plan Phase I (2011) identifies high-priority research and recommends the development of consistent protocols that answer clear

Biologists survey shorebirds.

management questions. It suggests resolving the lack of consistency in data management, analysis, and access. Addressing collaborative data-management needs will require not only new financial resources but also changes to internal agency and organizational policies.

Near-Term Challenges and Options for Project Implementation and Monitoring

Government and private funding sources need to be further diversified. Efforts should continue to develop a federally authorized program, such as the San Francisco Bay Restoration Act's proposal for a geographic program within the Environmental Protection Agency. Dedicated funding for wetlands should continue for state programs such as the San Francisco Bay Area Conservancy and the Wildlife Conservation Board. The state-legislated San Francisco Bay Restoration Authority is authorized to secure local and regional funding for wetlands restoration, but it has not yet secured such funding; regional ballot measures should be developed at a level adequate to successfully leverage nonlocal funds. Legislation, ballot language, and guidelines for new funding sources should allow funding for longer-term monitoring and management as well as wetland construction.

Nontraditional partnerships are being formed to leverage resources to both fund and deliver restoration projects. Examples include the integration of restoration into flood control and other Integrated Regional Water Management (IRWM) projects. The restoration community is coordinating with the dredging community to resolve issues that can lead to a greater reuse of dredge material to build marshes more quickly, enabling them to keep pace with sea-level rise. Cost has been identified as a major roadblock to expanded reuse; so it is necessary to find financial options that make reuse more viable as well as address persisting regulatory hurdles. In particular, Army Corps dredging projects should be authorized as restoration projects as well as maintenance projects to make reuse from their projects feasible. Such integrated alliances toward delivering habitat values will only become more important as climate change quickens.

Managers should continue to take advantage of fines and mitigation funding for public works projects. Regulatory agencies have directed fine and mitigation money toward high-priority restoration sites in the region, linking funding as closely as possible to the infraction or impact. This cooperative approach should continue to include other projects that address the impacts of sea-level rise.

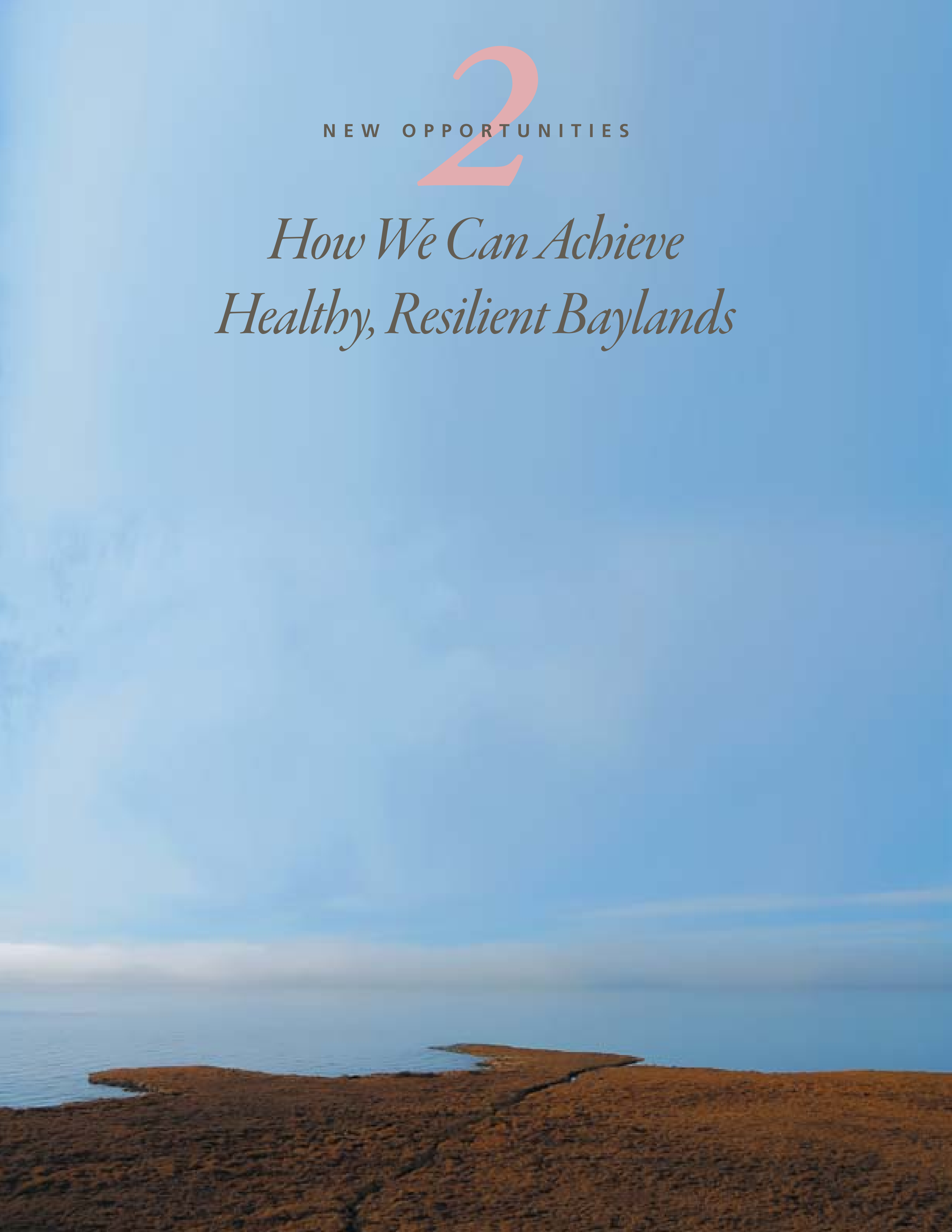
Monitoring criteria should be built into project designs to integrate planning and project delivery with management and should be reflected in funding prioritization criteria. Regulatory requirements represent opportunities to expand the existing sphere of knowledge related to wetland restoration in the bay and should be framed to (1) support the ease of permitting mechanisms for restoration projects and (2) inform improved restoration design and management practices. Existing information, including restoration projects' monitoring data, should be collected and consolidated, leading to a more expedited permit process.

Challenges should be met through new partnerships.

2

NEW OPPORTUNITIES

How We Can Achieve Healthy, Resilient Baylands



NEW OPPORTUNITIES

How we can achieve healthy, resilient baylands

Climate change threatens the baylands and their wildlife. It increases the magnitude and complexity of the challenges to achieving a sustainable baylands ecosystem, with urbanization, pollution, and invasive species continuing to pose significant obstacles as well. A corresponding increase in innovation, partnerships among stakeholders, and monetary investment is required to achieve ecological health in the baylands and to maintain the ecosystem services they provide to human communities.

INTRODUCTION

As human communities are threatened by climate change, so are the baylands and their wildlife. In the absence of mitigating human action, rising bay waters, reduced sediment supplies, warmer temperatures, lower freshwater inputs, more intense storms, and other changes are likely to cause significant loss of the baylands and their wildlife. If swift and sustained action is taken to achieve the project goals, as recommended here, then healthy baylands can persist into the future while protecting human communities from floods, improving water quality, and providing the recreational opportunities and wildlife habitat that are highly valued attributes of the Bay Area. Healthy and resilient baylands will help sustain healthy and resilient Bay Area communities.


A Snowy egret forages in the baylands.

Restoration practitioners strengthen the resilience of the baylands and their wildlife by restoring, enhancing, or emulating natural, dynamic physical and biological processes. Such actions rely on monitoring the baylands, taking innovative approaches, and applying a knowledge of past practices—and on these becoming a part of accepted restoration procedures and policies. To be successful, these actions also require more resources, closer collaboration among stakeholders, and quicker actions than before.

The recommended actions in this chapter update and replace those from the 1999 Baylands Goals Report. The actions are designed to preserve, protect, restore, enhance, and promote the resilience of baylands ecosystems to achieve the following vision for the next 100 years:

> *The San Francisco Estuary baylands will sustainably support robust populations of diverse native plant and animal species, while providing essential ecosystem services to human communities.*

The recommendations below lead off with overarching recommendation highlights, followed by 10 regional strategies and associated recommended actions that apply to most or all of the subregions and their segments. More detailed information for the subregions and segments follows. The recommendation highlights are the primary cross-cutting ideas that emerged from the scientific synthesis. The regional strategies elaborate on these ideas in more detail and include other recommended actions. The segment write-ups provide important contextual information about particular stretches of the baylands and indicate the most important recommended actions to take in each area.

HIGHLIGHTS

The following five highlights are the most critical overarching ideas from the recommendations. They will foster resilience to climate change so that the baylands can function as a healthy ecosystem and support native wildlife and human communities. The first two highlights directly increase baylands resilience, while the latter three improve the efficacy of resource stewardship and management.

1. Restore estuary–watershed connections that nourish the baylands with sediment and freshwater.

Finding

Sediment and freshwater are essential resources for restoring and maintaining the baylands. The rerouting of creeks, raising of levees, and building of infrastructure have removed the physical connections that deliver these resources to the baylands from their watersheds. Sediments allow baylands elevations to keep pace with sea-level rise, and freshwater is critical for moving watershed sediments directly into marshes. Freshwater also creates salinity gradients that increase biodiversity, help wildlife survive dry years, and support brackish marshes that rapidly accumulate peat, helping marshes maintain their elevation as sea levels rise and sequester carbon from the atmosphere. Historically the form of these watershed connections differed from creek to creek. Some forms of these freshwater connections can generate complex habitat mosaics of wetland types that further increase biodiversity and transition zone services. Protecting diverse watershed connection types where they exist and restoring the diversity of such connections as appropriate for local conditions and processes is important for fostering complexity (see highlight 2 below).

Watershed connections will become increasingly important to baylands sustainability.

Recommended Actions

- Restore and protect diverse types of sediment and freshwater connections as appropriate for local conditions and processes. In some cases, a connection could be restored as a natural landscape feature, such as a creek entering a marsh through a slough. In others, more artificial means may be needed to move sediment and water, such as dredging sediment from a flood channel and placing it on or near the baylands.
- Reconnect streams, and the sediment loads they carry, to the baylands. Determine how other freshwater sources, like treated wastewater effluent and stormwater, may be safely reconnected to the baylands through carefully monitored pilot projects.
- Use suitable dredged or excavated sediments (that have contaminant concentrations within acceptable limits) to the greatest extent possible within the baylands.

2. Design complexity and connectivity into the baylands landscape at various spatial scales.

Finding

A complex, connected landscape facilitates short-term population persistence and long-term species survival by enabling wildlife to adapt to a changing environment. Landscape complexity and connectivity are key to providing access to a variety of habitats that allow some portion of wildlife populations to survive hot years, dry years, extreme flooding, and other variability that is expected to increase. In addition, complex and connected landscapes promote the genetic and phenotypic diversity that is critical for wildlife to evolve in keeping with rapid environmental change. Finally, complex channel networks draining marsh plains allow natural water circulation that protects water quality.

Recommended Actions

- Restore and protect complex, connected landscapes that include topographic and salinity gradients; diverse habitat types; habitat mosaics, such as those found at the base of alluvial fans or in mature tidal marshes; variation within habitats, such as a complex of managed ponds with diverse salinities and depths; multiple habitat combinations (for example, a variety of transition zone types bordering tidal marsh); natural transitions between the habitats; and connections, like transition zone corridors or appropriately managed agricultural or parklands adjacent to baylands, that allow wildlife to pass from one area to another.
- Create connected gradients around the perimeter of the estuary. For example, connect marshes along the shoreline from salt marshes in the South Bay to brackish marshes in Suisun. At a smaller scale, protect and restore the watershed connections to the baylands. For example, maintain riparian corridors on creeks and broad transition zones between marshes and adjacent terrestrial habitats.
- Design baylands landscapes to be heterogeneous and connected at multiple spatial scales and across projects, so that no one area or project must provide all options, yet the full portfolio of complexity is represented across the region. Use local natural processes and historical and projected habitat configurations to design and create large-scale, self-maintaining, connected landscapes that support diverse native species.

3. Increase coordination among baylands stakeholder organizations to promote the successful implementation of the recommendations in this report.

Finding

Accelerating climate change drives a need for the immediate and efficient implementation of these recommendations before change becomes too rapid. The longer it takes to restore the baylands and undertake the other actions described here, the less likely it is that the ecological health of the baylands will be achieved and maintained. Environmental policies, regulations, and interjurisdictional relationships will need to evolve in keeping with new scientific information to enable the innovation and adaptive management necessary to implement the recommendations of this report successfully.

Recommended Actions

- Coordinate an adaptive management program that is based on testing hypotheses and learning from previous actions. It should (1) monitor the baylands landscape and wildlife to track ambient change and the effects of implemented actions, (2)

New scientific information drives innovation.

develop targeted applied studies, including modeling, to answer management questions and develop new approaches to restoration, and (3) develop projects to test hypotheses and new approaches and technologies.

- Centralize data access, statistical analysis, and interpretation through a consolidated effort managed by all key stakeholders that is supported by a long-term commitment to achieve regional goals with consistent funding. Apply local models like the Regional Monitoring Program for Water Quality, the Long-Term Management Strategy for Dredged Material, and the South Bay Salt Ponds Adaptive Management Program when designing the interjurisdictional partnerships.
- Facilitate and support dialogue between environmental scientists, managers, and regulators to promote the rapid diffusion of new information that allows policy to evolve in keeping with science. Create and support advisory forums to facilitate the incorporation of current science and the implementation of these recommendations into project design and management. Bring scientists together to build a better understanding of watershed processes, stream sediment dynamics, and the relationship of these factors to the accretion of sediment in the baylands.
- Coordinate more closely with the organizations that are stakeholders of delta environmental health to achieve better outcomes across the single estuary comprising the bay and delta.
- Incorporate the Science Update recommendations where appropriate in local and regional plans and resilience strategies.

Informed dialogue will improve restoration plans.

4. Create plans that factor in ecological outcomes after extreme events and other disasters.

Finding

Catastrophes in the Bay Area that are caused by extreme weather events and earthquakes are predictable in type and location but not in timing. Floods, drought, heat waves, and other environmental extremes are a significant risk to the ecological health of the baylands, and human responses to these events could impose an even greater risk over time. Planning ahead for such catastrophes can enable the development of nature-based flood-protection and other landscape designs that protect human communities while also protecting and even enhancing baylands ecosystems. Without such plans, engineered solutions may be implemented after a disaster that do not optimize the ecosystem services and ecological functions of the baylands, since these solutions are under the purview of agencies that often lack the requisite ecological mission or expertise. For example, after a flood some areas of shoreline might end up with hardened seawalls next to deep water even though a design with intertidal wetlands and subtidal habitats might offer a more optimal and durable solution for adjacent human communities.

Recommended Actions

- Integrate implementation of the actions recommended here as appropriate into response plans for catastrophes that are likely to affect the ecological functioning of the baylands, either through the catastrophe itself or the response to the catastrophe (such as building sea walls or raising levees). Opportunities for this may include updates to general plans and capital-improvement programs for cities, counties, and flood-control districts.
- In these plans, detail approaches that rely on natural processes to protect and restore ecosystem services and ecological functions. Such approaches—for

example, restoring physical processes that allow marshes to persist over time and protect the developed shoreline from erosion—will also create resilience to future events.

- Establish and cultivate relationships among the agencies entrusted with stewardship of the baylands and those that implement infrastructure changes after disasters, such as cities, counties, and flood-control districts.

5. Engage the citizenry in the baylands.

Finding

Successful implementation of the recommendations in this report is unlikely without a long-term increase in funding, education, and advocacy for the baylands. A strategy to develop the necessary level of resources must include efforts to inform and empower the local citizenry, elected officials, policy makers, and funding organizations to make decisions that promote healthy, resilient baylands. Directly engaging local residents in the baylands through recreation, volunteerism, and other field activities is another way to promote advocacy.

Recommended Actions

- Conduct outreach to voters and policy makers by framing messages about the baylands in terms the public can connect with (clean water, flood protection, recreational opportunities, water sustainability, climate change resiliency, wildlife) and providing clear and concise actions they can take.
- Partner more closely with educational organizations to transfer knowledge about baylands ecosystem services, threats to those services, the history of environmental change in the baylands, stories about local innovation and success in restoring ecological health, and interesting features of the baylands landscape and wildlife. Target audiences are registered voters in Bay Area counties, teachers in the K–12 and university-level educational system, and people who live, work, or own businesses on or near the baylands.
- Build direct engagement of the citizenry into implementation planning through appropriate recreational access to the baylands, citizen science contributions to monitoring (including crowdsourcing), volunteer labor for restoration projects, adventure learning, regional science competitions based on the challenges facing the baylands, and other such activities.

Stakeholder of the future baylands

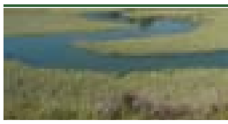
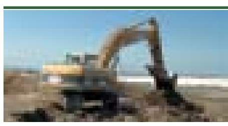
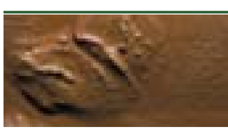
Figure 24 Artist's rendering of an envisioned future baylands depicting implementation of the regional strategies to promote resilience in the baylands landscape, its habitats, and wildlife. Here a local creek has been reconnected to the baylands, *delivering sediment and freshwater* directly into the marsh, which helps the marsh rise in elevation as sea level rises. This restored connection also creates a *gradient of fresh to brackish to salt marsh*, providing different habitats for wildlife. The salt marsh has a *robust, complex channel system*, pannes, and an undeveloped transition zone to the upland. *Protected and enhanced transition zone* supports native plants and animals, and provides a place for the *marsh to migrate landward* as sea level rises. The continuous transition zone

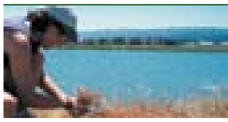
around the baylands and up the creek is a *corridor for wildlife movement* and a place for marsh animals to find *refuge from high water and predators*. A managed pond with constructed islands adds *complexity to the landscape mosaic* of habitats, providing essential support for water birds. This *complete tidal wetland system* also includes a mudflat, barrier beach and oyster reef on the bay side, all of which *support greater biodiversity and physically protect* the adjacent marsh and shoreline. The marsh restoration in progress at the far right *uses dredged sediment* to allow the restored marsh to *achieve a higher elevation* prior to sea-level rise acceleration around midcentury, which will *better sequester carbon* and create a continuous corridor of marsh for wildlife movement along the shore. *Integrated management and monitoring* allows for thriving natural systems in close proximity to urban citizens.

REGIONAL ACTIONS

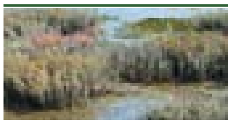
Regional recommended actions are grouped below into 10 strategies to promote the long-term resilience of the baylands and their wildlife. An abbreviated version of each strategy is provided in the table below for easy reference, and the full description of each strategy follows the table. Each action is stated only once for brevity, even though some actions are interconnected and mutually supportive and could be placed under multiple strategies. The scientific rationale for the actions and other background information is provided in the Science Foundation chapters.

REGIONAL STRATEGIES TO PROMOTE RESILIENCE IN THE BAYLANDS LANDSCAPE, HABITATS, AND WILDLIFE

	**1.**	**Restore estuary–watershed connections that nourish the baylands with sediment and freshwater.**
	**2.**	**Design complexity and connectivity into the baylands landscape.**
	**3.**	**Restore and protect complete tidal wetlands systems.**
	**4.**	**Restore the baylands to full tidal action before 2030.**
	**5.**	**Plan for the baylands to migrate.**
	**6.**	**Actively recover, protect, and monitor wildlife populations to avoid bottlenecks and to buffer population sizes.**
	**7.**	**Develop and implement a comprehensive regional sediment-management plan.**
	**8.**	**Invest in planning, policy, research, and monitoring as key elements of implementing these actions effectively.**



9. **Develop a regional transition zone assessment program.**



10. **Improve carbon management in the baylands.**

1. Restore estuary–watershed connections that nourish the baylands with sediment and freshwater. (This follows from recommendation highlight 1 above.)

Take advantage of sediment transport processes in local rivers and streams that nurture the vertical accretion of tidal marsh, create alluvial fans, and create more riverine transition zones.

A. Prioritize tidal marsh restoration in areas with high sediment loads from local rivers and streams. Realign some stream courses where necessary and feasible to restore natural sediment-delivery processes. Protect land, working with willing sellers as needed.

B. Identify ways to increase the availability of watershed sediment to tidal marshes and mudflats. Develop a better understanding of watershed sediment-transport processes, including sediment storage, transport, and delivery to the baylands. Preserve and re-create natural patterns of sediment transport in local streams. Restore and protect local stream hydrology to provide the flow regimes necessary to move fine sediments to the bay while protecting stream health. Evaluate ways of accessing sediment trapped behind dams.

C. Use suitable sediment from various sources (excavated or dredged) for baylands restoration and management. Identify approaches to placing sediment that mimic natural accretion processes. Research and test innovative approaches for applying sediment to baylands, such as thin layers that do not cause unacceptable impacts to biological processes. Place sediment in volumes and frequencies that mimic natural processes.

D. Identify and implement opportunities for taking advantage of treated wastewater and stormwater to create salinity gradients and maximize peat accumulation in the baylands, while protecting water quality and minimizing nutrient loading. Accumulate peat in diked baylands prior to breaching to increase elevations and sequester carbon.

2. **Design complexity and connectivity into the baylands landscape at various spatial scales (follows from recommendation highlight 2 above).** Create a baylands landscape of diverse, complex, and connected habitat mosaics with patches of tidal marsh several hundred acres in extent. In the process of creating this landscape, consider how changes in habitat type due to climate change or restoration will affect different wildlife groups, and compensate for these trade-offs.

    A. Connect large baylands habitat mosaics to each other and to local watersheds with a functionally connected transition zone around the perimeter and riverine riparian corridors that enable wildlife migration and dispersal. Restore and enhance gently sloped transition zones adjacent to tidal marsh and design them to support native wildlife species. Build naturalistic riverine levees as part of functionally connected riparian corridors along the bay's tributary streams to provide a high-functioning transition zone now and into the future. Incorporate agricultural land and managed wetlands as part of the matrix surrounding tidal wetlands.

    B. Preserve or create high channel complexity in tidal marshes, or restore the processes that allow complex channels to develop. Complex channel networks have several orders of channel size, are sinuous, have a channel density appropriate to the local salinity regime, and exhibit point bars, slump blocks, undercut banks, and other physical attributes that create valuable habitat and natural water circulation that maintains high water quality. Where appropriate, provide large, deep channels in restored marshes for fish, invertebrates, diving and dabbling ducks, and other aquatic animals. Maximize the habitat value of channel complexity by promoting structurally diverse native vegetation to provide cover and high-tide refuge for wildlife such as Ridgway's rails.

    C. Actively manage and restore diverse habitats for waterbirds and small mammals. Manage ponds in public ownership in the North and South Bay to maintain a range of salinities and water depths for waterbird foraging. Manage low-marsh vegetation, including native cordgrass) and establish beds of eelgrass, sago pondweed, widgeon grass, and native Olympia oysters to support waterbirds. Where possible, provide sufficient habitat for waterfowl, shorebirds, and small mammals by modifying managed ponds and taking advantage of opportunities to convert salt ponds to managed ponds and managed marsh. Ponds managed to support wildlife should be located in areas that facilitate operations and maintenance, as well as the long-term viability of the pond. They should also be located near other habitat resources (such as tidal mudflats for foraging) needed by the target species (generally waterbirds).

    D. Reduce landscape barriers to wildlife movement by modifying roads, highways, levees and similar structures to allow the successful dispersal of native plants and animals, while proactively managing against the spread of invasive species and nuisance predators. Where feasible, create corridors of native plantings and open space through suburban and urban areas to make these areas more permeable and hospitable to native wildlife. For example, create species-appropriate passages for wildlife under or over freeways at critical points for habitat connectivity, and take advantage of opportunities to re-landscape parks and greenways to provide greater wildlife support.

3. **Restore and protect complete tidal wetlands systems** to provide habitat and physical resilience. Include all the following components appropriate to the local setting: submerged aquatic vegetation (SAV) beds, oyster beds, algal beds, rocky habitats, beaches, mudflats, low marsh, marsh plain, high marsh, complex channel networks, and transition zones, including natural levees along channels, creeks, and waterways, and broad transitions to adjacent wetlands and uplands.

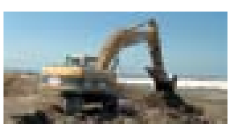
   A. Create high-water-refuge areas, including marsh mounds, restored and enhanced transition zones with appropriate vegetative cover, and diked wetlands where needed for wildlife such as salt marsh harvest mice.

   B. Provide buffers on undeveloped and agricultural lands (especially ones devoted to small grains, hay, and grazing areas) adjacent to the baylands to reduce disturbance and provide refugia from high water and other extreme conditions for wildlife, and to create the habitat mosaics needed for species that combine baylands and terrestrial habitats in their home range (e.g., northern harrier, dabbling ducks, and vernal pool species).

   C. Encourage where relevant the creation of appropriate wildlife habitats in developed areas adjacent to the baylands, and where feasible connect them through habitat islands and corridors to protected lands higher in the watersheds. Work with municipalities, land development companies, landscape architects, and others to incorporate habitat restoration, native plant landscaping, and other natural features that maximize support of baylands wildlife.

   D. Restore and create beaches, natural salt ponds, tidal marsh pans, and other diverse components of the baylands ecosystem to enhance wildlife support.

   E. Use restoration designs that integrate natural landscape characteristics and dynamics to maximize successful and sustainable outcomes and increase resilience, while minimizing long-term operational and maintenance costs.



4. **Restore the baylands to full tidal action before 2030** in strategic areas to maximize marsh accretion before the expected acceleration in sea-level rise and to sequester carbon sooner rather than later.

   A. Consider available information, including local sediment supply, erosion regimes, marsh-accretion models, and landscape position, to prioritize areas for restoration that are likely to persist as marsh for many decades.

   B. Accelerate funding and streamline the implementation of projects that restore the baylands to tidal action.

   C. Encourage baylands restoration as an outcome of, and a reason to accelerate, the realignment of infrastructure at risk from sea-level rise, including railroads, transmission lines, roads, fuel lines, and wastewater treatment systems.

5. **Plan for the baylands to migrate** by using projections of sea-level rise and other changes to identify shifts in habitat location and connectivity over time. Encourage the implementation of relevant recommendations from this report as part of plans for upgrading levees, railroads, highways and other roads, bridges, wastewater treatment plants, utility corridors, and other public works infrastructure that will affect outcomes in the baylands.

   A. Identify and protect existing and projected transition zone lands or flood easements. Focus on broad, minimally developed areas adjoining existing tidal marshes that support high native-species diversity or are wildlife source habitats. Prioritize areas projected to retain biodiversity across a range of future climate scenarios. Plan ahead for the likelihood that, as sea levels rise and transition zones become marsh, there will be a loss of transition zone habitat for sensitive species, such as vernal pool wildlife and burrowing owls.

   B. Inventory intact patches of wetland and nonwetland habitat types that adjoin the present transition zone, including grasslands, seasonal wetlands, and forests. These should be fully protected to prevent further degradation and a loss of transition zone extension and enhancement opportunities.

   C. Identify the habitat patches likely to be used in the future for a suite of umbrella species and other species of concern. Establish movement corridors between current habitat patches, and plan how to ensure connectivity to future habitat patches. Design corridors for intermittent or permanent connectivity that minimize the impact of nuisance predators and invasive species. Prioritize the connectivity of patches that can provide recruits or propagules to move into new areas as they become suitable. Compensate for habitat loss due to climate change in one area by providing it in another (for example, if mudflats are lost in one area, encourage mudflat formation elsewhere for use as harbor seal haul-outs).

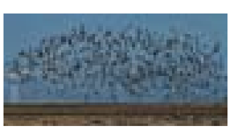
   D. Conduct a large-scale, long-term planning effort across the bay, delta, Central Valley, and other key areas of California to ensure that waterbirds that use the Pacific Flyway have sufficient habitat over the coming decades. Planning for restoration and conversion of waterbird habitats should be coordinated, so that

View of Salt Pond A20, which was restored to tidal flow in 2006

Salt pond breach

an optimal landscape (considering financial cost, habitat benefit, and implementation feasibility) can be pursued at the large scale that is biologically relevant for these highly mobile animals.

E. Encourage the modification and relocation of existing assets and infrastructure that are in the present and future flood-hazard zone to allow the reestablishment of physical processes such as full tidal flows. Discourage the development of new assets and infrastructure in present and future flood-hazard zones, as they may constrain restoration and other adaptation options that may help protect adjacent communities. Build in designs that allow wildlife to pass over, under, or through areas of infrastructure development to promote habitat connectivity and gene flow.



6. **Actively recover, protect, and monitor wildlife populations to avoid bottlenecks and to buffer population sizes** against extreme events. The regional actions recommended in this section should benefit wildlife by enhancing their habitats and the ecological functioning of the landscape as a whole. In addition, the actions below are specific recommendations for managing the wildlife populations themselves. As a rule, invasive or hands-on wildlife management (such as the lethal control of native predators and the translocation of individuals) should be pursued only as a last resort, after other solutions based on habitat and natural-process improvements have been implemented and found to be insufficient. There will likely be trade-offs between managing for different species, and taking action will require careful judgment of these trade-offs.

A. Emphasize protection efforts during and after extreme weather or other events that may cause population crashes.

- Emphasize nonnative and nuisance-predator control during and following times of short-term, stressful climatic conditions.
- In critical areas, construct systems that impede water flows for short time periods to reduce high water levels in times of acute stress.
- Monitor indicator species more frequently to know when and where such intervention is warranted. Use a rigorous process to identify key indicator species for the baylands to enable coordinated and comprehensive monitoring across the region.

B. Provide appropriate breeding and refuge habitat for species that need targeted management.

- Identify, conserve, and manage refugia for native baylands plants that may otherwise lose significant habitat due to sea-level rise. Focus on unique or core populations of rare or endangered species, especially in low marshes.
- Manage or create vernal pools of various sizes, depths, and salinities to facilitate a metapopulation structure for vernal pool plants and animals. Inoculate pools with nearby source populations of shrimp species and amphibian tadpoles. Control weeds and seed pools with vernal pool vegetation for several years until established.
- Provide spawning areas for fish, particularly open sandy beaches for grunion and clean, rough substrates in brackish waters of appropriate salinity for Pacific herring. Consider removing creosote pilings, and build new marine structures in the Suisun and San Pablo Bays with roughness, light availability, and other environmental characteristics in mind.
- Ensure that suitable ponds are appropriately inundated throughout the reproductive season for amphibians, with a focus on the needs of California red-legged frogs and California toads. Infrastructure, such as wells and pumps or water lines, may be necessary to provide additional water to ponds.
- Manage islands and levees and adjacent water levels to provide nesting, foraging, roosting, and high-tide-refuge habitat for birds. Add nesting substrate (such as sand and shell) to islands in the South Bay and, potentially, Suisun Bay for shorebirds. Minimize changes in water levels in seasonal wetlands during the breeding season to avoid flooding nests.

C. Maintain and enhance genetic diversity using active management when the passive landscape-design methods described earlier are insufficient.

- Translocate species requiring assistance (such as tidewater gobies or shrews) into newly created habitats or into formerly occupied patches after an extreme event causes extirpation.

- Assist the dispersal of high-marsh annual forbs and dispersal-limited or founder-limited populations of uncommon baylands plants of the high-marsh and transition zone to unoccupied locations near historic or existing populations. Assist their dispersal to restored marshes before nonnatives invade to facilitate their recovery after invasive species are eliminated, and keep seed sources restricted to local or subregional origin.
- Acquire more information about the genetic structure of baylands species with limited dispersal ability, including the ways that landscape barriers and corridors influence gene flow.

D. Reduce excessive predation impacts to sensitive species by managing nonnative and problematic native predators (such as red fox, cats, California gulls, crows, and ravens), and reducing predator access.

- Use integrated pest-management techniques over an appropriate time period, which is often the entire breeding season. Reduce impacts from cats by educating cat owners and working with animal shelters and trappers to remove feral cat feeding stations to areas of least impact and to handle nuisance animals properly. Emphasize mosquito-source-control methods based on natural physical and biological processes such as wind-generated waves and ripples, tidal flushing, and foraging by native insectivores. Minimize mosquitofish plantings during the California red-legged frog breeding season and avoid mosquitofish use in sensitive amphibian habitat.
- Remove or modify features that facilitate predator access to, and hunting in, the baylands (such as derelict fencing and utility towers used as perches by raptors). Reduce access from levees and other upland areas, and design any new levees to impede predator access. Where feasible, eliminate garbage dumps near the baylands. Provide cover from predators, especially during periods of exposure (e.g., extreme tides).

Plainfin midshipman

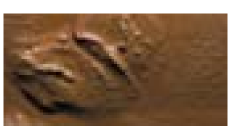
E. Manage and eliminate invasive plants, and use preventive measures in restoration projects and future transition zones. Avoid persistent soil-active herbicides that jeopardize seed banks of desirable plant species. Consider and minimize impacts to marsh fauna (including black rails, baylands shrews, and salt marsh harvest mice) from control measures.

Native gray fox

- ▹ In the near term, complete the elimination of invasive *Spartina* phenotypes (plants that act in the environment like the invasive hybrid), and prevent their reemergence. Where invasive phenotypes persist, focus efforts on lessening the impacts of invasive characteristics while promoting the long-term development of in-marsh structural complexity and native plant species abundance and diversity.
- ▹ Contain perennial pepperweed, and eliminate populations near the transition zone. Control pepperweed to prevent its spread into mature brackish tidal marshes that are not yet heavily infested.
- ▹ Aggressively control yellow flag, black rush, and Algerian sea lavender before they become a serious problem.

F. Reduce other stressors, mainly human disturbance and contaminant exposure.

- ▹ Design and manage recreational access to avoid and minimize disturbance to wildlife, especially during critical periods of their life cycle, such as nesting seasons, and during extreme high tides.
- ▹ Reduce wildlife exposure to contaminants, including methylmercury, pyrethroids, polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), and other organic contaminants.



7. Develop and implement a comprehensive regional sediment-management plan, building on existing regional sediment-management work that emphasizes the use of all suitable dredged or excavated sediment from the estuary, local rivers and streams, flood-control channels, local reservoirs, and other watershed sources. This comprehensive sediment-management system should be developed in close partnership with the bay dredging community.

A. Conduct research and monitoring to quantify (1) all potential sediment sources to the baylands, in particular their magnitude and spatial and temporal patterns of delivery, and (2) sediment transport and fate dynamics in baylands ecosystems, particularly mudflats and marshes.

B. Investigate if there will be enough sediment to maintain current marshes, mudflats, and managed ponds under specified sea-level rise projections and sediment-supply parameters, including local and Central Valley watersheds, until

2070 and 2100. In considering this question, studies should address the following scenarios:

- currently planned tidal marsh restoration
- the additional acreage needed to reach the 100,000-acre Baylands Goal for tidal marsh
- maintenance over time of the acreage goals for managed ponds
- planned restoration in the delta (specifying acreage, bathymetry, timing)
- potential extensive levee failure in the delta, Suisun, or North Bay
- beneficial reuse of all suitable dredged sediment from the estuary
- beneficial reuse of suitable excavated dirt from the watershed
- increasing watershed sources of sediment to the baylands (such as accessing sediment behind dams and other watershed management approaches)

C. Manage coarse bay sediment at the regional level for use in the baylands. Allow sand to move through the bay under natural forces to create and replenish barrier beaches.

8. Invest in planning, policy, research, and monitoring as key elements of implementing these actions effectively (follows from recommendation highlight 3 above).

A. Revisit these recommendations every 10 years and issue updates based on the understanding that has developed through research and adaptive management in the intervening time.

Active revegetation at Cogswell marsh

B. Develop designs and implementation plans for the management and restoration of large stretches of baylands to maximize the positive synergies among individual projects. Identify the appropriate boundaries of these areas based on the scale of natural processes, such as watersheds or patterns of sediment deposition and erosion along shorelines.

C. Adapt current policies to allow for the development and application of new, environmentally safe approaches that increase the ecological resiliency of the baylands. Existing regulations and policies have limitations on the use of bay fill to create habitat and on the reuse of dredged material. They also do not include specific recommendations or best management practices for new techniques such as sediment placement or the use of shells and other materials for subtidal restoration, horizontal levees, and improvements (like creosote removal or encapsulation) to living seawalls, living docks, and other existing infrastructure. Thoughtful experiments and data analyses of the new approaches listed here are needed, which will mean changes to existing policies and regulations.

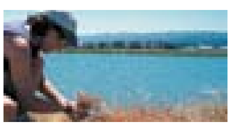
D. Consider all the elements of complete tidal wetland systems (including mudflats, the transition zone, and adjacent subtidal and terrestrial habitats) to be integral parts of baylands restoration at all scales, and encourage their inclusion in relevant regulatory framework and planning efforts.

E. Develop compatible approaches to baylands conservation for wildlife, public recreation, and traditional indigenous uses. Limit or restrict public access to areas with sensitive wildlife habitat value, particularly during breeding seasons. Where appropriate, provide access for wildlife-dependent activities such as fishing, hunting, wildlife observation, wildlife photography, interpretation, and environmental education. Develop other compatible public access in appropriate locations. Provide interpretive signage describing habitat values and promoting proper wildlife-viewing etiquette.

F. Ensure the continuity of programs to detect, manage, and eliminate invasive species. Establish and implement early-detection, rapid-response plans for novel outbreaking populations of invasive plants and animals to prevent their spread. This could be accomplished by reinitiating the Bay Area Early Detection Network (BAEDN) or providing similar capacity. Develop adaptive strategies for anticipated or newly arrived invasive species, including those that arrive because of climate-driven range shifts. Anticipate and prepare for the consequences of the impending invasion of the estuary by quagga and zebra mussels.

