Point Blue Conservation Science

SCIENCE SYNTHESIS

South Bay Salt Pond Restoration Project Phase 2

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South Bay Salt Pond Restoration Project
Phase 2 Science Synthesis Report

Report to the South Bay Salt Pond Restoration Project and the California Wildlife Foundation

Final Report – December 2019

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Point Blue Conservation Science

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SAN FRANCISCO BAY
RESTORATION AUTHORITY

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GLOSSARY OF TERMS

The following glossary is intended to orient the reader to terms and concepts referenced frequently throughout the report as they relate to the South Bay Salt Pond Restoration Project (Project).

Adaptive Management: Slow, phased implementation of restoration and project management actions. Management actions are closely monitored and the effects studied over time. Management strategies are adjusted and modified in each phase of implementation based on the scientifically measured effects that previous management actions have had on the ecosystem.

Adaptive Management Plan (AMP; Trulio et al. 2007): The guiding document written prior to the start of restoration actions to help direct the Project. The plan emphasized the importance of utilizing an adaptive management strategy for the Project, set forth project objectives, and established the initial Key Uncertainties associated with the Project.

Applied Studies: Scientific studies and monitoring conducted in and around the Project area specifically designed to address the Project's Key Uncertainties as outlined in the Adaptive Management Plan.

Applied Studies Questions: The highest priority questions identified in the Adaptive Management Plan related to the Key Uncertainties.

High Tide Refuge Islands: Constructed mounds in restored tidal marsh that act as habitat for wildlife during high tide, also known as "marsh mounds."

Key Uncertainties: The components of the project in which knowledge gaps significantly limit the ability to achieve project objectives. Key uncertainties inform future Applied Studies.

Knowledge Gaps: Aspects of the project in which there is a lack of scientific information. Knowledge gaps inform Key Uncertainties.

Phase 1 Summary (Valoppi 2018): A document that summarized Phase 1 Applied Studies results including the Project Management Team and Science Team's evaluation of how well the Project met expectations with respect to goals of the Adaptive Management Plan.

Project Objectives: The six South Bay Salt Pond Restoration Project Objectives, as set forth in the Adaptive Management Plan.

Restoration Targets: Quantitative restoration targets related to the Project Objectives that allow restoration progress to be tracked and are needed to inform adaptive management.

San Francisco Estuary: The geographic area containing San Francisco Bay, San Pablo Bay, and Suisun Bay, as well as the San Francisco Bay Delta and referred to as "Estuary" in this report.

"Sandbox": A conceptual study proposal in which one or more sites were selected to intensively study across all (or at least many) of the Key Uncertainties. Focusing on a single site enables coordination and efficiencies across disciplines and can lead to a more mechanistic understanding of system dynamics. The tradeoff for the sandbox approach is that the approach could lead to a lack of transferability of results to other sites, particularly if conditions among sites are dissimilar.

Stoplights: A method used in the Phase 1 Summary to indicate how well the Project met expectations with respect to the goals in the AMP. The "expanded stoplights" categories are: "Meets/exceeds expectations," "Uncertain, trending positive," "Uncertain," "Uncertain, trending negative," "Not meeting expectations" (Valoppi 2018).

INTRODUCTION

The San Francisco Estuary (hereafter, Estuary) contains some of California's most important ecosystems, providing human communities with invaluable benefits ranging from commercial fishing, recreation, pollutant filtration, strengthened shorelines, and habitat for diverse species including many endangered and endemic species. The people of San Francisco Bay value these benefits and as such, in an attempt to recover massive losses that occurred historically, have invested in the restoration of vast acres of baylands to tidal marsh and other productive habitats. Bay Area voters passing the $500 million Measure AA parcel tax in 2016 exemplifies the strong community support for protecting and restoring the Bay's wetland habitats.

As the largest tidal wetland restoration project on the West Coast, the South Bay Salt Pond Restoration Project (Project) plays a critical role in protecting and restoring the Bay. When complete, the Project will have restored 15,100 acres of industrial salt ponds to a rich mosaic