G. Conduct research and modeling to answer key science questions that will affect management decisions. One initial effort should be to model planned tidal restoration throughout the bay and delta, as well as changes to precipitation and reservoir operations, in order to estimate future salinity regimes and hydrodynamic changes.

The Don Edwards San Francisco Bay Refuge Environmental Education Center



9. Develop a regional transition zone assessment program as part of the actions described in recommendation highlight 3.

A. Develop a collaborative program of potential transition zone site assessment, project tracking, performance evaluation, applied research, and public reporting. Consider basing the program on the Wetland and Riparian Area Monitoring Plan and the tool set of the State Water Resources Control Board. The assessment program should, at the outset, provide a map of the full extent of transition zones as defined in the report, structured in a way that it can be updated as needed. The program should also allow local agencies to contribute to the updates. Methods to assess the existing and restored transition zone should be standardized, such that projects can be compared with each other and with background or ambient conditions over time. Information about the location and status of transition zone restoration projects should be readily available online, and the overall condition and prognosis of the transition zone throughout the region should be regularly explained to the public.

B. Establish a standing team of technical experts through an independent science organization to give advice on transition zone design, restoration, management, and assessment, such that these efforts are consistent with this and future updates of the Baylands Goals.

C. Develop a comprehensive portfolio of strategies for the conservation, restoration, and management of various transition zone types.

- Aim for consistency with natural landscape characteristics and dynamics in order to restore high levels of transition zone services when selecting and designing transition zone components. These include vernal pools, other seasonal depressional wetlands, moist grasslands and other slope wetlands, riparian forests along streams, tidal marsh, natural salt ponds, barrier beaches and berms, dunes, and shallow lagoons.
- Where appropriate, partially fill diked baylands and consider filling subtidal areas to create a transition zone on the bay side of levees.
- Develop methods to prepare terrestrial areas that will become transition zones. Conduct applied research on ways to encourage tidal-channel formation, topographic complexity, and native plant communities of the transition zone. Develop guidance for improving the management of agricultural baylands as an existing and future transition zone.

Slough channel and mudflats at sunset

10. **Improve carbon management in the baylands** to prevent further subsidence, increase organic matter accumulation, reduce greenhouse gas emissions, and sequester more carbon.

    A. In appropriate areas of managed freshwater marshes, promote the accumulation of belowground carbon by enhancing plant productivity while maintaining anaerobic soil conditions to inhibit decomposition. This can be achieved by gradually raising water levels. Maintain soil salinities close to 18 ppt to reduce the likelihood of methane emissions.

    B. On diked baylands with organic soils that are drained permanently or seasonally, raise the water tables to reduce soil carbon loss, fill ditches to reduce methane emissions, and reduce fertilizer or cattle densities, if appropriate, to reduce soil methane and nitrous oxide emissions.

    C. Develop approaches to make use of compost from recycled food waste, possibly integrated with wastewater disposal, on diked and other baylands as appropriate.

    D. Conduct applied research to inform better carbon and greenhouse gas management as a part of baylands restoration designs and management approaches. Quantify the greenhouse gas emissions from baylands of different habitat types, land uses (including all drained organic soils), and water-management regimes across the salinity gradient. Focus in particular on drained wetlands in Suisun, where peat is likely to be oxidizing and causing subsidence. Measure soil depths in current wetlands across the estuary so that existing pools of soil organic carbon can be calculated. Improve the understanding of the fate of carbon and nitrogen released from eroding tidal wetlands.

    E. Develop a more detailed plan for prioritizing activities to incorporate climate change mitigation into baylands management.

SUBREGION VISIONS AND SEGMENT ACTIONS

The following pages present the recommendations in greater detail by providing landscape visions for each subregion and actions for portions, or segments, of each subregion. There are 20 segments total; they are listed alphabetically (fig. 25) as shown on the map on the next page.

The subregional landscape visions provide a picture of what each subregion could look like if our recommendations were implemented. The recommended actions for segments are divided into two groups: (1) actions for habitats and the landscape in general to benefit baylands wildlife communities overall, and (2) actions for particular wildlife populations that need extra attention.

Fringing marsh along slough next to ponds

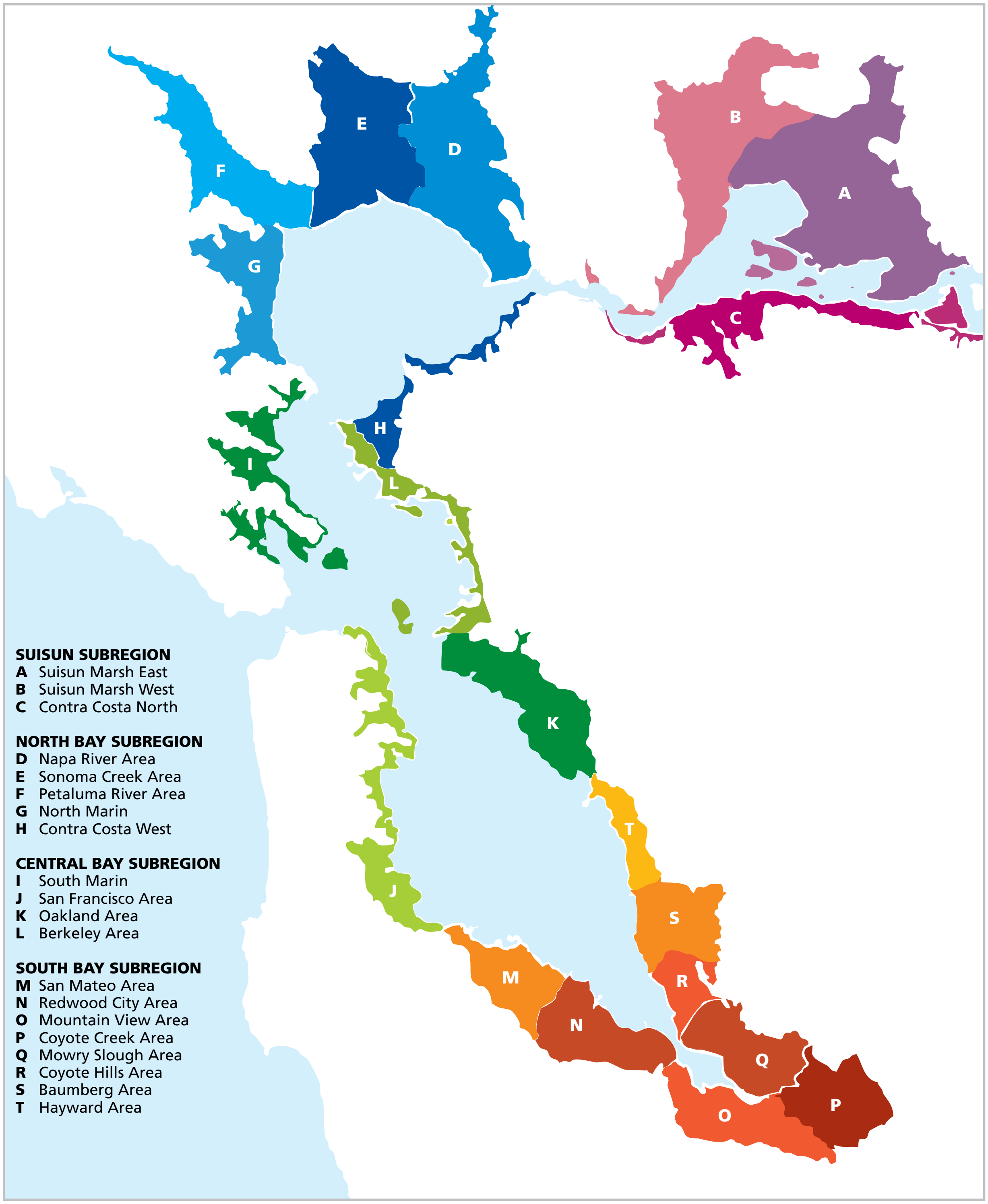
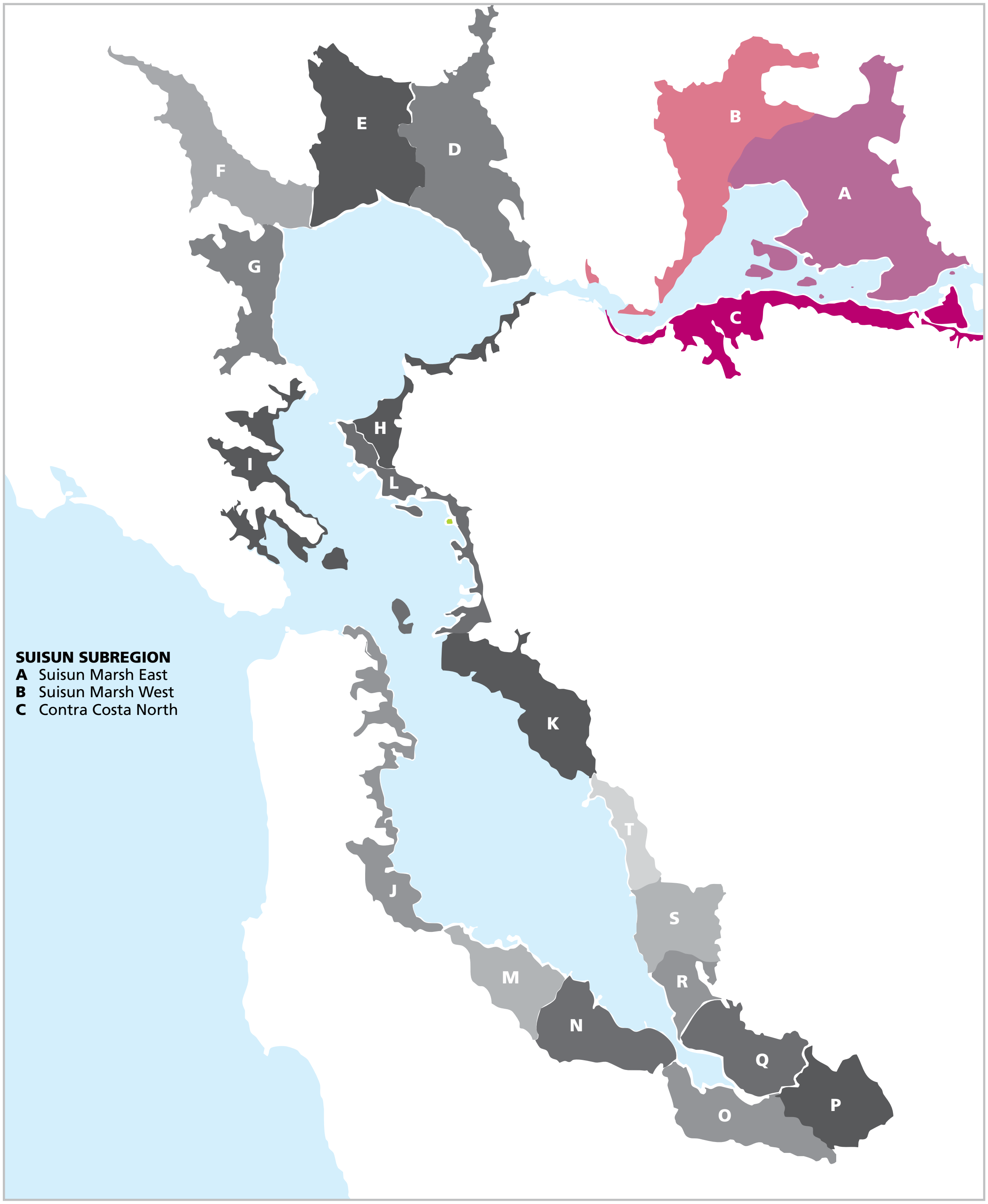


Figure 25 Project Area with Subregions and Segments

Suisun Subregion



Suisun Subregion

LANDSCAPE VISION

The Suisun subregion provides abundant opportunities to restore large patches of tidal marsh that adjoin broad transition zone areas while maintaining large tracts of diked marsh for intensive waterfowl management. The goal for the Suisun subregion is to restore large connected areas of tidal habitat in Suisun Marsh and along the Contra Costa shore; to conserve and enhance adjacent terrestrial areas and associated seasonal wetlands; and to enhance the remaining managed marsh habitat. Tidal marsh restoration should be prioritized adjacent to terrestrial areas with space for landward marsh migration.

Recommended Actions

- In Suisun Marsh, restore a functionally connected band of tidal marsh along the transition zone, providing space for landward marsh migration from the easternmost to the westernmost extent of the marsh. Blend the restored tidal marsh gradually with the adjacent grasslands to maximize plant diversity in the transition zone. Conserve low-intensity agricultural lands adjacent to tidal areas for future marsh and transition zone migration. Prioritize the areas near Nurse Slough, Hill Slough, and the head of Cordelia Slough that have naturally gentle slopes ideal for landward marsh migration. Restore tidal marsh in Suisun Marsh west of the railroad in conjunction with enlarging the small openings beneath the railroad tracks to accommodate current water flows and future sea-level rise.
- On the periphery of Suisun Marsh, enhance grasslands with vernal pools and enhance riparian vegetation along the tributary streams. These habitats should be protected and maintained with hydrological and ecological connectivity to the baylands.
- Along the southern edge of Suisun Marsh, restore a broad band of tidal marsh and open water habitat, in part to improve fish habitat and productivity. Restore a continuous tidal marsh corridor along Suisun Slough, providing connected marsh from Grizzly Bay to the slough's upstream extent and Hill Slough.
- Enhance diked unrestored areas of Suisun Marsh to tidal marsh by using best management practices to increase waterfowl diversity and carrying capacity, manage mosquitoes, reduce subsidence, and improve water quality. Best management practices may include increasing water-management capabilities, encouraging the diversification of seasonal wetland vegetation growth, and, where appropriate, promoting the accumulation of belowground carbon by enhancing plant productivity while maintaining anaerobic soil conditions to inhibit decomposition.
- On the Contra Costa shoreline, restore full tidal action to muted and diked marshes to create a tidal marsh corridor along the shore, including broad transition zones with diverse plant communities. Create terrestrial buffers along this corridor to protect baylands habitats and wildlife from disturbance. Restore riparian vegetation along as many stream corridors as possible.

Suisun Bay

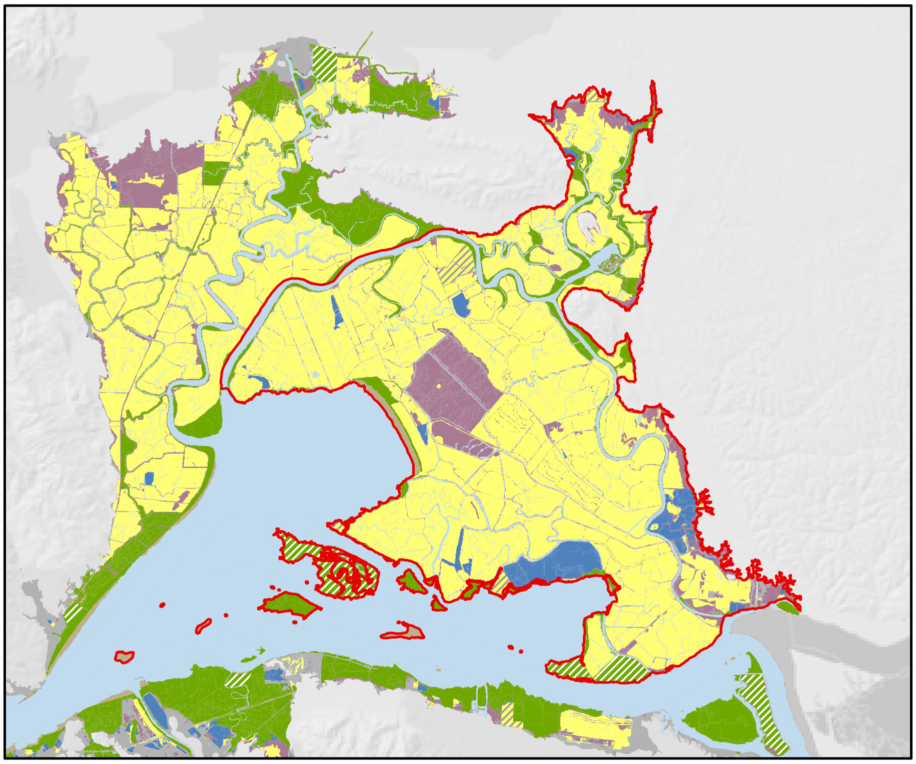
RECENT RESTORATION

Since 1999, only one tidal restoration project of approximately 70 acres has been completed in Suisun Marsh; one large tidal restoration project, the 2,200-acre Montezuma Project, is under construction; several other tidal restoration projects are being actively planned; and several unplanned partial breaches have occurred. The recently completed Suisun Marsh Plan (SMP) of November 2011 set a target of 5,000 to 7,000 acres of tidal restoration to be accomplished within the next 30 years. Additionally, the Fish Restoration Program Agreement (FRPA) requires the completion of 8,000 acres of intertidal and associated subtidal habitat, including a minimum of 800 acres within the Suisun subregion. The impacts of salinity changes due to tidal restoration in Suisun Marsh and the western delta should be assessed, as there are water-quality regulations (e.g., SWRCB D-1641) that must be met or reassessed in both areas.

CHALLENGES

Achieving the Suisun vision is subject to significant infrastructure constraints (including those posed by Highway 680, Highway 12, railroads, natural gas production infrastructure and pipelines, and petroleum pipelines); the arrival of invasive species (mainly clams, pepperweed, and certain submerged aquatic plants, such as *Egeria*); and subsidence in potential tidal marsh restoration areas. Private landowners and public entities will need to be willing to convert some duck clubs to tidal marsh in Suisun Marsh, to restore marshes to full tidal action on the Contra Costa shoreline, and to retrofit infrastructure in keeping with ecosystem health.

The Suisun subregion consists of segments A, B, and C.

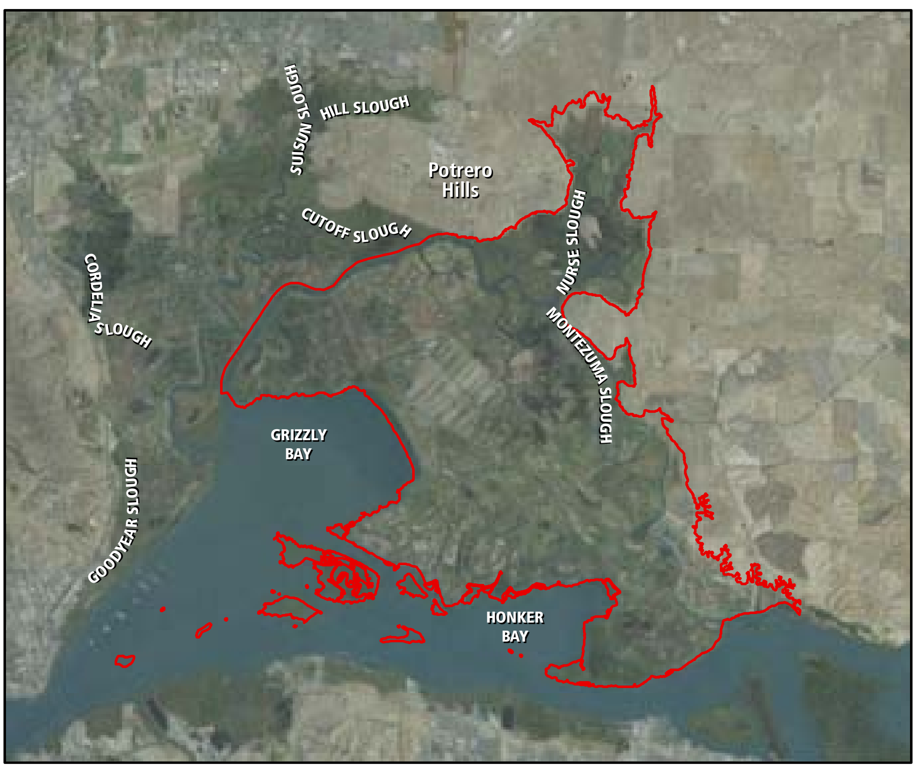


SUISUN MARSH EAST

Eastern portion of Suisun Marsh

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas



Red line shows the boundaries of Segment A.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Segment A's large size, current protected status (through the Suisun Marsh Preservation Act of 1977), and relative isolation make it an ideal location for habitat protection, enhancement, and restoration. Because of its location in the upper reach of the estuary, this segment offers a good opportunity to restore large areas of tidal marsh along the full salinity gradient. This segment contains the Montezuma Project currently under construction. Restoring tidal marsh at the periphery of Suisun Marsh would provide opportunities to reestablish the range of listed plants species, including the endangered soft bird's-beak and Suisun thistle. There are also opportunities to restore vernal pools with tadpole shrimp in the adjacent uplands. Many diked wetlands in this segment are well suited for continued management for waterfowl and other species.

Segment Features and Setting

Historically, this area was predominantly tidal fresh and brackish marsh, arrayed as low-lying islands in Suisun Bay and as wide plains between the bay and the adjacent uplands. Inside this broad expanse of marshes were sloughs, channels, ponds, and small bays. Except for parts of Suisun Bay, the segment had relatively few areas of tidal flat. Adjoining the baylands, especially along Montezuma Slough and near Potrero Hills, were extensive areas of moist grasslands with vernal pools. The relatively steep topography of Potrero Hills provided a unique and narrow marsh–upland transition zone.

Today, this segment is one of the least urbanized areas of the baylands ecosystem. Most of the marshes are diked and are managed as duck clubs, but some tidal marsh occurs in Suisun Bay, along the edge of Grizzly Bay, and in many of the sloughs. There are extensive tidal flats in Grizzly Bay. There are alkaline-saline vernal pool complexes in the surrounding grasslands that grade into the upper tidal marsh zone. Water and soil salinity in the diked areas are intensively managed, and the natural variability of channel water salinities are influenced by delta outflow and water project operations. For example, the salinity control gates in Montezuma Slough are operated to maintain channel salinity levels similar to levels that would have occurred before the start of water diversions from the delta.

Suisun Bay

Implications of Drivers of Change

The main drivers of change for segment A are climate change, sea-level rise, changes in upstream water quality and quantity, and managed wetland activities. As managed wetlands are converted to tidal wetlands, the regional water quality is expected to change, along with ecosystem functions. Salinity throughout segment A will likely be elevated for a longer duration each year as a consequence of sea-level rise and tidal restoration. Additionally, numerous areas within this segment are subsided and, with sea-level rise, current tidal and future restored tidal areas may become subtidal habitats. Wetland plant diversity in the managed and tidal habitats is expected to decrease with increasing salinities.

Ultimately, opportunities for restoration in this segment may be largely shaped by climate change and sea-level rise (SLR). Some managed wetlands may become unsustainable because of changes in flood-event frequency, unanticipated levee failures, high levee maintenance costs, subsidence, and so on. Changes in upstream water quality (sediment supply, salinity, contaminants, temperature, etc.) or quantity (the amount of freshwater water coming into segment A) can significantly affect ecosystem function and the effectiveness of restoration projects. The presence of a portion of Highway 12 and natural gas production facilities and pipelines in this segment presents an added challenge. As the impacts of these main drivers of change become more pronounced, some existing regulatory obligations (e.g., the Water Rights Decision 1641 mandating salinity standards) may become unachievable, thereby necessitating a revision of some regulatory obligations.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The target of 5,000 to 7,000 acres of tidal restoration set forth in the Suisun Marsh Plan (SMP) is to be accomplished within the next 30 years. Contributions to this acreage could come from the Fish Restoration Program (FRP) and the Ecosystem Restoration Program (ERP), which are funded efforts. The Bay–Delta Conservation Plan (BDCP), if it is approved and funded, could also contribute to the SMP's restoration acreage goal. A large portion of this tidal restoration acreage is likely to fall within segment A.

The impacts of salinity changes due to tidal restoration locally (within Suisun Marsh) and regionally (particularly in the western delta) should be assessed, as there are water-quality regulations—e.g., State Water Resources Control Board (SWRCB) D-1641—that must be met in both Suisun Marsh and the delta. For managed wetlands, waterfowl habitat should be improved following best management practices, and general management practices should be promoted that reduce land subsidence and improve water quality.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

The long-term vision for segment A is less certain. While achieving some tidal restoration goals is likely—such as restoring the remaining acreage described in the Fish Restoration Program Agreement (FRPA) or BDCP, restoration opportunities may be largely shaped by climate change and sea-level rise as managed wetlands become less sustainable because of changes in flood-event frequency, unanticipated levee failures, high levee maintenance costs, subsidence, and so on. As managed wetlands are converted to tidal wetlands, significant impacts to upstream water supply (e.g., more saline water) and ecosystem functions throughout Suisun Marsh and the delta are likely. Plans to contend with these challenges will be necessary for both large-scale tidal restoration and for the continued operation of managed wetlands.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large tidal marshes along the eastern side of Montezuma Slough, in the Nurse Slough area, near Denverton Creek, and at sites adjacent to Honker Bay.

Provide a tidal marsh corridor along the base of Potrero Hills between Nurse Slough and the marshes to the west.

- Enhance and restore a natural transition zone. Draft plans for a future connection to the Jepson Prairie, focusing on tidal marsh transitions, incorporating protective buffers wherever possible, and thus creating shoreline migration space.
- Optimize managed marshes (duck clubs) to ensure continued support for a diverse suite of waterbirds, prevent subsidence, protect water quality, store carbon, and accumulate peat in the face of increasing salinities, sea-level rise, and other changes.
- Protect and enhance existing vernal pools and other seasonal wetlands adjacent to Montezuma Slough, in the Nurse Slough area, and north of Potrero Hills.

FOR PARTICULAR WILDLIFE POPULATIONS

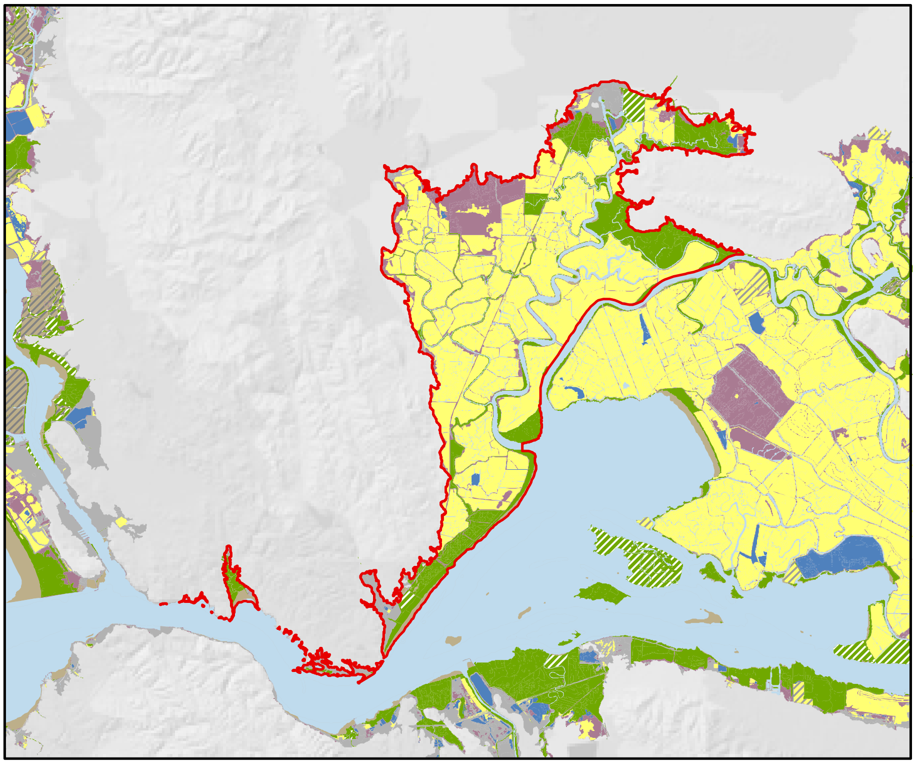
- If duck clubs are converted to other habitat types, compensate for the loss of managed marsh habitat for waterbirds.
- Contain perennial pepperweed, eliminate populations in proximity to marsh–terrestrial transition zones and in high-elevation marsh, and prevent the spread of invasives coincident with marsh migration. In particular, exclude pepperweed from mature brackish tidal marshes that are not yet heavily infested. Avoid persistent soil-active herbicides that jeopardize the seed banks of desirable species.
- Implement aggressive control measures for the invasive plant yellow flag, which could become a serious problem.

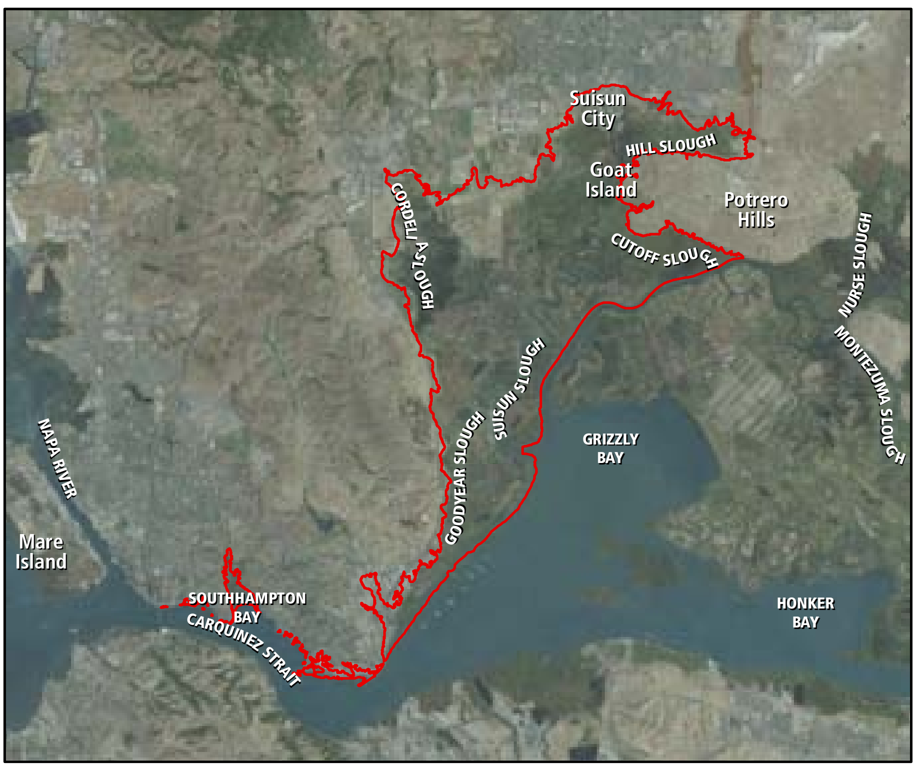
Restoration Benefits

Restoring tidal marshes in this segment would benefit the black rail, Suisun song sparrow, and other tidal marsh species. It also would increase detrital input to this very productive part of the estuary and increase habitat for aquatic organisms, including delta smelt, longfin smelt, striped bass, outmigrating salmon, and other fishes. Restoring large amounts of tidal marsh along the Montezuma and Suisun Sloughs would increase tidal flow and thus improve water circulation and reduce the need for dredging. Expanding tidal marsh along the estuarine–terrestrial transition zone would provide opportunities for restoring plant communities. Enhancing vernal pools and other seasonal wetlands on the periphery of the Suisun Marsh would help restore their declining plant and animal communities. Improving the managed marsh would benefit waterfowl, other waterbirds, songbirds, and a variety of mammals.

CHALLENGES

Flood-control considerations, levee maintenance, sedimentation of tidal creeks, water-salinity management, and water-quality impacts are of concern. Key regional restoration plans that involve this segment include the Suisun Marsh Plan, Delta Plan, BDCP, and FRPA.





SUISUN MARSH WEST

Western portion of Suisun Marsh

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment B.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

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Unique Opportunities

Segment B provides opportunities to restore large patches of tidal marsh adjacent to areas of moist grasslands and vernal pools and to enhance wide natural transitions between these habitat types. An existing large tract of tidal marsh can be expanded, and marsh migration facilitated, at Rush Ranch. Riparian vegetation can be restored and enhanced along streams, several of which support steelhead, that flow into the marsh from the north. Management of diked wetlands can be improved for waterfowl and other waterbirds. As with the eastern segment of the Suisun Marsh (segment A), this area's large size, current protected status, relative isolation, and location on the estuarine salinity gradient all increase its potential restored habitat value.

Segment Features and Setting

Historically, this part of Suisun Marsh was largely fresh and brackish marsh, with conditions more saline in the western portion. The marshland extended from Potrero Hills westward to the upper end of Carquinez Strait. Myriad channels and sloughs meandered through the marsh, and along the western side were many large tidal marsh ponds. Adjacent to the tidal marshes north of Potrero Hills were large areas of moist grassland with vernal pools. Moist grassland lay in scattered patches along the base of the hills to the west. Riparian woodland lined several of the larger creeks that flowed into the marshes from the north. Like the eastern part of Suisun Marsh (segment A), this segment had few areas of tidal flats.

Today, this segment is nearly all diked wetland that is managed as seasonal waterfowl habitat. An area in the northwestern portion is managed agricultural baylands. Tidal marshes are limited and are generally confined to areas along the Hill, Peytonia, Montezuma, Suisun, and Cutoff Sloughs and to First and Second Mallard Branches. None of the historical marsh ponds remain except in low areas in diked baylands, and the tidal channels have narrowed markedly or disappeared. A native species of submerged aquatic vegetation, sago pondweed,is distributed in the shallow subtidal areas adjacent to tidal marsh edges. Water regimes are highly managed primarily to regulate salinity. Only remnants of the moist grasslands and areas of vernal pools remain, and most have been degraded by years of grazing. The area is a stronghold for endangered soft bird's-beak and the site of the only known population of Suisun thistle.

Implications of Drivers of Change

The main drivers of change for segment B are climate change, sea-level rise, changes in upstream water quality and quantity, and managed wetland activities. Salinity throughout segment B will likely be elevated for a longer duration each year as a consequence of sea-level rise and tidal restoration. Numerous areas within this segment are subsided and, with sea-level rise, current tidal and future restored tidal areas may become subtidal habitats. Additionally, as managed wetlands are converted to tidal wetlands, regional water quality is expected to change, along with ecosystem functions.

Ultimately, opportunities for restoration in this segment may be largely shaped by climate change and sea-level rise as some managed wetlands become unsustainable because of changes in flood-event frequency, unanticipated levee failures, high levee maintenance costs, subsidence, and so on. Changes in upstream water quality (sediment supply, salinity, contaminants, temperature, etc.) and changes in water quantity (the amount of freshwater water coming into segment B) can significantly affect the ecosystem function and effectiveness of restoration projects. Furthermore, areas of limited hydrological connectivity to major sloughs within this section have questionable restoration benefits to fish species targeted for conservation or mitigation requirements. The presence of the railroad tracks, petroleum pipelines, and the proximity of I-680 and Suisun City present additional challenges to restoration. Investments will need to be made to update this infrastructure for sea-level rise. These upgrades may provide opportunities for improving landscape processes important to maintaining the baylands. As the impacts of these main drivers of change become more pronounced, some existing regulatory obligations (e.g., SWRCB D-1641 water-salinity standards) may become unachievable, thereby necessitating the revision of some regulatory obligations. With increasing salinity levels, wetland plant diversity in the managed and tidal habitats is expected to decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The target of 5,000 to 7,000 acres of tidal restoration set forth in the SMP is to be accomplished within the next 30 years. Contributions to this acreage could come from the Fish Restoration Program (FRP) and the Ecosystem Restoration Program (ERP), which are funded efforts. The Bay Delta Conservation Plan (BDCP), if it is approved and funded, could also contribute to the SMP's restoration acreage goal. A smaller portion of this tidal restoration acreage is likely to fall within segment B than in segment A.

Nonetheless, impacts of salinity changes due to tidal restoration locally (within Suisun Marsh) and regionally (particularly in the delta) should be assessed as water-quality regulations (e.g., SWRCB D-1641) must be met in both Suisun Marsh and the delta. For managed wetlands, waterfowl habitat should be improved following best management practices, and general management practices should be promoted that reduce land subsidence and improve water quality.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

Similar to the vision for segment A, the long-term vision for segment B is uncertain. While additional tidal restoration requirements are likely (such as remaining requirements of the FRP or BDCP), restoration opportunities may be largely shaped by climate change and sea-level rise as managed wetlands become less sustainable because of changes in flood-event frequency, unanticipated levee failures, high levee maintenance costs, subsidence, and so on). As managed wetlands are converted into tidal wetlands, significant impacts to upstream water supply (e.g., increased salinity) and ecosystem functions throughout Suisun Marsh and the delta are likely. The replacement or relocation of major infrastructure (e.g., portions of Highway 680, the railroad tracks, and petroleum pipelines) will likely be needed due to higher water levels. Plans to contend with these challenges to large-scale tidal restoration will be necessary.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large tracts of tidal marsh in the Hill Slough and upper Suisun Slough areas (including Goat Island), on Morrow Island south of the confluence of Goodyear and Suisun Sloughs, and at Southampton Bay. Connect these large areas of restored tidal marsh via a tidal marsh corridor along Cordelia Slough or other appropriate corridor location.
- Enhance and restore the natural transition zone, focusing on tidal marsh transitions, incorporating protective buffers wherever possible and thus creating shoreline migration space.
- Optimize managed marshes (duck clubs) to ensure continued support for a diverse suite of waterbirds, prevent subsidence, protect water quality, store carbon, and accumulate peat in the face of increasing salinities, sea-level rise, and other changes.
- Restore and enhance riparian vegetation along streams that flow into the marsh.
- Protect and enhance sago pondweed beds in the western portion of the segment. Study the ecosystem services and functions of beds, including the provision of habitat refugia and corridors for fish and aquatic species moving between the Carquinez Straight and tidal marshes, the provision of food to wildlife, and any other values associated with wave attenuation and shoreline protection.

FOR PARTICULAR WILDLIFE POPULATIONS

- If duck clubs are converted to other habitat types, compensate for the loss of managed marsh habitat for waterbirds.
- Contain perennial pepperweed, and eliminate populations in proximity to marsh–upland transition zones and in high-elevation marsh. In particular, exclude pepperweed from mature brackish tidal marshes that are not yet heavily infested. Use methods that do not jeopardize seed banks of desirable plant species by avoiding persistent soil-active herbicide.
- Complete the eradication of the invasive *Spartina* at Benicia State Park. Implement aggressive control measures for the invasive plant yellow flag, which could become a serious problem.
- Study the impacts of invasive feral pigs to determine appropriate control measures. Feral pigs disturb marsh vegetation. These disturbances may cause long-term damage, or they may enhance the recruitment of particular marsh plants.

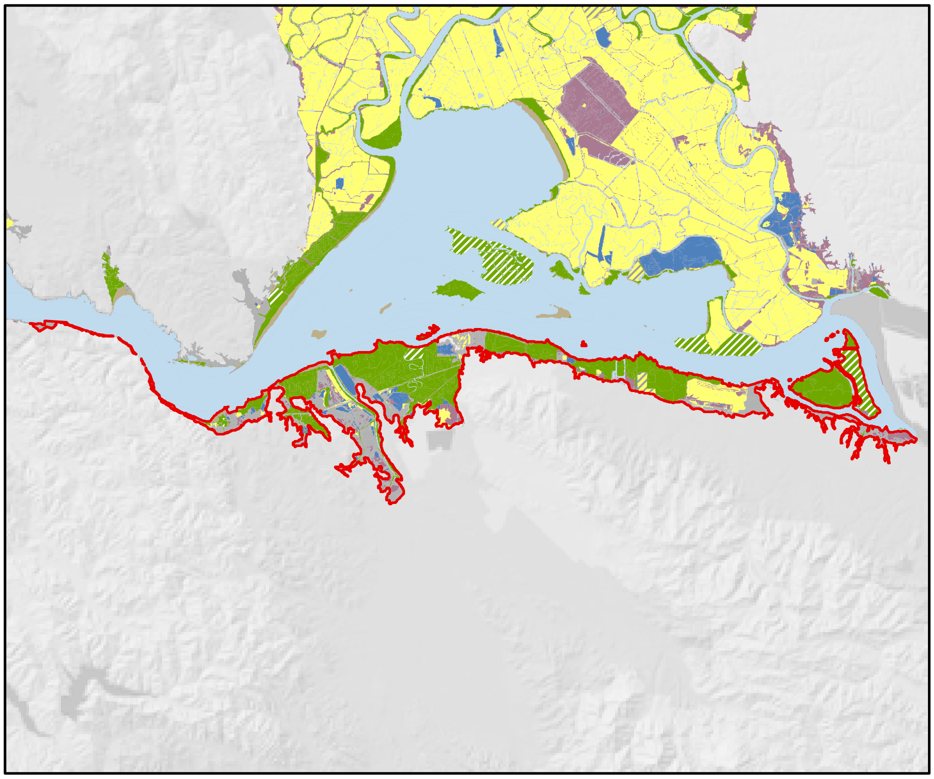
Duck hunter checking in

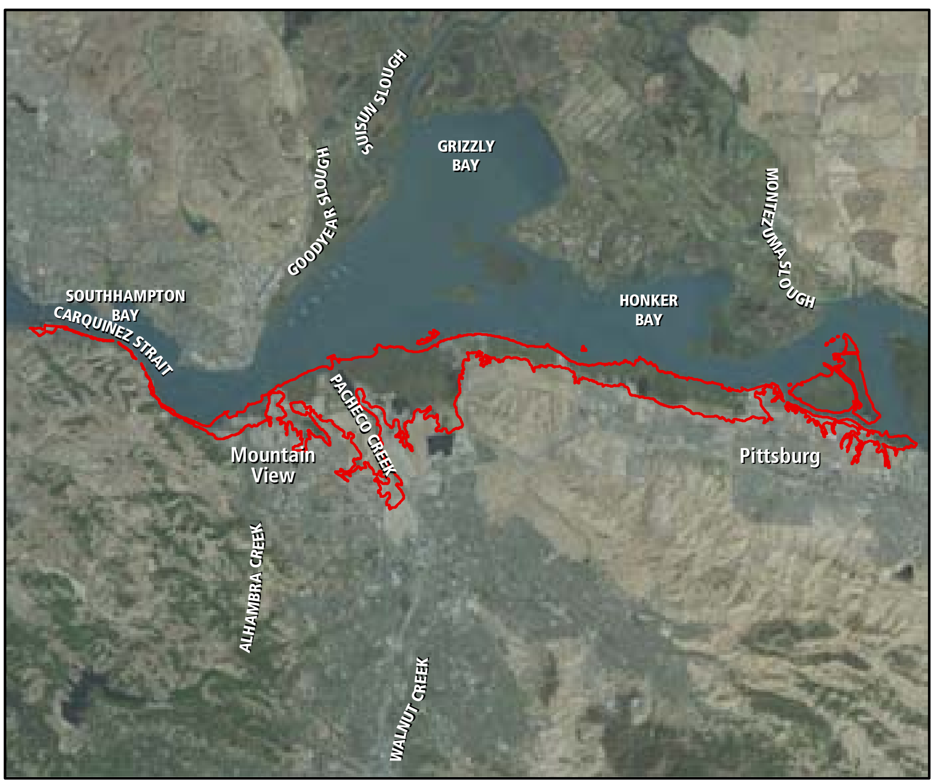
Restoration Benefits

Restoring tidal marshes in this segment would benefit many estuarine and anadromous fish species, including Chinook salmon, steelhead, and delta smelt. It would also benefit the Ridgway's rail. Restoring natural marsh–upland transition zones would improve conditions for endangered plant species, such as the soft bird's-beak, especially along the segment's northern edge. Protecting subtidal sago pondweed beds adjacent to marshes may help to improve habitat corridors for fish, provide additional habitat complexity and food resources, and play a role in protecting tidal marsh edges against erosion. Mammals that depend on transition areas for high-water-escape habitat would also benefit. The lower-elevation tidal marshes would provide habitat and food-web support for aquatic invertebrates and habitat for diving ducks. The remaining managed marshes would continue to provide waterfowl and shorebird habitat, and habitat for small mammals. Restoring tidal action to the upper reaches of Cordelia Slough would enhance habitats, improve channel flood-control capacity, and improve water conveyance to duck clubs.

Challenges

Posing the main challenges are Southern Pacific railroad tracks, industrial areas in the southwest portion, flood-control considerations, levee maintenance, sedimentation of tidal creeks, water salinity management, and water quality impacts. Effective tidal restoration on the west and north sides of segment B will be challenging due to limited hydroconnectivity and the constraints of Highway 680, railroad tracks, Suisun City, and petroleum pipelines. Key regional restoration plans that involve this segment include the Suisun Marsh Plan, Delta Plan, BDCP, and FRPA.





CONTRA COSTA NORTH

Southern edge of Suisun Bay between Carquinez Bridge and Broad Slough/San Joaquin River

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment C.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Miles

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Unique Opportunities

Many of Segment C's historical tidal marsh areas, although degraded by years of grazing, agriculture, and other activities, can be restored to full tidal action. Likewise, several of the seasonal diked wetlands are suitable for tidal restoration or enhancement. Lands adjacent to many of the streams are undeveloped and have high potential for riparian restoration and enhancement.

Segment Features and Setting

Historically, tidal brackish marsh lay along nearly the entire length of this segment except for the western portion along the Carquinez Strait. The area where the strait narrows is characterized by fast-moving waters, and sediments here reflect the sandy substrate typical of constrained areas with no adjacent marsh or tidal flats. These tidal marshes to the east of the strait along the southern shore extended into the lower reaches of several local streams, including Hastings Slough, Alhambra Creek, and Pacheco Creek. Tidal flats lay near the mouth of Pacheco Creek and at a few locations on the shoreline upstream toward the delta. Within the Walnut Creek watershed were several areas of moist grassland and large stands of willow groves and riparian forest.

Today, most of the tidal marsh in this segment has been diked, and several cities, numerous industrial plants, and a military facility sit on or near the shoreline. However, many tidal marshes remain, especially near Martinez and Pittsburg. Although most of these are degraded, some have significant populations of soft bird's-beak and salt marsh harvest mouse. Native eelgrass beds grow offshore, especially in the western and sandier portions of this segment. Only a few remnants of riparian forest remain.

Implications of Drivers of Change

Without enhancement , the existing tidal marshes may be unable to keep up as the rate of sea-level rise increases, resulting in increased inundation of the marsh plain. High marsh that is flooded only during spring tides may downshift to mid and low marsh that is regularly flooded, depending on sediment supply and accretion rates. Increasing tidal submergence coupled with wave erosion may ultimately result in the conversion of tidal marsh to mudflat and, where unconstrained, landward migration of the shoreline.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

In the near term, when sea-level rise rates will still be relatively low, immediate actions to enhance the existing baylands can provide ecological benefits that maximize resilience in this segment. Opportunities to partner with the industrial and residential communities along the shoreline might be pursued to create habitat bayward of flood-protection levees through horizontal levees, living shorelines, or other green infrastructure.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, the sea-level rise may outpace vertical accretion, and marshes in this segment generally do not have enough space to migrate landward to survive. Prior to reaching that point, a plan for restoring or relocating the functions within the existing tidal marshes out of the hazard zone should be developed and implemented.

Recommended Actions

FOR HABITATS AND LANDSCAPE IN GENERAL

- Restore large areas of tidal marsh in diked and muted tidal marsh areas.
- Where tidal marsh cannot be restored, improve water management to enhance diked wetlands through realigning levees and drainage ditches and connecting historic sloughs.
- Enhance and restore the natural transition zone, focusing on tidal marsh transitions, incorporating protective buffers wherever possible, particularly around the base of alluvial fans to provide sediment to the terrestrial side of marshes.
- Restore riparian vegetation, particularly willow sausals where appropriate, along small and large streams.
- Restore areas of historic pans where salt-making plants are no longer active.
- Protect and restore native eelgrass beds along the Carquinez Strait from the Carquinez Bridge to Pittsburg.
- Realign railways to allow for migration of the baylands with sea-level rise.

FOR PARTICULAR WILDLIFE POPULATIONS

- Contain perennial pepperweed and eliminate populations in proximity to marsh–upland transition zones and in high-elevation marsh. In particular, exclude pepperweed from mature brackish tidal marshes that are not yet heavily infested. Use methods that do not jeopardize seed banks of desirable plant species by avoiding persistent soil-active herbicide. Prevent the spread of invasive species coincident with marsh migration.
- Implement aggressive control measures for the invasive plant yellow flag, which could become a serious problem.

Restoration Benefits

Implementing these recommendations would improve habitat conditions for a variety of plants and animals. Restoring tidal marsh along the shoreline of Suisun Bay would improve habitats for estuarine and anadromous fishes, and would increase detrital input to aquatic habitats. Restored marshes would also provide improved habitat for Ridgway's rail, black rail, and salt marsh harvest mouse. Restoring the marsh–upland transition zone would benefit populations of soft bird's-beak, Mason's lilaeopsis, and delta tule pea.

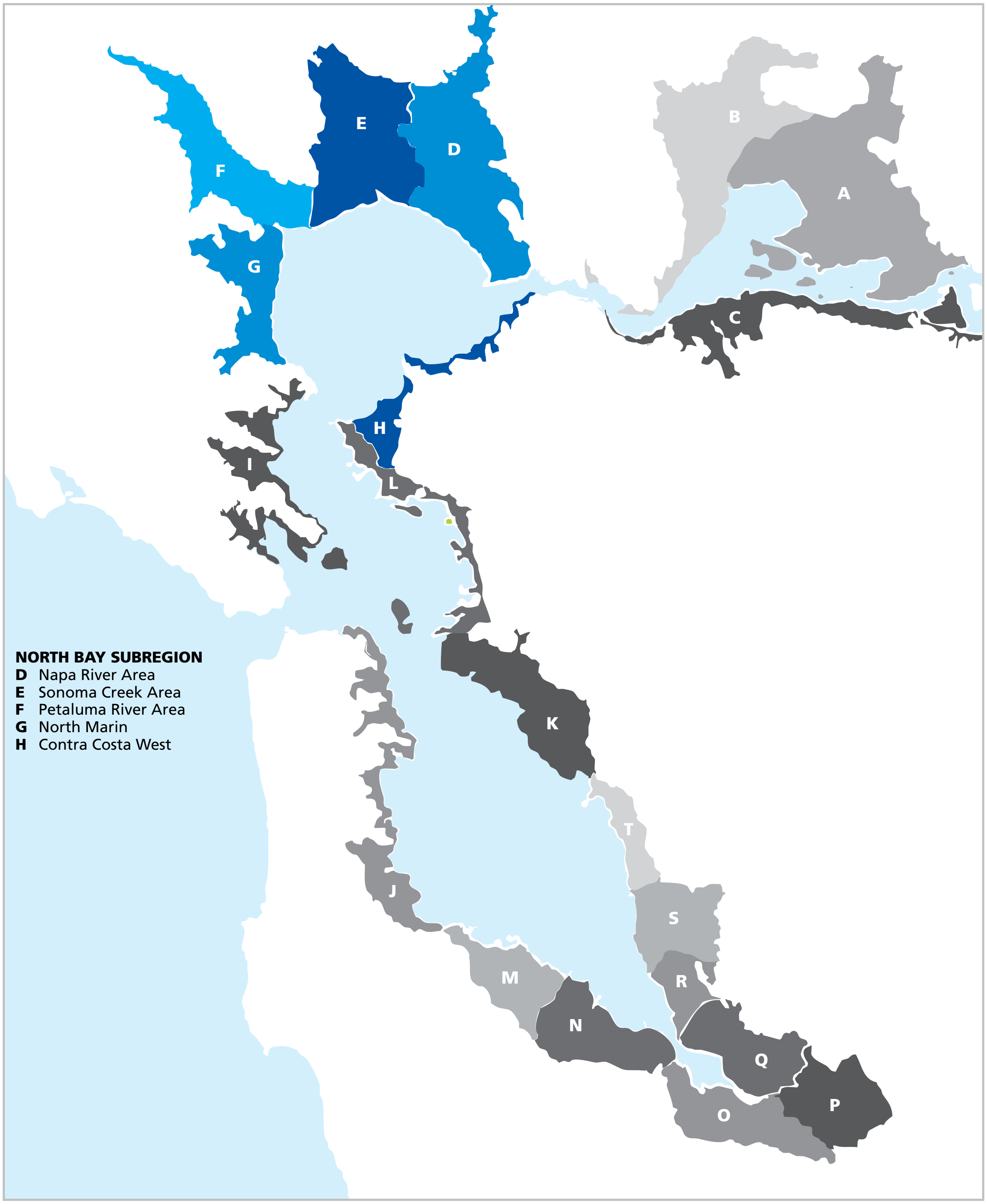
Reestablishing riparian vegetation along streams would provide corridors for amphibians, fish, small mammals, and birds, thereby improving the ecological connections between the baylands and the adjacent watersheds. Protecting subtidal eelgrass beds adjacent to marshes may improve habitat corridors for fish, provide additional habitat complexity and food resources, and play a role protecting tidal marsh edges against erosion.

Lower Walnut Creek Restoration Project

Challenges

Challenges are posed by railroads and roadways, flood management concerns, major pipelines, sewer lines, the Concord Naval Weapons Station, adjacent heavy industry (e.g., PG&E's Pittsburg power plant), and on-site contaminants. On the Contra Costa shoreline, achieving habitat goals will depend on the willingness of corporate, military, and private landowners to restore many marshes to full tidal action. Achieving the goals in Suisun will also depend on the willingness of transportation corridor managers to retrofit infrastructure for sea-level rise in a way that is compatible with wetland goals. Key regional restoration plans that involve this segment include the BDCP and FRPA.

North Bay Subregion



North Bay Subregion

LANDSCAPE VISION

The North Bay is envisioned as encompassing large restored tidal marshes as part of a mosaic of dynamic, diverse, connected habitats from the bay to the watersheds, along with enhanced managed ponds. Achieving this vision involves restoring, protecting, and improving the natural processes necessary to sustain resilient habitats that can accommodate climate change. The North Bay has extensive agricultural and other relatively undeveloped lands with fairly intact natural processes, compared with other parts of the bay. Napa River, Sonoma Creek, Petaluma River, Tolay Creek, and Novato Creek provide significant freshwater inputs and deltas. As a result, the North Bay has significant opportunities to connect the baylands to their watersheds.

Recommended Actions

- Restore a broad swath of tidal marsh along the shore as soon as possible, with the widest marshes being in the Napa–Sonoma Marsh. Manage the fringing marsh bordering northern San Pablo Bay to sustain high marsh as sea levels rise by minimizing artificial drainage obstructions and maximizing wave processes that deposit coarser sediment. Protect and enhance native submerged aquatic shellfish and vegetation beds (including native oysters and eelgrass in the southern extent of this subregion), taking advantage of opportunities that arise as turbidity declines. Incorporate interior tidal ponds suitable for widgeon grass and pond-weed in the restoration along tributaries.

Napa Ponds

- Reconnect major tributaries (Napa River, Sonoma Creek, Novato Creek, Tolay Creek, and Petaluma River) to extant tidal wetlands well into the watersheds. Restore riparian corridors, including floodplains, to connect the baylands to the lower watersheds. Protect wet meadows, vernal pools, and swales in the lowlands adjacent to the baylands and increase their connectivity to the baylands. Work with willing sellers to conserve valleys and plains with low-intensity agriculture adjacent to tidal areas for future marsh and transition zone migration.
- Elevate Highway 37 and modify or realign rail lines and other infrastructure to allow the full passage of water, sediment, and wildlife. Avoid placing new infrastructure on the baylands, and discourage new vineyards on diked baylands, where groundwater is likely to become saltier. Over time, eliminate barriers to stream flow and stop the exports of water from streams to irrigate vineyards.

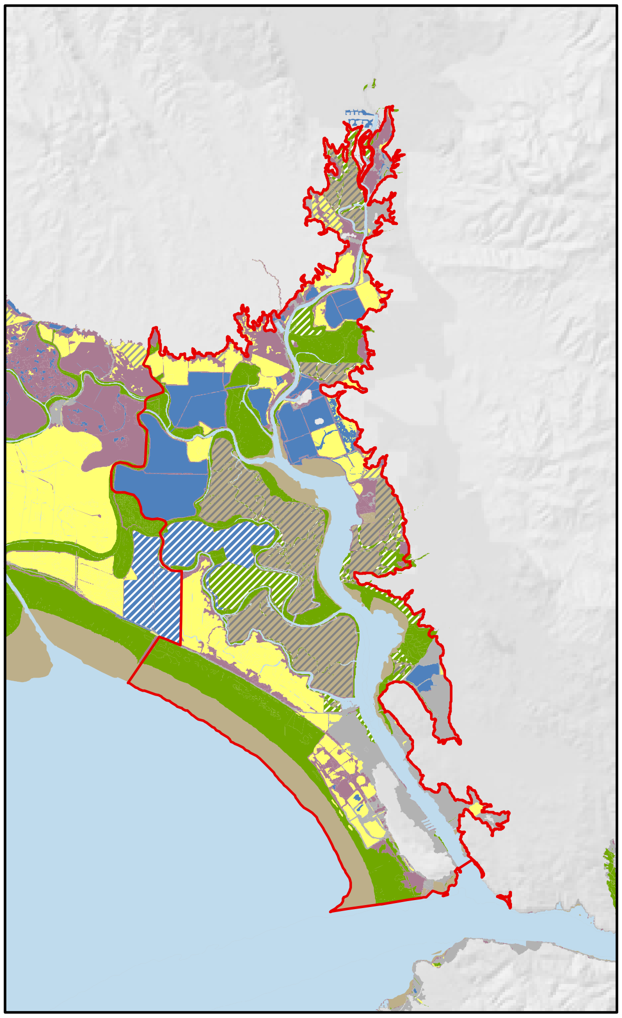
RECENT RESTORATION

Significant progress toward this vision is under way in the Napa–Sonoma Marshes, at the former Hamilton Air Force Base, and elsewhere in Marin, Sonoma, Solano, and Contra Costa Counties, such as Sears Point, Skaggs Island, Cullinan Ranch, and Breuner Marsh. Some managed ponds are being managed to optimize waterbird habitats, and others are being restored to tidal marsh. Tributary streams and riparian vegetation are being protected and enhanced.

CHALLENGES

Achieving the North Bay vision is subject to significant infrastructure constraints, the presence of invasive species, extensive subsidence in potential tidal marsh restoration areas (and the subsequent need for significant amounts of sediment to raise elevations), and the need to address flood-management issues for adjacent lands. Private landowners and public entities will need to be willing to retrofit infrastructure like Highway 37 and SMART rail lines in keeping with ecosystem health and to conserve and restore lowland migration space for the baylands. Control of pepperweed, Pacific bentgrass, and stinkwort are of particular concern in the North Bay. Groundwater pumping depressions near El Verano and the city of Sonoma have the potential to induce an intrusion of brackish water from the baylands into groundwater.

The North Bay subregion includes segments D through H.



NAPA RIVER AREA

Northern side of San Pablo Bay, extending from the Carquinez Bridge westward to the salt pond intake channel

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment D.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Miles

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Unique Opportunities

Segment D presents an excellent opportunity to restore several large patches of tidal marsh adjacent to a large riverine system—a vision that has largely been captured by the Napa-Sonoma Marsh Restoration Project. It is also a place where marsh can be restored around a major intact remnant of historic tidal marsh (Fagan Slough and Coon Island). Along the bayland edge are opportunities (e.g., the eastern side of Napa River near American Canyon) to ensure natural transitions between restored tidal marsh and the adjacent terrestrial areas. Also, along the periphery of the segment on both sides of the Napa River are opportunities to improve seasonal wetlands. Recycled water is already used in some ponds to maintain salinity gradients, and this use could be extended.

Segment Features and Setting

Historically, this segment was almost entirely tidal salt marsh and tidal brackish marsh dominated by the hydrology of the lower Napa River. Extensive sloughs and channels connected it to the lower portion of Sonoma Creek to the west. Tidal salt marsh extended to the bay, but there was very little bordering tidal flat except along the Napa River. Many of the tidal marshes along the eastern side of the Napa River reached into small valleys and swales and were bordered with moist grasslands.

Today, this segment remains relatively undeveloped. Managed ponds on the western side of the Napa River dominate its landscape. The Napa-Sonoma Marsh Restoration Project has seen significant progress since the 1999 Baylands Goals. The project has involved the restoration of nearly 10,000 acres of wetlands and associated habitats within the former Cargill salt pond complex in the North Bay. The first two phases were completed in 2006 and 2007, and the third is in progress. Phase I, completed in 2006, resulted in the opening of 3,000 acres of managed ponds (ponds 3, 4, and 5) to full tidal action. Phase II, completed in 2007, restored 1,700 acres (ponds 1/1A, and 2) to managed ponds to provide waterfowl and shorebird habitat. Phase III involves the restoration of the final 1,900 acres (ponds 6/6A, 7/7A, and 8) and bittern removal from pond 7. Narrow strips of tidal marsh lie on the outboard sides of the levees that border these managed ponds and also at several sites along the Napa River. Significant populations of Ridgway's rail and black rail inhabit Fagan Slough, Coon Island, and White Slough.

Extensive tidal flats border the salt marsh south of Highway 37. The Highway 37 Strip Marsh East lies on the outboard side of the highway near Mare Island and is part of the San Pablo Bay National Wildlife Refuge. The 1,400-acre strip marsh is recognized as one of the most ecologically significant tidal marshes in San Pablo Bay; until recently, its exceptionally dense, tall pickleweed vegetation of the high-marsh terrace supported what is likely the largest population of the endangered salt marsh harvest mouse in the North Bay. However, the marsh has experienced accelerating degradation over the past two decades due to artificial-drainage impediments that have caused prolonged flooding and extensive dieback of marsh vegetation. This intensified flooding has greatly reduced the ecological function of this important habitat area for the salt marsh harvest mouse.

Diked wetlands lie along the northern side of Highway 37 and along the base of the hills near Huichica Creek. At the bayland edge there are many localities of rare or extirpated species of high-marsh plants. Eelgrass and oysters can be found near the mouth of the Napa River.

Implications of Drivers of Change

Without enhancement, existing tidal marshes may be unable to keep up as the rate of sea-level rise increases, resulting in greater inundation of the marsh plain. High marsh that is flooded only during spring tides may downshift to mid and low marsh that is regularly flooded, depending on sediment supply and accretion rates. Increasing tidal submergence coupled with wave erosion may ultimately result in the conversion of tidal marsh to mudflat and landward migration of the shoreline.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term, as the Napa–Sonoma Marsh Restoration Project is completed and suspended-sediment concentrations are still sufficient to sustain marsh-building processes, presents significant opportunities to enhance and increase the resiliency of large areas of tidal marsh south of Highway 37. This site is a distinct marsh type—a high-marsh terrace sustained by wave overwash and episodic sediment deposition—and thus requires a new approach to establish natural, sustainable drainage patterns and high-marsh topography. Studies should explore the facilitation of drainage according to the natural morphology and provide elevation and drainage gradients within the prograded, wave-built marsh terrace.

Previous efforts to improve drainage and sedimentation have been temporary, as these channels rapidly filled with sediment. For example, breaches were cut in the natural levee; they headcut as expected, which resulted in massive sedimentation in the marsh interior. The cuts became unstable and were rapidly closed by wave sediment deposition within two years. Improved understanding of the distinctive morphology, drainage, and geomorphic processes operating at this wave-exposed high salt marsh should support practical management strategies to maintain it as a persistent major high salt marsh habitat. The Highway 37–Mare Island high-marsh terrace may provide a model for other similar sites and may be among the most resilient to sea-level rise during the coming century.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

While improved drainage will enhance the marshes to the south of Highway 37 in the short term, the long-term maintenance of the supratidal marsh terrace (a modern salt marsh berm built by waves, despite the erosional morphology of its scarp) is probably at least as important for resilience to sea-level rise. This may be the first opportunity in the bay to get the right processes (high wave energy and high suspended sediment combined at the same location) identified in the context of managing a sustainable high salt marsh. Sediment demand from the restored Napa–Sonoma marshes north of Highway 37 will increase as sea levels rise. An important factor to consider while making such land-use decisions is whether it is possible to enhance the natural sediment transport from San Pablo Bay through Sonoma Creek and the Napa River and reestablish pathways from watersheds to tidal marsh areas to help maintain marsh elevations.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large areas of managed pond to tidal marsh (e.g., the Napa–Sonoma Restoration Project, Cullinan Ranch).
- Consider ways to increase sediment supply to the tidal baylands. For example, dredged sediments can be placed directly on adjacent mudflats to be reworked by wave and tidal action in order to increase local suspended-sediment concentrations and marsh-accretion rates. Improve sediment supply to the restored marshes north of Highway 37, and consider methods of increasing their trapping efficiency to increase accretion rates. Consider the beneficial reuse of dredged material to elevate restored ponds such as at Cullinan Ranch.
- Optimize the management of ponds for a diverse suite of waterbirds and consider relocating, reconfiguring, or enhancing ponds to accommodate sea-level rise. Revisit the acreage of ponds needed based on changes in the overall acreage of different habitat types (e.g., mudflats along Napa River).
- Enhance existing shoreline tidal marsh ecosystems and their function by reconnecting drainages that run parallel to the bay shore from Cullinan and the top of the centennial strip marsh, and by providing connectivity between strip-marsh units (Sonoma Creek and west units).
- Elevate Highway 37 to a causeway and remove other barriers to achieve unimpeded tidal and other hydrological connectivity.
- Enhance and restore transition zone habitat adjacent to tidal marsh, including natural levees on creeks.
- Enhance and restore eelgrass and oyster beds at the mouth of the Napa River and nearby areas.
- Facilitate the long-term maintenance of the supratidal marsh terrace of the Highway 37–Mare Island marsh by providing sufficient space and coarser sediment for the wave-built salt marsh berm to function and evolve.
- Increase the use of recycled water to improve salinity gradients.

FOR PARTICULAR WILDLIFE POPULATIONS

- Enhance seasonal wetlands at the Mare Island dredged-material-disposal ponds to improve shorebird habitats.
- Reduce the runoff of agricultural contaminants and nutrients from agricultural activities to improve water quality for the aquatic food web in the adjacent wetlands.
- Identify, conserve, and manage selected refugia for native bayland plants. Focus on unique or core populations of uncommon plants, especially in low marshes and in transition zones.
- Contain perennial pepperweed and eliminate populations in proximity to marsh–upland transition zones and in high-elevation marsh. In particular, exclude

pepperweed from mature brackish tidal marshes that are not yet heavily infested and from restoration areas soon to be opened to tidal influence. Use methods that do not jeopardize seed banks of desirable plant species by avoiding persistent soil-active herbicide. Prevent the spread of invasive species coincident with marsh migration.

- Continue to control invasive *Spartina* in Strip Marsh East–Mare Island.

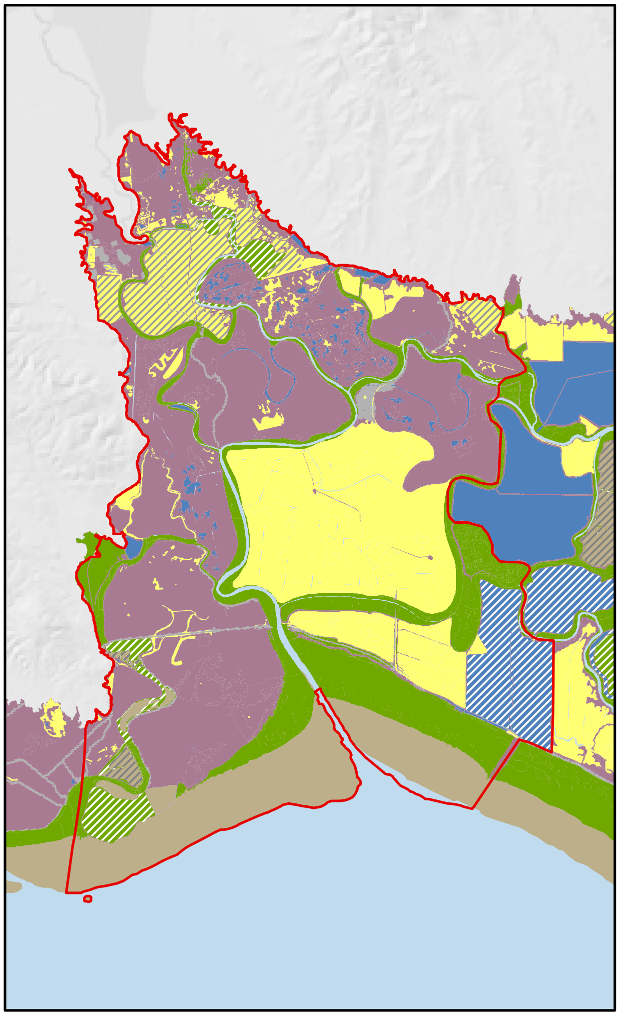
Restoration Benefits

Implementing these recommendations would improve habitat conditions throughout the segment for tidal marsh-dependent species, such as the salt marsh harvest mouse, Ridgway's rail, and soft bird's-beak. It also would improve habitats for species associated with seasonal wetlands. Large-scale restoration would widen and deepen many of the tidal channels, and this would benefit fish, diving ducks, and shorebirds as well as water circulation. Improving managed-pond habitat would also provide valuable deep-water foraging and resting habitat for diving ducks. Restoring riparian vegetation would benefit many amphibians, birds, and small mammals. Enhancing estuarine–terrestrial transitions would improve conditions for several rare and endangered plants. Conserving and reconnecting transition zones with the baylands ecosystem would provide critical migration space for high tidal marsh and brackish marsh to migrate as sea levels rise toward the end of the 21st century. Reestablishment of salinity gradients to tidal marsh will also provide critical brackish buffers to increasing salinity, thereby supporting tall emergent vegetation that forms essential high-tide cover. Recycled water could also enhance seasonal and brackish marsh habitat types that are rare in this part of the bay. Protecting subtidal eelgrass and oyster beds may help improve habitat corridors for fish from the Napa River to San Pablo Bay, provide additional habitat complexity and food resources, and help protect tidal marsh edges from erosion.

Napa Ponds

Challenges

Challenges for the existing marshes and future transition zone include California Northern railroad tracks, Highway 37, and PG&E power lines. Highway 37 tends to parallel the shoreline within the transition zone, making it a challenge to migration because in the near term it will prevent significant landward movement of the baylands. The Napa–Sonoma Marsh Restoration Project and the San Pablo Bay National Wildlife Refuge are the key regional entities for this segment. Planning will require coordination with local agencies and organizations, including the San Pablo Bay National Wildlife Refuge, California Department of Fish and Wildlife (CDFW), Napa County, Solano County, and Caltrans.



SONOMA AREA

Northern side of San Pablo Bay, extending from salt pond intake channel to just west of Tolay Creek

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment E.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Unique Opportunities

Segment E provides considerable opportunities to protect undeveloped land and restore diked wetlands to tidal marshes, which are more resilient to climate change. It also presents opportunities to restore extensive tidal marsh and natural marsh–upland transition zones. In addition to restoring large patches of tidal marsh (some as isolated marsh islands and others with natural transitions to the adjacent terrestrial habitats), wetlands restoration can also be integrated with watershed management in Sonoma and Tolay Creeks, thereby taking advantage of associated freshwater and sediment pathways. Finally, several large areas are well suited to be managed as diked wetlands for shorebirds and waterfowl.

Segment Features and Setting

Nearly all of the lands within this segment were once tidal salt marsh or tidal brackish marsh. Some limited areas of moist grasslands lay to the north and west, along upper Sonoma Creek, and in the drainages around and below Lake Tolay. A large area of vernal pool soils existed on the western side of upper Sonoma Creek.

Today, this segment is relatively undeveloped except for agriculture, and several restoration efforts have been made to enhance and restore tidal flows to diked wetlands along the periphery of the segment since the 1999 Baylands Goals. At Tolay Creek and Lower Tubbs Island, tidal marsh, subtidal, and marsh–upland transition zones have been restored by improving hydrological flow and tidal flushing, reestablishing connections between marsh areas, and restoring native plants along the transition zone. Internal levees and sills, which formed barriers to tidal flow and circulation, were breached or removed, and new channels that reconnect marsh areas to existing drainages were excavated. Projects at Skaggs Island, Sears Point, and adjacent to Sonoma Creek are under way with substantial areas slated for restoration. Tidal marsh is limited to the bay edge near Sonoma Creek and along the outboard sides of levees along the remaining channels. There are some muted tidal lagoons in Lower

Sandpipers and dowitchers at low tide

Tubbs Island and adjacent to Highway 37 and Tolay Creek. Spawning Chinook salmon have been observed in Sonoma Creek.

A Caltrans stakeholder process is under way to improve Highway 37, and the initial consensus among stakeholders (including the CDFW, US Fish and Wildlife Service, Regional Water Quality Control Board, and Ducks Unlimited) is to widen it to four lanes, plus bike lanes, into a causeway like the Yolo Bypass I-80 and I-5 designs. This process is encouraged for its significant benefits to baylands habitat and climate-change adaptation.

The Sonoma Resource Conservation District (RCD) conducts a permit program for 29 landowners who maintain over 60 miles of levee in the Sonoma Creek and Petaluma River Area segments. Each year, the Sonoma RCD gathers information from each landowner on the work done in the previous year and the work to be done the coming year and submits it to the permitting agencies. The permits restrict the extent and timing of levee-maintenance work and outline a series of best management practices to protect habitats for threatened and endangered species.

Implications of Drivers of Change

The United States Geological Survey (USGS) has collected site-specific baseline elevation, vegetation, and tidal data to assess elevation changes over 12 years for the Tolay Creek restoration. These results indicate that the tidal marshes and mudflats along the creek were accreting sediment during the past 12 years, and most of the site had accretion rates that outpaced sea-level rise during the study period. Thus, the area may keep pace with sea-level rise over the next few decades. However, in the longer term, the rates of sea-level rise are expected to increase, and sediment accretion is much less likely to keep pace, resulting in greater inundation of the marsh plain. High marsh that is flooded only during spring tides may downshift to mid and low marsh that is regularly flooded, depending on sediment supply and accretion rates. Increasing tidal submergence coupled with wave erosion may ultimately result in the conversion of tidal marsh to mudflat and landward migration of the shoreline. Finally, sea-level rise will put pressure on managed systems designed and maintained for particular water levels. For example, as water depths increase, outboard levees will be subject to increasing wave action and the damage associated with erosion and overtopping.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

In the near term, the acquisition of key agricultural lands from willing sellers and the restoration of tidal action by breaching levees and removing barriers should be pursued while suspended-sediment concentrations are still sufficient to sustain marsh-building processes. Improving drainage conditions in the fringing tidal marsh along Sonoma Creek south of Highway 37 and creating transition zones will help create a mosaic of habitat types, including critical high-tide refugia as sea levels rise. Existing and planned levees that are integrated with the San Francisco Bay Trail should be designed not to impede the objectives of tidal marsh connectivity, improved hydrology, and marsh migration.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

The long-term vision is to reduce the impact of migration barriers such as highways and railroads and to reconnect the baylands with watershed inputs of sediment and water. The goal is to reduce the flood risk to shoreline communities and infrastructure while increasing the resilience of the baylands to climate change. Sediment demand to maintain marsh elevations will increase as sea levels rise. It is important to consider enhancing the natural sediment transport through Sonoma Creek and the Napa River to tidal marshes to help maintain marsh elevations. Managed ponds and other diked baylands providing important bird habitat may need to be resituated in locations that will required less maintenance, including levee repairs.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large connected patches of tidal marsh across the entire sweep of San Pablo Bay, particularly near the mouths of sloughs and major streams. Protect and enhance the marshes on the bay side of Highway 37 to ensure connectivity between marshes along the full perimeter of San Pablo Bay. Improve drainage from Sonoma Creek East through a connection to Sonoma Creek. Allow full hydrological connections between diked areas (i.e., Lower Tubbs Island and Tolay Creek).
- Increase sediment supply to the tidal baylands, where appropriate for stream and watershed health. Reconnect stream channels in the Tolay Creek watershed into marshes, increase sediment supply to the restored marshes north of Highway 37, and augment the trapping efficiency of tidal baylands to foster accretion, as appropriate.
- Protect and restore agricultural lands and other open space to reestablish a transition zone adjacent to the tidal marsh and provide space for future landward migration.
- Elevate Highway 37 to a causeway and elevate, modify, or remove other barriers, such as the railroad, to achieve unimpeded tidal and other hydrological connectivity.
- Design and implement improved flood protection for adjacent developed areas that takes advantage of the natural infrastructure and promotes ecological resilience.
- Protect, restore, and enhance riparian habitat along Sonoma Creek in the Schellville area, in the Tolay Creek watershed, and along other waterways.

FOR PARTICULAR WILDLIFE POPULATIONS

- Establish managed marsh or enhanced seasonal pond habitat (especially for shorebirds) where feasible on agricultural baylands that are not restored to tidal marsh. Locate seasonal diked wetlands in close proximity to tidal flats to provide high-tide roosting habitat for shorebirds.
- Reduce the runoff of contaminants and nutrients from agricultural activities to improve water quality for aquatic food webs in the adjacent wetlands.

- Identify, conserve, and manage selected refugia for native bayland plants. Focus on unique or core populations of uncommon plants, especially in low marshes. Consider relocating rare plants to more appropriate areas as flooding and salinity conditions change.
- Increase the populations of threatened and endangered species through methods such as farming best practices to meet specific conservation objectives to buffer future impacts.
- Continue to control invasive *Spartina* along Sears Point, Sonoma Baylands, and Tolay Creek and Tubbs Island.

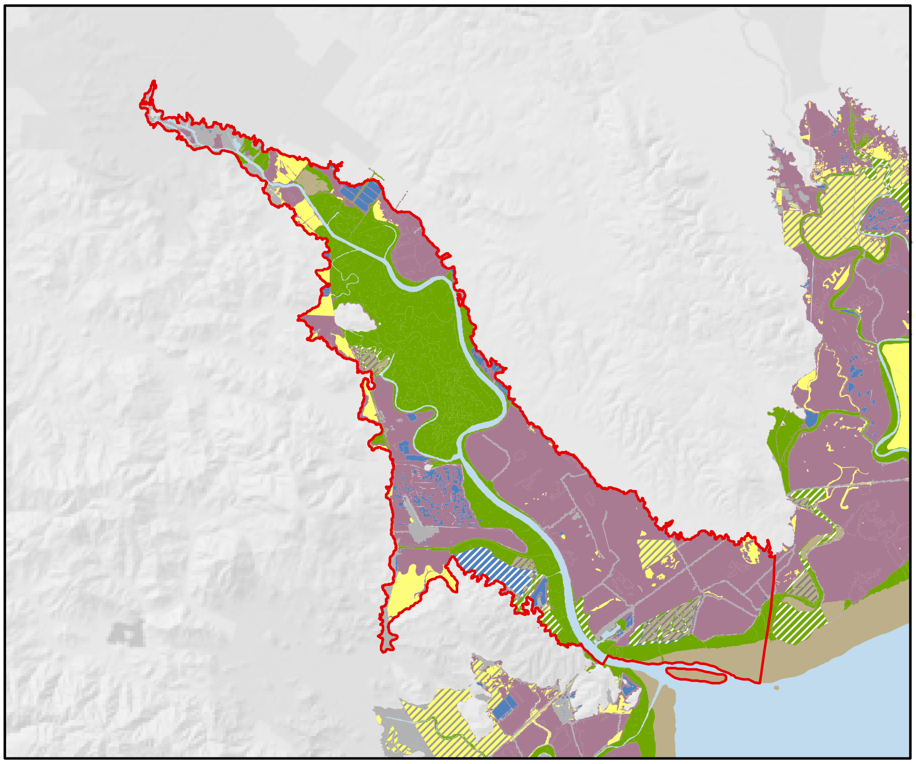
Restoration Benefits

Implementing these recommendations would increase the area of tidal marsh and expand suitable habitat and habitat connectivity for endangered tidal marsh species, such as the Ridgway's rail and the salt marsh harvest mouse. Restoring tidal marsh in this segment would also greatly enlarge the area of shallow- and deep-channel habitat for many fish species and diving ducks. Restoring marsh at the periphery of the baylands, where natural transitions to adjacent terrestrial habitats could develop, would benefit several rare plants as well as birds, mammals, and amphibians that depend on the transition zone. Furthermore, the conservation of transition zones and their reconnection with the baylands ecosystem provides critical migration space for high tidal marsh and brackish marsh to migrate as sea levels rise toward the end of the 21st century. Large areas of tidal marsh can reestablish the hydrological gradients between Sonoma Creek and the Napa River, greatly improving water circulation. Large areas of managed diked wetlands would provide important roosting and foraging habitat for shorebirds and waterfowl.

Challenges

Challenges for the existing marshes and future transition zone include California Northern railroad tracks, Highway 37, and PG&E power lines. Highway 37 tends to parallel the shoreline within the transition zone, making it a serious challenge because in the near term it will prevent any significant landward movement of the baylands. Planning will require coordination with local agencies and organizations, including Sonoma County, Sonoma RCD, San Pablo Bay National Wildlife Refuge, CDFW, the Sonoma Land Trust, Northwestern Pacific Railroad, SMART rail, and Caltrans.

Groundwater considerations also need to be addressed. Two groundwater-pumping depressions are apparent in the deep-zone groundwater elevation contour map southeast of the city of Sonoma and around El Verano. The pumping depression southeast of Sonoma has the potential to induce an intrusion of brackish water from the baylands area, which may be exacerbated by sea-level rise.



PETALUMA RIVER AREA

Northwestern edge of San Pablo Bay and lands in the lower Petaluma River drainage

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment F.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Unique Opportunities

Segment F provides opportunities to restore extensive tidal marsh and natural marsh–upland transition zones near the subregion's largest brackish marsh. It also provides opportunities to expand remnant populations of rare plants, such as the soft bird's-beak, into restored tidal marsh areas. There is the unique opportunity to enhance the transition zone between San Antonio Creek and tidal habitats, one of the few places where such restoration can take place. Opportunities also exist to significantly increase and enhance seasonal wetland habitats in the diked baylands and adjacent uplands, particularly on the eastern side of the Petaluma River. This segment also provides opportunities to restore and enhance current and future transition zones, particularly with oak woodlands.

Segment Features and Setting

Tidal marsh was once the dominant habitat type in this segment. Salt marsh existed near the mouth of the Petaluma River and became brackish upstream. There were relatively small tidal flats at the river mouth, but several large areas upstream at False Bay. Small patches of moist grassland dotted the northeastern edge of the baylands, and a very large area of this habitat lay near Petaluma. The Petaluma Estuary exhibits a low-energy wave system with high sediment availability, characterized by extensive high and mid-marsh plains served predominantly by tidal sloughs; mudflats are limited. Due to low wave energy, the main controlling factors determining wetland form and function are the tidal range and tidal prism of the system.

Today, this segment remains relatively undeveloped, and it contains Petaluma Marsh, the largest intact tidal marsh within the estuary. However, almost all of the extant transition zone is either separated from the tidal marsh by dikes and roads or agriculturally modified for cattle grazing or viticulture. This marsh exhibits many of the features that were characteristic of the estuary's historical marshes: pans, a system of extensive channels, and natural transitions to adjacent uplands. These are not readily apparent in most other bay marshes. This marsh includes brackish and salt marsh areas and supports a great diversity of native plant species, important populations of Ridgway's rails, black rails, waterfowl, and shorebirds. Adjacent to the baylands, the landscape retains much of the historical character of moist grassland bordered by oak woodland. Portions of the Petaluma Marsh are connected to hillslopes (such as Burdell Island), and portions border dikes or railroad berms that sever the marsh from terrestrial lowland valleys and flats. These lowland valleys in grazing lands, like those north of Gallinas Creek, still support natural fresh-to-brackish surface drainage and subsurface (groundwater) connections to the baylands. The segment receives freshwater flows from San Antonio Creek, which supports extensive riparian habitat, and from the Petaluma River and Adobe Creek, which support runs of steelhead.

Much of the marsh plain has been diked and drained. As a consequence of draining, the deep peats have subsided considerably. Fringing marshes along the Petaluma River remain, and these have maintained their position relative to the tide. As a result, the Petaluma River is bordered by relatively high marshes, behind which are large areas of lower-lying land cut off from tidal action.

The North Novato baylands include mature, wide, topographically complex tidal marsh and creek systems (the Toy/Green Point Marsh and outer Bahia marshes along

Northern shoveler

the Petaluma River) that support dense and large populations of Ridgway's rails and black rails. The wide fringing mature brackish-to-salt-marsh gradient along Black John Slough is also an important habitat for black rails and (particularly toward the east) Ridgway's rails. The Bahia tidal lagoon (silted former marina) and channel also support Ridgway's rails adjacent to the recent tidally restored Central Bahia baylands. The Central Bahia baylands (including former Mahoney Spur) are currently in early tidal mudflat–salt marsh succession following tidal restoration. These baylands support abundant waterbirds and are expected to provide extensive additional habitat for an expansion of the adjacent Ridgway's rail populations. The East Bahia lagoon supports an important foraging habitat for bay ducks, diving ducks, wading birds, and shorebirds. The filled peninsulas surrounding the East Bahia lagoons support ruderal (weedy) upland vegetation and seasonal wetlands. The West Bahia lagoon is a damped tidal brackish lagoon that supports extensive submerged aquatic vegetation (widgeon grass) beds and waterfowl and wading bird habitat. Nontidal seasonal and perennial fresh–brackish wetlands also support important waterfowl and shorebird roosting and foraging habitats in the former dredged-sediment-disposal and decant pond sites.

Since the 1999 Baylands Goals, the area of tidal marsh has increased in the segment following the restoration of tidal action to diked wetlands through initiatives such as the Sonoma Baylands Project, Bahia Marsh Restoration Project, and Petaluma Marsh Expansion Project. Additional efforts are under way, including the Sears Point Restoration Project, which encompasses 1,000 acres of future tidal marsh and critical transition zones that provide high-tide refugia and space for landward migration, as well as seasonal wetlands and vernal pool habitat north of the SMART rail and Highway 37.

Implications of Drivers of Change

The Petaluma Marsh area is expected to undergo divergent responses to sea-level rise, depending on its position within the sedimentation gradient along the Petaluma River and its initial topography (diked bayland or tidal marsh). The southern reaches of this subregion, which are relatively rich in suspended-sediment supply, are more likely to sustain fringing tidal marshes where they exist today, and to support tidal marsh restoration currently in progress. Subsided diked baylands (especially in northern reaches of the Petaluma Marsh in Marin County) are likely to undergo more frequent levee overtopping, breaching, or failure (conversion to open water) and to develop a greater demand for drainage where levees do not fail. The extensive tidal slough and marsh plains of the Petaluma Marsh may be subject to bank erosion along the river, and an expansion of pans and low marsh within the marsh plain as tidal energy increases. Prehistoric tidal marsh remnants are likely to shrink and to lose native species diversity as lower marsh zones expand and upper marsh zones contract. Undeveloped agricultural lands with valley gradients or gentle hillslopes bordering tidal marshes in this subregion (including areas that are currently diked nontidal wetlands) will provide some of the best opportunities to restore and conserve tidal marsh ecosystems that retain all the critical subhabitats and species of concern during an accelerated sea-level rise. Populations of invasive plant species are likely to expand where levees are armored or maintained more frequently.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

If current suspended-sediment concentrations persist, existing natural and restored tidal wetlands will likely be resilient to sea-level rise even at higher rates. If additional areas are opened up for restoration, they are also likely to evolve resiliently, particularly if they are connected to the natural gradually sloping topography of the estuary margin. Alternatively, high-value artificial habitat can be created through the management of water, creating shallow wetlands such as those at Rush Creek.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

Over time, with rising sea levels and potentially more extreme storms, flood protection along leveed edges will decline. In response to climate change, the options are either to improve flood protection along the existing levees or, as an adaptation strategy, selectively and opportunistically realign existing levees and concentrate flood protection along critical infrastructure (such as Highway 101). The railway will also come under progressive risk from tidal waters and will likely require upgrading. At such time, it would be beneficial to improve tidal connectivity to gradually sloping uplands, which would allow for the restoration of a potentially high-quality buffer habitat that with adequate space would be more resilient to sea-level rise.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Protect and restore tidal marsh on both sides of the Petaluma River, particularly on the eastern side, between Highway 37 and False Bay (Dustman Road), which is already vulnerable to flooding.
- Protect, restore, and manage agricultural lands and other open space to reestablish a transition zone and buffers adjacent to tidal marsh and to provide space for landward migration. Create transition zone habitats on gentle slopes in front of flood-risk-management levees.
- Enhance the stream–marsh transition zone between San Antonio Creek and tidal habitats, one of the few places where such restoration can take place.
- Consider ways to increase the sediment supply to tidal baylands. Reconnect stream channels into marshes, and augment the trapping efficiency of tidal baylands to foster accretion, as appropriate.
- Protect and enhance moist grassland habitats on the eastern portion of this segment.
- Elevate Highway 37 to a causeway, and remove, realign, or elevate other barriers (such as the SMART rail) to achieve unimpeded tidal and other hydrological connectivity.

FOR PARTICULAR WILDLIFE POPULATIONS

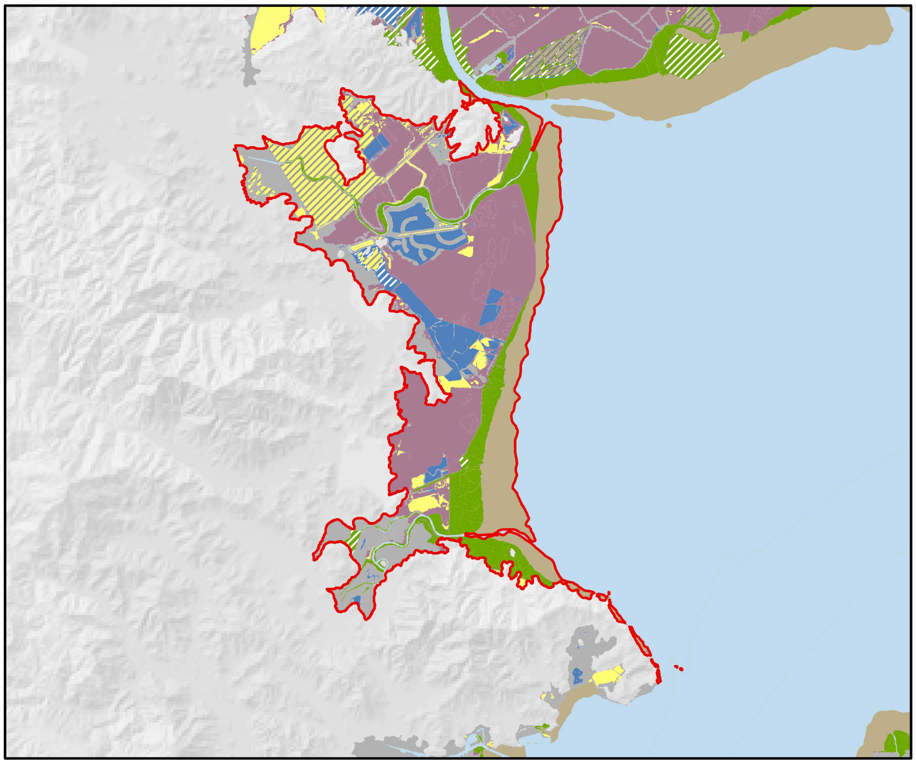
- Identify, conserve, and manage selected refugia for native bayland plants. Focus on unique or core populations of uncommon plants, especially in low marshes.
- Reduce the runoff of agricultural contaminants and nutrients from agricultural activities to improve water quality in the adjacent wetlands.
- Control perennial pepperweed invasions in otherwise intact tidal brackish marsh to prevent a loss of high-marsh plant diversity.
- Continue to control invasive *Spartina* in the Petaluma River and other tidal areas in this segment.

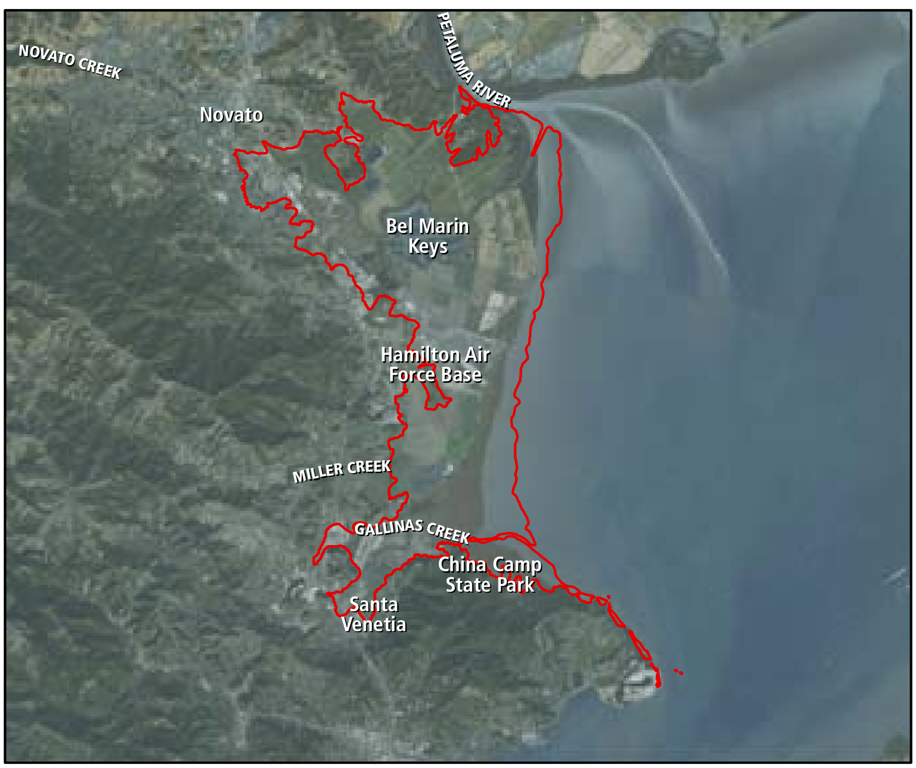
Restoration Benefits

Significant benefits for tidal marsh species such as the Ridgway's rail, black rail, and salt marsh harvest mouse could be achieved in this segment. Restoring tidal marsh would also improve nursery habitat for salmon, steelhead, starry flounder, and other aquatic species. Restoring and enhancing a fluvial/riparian–tidal marsh transition zone along San Antonio Creek and possibly Adobe Creek would benefit fish, amphibians, and plants. Restoring the estuarine–terrestrial transition zone would improve conditions for rare high-marsh and transition zone plant species. Furthermore, the conservation of transition zones and their reconnection with the baylands ecosystem would provide critical migration space for high tidal marsh and brackish marsh to migrate as sea levels rise toward the end of the 21st century.

Challenges

Challenges for the existing marshes and future transition zones are similar to those of the other segments between Novato Creek and the Napa River, namely, California Northern Railroad tracks, Highway 37 and Lakeville Highway east of the Petaluma River, and PG&E power lines. The Redwood Landfill was built in 1958 on historic marshes just north of Novato. It is bordered on three sides by San Antonio Creek. As with many other landfills, leachate drainage could be exacerbated if groundwater levels rise. The need to maintain and protect the landfill would be a constraint on the management of San Antonio Creek marshes with rising sea levels. Another area that will need to be protected is CBS Tower Field and the adjacent airfield at Gnoss Field. Here the drainage of the adjacent marshes has been considerably modified. Vineyard development on the adjacent hill slopes, changing the agricultural land use from low to high intensity, may constrain the options for managed realignment and flood protection. Planning will require coordination with local agencies and organizations, including Sonoma County, the Sonoma RDC, San Pablo Bay National Wildlife Refuge, CDFW, Sonoma Land Trust, Northwestern Pacific Railroad, SMART rail, and Caltrans.





NORTH MARIN

Western side of San Pablo Bay extending from the mouth of the Petaluma River to Point San Pedro

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment G.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Unique Opportunities

Segment G provides a unique opportunity to enhance tidal marsh in areas where natural terrestrial transition zones exist (e.g., China Camp State Park). In addition, transition zones can be secured in areas of low-intensity development because these zones will become the platform for tidal marshes by the late 21st century. The upper edges of transition zones will provide the foundation for limited high-marsh and brackish-marsh zones. Furthermore, riparian and tidal restoration along Novato, Gallinas, and Miller Creeks could enhance tributary streams for fish and amphibians.

Segment Features and Setting

Historically, this segment supported large areas of tidal marsh that were bordered by the widest mudflats in San Pablo Bay. The most extensive marshes lay between Novato and Gallinas Creeks and were exposed to significant wave action due to the orientation of the shoreline. Marsh berms formed along the shoreline, and ponds were abundant within the marsh plain as a result of the minimal internal drainage. The marshes north and south of Novato and Gallinas Creeks are more sheltered from wave action and formed well-drained plains with complex, sinuous channels. While Novato and Gallinas Creeks were the largest of the streams that flowed into and through the marshes, numerous ephemeral streams draining smaller watersheds flowed into the back of tidal marshes. Wide alluvial valleys supported riparian habitats through which steelhead and possibly coho salmon passed. Oak woodlands dominated the upland landscape. The Coast Miwok had permanent as well as seasonal village sites in the valleys and along the bayshore. This segment provided significant habitats for a variety of threatened and endangered species, including steelhead, Ridgway's rail, salt marsh harvest mouse, black rail, and tidewater goby.

Presently, much of the area near the bay is pasture or cultivated for oat hay, and residential developments have been established at Bel Marin Keys and several sites to the south. Since the original Baylands Goals report, the restoration of approximately 750 acres of wetlands on the former Hamilton Air Force Base has been completed, with restoration plans progressing on the adjacent 1,700-acre Bel Marin Keys property. A fairly large remnant marsh remains at the mouth of Gallinas Creek, including China Camp, which supports what appears to be the largest population of Ridgway's rails in the North Bay. Large freshwater emergent marshes are found along the western side of Novato Creek north of Highway 37 and at Pacheco Pond.

Implications of Drivers of Change

The primary driver of change in this segment will likely be the impacts of sea-level rise on flood protection in the city of Novato, the Santa Venetia community, and the Bel Marin Keys residential areas, where pressure to build engineering defenses against flooding and wave erosion, regardless of habitat impacts, may increase. However, tidal marsh restoration could be used to enhance flood protection. Without enhancement, existing tidal marshes may be unable to keep up as the rate of sea-level rise increases, resulting in greater inundation of the marsh plain. High marsh that is flooded only during spring tides may downshift to mid and low marsh that is regularly flooded, depending on sediment supply and accretion rates. Increasing tidal submergence coupled with wave erosion may ultimately result in the conversion of tidal marsh to mudflat and landward migration of the shoreline.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

As restoration projects are implemented and suspended-sediment concentrations are still sufficient to sustain marsh-building processes, the near term presents significant opportunities to restore large areas of tidal marsh with wide transition zones from China Camp to the Petaluma River. Since wave erosion is likely to increase as the bay deepens, coarse sediment nourishment may be needed in front of marsh scarps to reduce shoreline retreat. Similarly, along developed residential or commercial shorelines, narrow transition zones could be created to provide buffers against wave erosion and high-tide refugia. Restoring tidal marsh would provide opportunities to expand and reintroduce populations of rare plant species, such as northern salt marsh bird's-beak and salt marsh owl's-clover. Ridgway's rail could also expand into wide marshes remote from predator outposts and corridors. Reengineering levees to create gently sloping transition zones will buffer storm-wave runup and erosion, and lower the flood risk as well as facilitate landward migration of the marsh.

Lower Novato Creek Watershed

Large areas of public lands could be restored to a combination of tidal, seasonal, and riparian wetlands to create a mosaic of habitat types, including a large transition zone and a mix of fluvial–tidal habitats. This restoration would expand the tidal prism and reduce the need for dredging to maintain flood-channel capacity. Large freshwater marshes along the western side of Novato Creek north of Highway 37 and at the Pacheco Pond could also be enhanced as transition zone features. Similarly, treated wastewater and stormwater discharges might be realigned for diffuse discharge along wide, sloping engineered terraces on flood-control levees to provide some surrogate transition zone biogeochemical functions (nutrient transformation, sequestration, etc.). Simmonds Slough baylands (Atherton), currently managed as nontidal seasonal wetlands, may be hydrologically modified to restore tidal flows and establish brackish marshes influenced by wastewater discharge if upgrades are made to Highway 37.

Lower Miller Creek Watershed

The undeveloped area between the bay and Highway 101 (excluding China Camp State Park) provides rare, appropriate topography for extensive transition zone and connected high marsh. Complete tidal wetland systems should be restored here to connect the Hamilton marshes to those to the south.

Lower Gallinas Creek Watershed

Complete tidal wetland systems should be restored here to connect the marshes to the north and south. Steep artificial slopes and transition zones bordering the developed baylands of upper Gallinas Creek could be adapted to sea-level rise by engineering gentler slopes using suitable dredged flood-control-channel sediments. Again, treated wastewater could be used to create a seepage transition zone terrace and levee system, incorporating freshwater managed wetlands for waterfowl, within the existing and likely future transition zones near north Gallinas Creek baylands.

Long Term (latter half of the century, after SLR curve acceleration)

At some point the amount of sea-level rise may make it infeasible (cost ineffective) to maintain reliable flood protection for developed urban residential infrastructure in very low-lying areas. Land-use planning for a rising sea level will be imperative for cities to provide flood protection to the more densely populated areas while maintaining habitat benefits for a wide range of species. An important factor to consider while making such plans is whether it is possible to reestablish natural sediment transport from watersheds to tidal marsh areas to help maintain marsh elevations.

RECOMMENDED ACTIONS


China Camp State Park

For Habitats and the Landscape in General

- Restore an extensive transition zone and connected high marsh along the undeveloped area between the bay and Highway 101.
- Restore the large areas of public lands along lower Novato Creek to a combination of tidal, seasonal, and riparian wetlands to create a mosaic of habitat types, including a large transition zone and critical habitat at the fluvial–tidal interface.
- Protect and restore agricultural lands and other open space to reestablish transition zones and buffers adjacent to tidal marsh and provide space for landward migration, including oak woodlands and mixed evergreen forest along the entire ridge and hillslopes. Transition zone habitats can be created on gentle slopes in front of flood-risk-management levees.
- Consider ways to increase the sediment supply to tidal baylands. Improve the trapping efficiency of restored marshes to increase their accretion rates and reuse dredged sediments.

For Particular Wildlife Populations

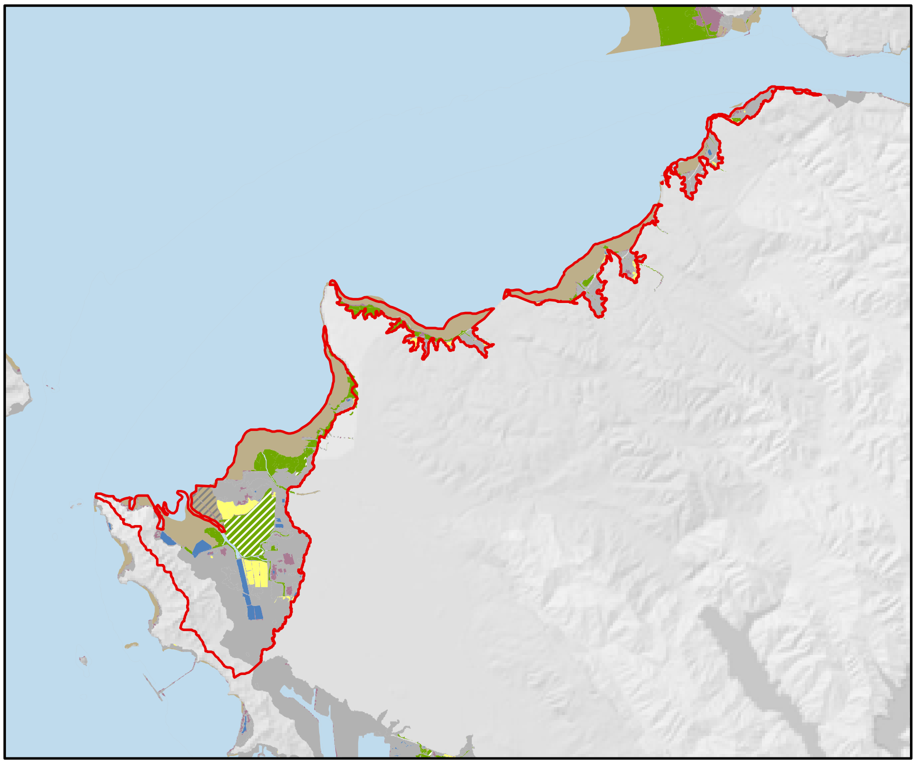
- Identify, conserve, and manage selected refugia for native bayland plants. Focus on unique or core populations of uncommon plants, especially in low marshes.
- Continue to control invasive *Spartina* in the mouth of Gallinas Creek, Hamilton Field, and other tidal marshes and restoration areas.

Restoration Benefits

Restoring tidal marshes, transition zones, and the lower reaches of streams would expand suitable habitat for many tidal marsh species, including rare and endangered plant, fish, bird, and mammal species such as the Ridgway's rail. The conservation of valleys and their reconnection with the baylands ecosystem would provide critical space for high tidal marsh and brackish marsh to migrate as sea levels rise toward the end of the 21st century. Reconnection of groundwater and surface stream discharges to tidal marsh would also provide critical brackish buffers to increasing salinity, thereby supporting tall, emergent vegetation that forms essential high-tide cover. The reuse of coarse-grained dredged sediment could simulate natural alluvial sediment transport that could help provide and enhance this groundwater–marsh connection. Wastewater flows could also be used to enhance seasonal and brackish marsh habitat types that are rare in this part of the Bay.

Challenges

Challenges include the commercial and residential developments at Bel Marin Keys, Hamilton Field, and at several sites to the south; diked intensive recreational land uses (golf) in subsided baylands at Black Point; low-lying segments of Highway 37, State Highway 101, other roads, and a railroad that may be renovated for commuter use. In some areas the railroad grade parallels the shoreline within the transition zone, making it a challenge to future migration because in the near term it will, along with other roads on the bay edge, prevent any significant landward migration of the baylands. The highway is further inland than the railroad and therefore represents a longer-term constraint. Development between the railroad and the highway is a long-term constraint as well. Each drainage channel that enters the existing transition zone or passes through areas of future transition zone presents significant flood-protection challenges. Also, multiple cultural sites relating to Coast Miwok habitation and early European and Asian settlements within the existing, near-term, and long-term transition zone must be considered during any effort to enhance, restore, or create transition zone habitat. Planning will require coordination with local agencies and organizations, including Marin County and Caltrans.



CONTRA COSTA WEST

Southeastern edge of San Pablo Bay between Point San Pablo and the Carquinez Bridge

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment H.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Unique Opportunities

In Segment H, many opportunities exist on public land, or may become available through conservation acquisitions of vacant land, to restore and enhance a wide range of subtidal offshore habitats as well as shoreline, stream, and terrestrial habitats; to restore connections among habitat types; and to set the stage for integrating habitat with shoreline protection. There is potential to restore a corridor of tidal marsh between Wildcat Marsh and San Pablo Marsh, as well as riparian vegetation along the streams that flow into these marshes. Multiple creeks (Wildcat, Pinole, and others) are already the focus of both community-based restoration efforts and US Army Corps of Engineers and Contra Costa County flood-control projects, and this work could be leveraged with additional activities that integrate climate-change adaptation techniques.

A variety of shoreline habitats could be restored on the Point Pinole and Point San Pablo peninsulas. From the north side of Point Pinole Regional Park to the Chevron refinery property, tidal and other disturbed wetlands and adjacent low-lying vacant uplands may become available for restoration, providing the opportunity to establish an extensive complex of diverse types of wetlands as well as upland transition zones, and enabling eventual wetland migration. Vacant low-lying uplands in creek floodplains could also be used as retention areas to relieve the upstream flooding of developed areas that may otherwise occur from storms of increasing intensity coupled with rising sea levels. Populations of tidal marsh plants of concern, including soft bird's-beak and salt marsh owl's-clover, could be restored. The segment also has multiple small habitat areas that include small but potentially viable populations, such as the steelhead run on Wildcat and Pinole Creeks. Conditions at some sites are suitable for native eelgrass and oyster restoration and enhancement. The largest eelgrass bed in the bay, offshore between Point Molate and Point Pinole, should be protected and enhanced.

The northeastern half of this segment will likely remain highly urbanized with limited opportunities for large-scale restoration, although there are larger opportunities southwest of Point Pinole Regional Shoreline. Many small-scale restoration and green engineering projects could be undertaken to meet the co-objectives of improving habitat quality and protecting the existing infrastructure, shorelines, and baylands. Partnerships should be pursued with the industrial and residential communities along the shoreline to create habitat bayward of their flood-protection levees through horizontal levees, living shorelines, or other green infrastructure. Pilot projects here could improve water quality and environmental health, provide preliminary data to inform similar adaptation designs in other segments, and provide benefits to the greater baylands. Point Molate Beach Park and Point Pinole Regional Shoreline provide unique, visible opportunities to educate the public about wildlife habitat needs.

Segment Features and Setting

This segment receives heavy marine influences and thus high-salinity waters. Historically, this segment was characterized by a narrow shoreline band of small tidal marshes, beaches, and extensive tidal flats. A broad tidal flat once bordered most of the portion of this segment north of Point Pinole, except along the steep shoreline near Carquinez Strait. A string of small tidal marshes lay in small coves along this shoreline and at the entrances to Garrity, Pinole, Refugio, and Rodeo Creeks. A large tidal marsh spanned much of the area between the San Pablo peninsula and Point Pinole and extended the length of lower Castro Creek. The adjacent uplands supported extensive areas of moist grassland and were dissected by numerous small streams that originated in the hills to the east. Some of these streams were bordered by riparian corridors and provided spawning and rearing habitat for steelhead. Some had lagoons at their mouth, and others terminated in willow groves.

This segment includes stretches of highly urbanized developed shorelines with a high-energy-wave environment and limited sources of local sediment. This segment has undergone considerable development, with cities, industrial areas, the Giant Powder Works plant, petroleum and natural gas facilities, wastewater treatment infrastructure, electrical utility projects, creek channelization, residential development, and transportation corridors. Landfills and other developments occupy many sites that were once tidal flat or marsh. Most of the tidal marsh in the Castro Creek basin has been filled for heavy industry (oil refinery and rail yard) and the West Contra Costa County Landfill. Some tidal marshes remain to the north and south of this landfill at the mouths of San Pablo and Wildcat Creeks, and a major tidal and seasonal wetland restoration project is under way at Breuner Marsh just south of Point Pinole. Union Pacific railroad tracks lie within a few yards of the shore for the entire distance north of Point Pinole, and almost no tidal marsh remains in this area. Tidal flats still abound throughout most of their historical distribution, and there are several sandy barrier beaches and lagoons. Small fringe beaches and rocky intertidal areas are present along many stretches of the segment, and intertidal and shallow subtidal areas support some of the most healthy and robust intertidal and subtidal eelgrass, oyster, and macroalgal beds in the bay. The largest eelgrass bed in the bay is located offshore between Point Molate and Point Pinole. Some vernal pools remain in the adjacent uplands.

Implications of Drivers of Change

The developed areas here will become increasingly difficult to protect as sea levels rise, but unlike segment L (Berkeley–Albany), this segment has some adjacent areas at appropriate elevations that could allow for the migration of baylands, particularly in the southwestern half.

Outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of the small remaining marsh edges, resulting in the narrowing and potential loss of marshes and other unique habitats such as coarse beaches and rocky intertidal areas. This largely urbanized segment has development that directly abuts the shoreline, which limits migration space and areas for restoration-based adaptation. Innovative and experimental approaches need to be tested, which

Shorebirds at sunset

may include sediment placement, the use of uncontaminated on-site fill in restoration designs, and integrated multihabitat designs with multiple biological and physical objectives.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

Immediate actions to enhance the existing baylands can help maximize resilience in this segment when sea-level rise rates will still be relatively low. Living breakwaters could be created around fringing marshes to preserve and enhance native eelgrass and oyster beds. Introducing fine sediment to recharge mudflats and marshes could increase vertical accretion rates. There are some opportunities to encourage the landward migration of marshland, but in many locations they are quite limited. However, opportunities to partner with the industrial and residential communities along the shoreline can be pursued to create habitat bayward of their flood-protection levees through horizontal levees, living shorelines, or other green infrastructure.

Diverse pocket habitats could be preserved, enhanced, or created, then linked together to form a subregional habitat corridor. Vertical enhancements could be installed in subtidal and intertidal areas where there is hardscape (living seawalls and substrate improvements to docks are two examples). Many existing habitats could be enhanced by improving tidegate management and removing trash, contaminated soils, and derelict boats.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea-level rise rates will likely outpace vertical accretion rates, and marshes in this segment generally do not have enough space to migrate landward to survive. Prior to that point, a plan for restoring or relocating the functions within the existing tidal marshes out of the hazard zone should be implemented. Creation of wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. The planned communities built over former wetlands and open bay in Hercules and other areas will be at risk for flooding as sea levels begin to rise. If opportunities for managed retreat become available, options to restore these areas to baylands habitats should be pursued.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Design and restore complete tidal wetland systems, even at a small scale, that include tidal marshes, beaches, lagoons, and broad transition zones. Develop techniques for implementing active revegetation, high-tide refuge islands, and subtidal habitat restoration.
- Restore a tidal marsh corridor along the eastern edge of the Richmond Landfill to reconnect Wildcat Marsh and San Pablo Marsh.
- Protect and restore native oyster beds and eelgrass beds from the Carquinez Bridge to Point San Pablo.

- Restore vernal pools in the adjacent uplands.
- Protect land as it may become available to incorporate transition zones into restoration designs.
- Use clean on-site bay fill creatively in restoration designs, including using it to construct seasonal wetlands that may become tidal wetlands with rising seas.

FOR PARTICULAR WILDLIFE POPULATIONS

- Enhance East Brother Island for harbor seal breeding habitat as Castro Rocks becomes inundated.
- Assess predator impacts caused by West County Landfill to define specific actions for improvement.
- Protect and enhance Pacific herring spawning areas, such as Point Molate.
- Develop projects to assess effectiveness of artificial floating islands for nesting and high-tide refugia.
- Control invasive species, especially perennial pepperweed in high-marsh rare-plant associations, and invasive *Spartina* across the full tidal frame.

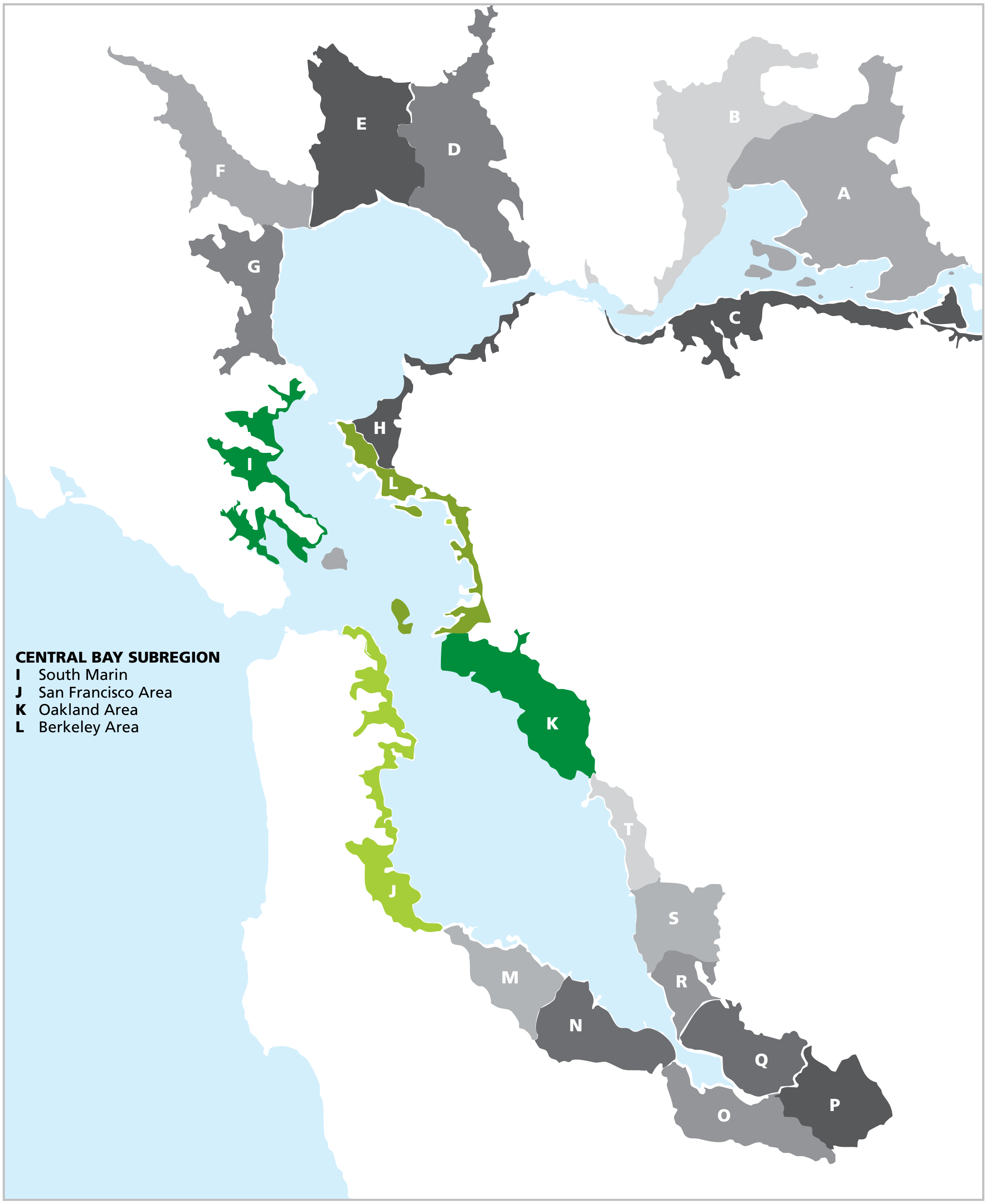
Restoration Benefits

The recommended projects for this segment would demonstrate to the public innovative techniques to restore and enhance habitats for many populations of key fish, amphibian, reptile, insect, mammal, and bird species. Restoring wetlands would enhance habitats for endangered species such as the Ridgway's rail and salt marsh harvest mouse. Reestablishing a tidal marsh corridor between the Wildcat and San Pablo Marshes would link these existing areas, increase tidal marsh acreage, and reduce the isolation of small-mammal populations. Restoring and improving marsh–upland transition zones would benefit populations of several rare plants. Restoring beach habitat could improve conditions for sensitive plant species. Protecting islands would assure suitable sites for colonial nesting birds. Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish, and might enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living-shorelines designs might provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

Challenges

The major challenges in this segment are the large urban population, extensive fill along the shoreline, on-site contaminants, the existing infrastructure, bridges, and wastewater treatment plants, railroad tracks and spurs, derelict creosote wharfs and piling structures, the West County Landfill, major highways, flood-control considerations, exotic predators (e.g., rats and red fox), and invasive *Spartina*.

Central Bay Subregion



Central Bay Subregion

LANDSCAPE VISION

The Central Bay is the region's most intensively developed shoreline, yet it is home to critical bayland resources. The vision for the Central Bay is to protect and enhance extant marshes and mudflats, while connecting urban residents to the baylands with restoration projects that demonstrate how climate change adaptation can provide vital ecosystem services while improving ecological health. This subregion will likely remain highly urbanized with limited opportunities for large-scale restoration, yet there are opportunities for small-scale restoration with the co-objectives of improving habitat quality and connectivity, protecting existing infrastructure and habitats, and generating new knowledge and new public–private partnerships and community involvement.

The goal for the Central Bay is to protect and restore tidal marshes, mudflats, beaches, rocky intertidal areas, subtidal habitats, and seasonal wetlands to create an archipelago-style corridor of tidal baylands.

Recommended Actions

- Restore tidal marsh wherever possible, and particularly where streams enter the baylands. Protect, enhance, and restore streams and riparian habitats so that they pass through, rather than around, tidal marshes. Restore natural salt ponds on the East Bay shoreline, and protect and enhance shallow subtidal habitats (including eelgrass and oyster beds) and shorebird roosts. Incorporate transition zones and terrestrial buffers beyond the existing transition zone into all appropriate projects. Find opportunities to create or improve floodplains, off-channel aquatic habitat, or low marsh along flood-control channels, including upstream areas. Improve dock substrates and tidegate management. Study and consider removing derelict creosote pilings, contaminated soils, and derelict boats. Reduce and remove trash that terminates in the bay.
- Pursue opportunities to enable the baylands to persist and migrate with sea-level rise, despite limitations from steep topography and urban and industrial development. Consider creating very low-slope transition zones bayward of the flood protection levees to provide space for landward migration, possibly using wastewater to develop wetlands on the slope. Use any of the following techniques where appropriate: recharge mudflats with sediment to increase the local supply, stabilize the bayward marsh edge with a coarse beach to prevent erosion, and improve natural-sediment-transport processes to maximize vertical accretion in the landward portion of the marsh. Create living breakwaters that incorporate native eelgrass and oyster beds and protect the habitats and infrastructure behind them. Develop living seawalls and docks for the region at critical infrastructure sites, such as the Port of San Francisco. If developed baylands are abandoned due to rising tides, pursue opportunities to restore these areas to functioning habitats that provide ecosystem services.

RECENT RESTORATION

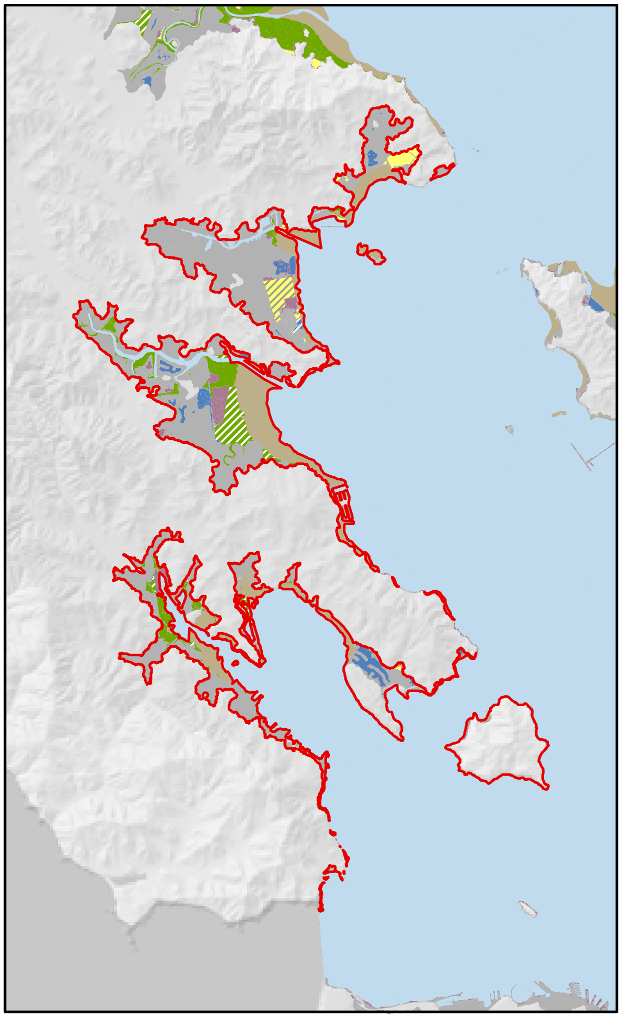
Despite the urbanization and limited baylands acreage in this region, several recent restoration projects have been completed at Crissy Field, Yosemite Slough, Lake Merritt, Martin Luther King Jr. Regional Shoreline, the Berkeley Meadow, and other areas.

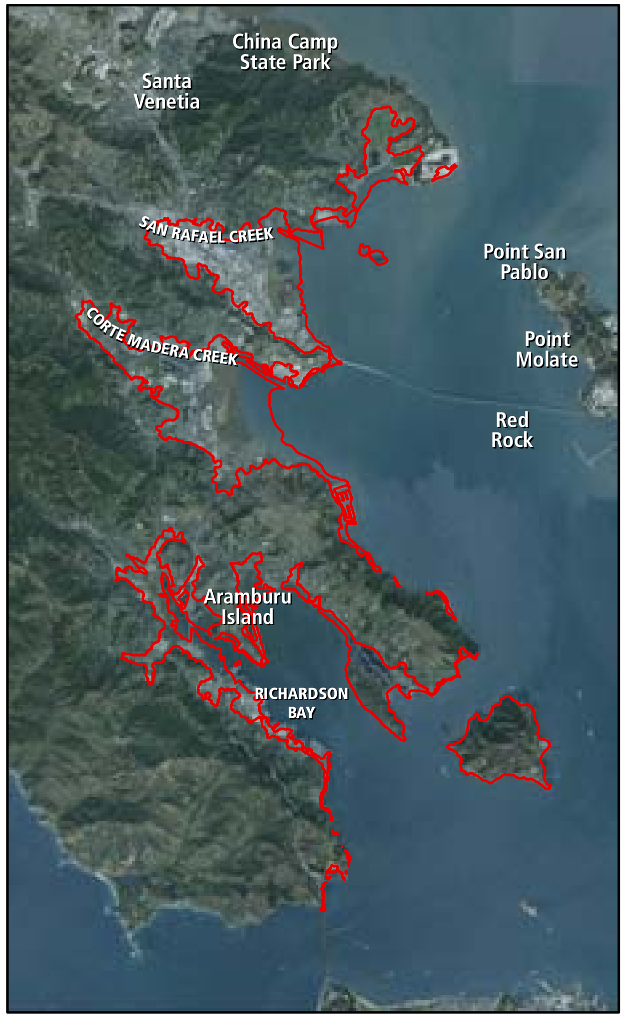
CHALLENGES

Achieving the Central Bay vision is subject to significant infrastructure constraints (e.g., those posed by ports and airports, military facilities, transportation and utility corridors, bridges, wastewater treatment plants, and landfills), the presence of invasive species (principally invasive *Spartina*), and the limitations of steep topography, urban and industrial development, and contamination at restoration sites. Private landowners and public entities will need to be willing to undertake habitat restoration and enhancement in the most urbanized portion of the baylands and to retrofit infrastructure in a manner in keeping with ecosystem health. Although largely under control, invasive *Spartina* remains a challenge for the Central Bay, including at sites such as San Leandro Bay. Other challenges include a large urban population, extensive fill along the shoreline, on-site contaminants, flood-control considerations, and exotic predators (e.g., rats and red fox).

The Central Bay subregion includes segments I through L.

Mudflats and shoreline armoring





SOUTH MARIN

Western edge of central San Francisco Bay extending from Point San Pedro to the Golden Gate

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment I.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Unique Opportunities

Segment I has low-lying urbanized lands that are not protected by large flood-control levees, and areas already subject to flooding. Thus, this segment can serve as a laboratory for testing ecological design concepts for sea-level rise adaptations that integrate flood control and habitat benefits. In particular, marshes can be used for wave attenuation, and coarse-grained beaches can buffer the impacts of wind–wave erosion. This segment is highly visible to the public. Demonstration projects could educate residents and raise awareness about the impacts of climate change and gain support for solutions to address these impacts. There are several opportunities to provide important wide transition zones and migration space for tidal salt marshes to migrate landward in response to sea-level rise. Nearshore eelgrass and oyster beds can be expanded at multiple locations as well.

Segment Features and Setting

Historically, the relatively steep bayshore topography of this segment limited large areas of tidal marsh to the lower reaches of San Rafael and Corte Madera Creeks and to the western part of Richardson Bay. In addition, there were many historic pocket and barrier beaches along sections of the Richardson Bay shoreline. The steep watersheds of Mount Tamalpais with their high sediment yields contributed fluvial sediment to the baylands.

Today, much of the baylands within this segment has been filled and developed for urban, transportation, and residential uses. Only a few remnants of the original tidal marshes remain (e.g., Heerdt Marsh and the Corte Madera Ecological Reserve). However, mature wide salt marsh habitat has regenerated near the mouth of Coyote Creek, supporting regionally rare plant populations, including some of the largest colonies of northern salt marsh bird's-beak in San Francisco Bay). The Corte Madera Ecological Reserve supports one of the densest populations of Ridgway's rails in northern San Francisco Bay; it also supports a black rail population. Important tidal mudflats remain in Corte Madera Bay (the Corte Madera Ecological Reserve), Richardson Bay (the Richardson Bay Audubon Sanctuary), and Mill Valley marshes. Eelgrass and oyster habitats occur along the length of this segment, from McNears Beach to Fort Baker.

Harbor seals formerly used the Corte Madera Marsh and Strawberry Spit areas for resting and pupping. Aramburu Island (on the north end of Strawberry Spit) has been rehabilitated with beaches next to both deep water and tidal flats to accommodate reoccupation by seals, terns, and shorebirds, but alternative seal haul-out and pupping habitats are limited in this segment.

Implications of Drivers of Change

High-tide inundation is already affecting the eastern Marin shoreline. During high-tide events the urbanized bay edge is subjected to direct flooding and roadway closures. Sea-level rise can be expected to significantly worsen these conditions as well as threaten critical infrastructure such as Highway 101. Subsidence due to development on bay mud exacerbates flooding; low-lying areas have elaborate systems of pump stations and detention ponds that are not necessarily sized to accommodate future conditions. The flood-control requirement to protect existing infrastructure and both residential and commercial areas will be a large driver of change, and the way that flood control integrates with habitat goals will be a challenge. Outboard levees, trails, and roadways in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the ongoing erosion of marsh edges, resulting in the narrowing of marshes and a loss of habitat. A reduced sediment supply also threatens the ability of the natural marshes to keep pace with sea-level rise.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term presents significant opportunities to build on studies completed at the mouth of Corte Madera Creek as well as in Richardson Bay (Aramburu Island). Pilot projects could demonstrate ecological design concepts for the fringing marshes and pocket beaches.

Sediments dredged from creeks for flood control could be recycled for marsh and mudflat nourishment within the sub-embayments of Richardson and Corte Madera Bays, following the natural deposition patterns that established the existing marsh landscape positions. Sediment could be placed directly as hydraulic thin-layer deposits, or placed on adjacent mudflats to be resuspended and then dispersed by tidal action through creek networks into the interior marsh plains.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the longer term, if sea-level rise accelerates and sediment supply falls as projected, providing flood protection for the highly urbanized edge will become increasingly important. Existing tidal marshes will be subject to greater erosion, further narrowing the fringing marshes. Tidal marshes may be unable to keep up with sea-level rise, resulting in more inundation of the marsh surface. This will likely lead to a habitat conversion to low marsh, mudflat, and ultimately subtidal areas. Landward migration of the marsh should be undertaken where there is room for managed retreat. Construction of a gently sloping transition zone bayward of the levee would facilitate such migration. Coarse-grained beach will need to be strengthened and perhaps augmented with larger-grained sediments as wave energy increases with rising sea levels.

Harbor seals

At some point, the amount of sea-level rise will make protection of residential and commercial developments and infrastructure from both direct bay coastal flooding and fluvial flooding (from backwater storm-drain flooding from a higher bay level) a preeminent public safety goal. Other approaches such as muting high tides with engineered barriers may be required to maintain public safety during flooding events. Working with local governments to explore managed retreats and changes to building and planning codes should be considered in long-term planning.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Design and restore complete tidal wetland systems, even at a small scale, that include tidal marshes, beaches, lagoons, and broad transition zones. Develop techniques for implementing active revegetation, high-tide-refuge islands, and subtidal habitat restoration.
- Tidal restoration should stress wide platforms for high salt marsh and local native terrestrial transition zone (wet meadow) vegetation tolerant of infrequent tidal flooding, rather than an expanded intertidal marsh plain that is subject to drowning as the sea-level rise accelerates.
- Incorporate seasonal and perennial wetland features in the transition zone by using freshwater discharges (subsurface or diffuse sheetflow) from treated stormwater.
- Create transition zone habitats on gentle slopes in conjunction with flood-risk-management features (or other high-ground areas). Consider preparing transition zones with dredged material and treated wastewater to encourage tidal-channel formation and pan development, resulting in topographic complexity (high-tide refugia).
- Protect fringe marshes throughout the segment.
- Protect subtidal habitat including mudflats, native oyster beds, and eelgrass beds.
- Consider ways to increase sediment supply to the tidal baylands. For example, dredged sediments could be placed directly on local marshes or adjacent mudflats to be reworked by wave and tidal action to build up local suspended-sediment concentrations and marsh-accretion rates.
- Reduce the horizontal erosion of marshes by creating coarse beaches in front of marsh scarps.
- Evaluate the construction of a steep transition zone using strategically placed fill in areas of the bay to decrease wave attenuation and reduce costs for levee protection.

FOR PARTICULAR WILDLIFE POPULATIONS

- Provide additional harbor seal haul-out and pupping sites in Corte Madera Marsh and at Richardson Bay.
- Protect and enhance Pacific herring spawning areas.

- Incorporate the management of rare and uncommon estuarine plant populations (augmenting their population, giving additional colonies wider distribution) in tidal marsh restoration and management projects, including sediment nourishment.
- Preserve existing populations of rare high-marsh and transition zone plants as seed sources for future reintroduction and population management as long as feasible.
- Control the spread of pepperweed in rare high-marsh plant associations and control and prevent the reemergence of invasive *Spartina* at all locations.

Restoration Benefits

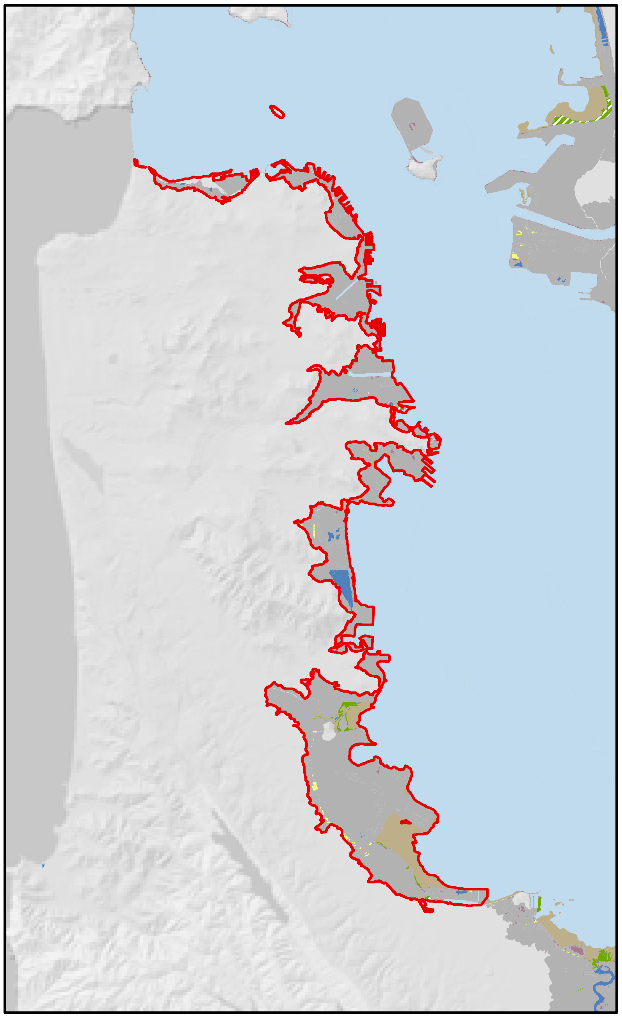
Constructing wide terrestrial transition zones landward of existing major salt marsh habitats of the Corte Madera Ecological Reserve would significantly improve the resilience of existing Ridgway's rail and black rail populations, improve wildlife buffers along trails, and offset tidal marsh submergence and the loss of high-tide cover as existing marsh plains submerge. Implementing the recommendations for this segment would improve habitat support for harbor seals, salt marsh harvest mice, and other mammals.

Enhancing seasonal wetlands would provide improved high-tide roosting habitat for shorebirds. Enhancing riparian and instream habitats would benefit migratory songbirds and steelhead. Restoration of coarse-grained gravel beach habitat at various locations would provide high-tide roosting habitat for shorebirds and terns. Isolated (islandlike) marsh-fringing beaches may provide additional nesting sites for terns. Restoration of native oyster and eelgrass beds offshore would provide habitat for birds and fish, and might enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living-shorelines designs may provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

Challenges

Challenges in this segment include Highway 101, an urbanized edge with roadways and infrastructure that currently flood (e.g., Miller Avenue, Manzanita parking areas, the Mill Valley sewer plant), Northwestern Pacific railroad tracks, flood-control considerations, erosion from the Larkspur Ferry, and exotic predators (e.g., rats and red fox), invasive *Spartina*, and on-site contaminants.

BAYLANDS SEGMENT J



SAN FRANCISCO AREA

Western side of central San Francisco Bay between the Golden Gate and Coyote Point

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment J.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Unique Opportunities

Segment J provides an opportunity to restore tidal wetlands, beaches, sand dunes, intertidal rocky areas, and subtidal habitats that enhance its ecological connections. Tidal marshes at several sites south of San Francisco can also be restored or enhanced. The locally extirpated California seablite and associated rare or uncommon high-marsh plant species can be reestablished. West of the airport are opportunities to enhance freshwater marshes and adjacent seasonal wetlands for the San Francisco garter snake and red-legged frog. Conditions at some sites are appropriate for native eelgrass and oyster restoration. Other habitats, including several roosting sites, can also be protected and restored.

The segment is highly visible to the public. Demonstration projects could educate residents, strengthen their connection to the environment, raise awareness about the impacts of climate change, and promote solutions that improve the health of the baylands and its resources. Multiple creeks (including creeks in the Presidio and Colma Creek) are already the focus of community-based restoration efforts, and this work could be leveraged with other activities integrating climate-change-adaptation techniques. Crissy Field, the San Francisco waterfront, San Francisco International Airport (SFO), and multiple large marinas provide unique, visible opportunities to educate the public about wildlife habitat needs.

This segment will remain highly urbanized, with limited opportunities for large-scale restoration, but it presents many opportunities to develop small-scale restoration and green engineering projects toward meeting the co-objectives of improved habitat quality and the protection of existing infrastructure, shorelines, and baylands. Critical infrastructure, such as SFO will need to be protected, but there are ample opportunities for small improvements that may result in enhanced habitat corridors and better linkages for species that use the bay and baylands.

Segment Features and Setting

Historically, this segment supported many kinds of habitats. Barrier beaches and marshes existed in small coves between the local headlands, often in connection with the mouths of streams. Tidal marsh was also present along the lower reaches of streams and in several small embayments at sites such as China Basin, Islais Creek, and Hunters Point. A wide band of tidal marsh extended from near Candlestick Point southward to Coyote Point. This area was one of the major historical localities of the locally extirpated California seablite.

This segment receives heavy marine influences and high salinity. It includes highly urbanized shorelines, a high-energy-wave environment, and limited sources of local sediment. Today, cities, military bases, industrial sites, marinas, and port facilities line much of the shore. The Port of San Francisco and its piers cover much of the San Francisco shoreline. SFO is in the middle of a former large tidal marsh. West of the airport is an area of seasonal wetlands and permanent freshwater marsh. At several sites along the modern shoreline, shell and sand beaches have re-formed naturally. Restoration of tidal marsh and other habitats is under way at Crissy Field, Heron's Head Park, and Yosemite Slough. Much of the shoreline south of San Francisco has been altered by Highway 101 and residential and industrial development. This area includes remnant fringe marshes, lagoons, mudflats, rocky intertidal areas, fragmented small native oyster populations, and other remnant habitats.

Implications of Drivers of Change

The developed areas in this segment will become increasingly difficult to protect as sea levels rise, and there are limited natural areas and elevations that could allow for the migration of baylands. Seawalls, piers, and communities offshore from Highway 101 in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of the remaining small marsh edges, resulting in the narrowing and potential loss of marshes and other unique habitats such as coarse beaches and rocky intertidal areas. This urbanized segment has a great deal of existing development that directly abuts the shoreline, limiting the migration space and areas for restoration adaptation. Innovative and experimental approaches need to be tested that may include sediment placement, the use of uncontaminated on-site fill in restorations, and integrated multihabitat designs with multiple biological and physical objectives.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

This segment is highly urbanized and constrained by steep shorelines and development directly adjacent to the baylands. In the near term, when sea-level rise rates will still be relatively low, actions that enhance the existing baylands and provide immediate ecological benefits will maximize shoreline resilience. Living breakwaters could be created around fringing marshes to preserve and enhance unique features like native eelgrass and oyster beds. Partnerships should be pursued with the industrial and residential communities along the shoreline to create habitat bayward of their flood-protection levees (through horizontal levees, living shorelines, or other green infrastructure).

Major land uses such as the Port of San Francisco will remain largely in current configurations, and they will need to be protected, providing opportunities for approaches that haven't yet been tried locally, such as "living seawalls." Diverse pocket habitats could be preserved, enhanced, and created, then linked together to create a subregional habitat corridor. Vertical enhancements (living seawalls, substrate improvements to docks, etc.) could be made in a few subtidal and intertidal areas where there is hardscape. Many existing habitats could be enhanced by improving tidegate management and removing contaminated soils and derelict boats. A stronger focus could be placed in removing trash that terminates in the bay. Habitats could be created along flood-control channels, floodplains, and off channels. Low-elevation marsh and wetland could be restored. Upstream opportunities are limited but should be included in any plans.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea-level rise rates will likely outpace vertical accretion rates, and marshes in this segment generally do not have enough space to migrate landward to persist. Prior to that point, a plan for restoring or relocating the functions within the existing tidal marshes should be implemented. Creating wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. The planned communities built over former wetlands and open bay in Millbrae and other areas will be at risk for flooding as sea levels rise. If opportunities for managed retreat become available, options should be pursued to restore areas to baylands or to connect bay habitats.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Preserve, enhance, and create diverse pocket habitats that are linked in a subregional habitat corridor that encompasses sand beaches, eelgrass, oyster beds, macroalgal beds, mudflats, rocky intertidal areas, and tidal marsh.
- Design and restore complete tidal wetland systems, even at a small scale, that include tidal marshes, beaches, lagoons, and broad transition zones. Develop techniques for implementing active revegetation, high-tide-refuge islands, and subtidal habitat restoration.
- Consider ways to increase sediment supply to the tidal baylands, including reconnecting stream channels into marshes and augmenting the trapping efficiency of tidal baylands to foster accretion, as appropriate.
- Protect and restore native oyster and eelgrass beds in suitable areas.
- Protect land as it may become available to incorporate transition zones into restoration designs. This may include remediating contaminated land (wastewater treatment ponds, industrial areas, flat unfilled lands) to create habitat.

FOR PARTICULAR WILDLIFE POPULATIONS

- Protect and enhance Pacific herring spawning areas.
- Protect and enhance critical avian stopover sites.
- Reestablish the California seablite and the associated high salt marsh plant species on the sandy edges of "pocket" marshes.
- Eliminate core populations and advancing-edge populations of invasive *Spartina*.

Restoration Benefits

The recommended projects for this segment would demonstrate innovative techniques to restore and enhance habitats for many populations of key fish, amphibian, reptile, insect, mammal, and bird species. Restoring tidal marsh would facilitate the dispersal of tidal-marsh-dependent birds, such as the Ridgway's rail and black rail, by providing roosting and foraging habitat. Restoring marsh–upland transition zones would benefit both plant and animal species, including populations of several rare

San Francisco Pier 94 restoration area

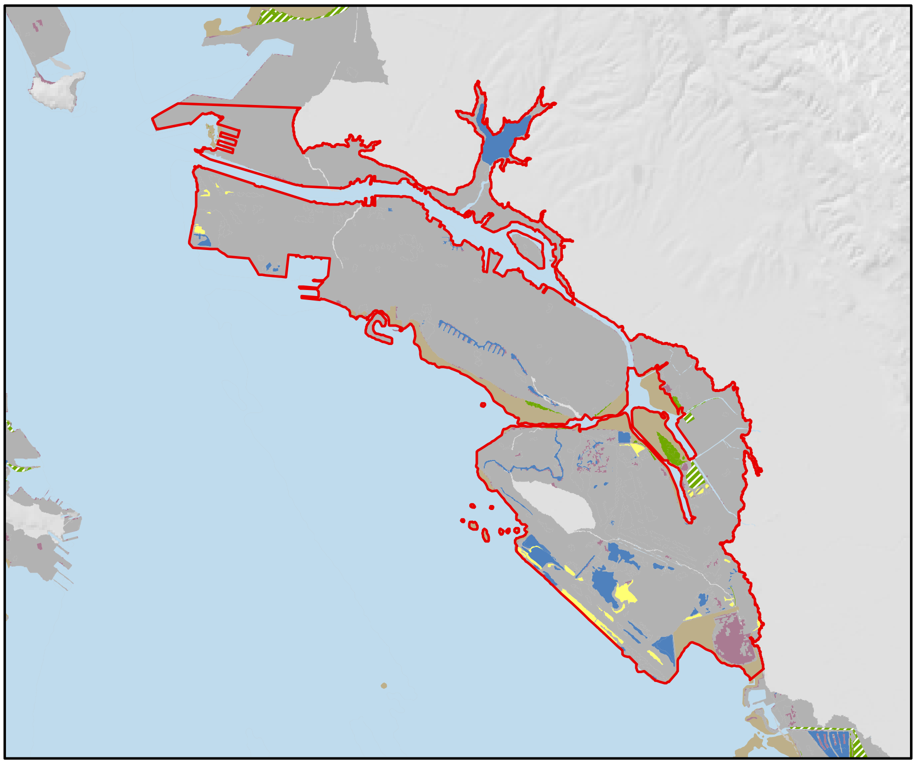
plants. Enhancing the habitats west of Highway 101 near SFO would benefit the San Francisco garter snake and the California red-legged frog. Reestablishing a tidal marsh corridor between the San Francisco and San Bruno Marshes would link these existing areas, increase tidal marsh acreage, and reduce the isolation of small-mammal populations. Restoring beach habitat could improve conditions for sensitive plant species. Protecting islands would assure suitable sites for colonial nesting birds. Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish, and might enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living shorelines might provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

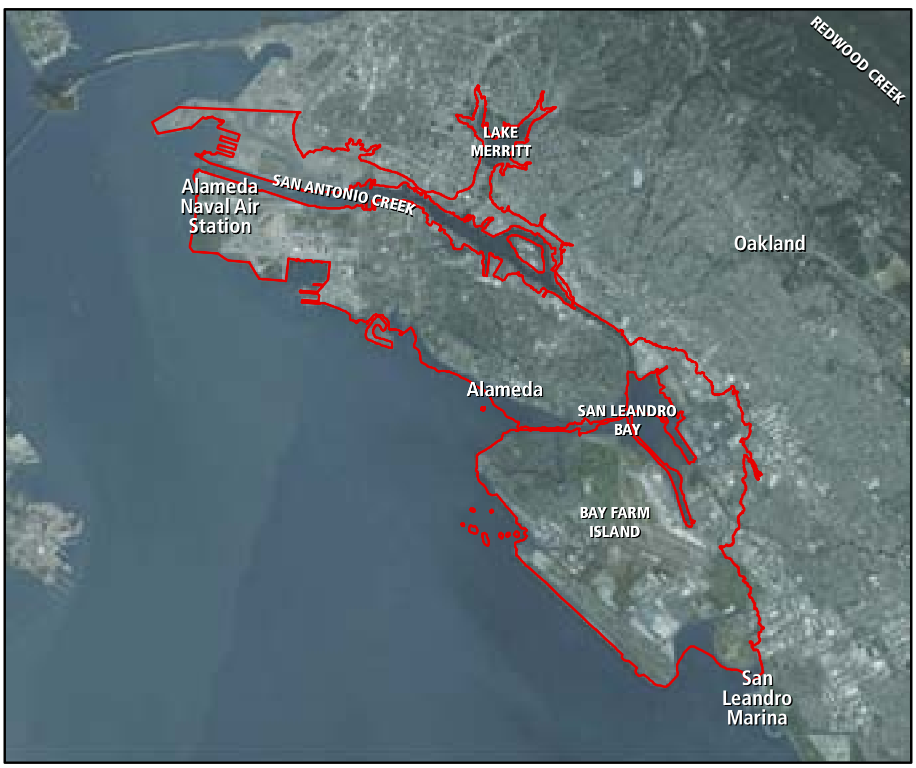
Experimental pilot projects should be conducted using new approaches that are carefully tested in phases. Integrating native oyster and eelgrass restoration adjacent to tidal wetlands, creating living shorelines, and incorporating features such as high-tide-refuge islands might improve small areas of habitat. They would also provide information on how well these approaches succeed and whether they can be scaled up to larger areas in this segment. Such information could be applied to other segment adaptation planning.

Including public education and awareness components in any restoration initiative is critical to building the public and financial support that is needed to test adaptation approaches and work toward large-scale implementation of innovative techniques.

Challenges

The major challenges in this segment are its large urban population, extensive fill along the shoreline, on-site contaminants, port and military facilities, Highway 101, wastewater treatment facilities, SFO, many large shoreline fills, utility corridors, bridges, water-treatment plants, railroad tracks and spurs, landfills, flood-control considerations, exotic predators (e.g., rats and red fox), and invasive *Spartina*.





OAKLAND AREA

Eastern edge of central San Francisco Bay between the San Leandro Marina and Oakland outer harbor

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment K.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Port of Oakland

Unique Opportunities

Segment K will likely remain highly urbanized with limited opportunities for large-scale restoration, but it presents many opportunities to develop small-scale restoration and green engineering projects to meet the co-objectives of improving habitat quality and protecting the existing infrastructure, shorelines, and baylands. This segment provides the opportunity to create additional nesting habitat for California least terns, to enhance degraded nesting habitat for Caspian terns, and to restore tidal wetlands and subtidal offshore habitats in several areas. Conditions at some sites are appropriate for native eelgrass and oyster restoration. Lake Merritt and the Oakland Estuary provide unique, visible opportunities to educate the public about wildlife habitat needs.

Very few large tracts of land are available for habitat acquisition or restoration, but this segment has multiple small habitat areas that include small but viable wildlife populations such as the steelhead run on San Leandro Creek.

Segment Features and Setting

Historically, this area was predominantly tidal flat and tidal salt marsh. Most of the baylands in the Oakland Estuary were tidal flat, tidal wetlands fringed by sandy beaches, or open bay. The estuary extended well into the current site of Lake Merritt. Native eelgrass and oyster beds were distributed throughout this segment. Most of the area surrounding Bay Farm Island was tidal flat and tidal wetlands fringed by sandy beaches. Oakland, Alameda, and Bay Farm Island were major strongholds for the locally extirpated California sea-blite. Large areas of oak woodland existed on the higher lands near the estuary, and moist grassland bordered the tidal marsh in the southern half of the segment. Perennial ponds, riparian zones, and willow groves also existed here.

Today, this segment is highly developed with urban, industrial, and transportation uses, and many of its historical and unique habitat features are gone. Most of the tidal flats and marshes along the bayshore have been filled to allow the development of railroad, military base, port, shipyard, and other facilities. Lake Merritt is an urban wildlife refuge ringed by concrete walkways. The marshes and other habitats near Bay Farm Island have been filled; they are now the site of the Oakland Airport. This segment receives heavy marine influences and high salinity. It includes highly urbanized shorelines, a high-energy-wave environment, and limited sources of local sediment. It still supports oyster and eelgrass beds in limited areas.

Implications of Drivers of Change

The developed areas in this segment will become increasingly difficult to protect as sea levels rise. Outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of the small remaining marsh edges, resulting in the narrowing and potential loss of marshes and other unique habitats such as coarse beaches. This urbanized segment has a great deal of development that directly abuts the shoreline, limiting the migration space and areas for restoration adaptation. More experimental approaches to address these limits might include vertical adaptation with new techniques such as living seawalls and breakwaters.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

In the near term, when sea-level rise rates will still be relatively low, enhancing the baylands will provide immediate ecological benefits and maximize their resilience. Living breakwaters could be created around fringing marshes to preserve and enhance unique features like native eelgrass and oyster beds. Introducing fine sediment through mudflat and marsh recharge could increase vertical accretion rates. There are limited opportunities for landward migration of marshland, and it is likely that the fringing tidal marshes will drown as sea levels rise. However, opportunities exist to partner with the industrial and residential communities along the shoreline to develop green infrastructure such as horizontal levees, which would create habitat bayward of the flood-protection levees.

Major land uses, such as Highway 880, will remain largely in current configurations and will need to be protected. Innovative approaches such as living seawalls may provide an opportunity to do so. Diverse pocket habitats could be preserved, enhanced, and created, then linked together to create a subregional habitat corridor. Vertical enhancements (living seawalls, substrate improvements to docks, etc.) could be made in a few subtidal and intertidal areas where there is hardscape. Many existing habitats could be enhanced by improving tidegate management, removing contaminated soils and derelict boats, and removing trash that ends up in the bay. Habitats could be created along flood-control channels, floodplains, and off channels, and low-elevation marsh and other wetland could be restored. Upstream opportunities are limited but important to consider.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea-level rise rates will likely outpace vertical accretion rates, and marshes in this segment generally do not have enough space to migrate landward to survive. Prior to that point, a plan for restoring or relocating the functions within the existing tidal marshes should be implemented. Creating wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. The planned communities built over former wetlands at Bay Farm Island, Alameda Island, and around the Oakland Airport will be at risk for flooding as sea levels begin to rise. If opportunities for managed retreat become available, options should be pursued to restore such areas to marshland.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Preserve, enhance, and create diverse pocket habitats that are linked in a subregional habitat corridor that encompasses sand beaches, eelgrass, oyster beds, macroalgal beds, mudflats, rocky intertidal areas, and tidal marsh.
- Develop extensive and connected segments of native tidal marsh for small mammals and marsh-dependent birds.
- Protect and restore eelgrass and oyster beds in suitable locations.
- Enhance and expand tidal and diked habitats at all potential areas throughout the segment, for example, Alameda Island, Bay Farm Island, Martin Luther King Jr. Regional Shoreline Park, and the vicinity of the Oakland Airport.
- Enhance riparian corridors along streams throughout the segment and reconnect tributary streams to the Bay.

FOR PARTICULAR WILDLIFE POPULATIONS

- Preserve salmonid habitat in all creeks, and remove barriers to fish passage in areas of known populations.
- Enhance and protect suitable habitat (e.g., barren or sparsely vegetated areas protected from predators) for the snowy plover and least tern at Alameda Naval Air Station, Oakland Airport, Bay Farm Island, and other locations.
- Enhance cover for wildlife in existing tidal wetlands through active revegetation and by constructing high-tide-refuge islands within the marsh plains. Conduct pilot projects to assess the effectiveness of artificial floating islands for Ridgway's rail nesting and high-tide refugia.
- Restore pockets of low-lying sand beaches in sheltered sites to support reintroduced colonies of California sea-blite.
- Increase habitat in and around San Leandro Bay for harbor seals.
- Continue to control invasive *Spartina* throughout the segment and especially in San Leandro Bay.

Restoration Benefits

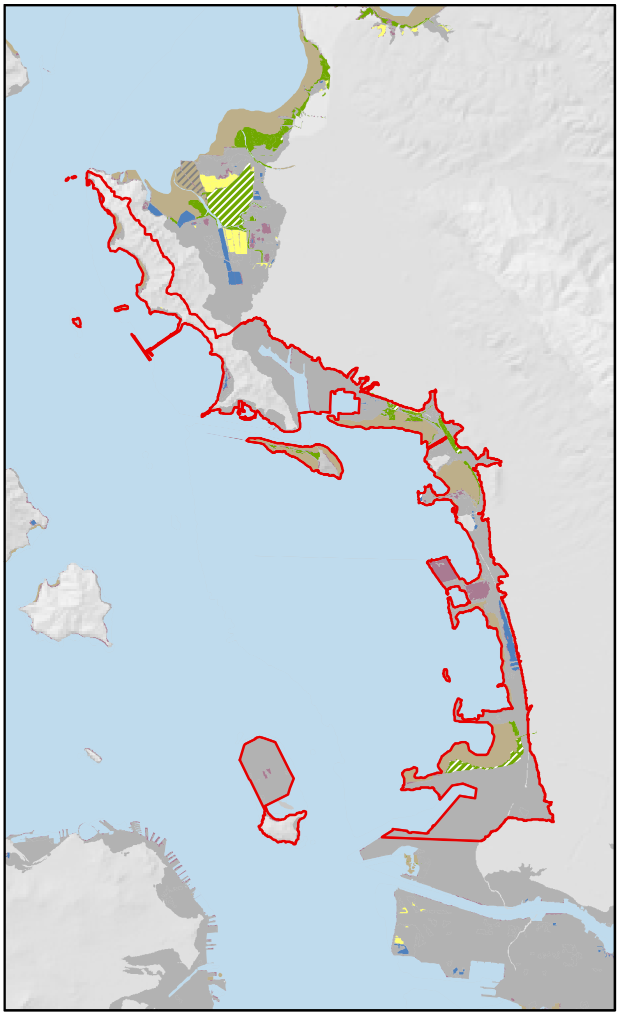
Implementing the recommended projects for this segment would demonstrate innovative techniques to restore and enhance habitat for many populations of key fish, amphibian, reptile, insect, mammal, and bird species. Restoring wetlands would enhance habitats for endangered species such as the Ridgway's rail and salt marsh harvest mouse. Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish, and might enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living-shorelines designs might provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

Experimental pilot projects should be conducted using new approaches that are carefully tested in phases. Integrating native oyster and eelgrass restoration adjacent to tidal wetlands, creating living shorelines, and incorporating features such as high-tide-refuge islands might improve small areas of habitat. They would also provide information on how well these approaches succeed and whether they can be scaled up to larger areas in this segment. Such information could be applied to other segment adaptation planning.

Including public education and awareness components in any restoration initiative is critical to building the public and financial support that is needed to test adaptation approaches and work toward large-scale implementation of innovative techniques.

Challenges

Major challenges in this segment are its large urban population, extensive fill along the shoreline, bridges, water-treatment plants, railroad tracks and spurs, major highways, exotic predators (e.g., rats and red fox), and on-site contaminants. Invasive *Spartina* control remains a critical priority, constraint, and consideration for some existing marshes and for restoration planning.



BERKELEY AREA

Eastern edge of San Francisco Bay between the Oakland outer harbor and Point San Pablo

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment L.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Unique Opportunities

Although very few large tracts are available for habitat acquisition or restoration, Segment L has multiple small habitat areas that include small but viable wildlife populations, such as the steelhead run on Codornices Creek. This segment will likely remain highly urbanized, with limited opportunities for large-scale restoration, but it presents many opportunities to develop small-scale restoration and green engineering projects toward meeting the co-objectives of improving habitat quality and protecting existing infrastructure, shorelines, and baylands. Critical infrastructure will need to be protected, but many improvements can be made to enhance habitat corridors and provide better linkages for species that use the bay and baylands. In several areas the ecological connections between creek mouths, tidal wetlands, and subtidal offshore habitats can be enhanced. Conditions at some sites are appropriate for native eelgrass and oyster restoration, and oysters are part of the rocky intertidal habitat being incorporated into a large-scale bank-stabilization project near Albany Beach and Brooks Island. Many tidal habitats can be restored and enhanced in this segment; examples include Hoffman Marsh, Emeryville Crescent, and the mouth of Codornices Creek. Moist grassland and seasonal wetlands such as the Richmond Field Station can also be protected and restored. Projects here could improve local water quality and environmental health, provide preliminary data to inform similar adaptation designs in other segments, and may provide benefits to the greater baylands.

The focus of the landscape vision for this segment is on creating a connection between urban residents and the environment and promoting demonstration projects that improve the health of the baylands and raise public awareness of baylands resources. Multiple creeks (Strawberry, Marin, Cordonices, etc.) are already the focus of community-based restoration efforts, and this work could be leveraged with other activities integrating climate-change-adaptation education and restoration activities. McLaughlin Eastshore State Park, the Berkeley Marina, Aquatic Park, and the Richmond shoreline provide unique, visible opportunities to educate the public about wildlife habitat needs.

Segment Features and Setting

Historically, this segment was characterized by a narrow shoreline band of small tidal marshes, sand dunes, beaches, and extensive tidal flats. The adjacent terrestrial areas supported extensive areas of moist grassland and were dissected by numerous small streams that originated in the hills to the east. Some of these streams were bordered by riparian corridors and provided spawning and rearing habitat for steelhead. Some had lagoons at their mouths, and others terminated in willow groves.

Today, this segment is highly developed with cities, industrial areas, ports, and transportation corridors, and many of its historical and unique habitat features are gone. Landfills, hotels, and other developments have taken over many sites that once were tidal flat or marsh. Several relatively small isolated tidal flats, adjoining marshes, and other features continue to provide important habitat functions. Examples of high-quality habitat in this segment are the tidal marsh and mudflats at the Emeryville Crescent and the small marshes and extensive mudflats north of Point Isabel. Small fringe beaches and rocky intertidal areas are present along almost the full length of the segment, and intertidal and shallow subtidal areas support eelgrass, oyster, and macroalgal beds. This segment receives heavy marine influences and high salinity. It includes highly urbanized shorelines, a high-energy-wave environment, and limited sources of local sediment.

Implications of Drivers of Change

The developed areas in this segment will become increasingly difficult to protect as sea levels rise. Outboard levees and fringing marshes will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will accelerate the erosion of the small remaining marsh edges, resulting in the narrowing and potential loss of marshes and other unique habitats such as coarse beaches. This urbanized segment has a great deal of development that directly abuts the shoreline, limiting the migration space and areas for restoration adaptation. More experimental approaches to address these limits might include vertical adaptation with new techniques such as living seawalls and breakwaters.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

This segment is highly urbanized and constrained by development directly adjacent to the baylands. In the near term, when sea-level rise rates will still be relatively low, enhancing the baylands will provide immediate ecological benefits and maximize their resilience. Living breakwaters could be created around fringing marshes to preserve and enhance unique features like native eelgrass and oyster beds. Introducing fine sediment through mudflat and marsh recharge could increase vertical accretion rates. There are limited opportunities for landward migration of marshland, and it is likely that the fringing tidal marshes will drown as sea levels rise. However, opportunities exist to partner with the industrial and residential communities along the shoreline to develop green infrastructure such as horizontal levees and living shorelines, which would create habitat bayward of the flood-protection levees.

Bay Trail in Richmond

Major land uses such as Highway 80 will remain largely in current configurations and will need to be protected, providing opportunities for approaches that haven't yet been tried locally, such as living seawalls. Diverse pocket habitats could be preserved, enhanced, and created, then linked together to create a subregional habitat corridor. Vertical enhancements (living seawalls, substrate improvements to docks, etc.) could be made in a few subtidal and intertidal areas where there is hardscape. Many existing habitats could be enhanced by improving tidegate management, removing contaminated soils and derelict boats, and reducing the amount of trash that terminates in the bay. Habitats could be created along flood-control channels, floodplains, and off channels. Low-elevation marsh and wetland could be restored. Upstream opportunities should be explored wherever possible in order to reconnect watershed processes with the bay.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea-level rise rates will likely outpace vertical accretion rates, and marshes in this segment generally do not have enough space to migrate landward to survive. Prior to that point, a plan for restoring or relocating the functions within the existing tidal marshes should be implemented. Creating wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. The planned communities built over former wetlands and open bay at Powell Street in Emeryville, Marina Bay in Richmond, and other areas will be at risk for flooding as sea levels begin to rise. If opportunities for managed retreat become available, options should be pursued to restore areas to baylands or to connect bay habitats.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Design and restore complete tidal wetland systems, even at a small scale, that include tidal marshes, beaches, and lagoons, broad transition zones, and develop techniques for implementing active revegetation, high-tide-refuge islands, and subtidal habitat restoration.
- Restore, enhance, and protect a diversity of habitats, including tidal marsh, shorebird roosting sites, and seasonal wetlands.
- Create transition zone habitat where feasible at the edges of existing marshes or where land becomes available.
- Protect and restore native oyster beds and eelgrass beds throughout this segment, including the area around the Bay Bridge.
- Protect land as it may become available in order to incorporate transition zones into restoration designs.

FOR PARTICULAR WILDLIFE POPULATIONS

- Protect gull, tern, and egret nesting habitat at Brooks Island, Red Rock, and Castro Rocks.
- Implement a pilot project with citizen involvement to hang oyster-shell bags off marina docks to use later in building reefs.
- Conduct pilot projects to assess the effectiveness of artificial floating islands for nesting and high-tide refugia for Ridgway's rail.

Restoration Benefits

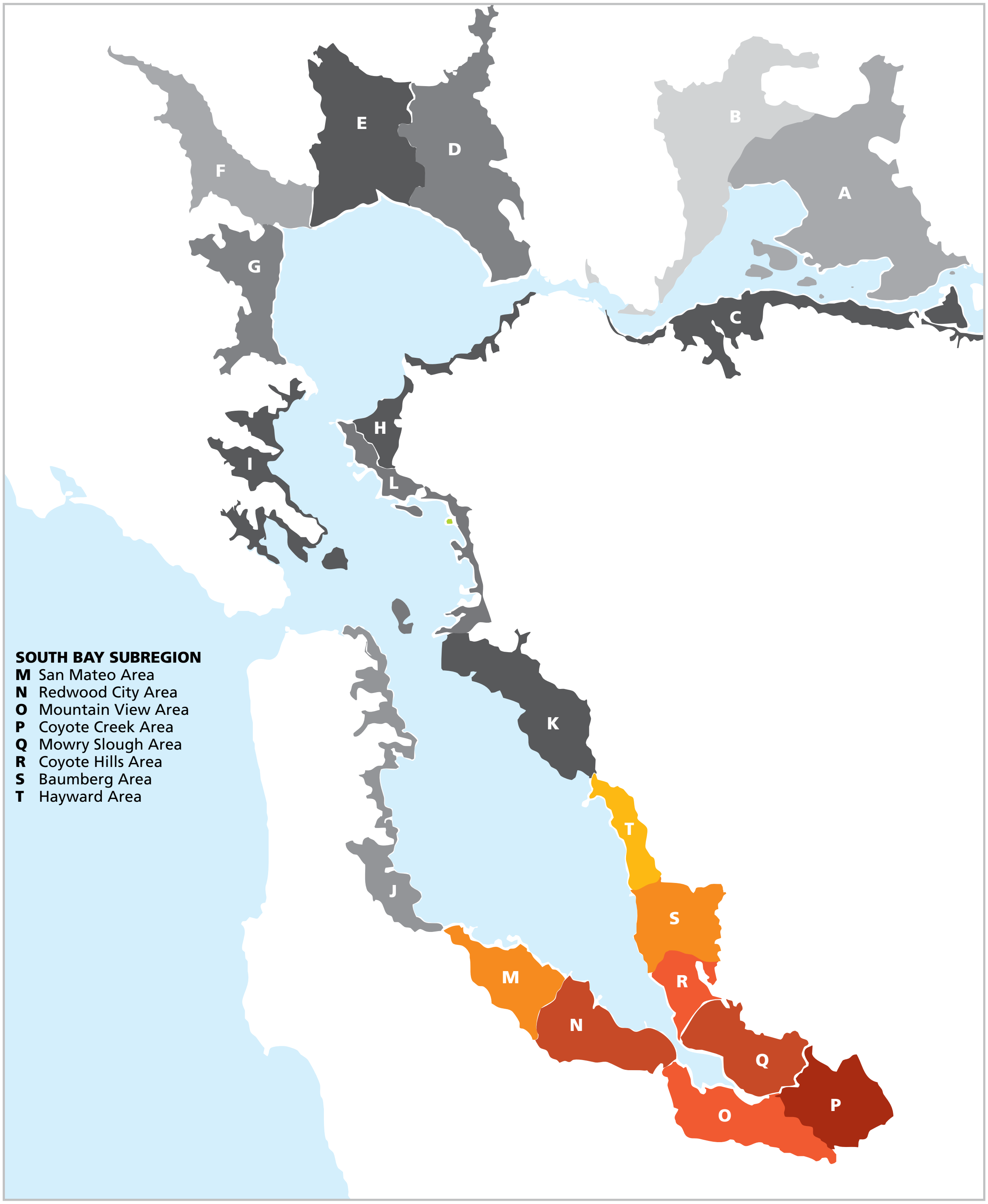
The recommended projects for this segment would demonstrate innovative techniques to restore and enhance habitats for many populations of key fish, amphibian, reptile, insect, mammal, and bird species. Restoring wetlands would enhance habitat for endangered species such as the Ridgway's rail and salt marsh harvest mouse. Restoring beach habitat could improve conditions for sensitive plant species. Protecting islands would assure suitable sites for colonial nesting birds. Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish, and might enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living-shorelines designs might provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

Including public education and awareness components in any restoration initiative is critical to building the public and financial support that is needed to test adaptation approaches and work toward large-scale implementation of innovative techniques.

Challenges

Major challenges in this segment are its large urban population, extensive fill along the shoreline, bridges, wastewater treatment plants, railroad tracks and spurs, major highways, exotic predators (e.g., rats and red fox), invasive *Spartina*, and on-site contaminants.

South Bay Subregion



South Bay Subregion

LANDSCAPE VISION

The South Bay provides some of the most extensive opportunities in the region to restore baylands habitat. The goal for South Bay is to restore large tidal marshes as soon as possible.

Recommended Actions

- Given the large areas available for restoration and generally high sedimentation rates, prioritize tidal marsh restoration, including the creation of transition zones. Supplement local sediment availability to increase long-term shoreline resilience and investigate novel approaches to beneficial reuse. Reconnect local tributaries more directly to and through the tidal baylands. Protect and restore riparian corridors and willow groves wherever possible.
- Connect all types of tidal marshes with wide corridors along the perimeter of the bay. Restore natural transitions from mudflat through tidal marsh to adjacent terrestrial habitats wherever possible. Restore naturalistic, unmanaged saline ponds (facsimiles of historical hypersaline backshore pans), especially on the Hayward shoreline. Protect and enhance adjacent moist grasslands, particularly those with vernal pools. Protect undeveloped lands adjacent to the baylands, and create broad transition zones adjacent to flood-risk management levees.
- Intersperse pond complexes, managed to optimize waterbird support, throughout the subregion in locations appropriate for long-term operations and maintenance.
- Create eelgrass beds and oyster reefs wherever possible, especially adjacent to tidal mudflats and marshes or other baylands that would benefit from physical protection. Create coarse beaches, where appropriate, to reduce bay-edge erosion of marshes.

View of island ponds restored to tidal marsh

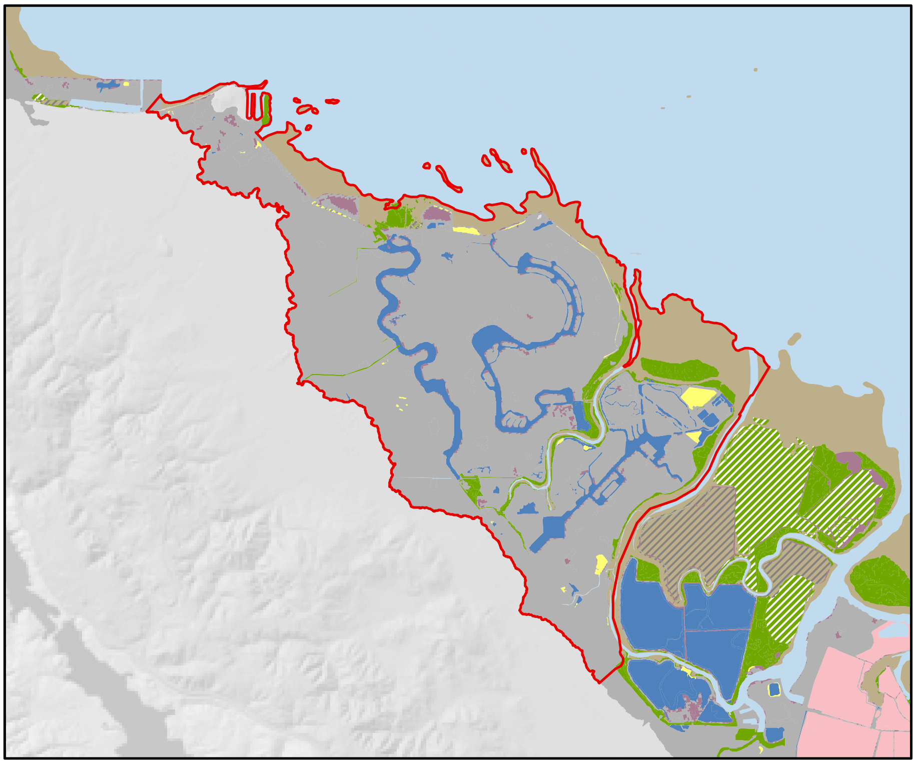
RECENT RESTORATION

Since the 1999 Goals Report, the South Bay Salt Pond Restoration (SBSPR) project has made major progress toward baylands restoration. The Cargill Salt Division, whose operations were described as a "challenge" in the 1999 Goals Report, was willing to undertake major operational changes and transfer 15,100 acres into public ownership in 2003 through a combination of purchase and donation. Since that time, the SBSPR project has completed long-term planning for this area as well as the first phase of restoration projects, resulting in over 3,700 acres of restored or enhanced habitats, and an overall new pond management regime designed to benefit wildlife. Other significant restoration projects that are completed or nearly completed include Cooley Landing and Bair Island.

CHALLENGES

Progress in the South Bay will depend on the efforts of many other private and public landowners as development pressures increase and shoreline migration space becomes scarcer. Regulatory and logistical hurdles complicate achieving regional sediment management, the beneficial reuse of sediment in the baylands, and the creation of broad transition zones. Although largely under control, invasive *Spartina* remains a challenge for the South Bay, especially as newly restored tidal areas are breached. If baylands habitat patches become smaller, human-associated predator management will become a larger challenge.

The South Bay subregion consists of segments M through T.



SAN MATEO AREA

Western edge of San Francisco Bay between Coyote Point and Steinberger Slough

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment M.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Segment M offers limited but important opportunities to protect and enhance remaining tidal marshes and other wetlands. The California sea-blite and associated rare high-marsh plant species could potentially be reintroduced around sheltered shell beaches. Historically, this segment supported extensive oyster beds, presenting an opportunity to restore the subtidal habitat offshore. This could be done by building artificial reefs to create breakwaters to protect fringing marshes, or using artificial rock groins to capture coarse material to form small beaches such as those at Seal Slough. Additionally, green infrastructure such as horizontal levees could be built as the residential communities along the shoreline invest in flood protection against future sea-level rise.

Segment Features and Setting

Most of this segment was once tidal marsh, and the marshes in this relatively flat area of the baylands included a transition zone of varying width into the coastal hills. Many of the tidal marshes had oyster shell ridges or beaches along their foreshores. Tidal flats and moist grassland were limited, as they are today.

Today, most of the former wetlands are developed urban or industrial areas (Foster City, Redwood City, and San Mateo). Because of the extensive development along the shoreline, there are few restoration opportunities in this segment. The wetlands that remain are fragmented narrow marshes, mostly along sloughs. Bird Island and the adjacent strip marshes along the levees are the most significant tidal wetlands in the segment. Generally, the transition zones of these tidal marshes exist in narrow strips along steep flood-protection levees. Small areas of diked marsh and seasonal wetlands persist in some of the developed areas (area H and the Redwood Shores Ecological Reserve in Redwood City, and Sun Cloud Park in Foster City), and at Seal Slough Mouth in San Mateo, at Bird Island, and along the Foster City shoreline at the mouth of Belmont Slough. Shell mounds and beaches were once prominent in this segment, and remnants can still be found.

Implications of Drivers of Change

The developed areas in this segment will become increasingly difficult to protect as sea levels rise. Outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of the small remaining marsh edges, resulting in the narrowing and potential loss of marshes and other unique habitats such as coarse beaches.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

In the near term, when sea-level rise rates will still be relatively low, actions enhancing the baylands will provide immediate ecological benefits and maximize their resilience. Breakwaters could be created around fringing marshes to preserve unique features like shell mounds. Introducing fine sediment through mudflat and marsh recharge could increase vertical accretion rates. The remnant oyster shell beaches provide a unique opportunity for the restoration of adjacent subtidal habitats, including native oyster and eelgrass beds. Effort should be placed on creatively building environmental considerations into flood-protection projects and upgrades and protecting small habitat pockets only where feasible. A patchwork of small habitat nodes may provide some support for particular wildlife species. Opportunities exist to partner with the residential communities along the shoreline to develop green infrastructure such as horizontal levees, which would create habitat bayward of their flood-protection levees.

One small pocket of opportunity for restoring transition zone exists along the Foster City shoreline at the mouth of Belmont Slough, where restoration could create an estuarine–terrestrial transition zone and beach habitat along the bayward edge.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea-level rise rates will likely outpace vertical accretion rates, and marshes will need to migrate landward to survive. Prior to that point, a plan for restoring or relocating the functions of the existing tidal marshes should be implemented. Creating wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. The planned communities built over former wetlands at Foster City, Redwood Shores, and portions of San Mateo along Seal Slough will be at risk for flooding as sea levels begin to rise. If opportunities for managed retreat become available, options should be pursued to restore these areas to marsh.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Maintain and enhance tidal marsh and marsh connectivity along the shoreline.
- Protect subtidal habitat including mudflats, native oyster beds, and eelgrass beds. Protect and improve oyster shell ridges near Foster City, Seal Slough, and on the Redwood Shores Peninsula.
- Protect open space adjacent to the baylands, including developed areas that may become available in the future due to flood risk.
- Create transition zones on gentle slopes in front of flood-risk-management levees (or other high-ground areas).
- Reduce nearshore wave energy by constructing low-crested berms of gravel and shell (similar to the natural breakwaters at Seal Slough Mouth), which could roll landward as sea levels rise. Enhance existing unique features such as shell mounds and coarse beaches.
- Connect wastewater and storm water to bayland habitats where appropriate to enhance the transition zone slope and reestablish a salinity gradient within marshes
- Increase local sediment availability by placing fine sediment in areas that will be reworked by wave and tidal action to accelerate the vertical accretion of marshes.

Dredge at sunset

FOR PARTICULAR WILDLIFE POPULATIONS

- Improve the Foster City and Redwood Shores canal systems for wildlife support and water quality.
- Protect and enhance seasonal wetland areas for shorebirds and waterfowl.
- Implement aggressive control measures for invasive *Spartina*, and for the invasive plants black rush and Algerian sea lavender, which could become a serious problem.

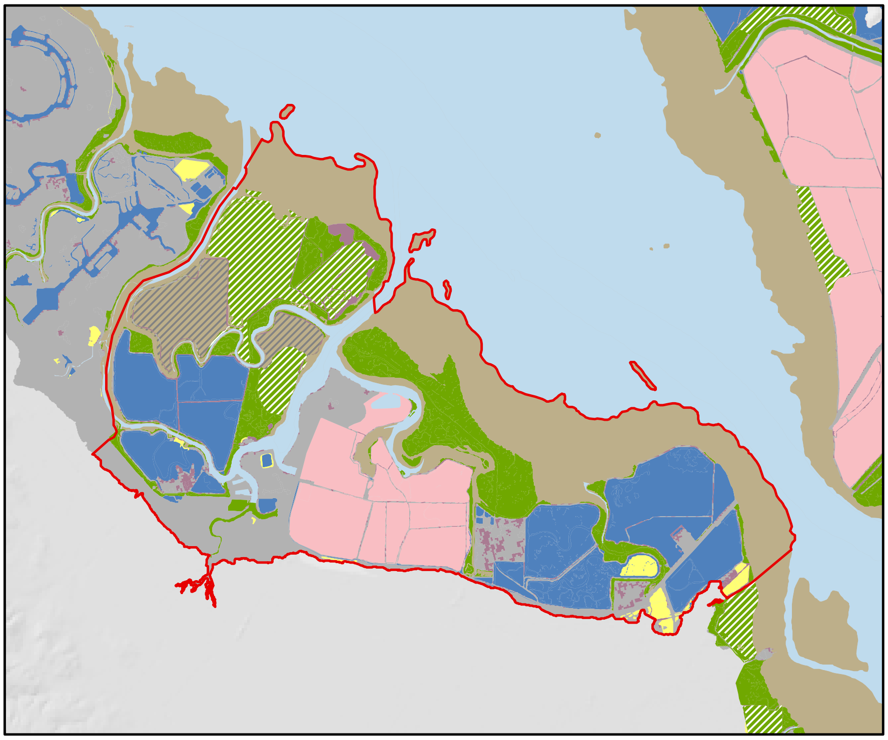
Restoration Benefits

Restoring oyster shell ridges would enhance habitat for some unique and rare plants and would provide roosting sites for shorebirds. Providing an enlarged tidal marsh corridor may facilitate the dispersal of Ridgway's rails northward from population centers in segment N to the south. The nearest northward location with significant habitat is in Marin County. However, Ridgway's rails have been known to breed in small tidal marsh pockets such as Heron Head's Park.

Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish and may provide some flood protection in the near term for developments on the shoreline.

Challenges

Challenges in this segment include an extensive urban interface, major transportation corridors, flood-control considerations, predator corridors, limited opportunity for predator management, and intensely used public access along the Bay Trail. The presence of the Atlantic oyster drill in the South Bay may inhibit the restoration of native oyster beds. Planning will require coordination with local agencies and organizations, including San Mateo County.



REDWOOD CITY AREA

Western edge of San Francisco Bay between Steinberger Slough and the Dumbarton Bridge

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment N.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Segment N has high potential for tidal marsh restoration and the enhancement of seasonal wetlands and ponds for shorebirds and waterfowl. This segment contains Bair Island, which is in the final stages of restoration. The Ravenswood pond complex offers an opportunity to maintain and enhance wetland habitat in close proximity to the large tidal flats that are critical for foraging shorebirds. Enhancing the salt pan could improve nesting habitat for the snowy plover. The Redwood City crystallizers and associated salt ponds are currently part of an operating business; however, they remain relatively undeveloped and are at elevations that make them attractive for potential future tidal habitat restoration. Bedwell Bayfront Park allows for some area of marsh migration as sea levels rise. Local sediment and water supplies could also be used for habitat creation.

Segment Features and Setting

Historically, this area was mostly tidal marsh with moist grassland habitat on the adjacent lands to the west. Large, well-developed channels and associated slough systems and numerous ponds characterized the tidal marshes in this segment. Outboard of the marshes were oyster shell beaches, large expanses of tidal flats, and oyster beds.

A natural deep-water channel at the mouth of Redwood Creek was developed into the Port of Redwood City. Due to regular deep dredging of this channel for the port, the Redwood Creek shipping channel acts as a sediment sink. Sloughs in this segment, including Steinberger, Corkscrew, and Smith, have silted in with the fill and diking off of most of the tidal marshes. A former landfill site, Bedwell Bayfront Park, is a small open space with a hilly grassland terrain that is found adjacent to the Ravenswood pond complex, Greco Island, and commercial property. Fringing tidal marsh exists in a narrow band along much of this segment.

Today, this area is highly developed, and many of the historical tidal marshes have been converted to salt ponds, managed ponds, and urban uses. Greco Island, the largest contiguous tidal marsh on the western side of the bay, is relatively protected from human disturbance; it is one of the main population centers of Ridgway's rail in South Bay. Next to Greco Island, Middle and Outer Bair Islands have recently been restored to tidal action, and all are a focus of invasive *Spartina* treatment, native *Spartina* revegetation, and enhancement projects for rails. Inner Bair Island is also nearing restoration completion and will comprise both tidal marsh and transition zone habitats. The restoration of Bair Island, combined with tidal marsh restoration of portions of the Ravenswood pond complex as part of the South Bay Salt Pond Restoration Project (SBSPRP), would improve the continuity of tidal marsh habitat between Bair Island in the north of this segment, south to the Palo Alto baylands in segment O.

Northern pintail

Outer Bair Island historically supported a variety of nesting terns (Caspian, Forster's and California least), as well as a large egret and heron rookery. The egret and heron rookery has returned, though its size has probably decreased. A large colony of cormorants can be found on the PG&E towers in Steinberger Slough. Western snowy plovers use levees and salt pan habitat in the Ravenswood pond complex year-round for nesting and overwintering. The SBSPRP has constructed islands for nesting at pond SF2 within this segment (and within segments S and P). These islands provide nesting habitat for snowy plovers, American avocets, black-necked stilts, and Forster's terns. The large isolated channels in the Corkscrew Slough area provide haul-out areas for harbor seals, and the bay's extensive tidal flats continue to provide excellent foraging habitat for shorebirds. Nearly all of the moist grassland areas have been urbanized.

Implications of Drivers of Change

Managed ponds in this segment will become increasingly difficult to maintain and operate at their current elevations. As sea levels rise, levees protecting the ponds will need to be maintained and raised, tide gates will have to be modified, and gravity-driven systems will have to be supplemented by pumping. Outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate erosion of marsh edges, resulting in a narrowing of marshes. Sedimentation rates on existing and inside restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term offers significant opportunities to restore tidal marsh in managed ponds that will help create a continuous corridor of tidal marsh along the bayshore. The potential for land-use change at the Redwood City crystallizers should be monitored. The SBSPRP planning process has identified ponds R4, R1, and R2 as suitable for restoration in the near term. This restoration would include the reconnection of complex channel networks, incorporating topographic variation by placing material to mimic features such as natural levees, and could incorporate shallow pans. To accelerate the accretion of marsh surface in the subsided ponds, dredge sediment could be placed either directly within ponds or on adjacent mudflats to be taken by wave and tidal action into the ponds. Slopes to create elevation gradients and a transition zone between tidal marsh and lowland areas (as well as the upland habitats at Bedwell Bayfront Park) could be created adjacent to existing levees to provide buffer and high-tide refugia as well as habitat in its own right.

While rates of sea-level rise are low, some of the ponds could continue to be managed to provide habitat for shorebirds and waterfowl by changing their water levels and salinity (within the infrastructure limits). Levees surrounding the ponds would have to be built up to maintain these ponds for waterbirds as sea levels rise further. Snowy plover habitat in the Ravenswood pond complex would need active management to be maintained.

Bair and Greco Islands are generally of uniform elevation and will be threatened as sea levels rise. A levee will need to be built to protect Highway 101 along the western side of Inner Bair. A levee will also be needed next to the Ravenswood pond complex to prevent flooding Highway 84 and adjacent urban development.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the longer term, if sea-level rise accelerates and sediment supply falls as projected, marsh plains will probably give way to narrower fringing marshes. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat. In addition, landward migration of the marsh is expected, and a gently sloping transition zone bayward of the levee would facilitate such a migration. If the area were to become available, restoring the Redwood City crystallizers could help provide large areas of restored tidal marsh, transition zone, and snowy plover habitat.

At some point in the future, the degree of sea-level rise may make it unrealistic to maintain the managed ponds to benefit waterbirds. Prior to that point, a plan for restoring or relocating the functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large areas of tidal marsh with gradual bayside slopes, providing a continuous band along the bayfront for the entire length of the segment.
- Restore and enhance oyster beds and eelgrass beds at appropriate locations within this segment.
- Create transition zones on gentle slopes in front of flood-risk-management levees (or other high-ground areas).
- Protect lands adjacent to baylands to increase habitat and decrease flood risk to properties within the baylands. Work with willing landowners to protect undeveloped diked baylands as future tidal habitats and transition zone.
- Reduce the horizontal erosion of marshes by creating shell beaches in front of marsh scarps.

FOR PARTICULAR WILDLIFE POPULATIONS

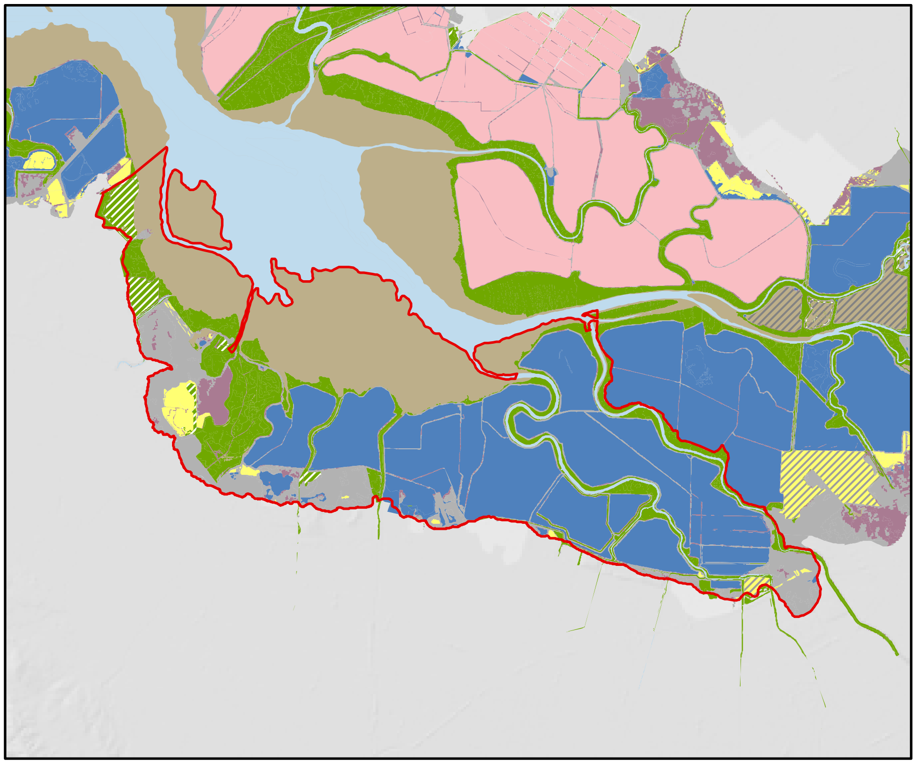
- Manage select ponds and areas to enhance snowy plover breeding success.
- Reintroduce rare and uncommon high-marsh plant species at sheltered shell ridges.
- Develop SBSPRP operation plans of managed ponds to maximize utility to waterbirds.
- Partner with current landowners of properties with current or potential benefits to wildlife and their habitat (e.g. Cargill, Bedwell Bayfront Park, Facebook). Partner with local municipalities to manage stormwater in Ravenswood ponds to benefit wildlife.
- Maintain and enhance pond management and predator management for snowy plovers and other waterbirds.
- Implement aggressive control measures for invasive plants including Algerian sea lavender, which could become a serious problem.
- Continue treatment of invasive *Spartina* at Bair Island and other sites, and continue revegetation plantings and other enhancements, such as high-tide-refuge islands.

Restoration Benefits

Implementing the recommendations would provide a large tidal salt marsh core area that would maintain and enhance the associated channel system. This would benefit harbor seals and several fish species. The tidal salt marsh restoration would directly benefit the salt marsh harvest mouse and the Ridgway's rail. Enhancing and restoring ponds would benefit shorebirds and waterfowl and would provide an opportunity to create or improve snowy plover nesting habitat.

Challenges

Challenges in this segment include PG&E transmission lines, substation, and other utility corridors; flood protection for urbanized areas and associated infrastructure (e.g., Highways 84 and 101); residential development adjacent to natural areas; the Port of Redwood City and adjacent development; other commercial industry; and the need for long-term predator management (including the political power to eliminate feral cat colonies). The depredation of snowy plover nests continues to be an issue where nesting habitat exists. Ongoing hazing and removal of predators is needed to reduce the nest-habitat displacement and depredation of snowy plovers. Invasive *Spartina* remains a critical priority, constraint, and consideration for some existing marshes and for restoration planning in this segment. Oyster drill populations could limit native oyster restoration. The SBSPRP is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations, including Caltrans, the US Fish and Wildlife Service, Menlo Park, Redwood City, the San Francisquito Creek Joint Powers Authority, PG&E, and Cargill.



MOUNTAIN VIEW AREA

Western edge of San Francisco Bay between Dumbarton Bridge and Alviso Slough

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment O.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Segment O presents opportunities to enlarge existing marshes and to provide dispersal corridors (where none now exist) that link the eastern and western parts of South Bay for tidal-marsh-dependent species. Ponds could be managed for the benefit of large numbers of shorebird species that forage on nearby mudflats. Retaining and modifying managed ponds would also benefit nesting snowy plovers, postbreeding least terns, and waterfowl. Enhancing tributary streams such as San Francisquito Creek and the Guadalupe River could benefit riparian-dependent species and could help restore steelhead runs.

Segment Features and Setting

Historically, this segment contained large expanses of tidal flats. Next to these flats were tidal salt marshes that intergraded into moist grasslands in the adjacent uplands. These marshes supported extensive channel systems and an abundance of tidal pans. Many of the marshes had backshore pans along the transition zone. Much of the moist grassland habitat supported seasonal ponding in the rainy season. Streams that drained the coastal hills were bordered with riparian vegetation. Many of the streams did not reach the bay, and streams in some willow groves and ponds terminated near the baylands. Limited zones of brackish marsh were present along the tidal reaches of San Francisquito Creek and the Guadalupe River, both of which supported steelhead runs.

Today, most of the segment is managed ponds, sewage-treatment ponds, managed flood basins, or urban development, except for a few tidal marshes in the Palo Alto area. These tidal marshes are limited in extent, but they are the most productive and densely populated marshlands in the Bay Area for Ridgway's rails. These marshes are essentially "islands" isolated from other tidal marshes by managed ponds and human development. The mudflats along the bay margin in this segment provide important feeding and roosting habitat for shorebirds.

Since the initial Goals Report, all the managed ponds in this segment have become part of the Don Edwards San Francisco Bay National Wildlife Refuge and the South Bay Salt Pond Restoration Project (SBSPRP). These ponds are particularly important for wintering and migratory waterfowl due to their depth and low salinity. The managed ponds in this area provide postbreeding habitat for least terns, and foraging and roosting habitat for shorebirds and for very large numbers of waterfowl in the deeper ponds.

California vole

The SBSPRP has initiated tidal-marsh-restoration actions in segment O. Pond A6 was breached to tidal flows on December 6, 2010, and high sediment-accumulation rates were observed in the first year with an average of 23 cm/year. These results indicate that high suspended-sediment concentrations in the South Bay can, if sediment supplies remain as they have historically, sustain marsh restoration and sustainability to some extent into the future. The SBSPRP has also begun to experiment with reconfiguring ponds to increase habitat quality for foraging, roosting, and nesting waterbirds and restoring muted tidal action to ponds with legacy mercury contamination; it is also planning further tidal marsh restoration in the Mountain View area. The San Francisquito Creek Joint Powers Authority is also developing both fluvial and tidal flood-control projects in segment O.

The SBSPRP, in the first 10 years that ponds have been managed to benefit waterbirds, has seen greater numbers of shorebirds and dabbling ducks and steady numbers of diving ducks. The project has also constructed features that could enhance the carrying capacity of the managed ponds to benefit migratory, wintering, and breeding waterbirds.

Implications of Drivers of Change

Managed ponds in this segment will become increasingly difficult to maintain and operate at their specified elevations and salinities. As sea levels rise, levees protecting the ponds will need to be maintained and raised. Tide gates will have to be modified, and gravity-driven systems supplemented by pumping. The outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of marsh edges, resulting in a narrowing of marshes. Sedimentation rates on existing and restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term presents significant opportunities to restore tidal marsh in managed ponds that will help create a continuous corridor of tidal marsh along the bayshore. The SBSPRP planning process has identified ponds A1 and A2W as potentially suitable for restoration. This restoration would include the reconnection of complex channel networks, incorporating topographic variation by placing material to mimic features such as natural levees and islands, and could incorporate shallow pans. To accelerate the accretion of marsh surface in the subsided ponds, dredge sediment could be placed either directly within the ponds or on adjacent mudflats to be taken by wave and tidal action into the ponds. Slopes to create elevation gradients along the transition zone between tidal marsh and terrestrial areas could be created next to existing levees to provide buffers and high-tide refugia as well as habitat in its own right. Charleston Slough could also become marsh habitat by increasing tidal flows and connecting a restored pond A1.

While rates of sea-level rise are low, some of the managed ponds could continue to be managed to provide habitat for shorebirds and waterfowl by changing their water levels and salinity (within the infrastructure limits). Levees surrounding the ponds would have to be built up to maintain these ponds as sea levels rise further.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the longer term, if the sea-level rise increases and sediment supply decreases as projected, it seems likely that the marsh plains will give way to narrower fringing marshes. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat. In addition, landward migration of the marsh is expected, and a gently sloping transition zone bayward of the levee would facilitate such a migration. Since there is considerable infrastructure in this segment, consideration should be given to filling in some of the managed ponds with material to create a gently sloping transition zone bayward of the levee. This would create space for marsh migration in the long term (and high-tide refugia in the short term).

At some point in the future, the degree of sea-level rise may make it unrealistic to maintain the managed ponds to benefit waterbirds. Prior to that point, a plan for restoring or relocating the functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large areas of tidal marsh prior to 2030 and create a continuous corridor of tidal marsh along the bayshore. Protect all undeveloped diked baylands as future tidal habitats and transition zones.
- Optimize the management of ponds for a diverse suite of waterbirds, including shorebirds and waterfowl. Modify pond management as necessary to accommodate sea-level rise and other changes by modifying water-control structures, managing ponds to facilitate warping, and reconfiguring or relocating ponds as necessary.
- Consider ways to increase sediment supply to the tidal baylands. Methods could include managing the sediment-delivery potential of local watersheds, placing sediment directly in marshes or placing dredged sediments on adjacent mudflats to be reworked by wave and tidal action to increase local suspended-sediment concentrations and marsh-accretion rates.
- Enhance and restore natural transition zone and landward buffers, including natural levees on creeks, while focusing on tidal marsh transitions. Create transition zone habitats on gentle slopes in front of flood-risk-management levees.
- Reestablish native vegetation and otherwise enhance the riparian corridor along San Francisquito Creek, Guadalupe River, and other tributary streams.
- Maintain current mudflat habitat and buffers from human disturbance.
- Enhance and restore native oyster beds at suitable areas.

FOR PARTICULAR WILDLIFE POPULATIONS

- Continue hazing and predator management at sensitive nesting habitats.
- Enhance the seasonal wetlands and burrowing owl habitat in the Sunnyvale baylands.
- Continue treatment of invasive *Spartina* at the Knapp Tract and other sites, and continue revegetation plantings and other enhancements, such as high-tide-refuge islands.

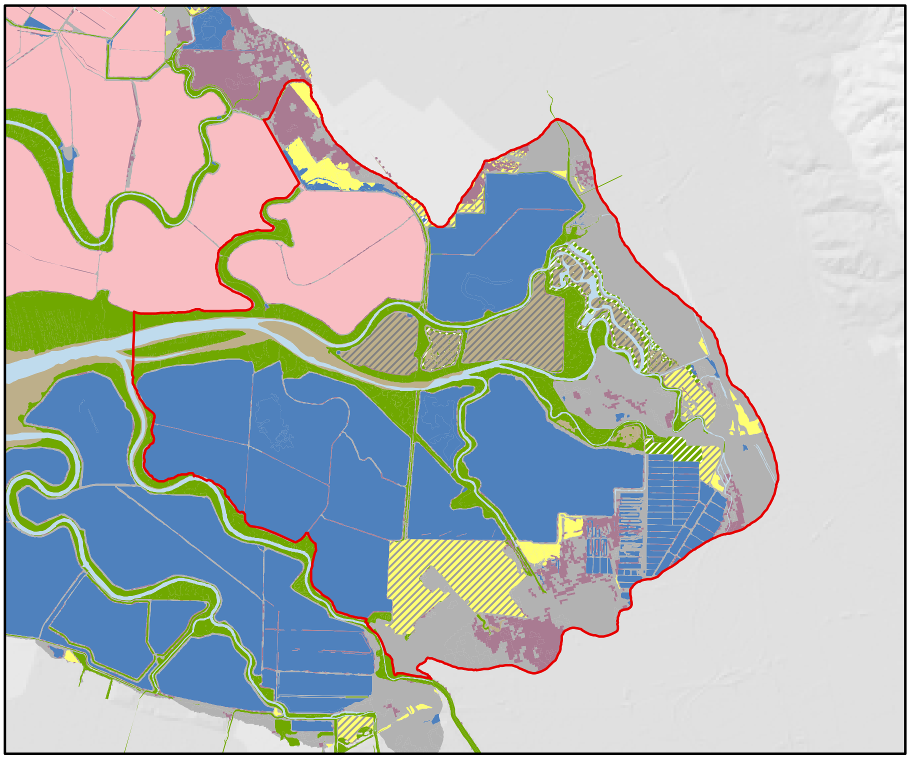
Restoration Benefits

Linking the eastern and western portions of South Bay and restoring tidal marsh along the bayshore would provide dispersal corridors (where none now exist) for the Ridgway's rail and the salt marsh harvest mouse, allowing these species to move between neighboring segments while minimizing predation and decreasing their vulnerability to local extinction. Restoring and enhancing tributary streams would improve riparian habitat and benefit anadromous fishes, amphibians, small mammals, and birds.

Enhancing managed ponds would provide high-tide foraging and roosting habitat for shorebirds and waterfowl. This could also provide postbreeding foraging habitat for least terns and nesting habitat for the snowy plover and other resident shorebirds and terns.

Challenges

Challenges in this segment include legacy mercury contamination, PG&E transmission lines and other utility corridors, flood-protection considerations, historical land subsidence, freshwater outflow from wastewater-treatment facilities, and predator management. Invasive *Spartina* remains a critical priority, constraint, and consideration for some existing marshes and for restoration planning. Oyster drill populations may limit native oyster restoration. The SBSPRP is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations, including NASA Ames; the cities of Santa Clara, Mountain View, and Palo Alto; the San Francisco Public Utilities Commission; the San Francisquito Creek Joint Powers Authority; the US Fish and Wildlife Service; and the Santa Clara Valley Water District.



COYOTE CREEK AREA

Southern end of San Francisco Bay between Alviso Slough and Albrae Slough

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment P.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Segment P provides excellent opportunities to develop large patches of tidal salt marsh along a major salinity gradient. This is one of few South Bay segments where it is possible to restore tidal brackish marsh. It is the only segment in South Bay that has a large area of vernal pools near the baylands. It also is the only area where a wide transition zone can be re-created between restored tidal marsh and a complex of vernal pools.

Segment Features and Setting

Historically, most of this segment was tidal marsh. There were numerous sloughs and ponds throughout the marshes, but very little adjacent tidal-flat habitat. Salinity was strongly influenced by high seasonal freshwater flows through Coyote Creek, one of the major tributaries to the subregion. On the northern edge of the segment was the only large area of vernal pools in South Bay, currently encompassing 719 acres and 250 ponds in the Warm Springs vernal pool unit of Don Edwards San Francisco Bay National Wildlife Refuge. Moist grasslands bordered much of the eastern side of the segment.

Today, much of this segment is developed. Managed ponds dominate the landscape, along with large landfills and the largest local sewage-treatment facility. Some narrow strips of tidal marsh occur outboard of the pond levees, and year-round discharge from the sewage-treatment plant creates brackish marsh in areas. Although the Warms Springs vernal pool area still exists, nearly all of the moist grassland in this segment has been developed for light industry or housing. Since the initial Goals Report, nearly all of the managed ponds in this segment have become part of the Don Edwards refuge and the South Bay Salt Pond Restoration Project (SBSPRP). These ponds are particularly important for wintering and migratory waterfowl due to their depth and low salinity.

The managed ponds in this area provide foraging and roosting habitat for shorebirds and for very large numbers of waterfowl in the deeper ponds. Some islands and levees in managed ponds and diked marshes also provide nesting habitat for snowy plovers (A22, A23), American avocets, black-necked stilts, double-crested cormorants, California gulls, Caspian terns, and Forster's terns.

The SBSPRP, in the first 10 years that ponds have been managed to benefit waterbirds, has seen greater numbers of shorebirds and dabbling ducks and has maintained the number of diving ducks using the managed ponds. The SBSP has also constructed islands for nesting at pond A16 within this segment (and within segments S and O) and other features that have the potential to enhance the carrying capacity of the managed ponds to benefit migratory, wintering, and breeding waterbirds.

The SBSPRP initiated tidal marsh restoration actions in adjacent areas starting with the breaching of ponds A21, A20, and A19 in the spring of 2006. Sedimentation was rapid, with some locations in pond A21 accumulating more than 220 mm in two to three years. These results indicate high suspended-sediment concentrations in the South Bay can, if sediment supplies remain as they have historically, sustain marsh restoration and sustainability to some extent into the future. Pond A17 was breached in October 2012.

The Warm Springs area of the SBSPRP (ponds A22 and A23) supports nesting snowy plovers. The depredation of snowy plover nests continues to be an issue where nesting habitat exists, particularly in this area adjacent to grassland and landfills, both of which attract common ravens and other predators. Ongoing hazing and removal of predators is needed to reduce the depredation of snowy plovers.

The South San Francisco Bay Shoreline Study conducted by the US Army Corps of Engineers and the Santa Clara Valley Water District is also making progress. It has drafted plans for a tidal flood-protection levee to be constructed on the inland side of ponds A12, A16, and A18, with proposed tidal marsh restoration on some of the outboard ponds (pending further data on waterbird numbers in response to restoration actions). Construction is scheduled to begin on the levee in 2017.

The city of San Jose manages the San Jose–Santa Clara Water Pollution Control Plant (WPCP) and surrounding plant lands, totaling about 2,680 acres. The city prepared a Plant Master Plan to identify WPCP improvements needed to address the aging infrastructure, changing regulations, and odors, and to develop a comprehensive land-use plan for the site. The master planning effort yielded a preferred alternative that included near-term and long-term (to 2040) improvements to the plant, and various environmental, economic, and recreation uses for the plant lands. The city certified an environmental impact report and adopted the Plant Master Plan in November 2013. It is proceeding with the implementation of near-term WPCP improvements.

Implications of Drivers of Change

Managed ponds in this segment will become increasingly difficult to maintain and operate at their specified elevations and salinities. As sea levels rise, levees protecting the ponds will need to be maintained and raised. Tide gates will have to be modified, and gravity-driven systems supplemented by pumping. The outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of marsh edges, resulting in a narrowing of marshes. Sedimentation rates on existing and restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term presents significant opportunities to restore tidal marsh in managed ponds that will help create a continuous corridor of tidal marsh along the bayshore. This restoration would include the reconnection of complex channel networks, incorporating topographic variation by placing material to mimic features such as natural levees, and could incorporate shallow pans. To accelerate the accretion of marsh surface in the subsided ponds, dredge sediment could be placed either directly within the ponds or on adjacent mudflats to be taken by wave and tidal action into the ponds. Slopes to create elevation gradients along the transition zone between tidal marsh and terrestrial areas could be created next to existing levees to provide buffers and high-tide refugia as well as habitat in its own right.

Dumbarton Cutoff Line —Newark Slough Swing Bridge

While rates of sea-level rise are low, some of the managed ponds could continue to be managed to provide habitat for shorebirds and waterfowl by changing their water levels and salinity (within the infrastructure limits). Levees surrounding the ponds would have to be built up to maintain these ponds as sea levels rise further.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the longer term, if the sea-level rise increases and sediment supply decreases as projected, it seems likely that the marsh plains will give way to narrower fringing marshes. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat. In addition, landward migration of the marsh is expected, and a gently sloping transition zone bayward of the levee would facilitate such a migration. Since there is considerable infrastructure in this segment, consideration should be given to filling in some of the managed ponds with material to create a gently sloping transition zone bayward of the levee. This would create space for marsh migration in the long term (and high-tide refugia in the short term).

At some point in the future, the degree of sea-level rise may make it unrealistic to maintain the managed ponds to benefit waterbirds. Prior to that point, a plan for restoring or relocating the functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore tidal marsh throughout most of the segment prior to 2030, providing a continuous corridor of tidal marsh along the shore across a gradient of salt to brackish marsh.
- Create transition zones on gentle slopes in front of flood-risk-management levees (or other high-ground areas). Protect open space, including landfills, as it becomes available to incorporate into future transition zone designs.
- Optimize the management of ponds for a diverse suite of waterbirds, including shorebirds and waterfowl. Modify pond management as necessary to accommodate sea-level rise and other changes by modifying water-control structures, managing pond to facilitate warping, and reconfiguring or relocating ponds as necessary.
- Reestablish native riparian vegetation and otherwise improve the riparian corridor along Coyote Creek in conjunction with the City of San Jose Plant Master Plan.
- Restore vernal pools near baylands, and develop methods to enhance freshwater inputs to them in the event of prolonged extreme drought conditions.

- Consider ways to increase sediment supply to the tidal baylands. Methods could include placing sediment directly in marshes or placing dredged sediments on adjacent mudflats to be reworked by wave and tidal action to increase local suspended-sediment concentrations and marsh-accretion rates.
- Enhance and restore native oyster beds at suitable areas.
- Remove or elevate the railroad currently bisecting habitat.

FOR PARTICULAR WILDLIFE POPULATIONS

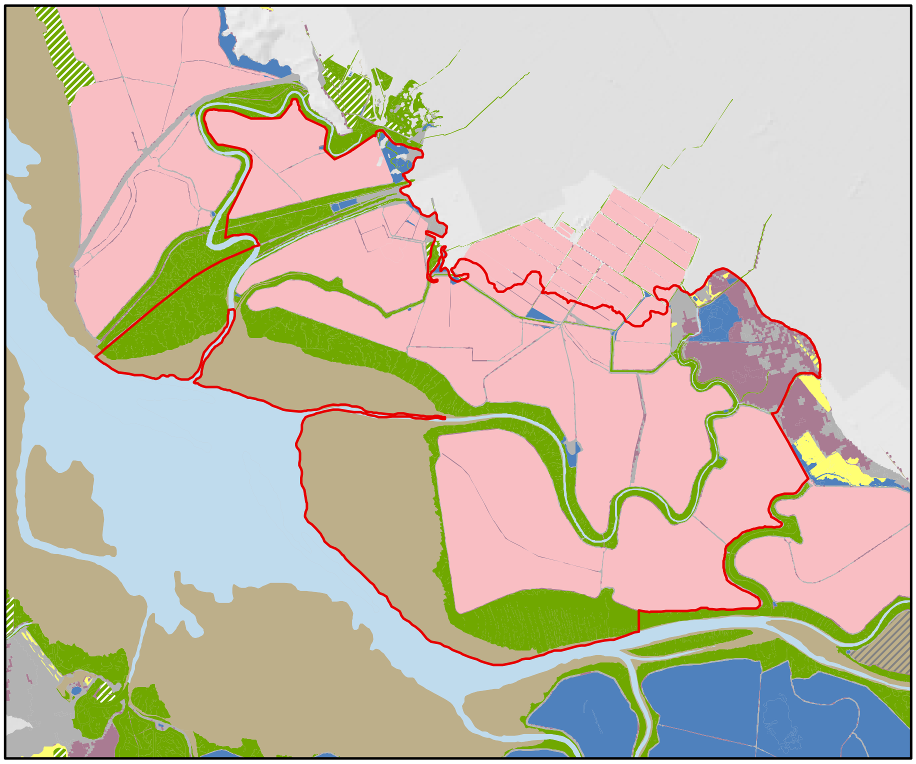
- Modify and manage ponds to enhance snowy plover breeding success in ponds A22 and A23, and islands in A16, as well as habitat for other waterbirds on islands and levees in managed ponds.
- Continue predator management at waterbird nesting habitats.
- Continue treatment of invasive *Spartina*, and consider revegetation plantings, high-tide-refuge islands, and other enhancements.

Restoration Benefits

Restoring tidal marsh along the shore would provide dispersal corridors (where none now exist) for the Ridgway's rail and the salt marsh harvest mouse, allowing these species to move between neighboring segments while minimizing predation and decreasing their vulnerability to local extinction. Implementation of the recommendations would increase rare plant species populations by enhancing the tidal marsh–moist grassland transition zone and vernal pools in the Warm Springs area. This would benefit the only remaining populations of California tiger salamander and tadpole shrimp near the baylands. Enhancing in-stream conditions in Coyote Creek could benefit steelhead populations. Freshwater discharges from the San Jose treatment facility should be managed to minimize large-scale conversion of saline–brackish tidal marsh while maintaining the large heron and egret rookery in Artesian Slough.

Challenges

Challenges in this segment include legacy mercury contamination, PG&E transmission lines and other utility corridors, flood-protection considerations, historical land subsidence, freshwater outflow from wastewater-treatment facilities, landfills as a source of avian predators, the presence of heavy metals in some of the older sewage-treatment ponds, the operation and maintenance of salt ponds in the absence of salt production, the loss of snowy plover habitat, and predator management. Invasive *Spartina* remains a critical priority, constraint, and consideration for some existing marshes and for restoration planning in this segment. Oyster drill populations may limit native oyster restoration. The SBSPRP is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations, including the Don Edwards San Francisco Bay National Wildlife Refuge, San Jose Water Pollution Control Plant, Santa Clara Valley Water District, and the community of Alviso.



MOWRY SLOUGH AREA

Eastern edge of San Francisco Bay between Albrae Slough and Highway 84 (Dumbarton Bridge)

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment Q.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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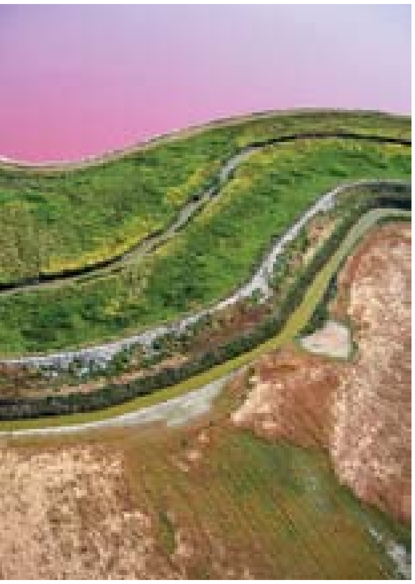
Miles

N



Mowry Slough

Unique Opportunities

Segment Q provides an opportunity to restore and enlarge the Dumbarton–Mowry marsh complex of tidal wetlands, potentially expanding available habitat for a core population of the Ridgway's rail. Managed ponds could be modified and maintained for the benefit of large numbers of shorebird species that forage on nearby mudflats, as well as high-salinity specialists such as eared grebes. There are opportunities to restore historic tidal marsh–upland transition zones and associated vernal pool habitat at the upper ends of Newark, Plummer, Mowry, and Albrae Sloughs. This segment has a considerable amount of open space that could be used as transition zone, including the former Pintail Duck Club and Newark areas 3 and 4 (the upper end of Mowry Slough).

Segment Features and Setting

Nearly all the wetlands within this segment were historically tidal salt marsh. These marshes supported extensive channel systems and numerous tidal marsh pans, including backshore pans along the transition zone. The mudflats outboard of the tidal marshes in the segment were moderate in size, with channel and shallow bay habitat more abundant than today. In the adjacent uplands, extensive areas of poorly drained moist grasslands supported vernal pools. Few streams entered the bay in this area; consequently, riparian habitat was limited. Alameda Creek may have variously entered the bay north of Coyote Hills or south, in the vicinity of present-day Plummer Creek.

Today, the majority of the area is composed of diked salt ponds that are still being operated for salt production. However, this segment does contain some of the largest acreage of natural tidal marsh in South Bay, including the Dumbarton, Mowry, and Calaveras Point Marshes. These marshes are important for the Ridgway's rail and the salt marsh harvest mouse. Mowry Slough provides an isolated haul-out area and pupping site for harbor seals. Newark Slough likewise provides a harbor seal haul-out site. The expansive mudflats in this segment are important foraging areas for shorebirds. Fringing marshes in this area have been very stable in recent decades, perhaps due to the lower wave energy and higher deposition rates in extant and restoring marshes than in other sections north of segment Q. Large numbers of California gulls nest along the levees and on islands in the southern portion of this segment. Small numbers of Forster's terns, American avocets, and killdeer nest on internal levees and islands.

Implications of Drivers of Change

Salt-evaporation ponds in this segment will become increasingly difficult to maintain and operate at their specified elevations and salinities. As sea levels rise, levees protecting the ponds will need to be maintained and raised. The outboard levees in particular will be subject to increasing wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of marsh edges, resulting in a narrowing of marshes. Sedimentation rates on existing and restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The ponds in this segment are owned in fee title by the Don Edwards San Francisco Bay National Wildlife Refuge. However, Cargill is still actively producing salt in this area and has indicated that it does not plan to make any changes. If that situation changes for any reason, the property would almost certainly be the subject of a large restoration effort. Restoring tidal marsh would help create a continuous corridor of tidal marsh along the bayshore. These restorations could include the reconnection of complex channel networks while incorporating topographic variation by placing material to mimic features such as natural levees, and could incorporate shallow pans.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

At some point the degree of sea-level rise may make it unrealistic to maintain the pond levees. Prior to that point, a plan for restoring or relocating the ecological functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

If tidal restoration is not an option for the short term, and the sea-level rise accelerates and sediment supply falls as projected, the marsh plain shoreline will likely give way to narrower fringing marshes over the longer term. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore and enhance tidal marsh along the bayfront to provide a continuous corridor of tidal marsh for the entire length of the segment, particularly around Dumbarton Point (contiguous with segment R).
- Work with willing sellers to protect open space as it becomes available for conservation. Evaluate the feasibility of restoring tidal marshes in this area should ponds not remain in salt production.
- Optimize the management of ponds for a diverse suite of waterbirds, including shorebirds and waterfowl. Modify pond management as necessary to accommodate sea-level rise and other changes by modifying water-control structures, managing ponds to facilitate warping, and reconfiguring or relocating ponds as necessary.
- Elevate or remove the railroad and Hetch Hetchy pipeline and remove other barriers to achieve unimpeded tidal and other hydrological connectivity and reduce predator access to the marsh.
- Protect and enhance the tidal marsh–upland transition zone at the upper end of Mowry, Newark, Plummer, and Albrae Sloughs and in the area of the former Pintail Duck Club.

- Create transition zone habitats on gentle slopes in front of flood-risk-management levees (or other high-ground areas)
- Enhance and restore native oyster beds at suitable areas.

FOR PARTICULAR WILDLIFE POPULATIONS

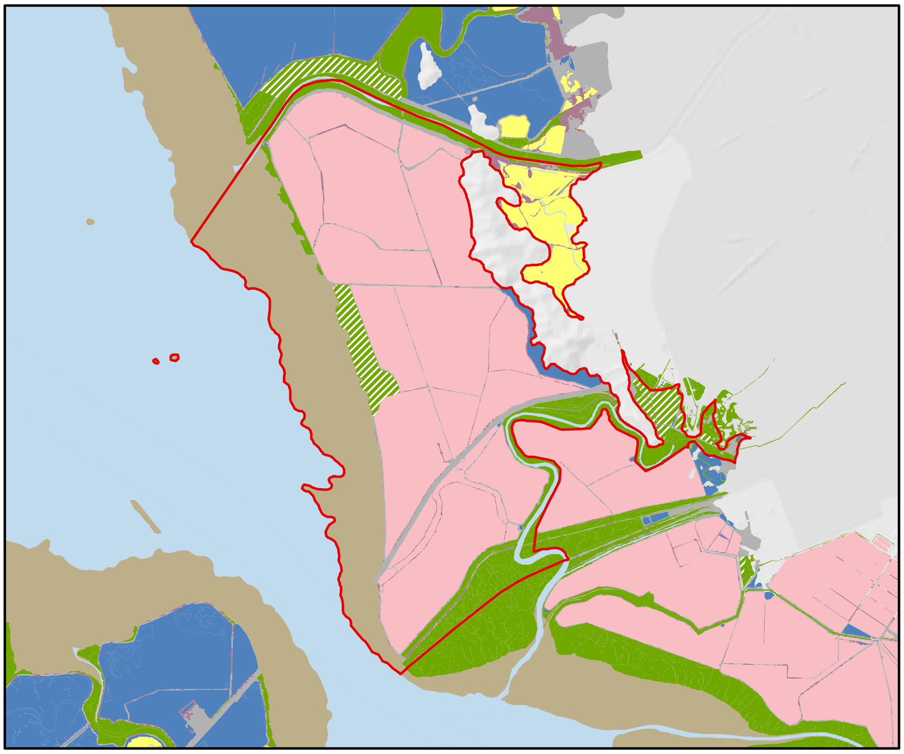
- Protect the area of harbor seal haul-out along lower Mowry Slough and at the mouth of Newark Slough.
- Continue treatment of invasive *Spartina* at Calaveras Marsh and other sites, and consider revegetation plantings, high-tide-refuge islands, and other enhancements.

Restoration Benefits

The Dumbarton and Mowry Marshes contain a large population of Ridgway's rail. This species could potentially colonize any restored tidal marsh in this segment. (Ridgway's rails have colonized several small diked wetlands that were recently restored to tidal action in the upper reaches of Newark Slough.) One of the contributing factors to the health of Ridgway's rail populations in this segment is that the marshes are large and have not been fragmented by levees as much as in other segments. This makes them relatively resistant to terrestrial mammalian predators due to the absence of main travel corridors (with notable exceptions such as the Hetch Hetchy Aqueduct and the railroad tracks). Modifying and managing a system of seasonal ponds (dry in summer) or islands would increase nesting habitat for the snowy plover as well as other waterbirds.

Challenges

Challenges in this segment include the Union Pacific railroad tracks; PG&E transmission lines, Hetch Hetchy Aqueduct, and other utility corridors; flood-control considerations; the need for continued operation and maintenance of salt ponds; the presence of bittern in some ponds; and predator corridors along levees and other linear features. Controlling invasive *Spartina* remains a critical priority, constraint, and consideration for some existing marshes and for restoration planning. Oyster drill populations could limit native oyster restoration. The South Bay Salt Pond Restoration Project is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations including the US Fish and Wildlife Service, Cargill, the San Francisco Public Utilities Commission, Alameda County, and the cities of Fremont and Hayward.



COYOTE HILLS AREA

Eastern edge of San Francisco Bay between Highway 84 and Alameda Creek Flood Control Channel

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment R.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2

Miles

N

Unique Opportunities

A corridor of tidal marsh along the bayshore could be restored in this segment. This corridor would connect the Dumbarton Marsh with the existing marsh to the north along the Alameda Creek Flood Control Channel. Salt ponds adjacent to the restored marshes could be managed to provide habitat for waterbirds. La Riviere Marsh and Mayhew's Landing and the adjacent lands offer opportunities for marsh enhancement and migration inland. Both of these harbor salt marsh harvest mice, and La Riviere has a substantial number of Ridgway's rails. Black rails have also been found in La Riviere Marsh in recent years. The hill where the Don Edwards refuge headquarters is located also offers marsh–upland transition zone migration opportunity. This segment has excellent opportunities for restoring a natural marsh–upland transition zone on the western edge of Coyote Hills. On the eastern side of Coyote Hills are seasonal wetlands, grasslands, and willow grove habitat that could be restored or enhanced to allow for marsh migration inland.

Segment Features and Setting

This area is dominated by Coyote Hills and salt ponds. Historically, the majority of the segment was tidal marsh. The marshes were expansive, with well-developed channels and high marsh and abundant tidal marsh pans. The marshes encircled Coyote Hills except to the east, where moist grassland bounded the upper margin of the marsh. These grasslands were characterized by springs and seeps, willow groves, seasonal ponds, and a permanent freshwater pond at the foot of the eastern slope of the hills. Alameda Creek may have variously entered the bay south of Coyote Hills, in the vicinity of present-day Plummer Creek, or just north of this segment. Outboard of the marshes were extensive tidal flats that continued north through segments S and T.

Today, the majority of the area is composed of diked salt ponds that are still being operated for salt production. Very little fringe marsh exists along the salt ponds, with the exception of Ideal Marsh. Coyote Hills and the large Alameda Creek Flood Control Channel are unique features. The diked baylands east of Coyote Hills support the largest remaining willow groves in the baylands ecosystem, seasonal and diked wetlands, and a permanent freshwater pond. The realignment of Alameda Creek through the northern portion of this segment has dramatically altered the hydrology of the area. The mudflats in this segment are very important foraging areas for shorebirds. California gull colonies and much smaller Caspian tern colonies nest on interior levees in this segment. Small numbers of Forster's terns, American avocets, and killdeer nest on internal levees and islands.

Implications of Drivers of Change

Salt-evaporation ponds in this segment will become increasingly difficult to maintain and operate at their specified elevations and salinities. As sea levels rise, levees protecting the ponds will need to be maintained and raised. The outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of marsh edges, resulting in a narrowing of marshes. Sedimentation rates on

Tidal channel in La Riviere Marsh

existing and restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The ponds in this segment are owned in fee title by the Don Edwards San Francisco Bay National Wildlife Refuge. However, Cargill is still actively producing salt in this area and has indicated that it does not plan to make any changes. If that situation changes for any reason, the property would almost certainly be the subject of a large restoration effort. In the near term, there are significant opportunities to restore tidal marsh in existing ponds that would help create a continuous corridor of tidal marsh along the shore. These restorations could include the reconnection of complex channel networks while incorporating topographic variation by placing material to mimic features such as natural levees, and could incorporate shallow pans.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

At some point the degree of sea-level rise may make it unrealistic to maintain the pond levees. Prior to that point, a plan for restoring or relocating the functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

In the longer term, if the sea-level rise accelerates and sediment supply falls as projected, marsh plains will probably give way to narrower fringing marshes. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat. This area could be targeted for a managed pond landscape that meets the needs of specific wildlife species in the longer term.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large areas to tidal marsh, creating a continuous corridor of tidal marsh around Dumbarton Point (contiguous with segment Q).
- Create transition zone habitat where feasible at the edges of existing marshes at Coyote Hills, on gentle slopes in front of flood-risk-management levees, and other suitable locations.
- Maintain and manage a small complex of salt ponds for shorebirds and waterfowl. Modify pond management as necessary to accommodate sea-level rise and other changes by modifying water-control structures, managing ponds to facilitate warping, and reconfiguring or relocating ponds as necessary.

- Work with willing sellers to protect open space as it becomes available for conservation. Evaluate the feasibility of restoring tidal marshes in this area should ponds not remain in salt production.
- Protect and enhance existing willow groves and seasonal wetlands.
- Consider removing the flood-control levees on the north side of the Alameda Creek Flood Control Channel's lower reaches as part of restoration planning for this area.
- Restore and enhance oyster beds and eelgrass beds at appropriate locations.
- Reduce the horizontal erosion of marshes by creating shell beaches in front of marsh scarps and by creating coarse beaches and berms in front of the outboard levee to protect managed ponds.
- Explore the use of creative flood-management techniques that take advantage of the benefits of restored tidal wetlands.

FOR PARTICULAR WILDLIFE POPULATIONS

- Control invasive *Spartina* to minimize its spread to newly restored neighboring marshes.

Restoration Benefits

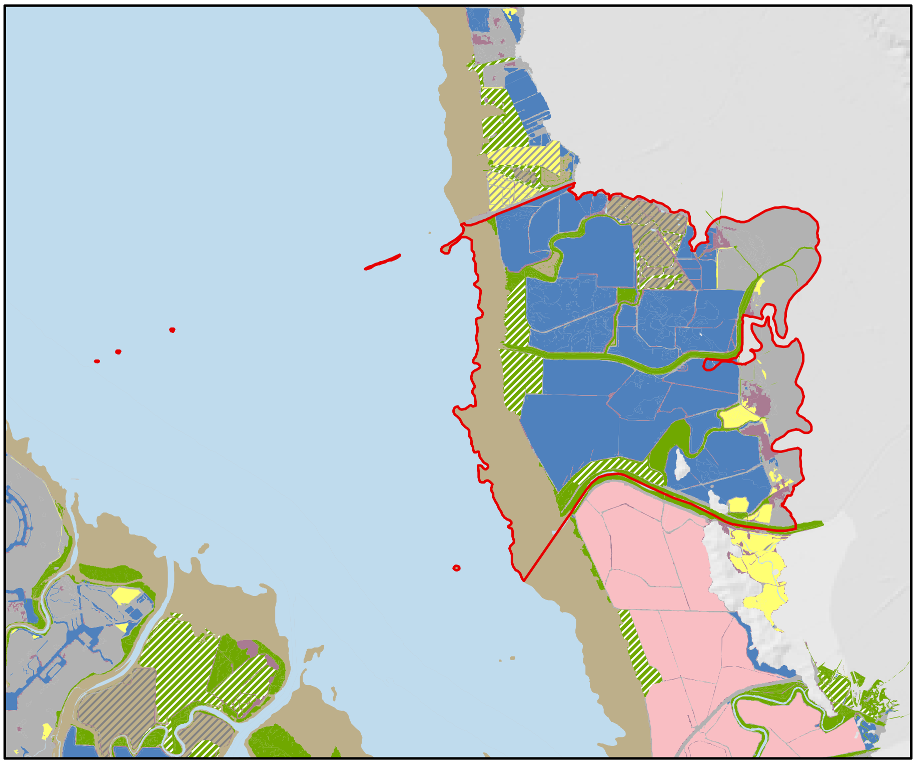
Restoring tidal wetland along the bayshore west of Coyote Hills would provide a dispersal corridor for Ridgway's rails and salt marsh harvest mice between the Dumbarton and Ideal Marshes and the marshes north of the Alameda Creek Flood Control Channel. Restoring the tidal marsh–upland transition zone would provide high-tide refugia for tidal species and increase habitat for rare plants.

On publicly owned ponds, maintaining and managing a system of seasonal ponds and islands would provide snowy plover nesting habitat and roosting and foraging habitat for other shorebirds and waterfowl.

Challenges

Challenges in this segment include the presence of invasive *Spartina*, flood-protection considerations, Highway 84, predator corridors along numerous levees, the potential for oyster drills to limit oyster restoration, the continued planned operation of salt production, and station KGO.

The South Bay Salt Pond Restoration Project is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations, including Alameda County, the US Fish and Wildlife Service, Cargill, the East Bay Regional Park District, Caltrans, and the cities of Hayward and Fremont.



BAUMBERG AREA

East Bay between Alameda Creek Flood Control Channel and Highway 92

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment S.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

0 2
Miles

N

Unique Opportunities

Tidal marsh in Segment S could be restored to provide a dispersal corridor for salt marsh harvest mice, Ridgway's rails, and other native marsh species where no corridor currently exists. The excavation of small, shallow depressions to restore backshore pan habitat was included within the muted tidal eastern portion of Mount Eden Creek as part of tidal restoration plans for the original Eden Landing Ecological Reserve (ELER) Baumberg Tract. Pond complexes could be further reconfigured, modified, and managed to provide foraging and roosting habitat for resident and migratory shorebirds and waterfowl. Finally, the southern extent of the segment provides opportunities for projects to reconnect anadromous fish runs in the Alameda Creek Flood Control Channel to nursery tidal areas. Freshwater outflow (including treated water from the Union Sanitary District and East Bay Dischargers Authority) may be discharged locally for the restoration of more brackish tidal marsh. Large areas of restorable managed ponds between the bay and the developed environment provide an opportunity for innovative flood-risk-management techniques that use the storage capacity and wave-damping effects of marshes to assist in tidal flood protection.

Segment Features and Setting

Most of this segment was historically tidal marsh. These tidal marshes were very broad, with well-developed channels and abundant and large tidal marsh pans, including some backmarsh pans in the ELER Baumberg area. Outboard of the tidal marsh were large areas of tidal flat. At the upland boundary of the marshes were grasslands, of which a limited area was moist grassland capable of supporting seasonal ponding. The majority of this habitat was associated with the backshore pans near Eden Landing. Alameda Creek, a major tributary to South Bay, entered the bay in this segment. Due to its size, the creek provided a significant zone of brackish tidal marsh, a well-developed riparian habitat, and a run of steelhead. Turk Island, a northern extension of Coyote Hills, is in the southern portion of the segment.

Almost all of the tidal marsh has been converted to managed ponds. Currently they mainly remain managed, with a number of them recently restored to tidal action. (These include the Baumberg Tract, Mount Eden Creek, and North Creek Marshes; and areas E8A, E9, and E8X as part of the South Bay Salt Pond Restoration Project.) The largest extant tidal marsh is Whale's Tail Marsh, which was diked for salt production but abandoned in the 1920s. The other tidal marsh in the segment is just north of the Alameda Creek Flood Control Channel. This area was a managed pond restored with dredged material from the construction of the channel. Inadvertently, the restoration created a tidal marsh–upland transition zone by placing fill material above the intertidal zone on the eastern end of the site. Diked marshes in this area (including the Munster Tract, part of the refuge) and other duck hunting clubs exist here east of the Eden Landing Ecological Reserve.

Most of the snowy plover nesting in the South Bay subregion occurs in this segment, north of Old Alameda Creek, with limited nesting also in segment T to the north, segment P to the south, and segment N across the bay. The managed ponds in this area are important foraging and roosting habitat for migratory shorebirds and some waterfowl that use the nearby tidal flats. Some islands and levees in managed

Near the mouth of
Mt. Eden Creek

ponds also provide nesting habitat for small numbers of American avocets, black-necked stilts, and Forster's terns.

Implications of Drivers of Change

Managed ponds in this segment will become increasingly difficult to maintain and operate at their specified elevations and salinities. As sea levels rise, levees protecting the ponds will need to be maintained and raised; tide gates will have to be modified, and gravity-driven systems supplemented by pumping. The outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of marsh edges (including coarse beaches), resulting in a narrowing of marshes. Sedimentation rates on existing and restored tidal wetlands are expected to slow over time as suspended-sediment concentrations in the bay decrease.

Considerations for Implementing the Actions

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

The near term offers significant opportunities to restore tidal marsh in managed ponds in the Eden Landing Ecological Reserve that will help create a continuous corridor of tidal marsh along the shore between Old Alameda Creek and the Alameda Creek Flood Control Channel, as well as inland to the urban edge. The following areas have been deemed suitable for tidal restoration in conjunction with appropriate flood-risk-reduction measures: all former salt ponds between the creek and channel, as well as some of the diked wetlands and detention areas used by the Alameda County Flood Control District. Tidal restoration actions could include the reconnection of complex channel networks while incorporating topographic variation by placing material to mimic features such as natural levees and high-ground transition zones, and could incorporate shallow pans. Preliminary planning for flood-risk management involves building up the existing berm at the edge of the bay and using restored marshes to damp the incoming tides.

To accelerate the accretion of the marsh surface in the moderately subsided ponds, dredge sediment could be placed either directly within the ponds or on adjacent mudflats to be redistributed by wave and tidal action into the ponds. Slopes to create elevation gradients along the transition zone between tidal marsh and adjacent upland areas could be created within existing ponds (prior to restoration) or adjacent to existing high ground and levees to provide buffers and high-tide refugia as well as habitat in its own right. In addition, salinity gradients could be re-created by seeping treated wastewater effluent from the Union Sanitary District site through created transition zones in order to incorporate brackish tidal marsh. Old Alameda Creek and the Alameda Creek Flood Control Channel could be connected to the adjacent marshes by levee breaches or water-control structures that accommodate fish passage, creating fish nursery grounds and allowing water, plant propagules, and sediment to enter the marshes from the creek.

While rates of sea-level rise are low, the water level and salinity of some of the managed ponds could continue to be managed to provide habitat for shorebirds and waterfowl. The SBSPRP planning process has identified a portion of the ponds north of Old Alameda Creek as suitable for this type of management. The ponds would require continued protection of the outboard levee to ensure its integrity. This may be an opportunity to create coarse sediment beaches, berms, and estuarine–terrestrial transition zones at the bay's edge to reduce erosion of the levee and re-create historical habitat that has been missing from the bay. Such a coarse beach could also be continued south along the marsh scarp or any flood-control features constructed on the bay's edge.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the longer term, if the sea-level rise accelerates and sediment supply falls as projected, marsh plains will probably give way to narrower fringing marshes. Tidal marshes may be unable to keep up with the rising sea level, resulting in increased inundation of the marsh surface. This may lead to habitat conversion, perhaps to low marsh and mudflat, and may accelerate the need for imported material. In addition, inland migration of the marsh is expected, and a gently sloping transition zone would facilitate such a migration. At the same time the coarse beach would be expected to roll landward as sea levels rise.

At some point the degree of sea-level rise may make it unrealistic to maintain the managed ponds. Prior to that point, a plan for restoring or relocating the functions of these ponds should be implemented that would move them outside the hazard zone. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Restore large areas of managed ponds to tidal marsh connected to the Alameda Creek Flood Control Channel, Old Alameda Creek, and Mount Eden Creek.
- Maintain and manage a small complex of managed ponds for shorebirds and waterfowl. Modify pond management as necessary to accommodate sea-level rise and other changes by modifying water-control structures, managing ponds to facilitate warping, and reconfiguring or relocating ponds as necessary.
- Restore natural (e.g., Turk Island) and created marsh–upland transition zones. Fill ponds at the landward edge prior to tidal restoration to create a transition zone.
- Restore willow groves, seasonal wetlands, and natural salt pans where possible.
- Restore and enhance oyster beds and eelgrass beds at appropriate locations.
- Connect waste- and stormwater to bayland habitats where appropriate to enhance the transition zone slope and reestablish a salinity gradient within marshes.
- Reduce the horizontal erosion of marshes by creating coarse beaches in front of marsh scarps; these would roll landward with sea-level rise. Fortify the bay edge to ameliorate marsh erosion and facilitate restoration.

FOR PARTICULAR WILDLIFE POPULATIONS

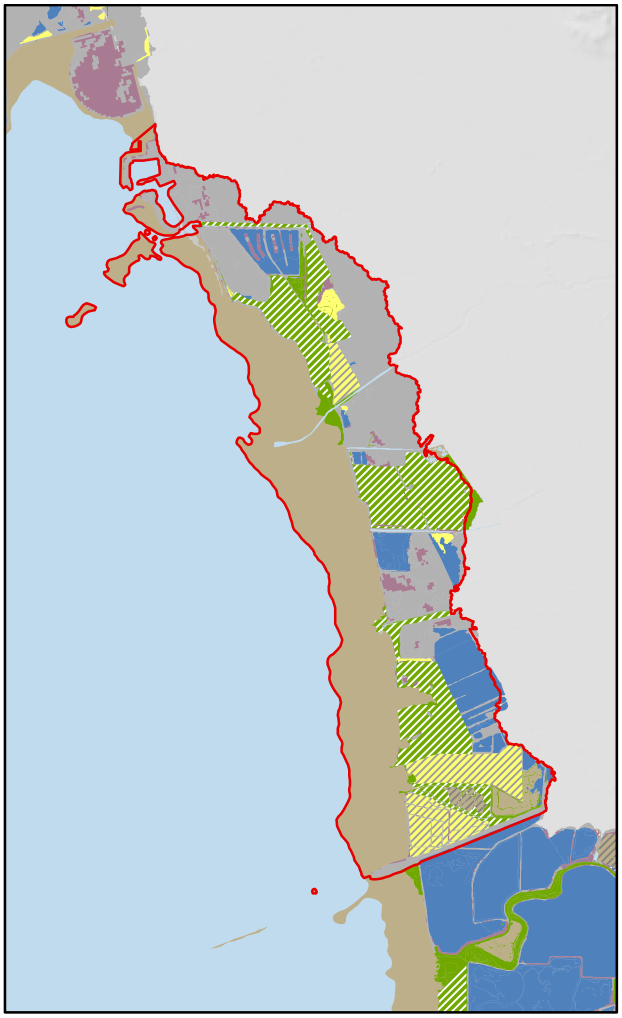
- Protect existing muted tidal wetland for the salt marsh harvest mouse as insurance against fully tidal wetland being lost as a result of sea-level rise.
- Target the management of ponds for nesting snowy plovers and foraging small and medium-size shorebirds.
- Control invasive *Spartina* before restoring large diked areas to tidal marsh.

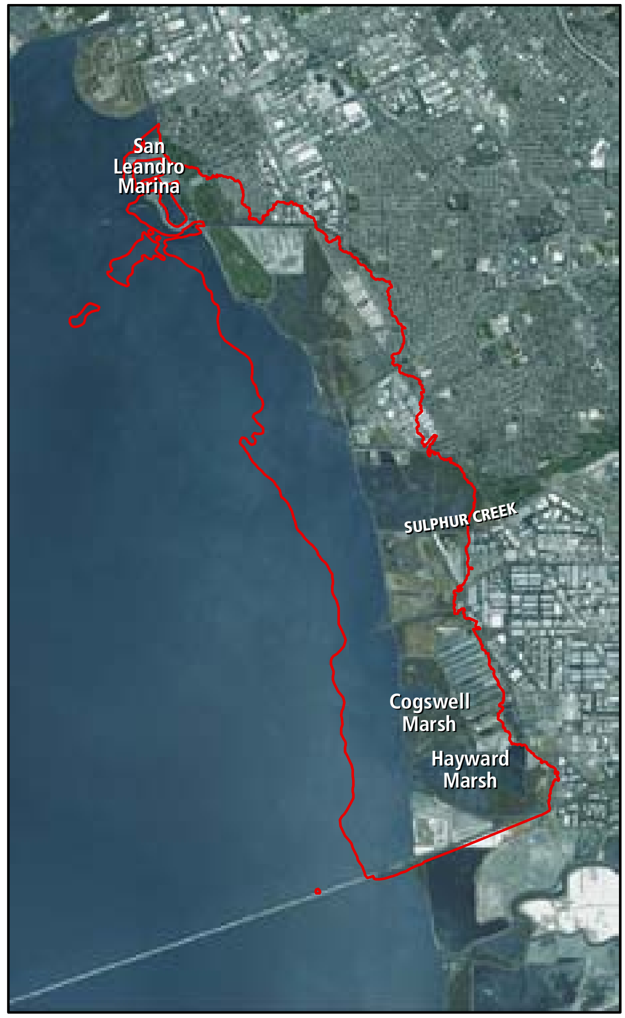
Restoration Benefits

Restoring tidal marsh and the associated tidal marsh and backshore pans as well as coarse barrier beaches could benefit sensitive plant species and provide refugia for tidal marsh species and shorebirds. Managing a system of seasonal ponds (dry in summer) would provide nesting habitat for snowy plovers and other resident shorebirds. Ponds managed with year-round open water and exposed berms and islands would provide nesting, foraging, and roosting habitat for terns; they also would provide waterfowl habitat at the correct depth and salinity. Connecting the Alameda Creek Flood Control Channel to restored tidal marshes would enhance in-channel efforts for fisheries.

Challenges

Challenges in this segment include invasive *Spartina*, flood-protection considerations, the East Bay Dischargers Authority wastewater pipeline, PG&E transmission lines and other utility corridors, major predator access corridors, the potential for oyster drills to limit oyster restoration, the operation and maintenance of managed ponds in absence of salt production, and public access and recreation. The South Bay Salt Pond Restoration Project is one of the key regional plans for this segment. Planning will require coordination with local agencies and organizations, including the California Department of Fish and Wildlife, Alameda County, the Union Sanitary District, Caltrans, the East Bay Regional Park District, and the cities of Hayward, Union City, and Fremont.





HAYWARD AREA

Eastern edge of San Francisco Bay between Highway 92 and San Leandro Marina

Baylands 2009

- Bay/Channel
- Diked Wetland
- Salt Pond
- Managed Pond
- Tidal Flat
- Tidal Marsh
- Agriculture and Other Undeveloped Areas
- Developed Areas

Red line shows the boundaries of Segment T.

Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes BAARI (v1, 2009) Baylands and Wetlands, NLCD 2006, and wetland tracker data.

Imagery: ESRI World Imagery (updated 2015)

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Miles

N

Unique Opportunities

Segment T offers several opportunities to restore and enhance tidal habitats and to strengthen the linkages between subtidal, baylands, creeks, and terrestrial habitats. Other habitats such as moist grassland and seasonal wetlands adjacent to the Roberts Landing area, as well as several roosting sites, could also be protected and restored. Multiple creeks (Saulfur and others) are already the focus of community-based restoration efforts, and this work could be leveraged with additional activities integrating climate-change-adaptation techniques. The San Leandro Marina, Oro Loma Marsh, and the Hayward Regional Shoreline provide unique, visible opportunities to educate the public about wildlife habitat needs. Conditions at some sites are appropriate for native eelgrass and oyster restoration, and existing eelgrass and oyster beds offshore from Oyster Point Regional Shoreline and Hayward Regional Marsh could be enhanced.

Segment Features and Setting

Most of this segment was historically tidal marsh and large natural salt ponds, including Crystal Salt Pond. Along the foreshore of the bay were narrow sandy beaches near San Leandro and a continuous band of mudflats that became progressively wider moving south. Along the backshore were large areas of freshwater seeps and seasonal wetlands in the extensive moist grasslands. Several willow groves existed adjacent to Sulfur and San Lorenzo Creeks.

In the 1850s, much of the tidal marsh was diked to create land for salt production, and landings were established to move salt and other agricultural products to San Francisco. After salt production ceased in the 1940s, many of these diked wetlands became seasonal wetlands and have been recently restored to tidal action. The area north of Roberts Landing was restored to mostly muted tidal systems (e.g., Citation Marsh) in the 1990s for mitigation. To the south, within the Hayward Regional Shoreline, Cogswell Marsh, the Hayward Area Recreation District (HARD) Marsh, and Oro Loma Marsh represent large systems restored to tidal action in the 1980s and 1990s to improve habitat values. Multiple active revegetation enhancement projects are under way to increase native *Spartina* and marsh gumplant populations at Oro Loma, Cogswell, and HARD Marshes. The Hayward Regional Shoreline also contains multiple managed marsh and pond systems: Triangle Marsh, Hayward Marsh, and a five-basin managed fresh and brackish system that relies on secondary treated wastewater from the Union Sanitary District, Salt Marsh Harvest Mouse Preserve, and Oliver Salt Ponds. Oliver Salt Ponds used to provide important snowy plover habitat. However, the berms are increasingly overtopped, and Eden Landing provides superior habitat.

Today, there is considerable industrial development in this segment, with cities, industrial areas, natural gas lines, wastewater treatment infrastructure, electrical utility projects, creek channelization, residential developments, and transportation corridors. Landfills, managed ponds, parks, the San Leandro Marina, and other developments occupy sites that once were tidal flat or marsh.

Tidal flats still exist throughout most of their historical distribution, and there are several sandy barrier beaches and lagoons. Small fringe beaches and rocky intertidal areas are present along almost the full length of the segment, and intertidal and shallow subtidal areas support eelgrass, oyster, and macroalgal beds. Some vernal pools remain in the adjacent uplands.

The South Bay's only existing California least tern colony is in this segment on an island in one of the Hayward Regional Shoreline treatment ponds. Snowy plovers also nest on this island, albeit in small numbers and with limited success. A large Forster's tern colony nests on an adjacent island, and a heron and egret rookery is present, although it may have been declining in recent years. The water-treatment ponds have been suffering from repeated outbreaks of avian cholera and avian botulism for the past few years, causing large numbers of dead waterfowl and a possible population decline in the rookery. New management plans for these ponds are being considered by the East Bay Regional Park District.

Implications of Drivers of Change

Sea-level rise will increase the erosion caused by storm surges and wave energy, and increase the depth, duration, and frequency at which baylands are inundated.

The developed areas will become increasingly difficult to protect as sea levels rise but, unlike segment L (Berkeley–Albany), this segment has some adjacent areas at appropriate elevations that could allow for baylands migration. Increasing wave energy will increase the ongoing marsh edge erosion, while increasing inundation coupled with declining sediment supply will lead to a downshifting of bayland habitats and eventual drowning. The water levels and salinities of muted tidal marshes and ponds will become increasingly difficult to manage. Outboard levees in particular will be subject to greater wave action as water depths increase, allowing larger waves to propagate inshore. Increasing wave action will also accelerate the erosion of the small remaining marsh edges, resulting in the narrowing and a potentially complete loss of marshes and other unique habitats such as coarse beaches and rocky intertidal areas. This urbanized segment has a high degree of existing development that directly abuts the shoreline, resulting in limited accommodation space and limited areas for restoration adaptation. There is a need for innovative and experimental approaches that may include sediment placement, the use of uncontaminated on-site fill in restoration designs, and integrated multihabitat designs with multiple biological and physical objectives.

Considerations for Implementing the Actions

Significant restoration investment has already been made along the shoreline. The remaining opportunities involve select areas that could be evaluated to provide tidal marsh and transition zone habitat. The East Bay Dischargers Authority (EBDA) pipeline runs along the back of the Hayward Regional Shoreline from Hayward's Landing to Highway 92, and there may be co-benefits associated with preparing transition zone slopes for landward migration and treating wastewater. Modifying the managed pond systems could also provide for a broader range of habitat and species needs. The fact that the Hayward Regional Shoreline is a recreation destination may bolster public engagement in its restoration. Because the area is managed by a joint-powers authority (the Hayward Area Shoreline Planning Agency) it may be easier to raise funds, initiate studies, and go through the environmental review process for restoration projects.

NEAR TERM (NOW TO MIDCENTURY, PRIOR TO SLR CURVE ACCELERATION)

In the near term, when sea-level rise rates will still be relatively low, actions enhancing the baylands will provide immediate ecological benefits and maximize their resilience. Low-crested berms could reduce nearshore wave energy, coarse beaches could be created to reduce marsh-edge erosion, and the introduction of fine sediment through mudflat and marsh recharge could increase vertical accretion rates. Generally, restored marshes in this segment have dendritic tidal-channel networks, and the existing habitat is of fairly high quality, but the marsh plains could be further enhanced by active revegetation to speed up tidal-marsh-plant establishment. In addition, the construction of features such as high-tide-refuge mounds or artificial floating islands could be explored to create additional high-tide refugia within existing marsh plains. Living breakwaters could be created around fringing marshes to preserve and enhance unique features like native eelgrass and oyster beds.

This segment is highly urbanized, and landward migration of marsh is constrained by development directly adjacent to the baylands. Major land uses such as the city of Hayward's Water Pollution Control Facility adjacent to Hayward Marsh will need to be protected with approaches that haven't yet been tried locally, such as co-objective projects like the Hayward Shoreline–East Bay Dischargers Authority project noted earlier. Diverse pocket habitats could be preserved, enhanced, and created, then linked together to create a subregional habitat corridor. Vertical enhancements (living seawalls, substrate improvements to docks, etc.) could be made in a few subtidal and intertidal areas where there is hardscape. Many existing habitats could be enhanced by improving tidegate management, removing contaminated soils and derelict boats, and removing trash that ends up in the bay. Habitats could be created

Forster's terns

along flood-control channels, floodplains, and off channels. Low elevation marsh and wetland could be restored. Upstream opportunities are limited but should be included in any plans.

LONG TERM (LATTER HALF OF THE CENTURY, AFTER SLR CURVE ACCELERATION)

In the long term, sea level rise rates will likely outpace vertical accretion rates, and marshes in this segment generally do not have enough space to migrate landward to survive. Prior to that point, a plan for restoring or relocating the functions of the existing tidal marshes should be implemented. Creating wetlands bayward of the flood-protection levees, possibly using wastewater to enhance habitat on the slope, could provide space for landward migration. Simply restoring tidal action to the managed ponds late in the century may result in the creation of deep tidal ponds. To alleviate this, "warping up" the ponds could be undertaken during the earlier part of the century, allowing the accretion of the pond to be managed as well. The planned communities built over former wetlands and bay will be at risk for flooding as sea levels begin to rise. If opportunities for managed retreat become available, options should be pursued to restore areas to baylands or to connected bay habitats.

Recommended Actions

FOR HABITATS AND THE LANDSCAPE IN GENERAL

- Design and restore complete tidal wetland systems, even at a small scale, that include tidal marshes, beaches, and lagoons, broad transition zones, and develop techniques for implementing active revegetation, high-tide-refuge islands, and subtidal habitat restoration.
- Work with willing landowners to protect area landward of tidal marshes to create a transition zone and future tidal marsh habitat where feasible. A few opportunities may exist to acquire private shoreline land along the length of this segment.
- Reduce marsh-edge erosion by creating coarse beaches (with a sand foreshore transitioning to a coarse sand and gravel berm in front of the existing marsh scarp), which could also roll landward as sea levels rise.
- Increase local sediment availability by placing fine sediment in areas that will be reworked by wave and tidal action to increase suspended-sediment concentrations, which could then increase vertical accretion rates.
- Manage water levels in ponds for depth and salinity, and modify water-control structures to accommodate sea-level rise, which may require increasing the sedimentation in ponds (warping) to avoid having overly deep ponds. Ponds may need to be reconfigured or relocated over the long term.
- Create transition zone habitats on gentle slopes in conjunction with flood-risk-management features (or other high-ground areas). Consider transition zone preparation that reuses dredged material or treated wastewater, and encourages tidal-channel formation and pan development, resulting in topographic complexity (high-tide refugia). Fill ponds at the landward edge prior to tidal restoration to create a transition zone.

- Protect, enhance, and restore intertidal and subtidal habitats, including native oyster beds and eelgrass beds.

FOR PARTICULAR WILDLIFE POPULATIONS

- Target the management of ponds for nesting snowy plovers and foraging small and medium-size shorebirds.
- Control invasive *Spartina* before restoring large diked areas to tidal marsh.

Restoration Benefits

Restoring tidal marsh and transition zone habitat could benefit shorebirds and sensitive tidal marsh plant and animal species, as well as provide critical high-tide refugia. The use of dredged material to create the transition zone slopes and the local reuse of treated wastewater would repurpose to the fullest extent possible resources that are currently not reused. Constructing wide terrestrial transition zones landward of existing major salt marsh habitats would significantly improve the resilience of existing Ridgway's rail and black rail populations and their habitats as sea-level rise accelerates. Providing wide terrestrial transition zones would also improve wildlife buffers along trails and offset tidal marsh submergence and the loss of high-tide cover as existing marsh plains submerge. Implementation of the recommendations for this segment would improve habitat support for harbor seals, salt marsh harvest mice, and other mammals.

Enhancing seasonal wetlands would improve high-tide roosting habitat for shorebirds. Enhancing riparian and instream habitats would benefit migratory songbirds and steelhead. Restoring coarse-grained gravel beach habitat at various locations would provide high-tide roosting habitat for shorebirds and terns. Isolated (island-like) marsh-fringing beaches may provide additional nesting sites for terns. The use of treated wastewater to create freshwater and brackish marsh–terrestrial transition zone habitat at sites such as the existing marsh complex at Oro Loma–Hayward Shoreline would provide dense, tall, and extensive high-tide cover for rail species and would attenuate tidal flooding and wave runup. Restoring native oyster and eelgrass beds offshore would provide habitat for birds and fish, and may enhance food and nursery resources for species that use both wetlands and offshore shallow subtidal habitats. Living-shorelines designs may provide wave attenuation, sediment stabilization, and some flood protection in the near term for tidal marsh habitats on the shoreline.

Integrating native oyster and eelgrass restoration adjacent to tidal wetlands, creating living shorelines, and incorporating features such as high-tide-refuge islands could improve small areas of habitat. This would also provide information on how well these approaches succeed and whether they can be scaled up to larger areas in this segment. Such information could be applied to other segment adaptation planning.

Including public education and awareness components in any restoration initiative is critical to building the public and financial support that is needed to test adaptation approaches and work toward large-scale implementation of innovative techniques.

Challenges

Challenges in this segment include Highway 880, an urbanized edge with roadways and infrastructure, railroad tracks, flood-control considerations, exotic predators (e.g., rats and red fox), the potential for oyster drills to limit oyster restoration, invasive *Spartina*, and on-site contaminants. The shoreline has eroding bayfront levees and is crisscrossed with a variety of regionally critical infrastructure, including landfills, wastewater-treatment facilities, storm drainage channels, high-voltage electrical transmission lines, railroads, and freeways. As both sea level and groundwater rise, the risk of levee failure and a resulting damage to these utilities will increase over time. Planning will require coordination among agencies and organizations, including the Hayward Area Shoreline Planning Agency (which consists of the Hayward Area Recreation and Park District, East Bay Regional Park District, and city of Hayward), the Union Sanitary District, the Oro Loma Sanitary District, the East Bay Dischargers Authority, the city of San Leandro, Alameda County, and Union Pacific.

SPECIES LIST

This reference list is for the common names of species mentioned in the report and is not a comprehensive list of baylands species. The latter can be found in the Baylands Ecosystem Habitat Goals Project (1999) and accompanying Baylands Ecosystem Species and Community Profiles (2000).

GROUP	COMMON NAME	SPECIES
Plant		
	Algerian sea lavender	*Limonium ramossiumum*
	black rush	*Juncus gerardii*
	Brazilian waterweed	*Egeria densa*
	California sea-blite	*Suaeda californica*
	Delta tule pea	*Lathryus jepsonii*
	eelgrass	*Zostera marina*
	gum plant	*Grindelia stricta*
	invasive *Spartina* (cordgrass)	Primarily *Spartina alterniflora x foliosa (hybrid)*
	Mason's lilaeopsis	*Lilaeopsis masonii*
	native *spartina* (cordgrass)	*Spartina foliosa*
	Pacific bentgrass	*Agrostis avenacea*
	perennial pepperweed	*Lepidium latifolium*
	pickleweed	*Sarcocornia pacifica*
	sago pondweed	*Stuckenia pectinata*
	salt grass	*Distichlis spicata*
	salt marsh bird's-beak (northern)	*Chloropyron maritimum*
	salt marsh owl's-clover	*Castilleja ambigua*
	soft bird's-beak	*Chloropyron molle*
	stinkwort	*Dittrichia graveolens*
	Suisun thistle	*Cirsium hydrophilum*
	water hemlock	*Cicuta maculata bolanderi*
	widgeon grass	*Ruppia maritima*

GROUP	COMMON NAME	SPECIES
	yellow flag	*Iris pseudacorus*
Invertebrate		
	Atlantic oyster drill	*Urosalpinx cinerea*
	Dungeness crab	*Metacarcinus magister*
	Olympia oyster	*Ostrea lurida*
	overbite clam	*Corbula amurensis*
	quagga mussel	*Dreissena bugensis*
	zebra mussel	*Dreissena polymorpha*
Fish		
	Chinook salmon	*Oncorhynchus tshawytscha*
	delta smelt	*Hypomesus transpacificus*
	flounder	*Paralichthys californicus*
	longfin smelt	*Spirinchus thaleichthys*
	longjaw mudsucker	*Ghillichthys mirabilis*
	mosquitofish	*Gambusia affinis*
	northern anchovy	*Engaulis mordax*
	Pacific herring	*Clupea pallasii*
	plainfin midshipman	*Porichthys notatus*
	steelhead	*Oncorhynchus mykiss irideus*
	striped bass	*Morone saxitilis*
	starry flounder	*Platichthys stellatus*
	tidewater goby	*Eucyclogobius newberryi*
	white seabass	*Agtractoscion nobili*
Amphibian		
	California tiger salamander	*Ambystoma californiense*
Reptile		
	California red-legged frog	*Rana draytonii*
	California toad	*Anaxyrus boreas halophilus*
	San Francisco garter snake	*Thamnophis sirtalis tetrataenia*
Bird		
	American avocet	*Recurvirostra americana*
	American wigeon	*Anas amaricana*
	American white pelican	*Pelecanus erythrorhynchos*
	black-necked stilt	*Himantopus mexicanus*
	black rail	*Laterallus jamaicensis coturniculus*
	bufflehead	*Bucephala albeola*
	California gull	*Larus californicus*
	canvasback	*Aythya valisineria*
	Caspian tern	*Hydroprogne caspia*

GROUP	COMMON NAME	SPECIES
	common yellowthroat	*Geothlypis trichas sinuosa*
	double-crested cormorant	*Phalacrocorax auritus*
	eared grebe	*Podiceps nigricollis*
	Forster's tern	*Sterna forsteri*
	gadwall	*Anas strepera*
	greater scaup	*Aythya marila*
	green-winged teal	*Anas crecca*
	killdeer	*Charadrius vociferus*
	least tern	*Sternula antillarum browni*
	least sandpiper	*Calidris minutilla*
	lesser scaup	*Aythya marila*
	mallard	*Anas platyrhynchos*
	marsh wren	*Cistothorus palustris*
	northern harrier	*Circus cyaneus*
	northern pintail	*Anas acuta*
	northern shoveler	*Anas clypeata*
	Ridgway's rail	*Rallus obsoletus obsoletus*
	ruddy duck	*Oxyura jamaicensis*
	snowy egret	*Egretta thula*
	snowy plover	*Charadrius nivosus alexandrinus*
	song sparrow	*Melospiza maxillaris*
		M. m. pusillula
		M. m. samuelis
	surf scoter	*Melanitta perspicillata*
	western sandpiper	*Calidris mauri*
Mammal		
	California vole	*Microtus californicus eximius*
		M. c. pauldicola
		M. c. sanpabloensis
	gray fox	*Urocyon cinereoargenteus*
	harbor seal	*phoca vitulina*
	North American river otter	*Lontra canadensis*
	ornate shrew	*Sorex ornatus californicus*
	red fox	Vulpes vulpes
	salt marsh harvest mouse	*Reithrodontoys raviventris*
	salt marsh wandering shrew	*Sorex vagrans halicoetes*
	Suisun shrew	*Sorex ornatus sinuosus*
	wild pig	*Sus scrofa*

PHOTOS

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Pages 138; 144

ILLUSTRATIONS

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Project: n8kauffman.com
Pages xxv, bottom; Figure 24, pages 102–103

Lisa Schile
Figure 23

Valerie Winemiller
Figures 1, 3, 10, 12, 13, 15

Figures 11, 18, 19: adapted from Environmental
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Figures 16, 17, 20: adapted from Josh Collins and
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Figure 21: adapted from Peter Baye

Figure 22: adapted from Transition Zone
Workgroup

Prepared by

THE SAN FRANCISCO BAY AREA WETLANDS ECOSYSTEM GOALS PROJECT

The wetlands at the shore of the San Francisco Bay are an integral part of the region's iconic beauty, and they provide numerous benefits for our economy and quality of life. These baylands support abundant wildlife, clean water, open space for recreation, and flood protection. More than 100 scientists who study the bay, its wetlands, and watersheds have concluded that now is the time to ensure that these ecosystems continue to provide such benefits.

www.baylandsgoals.org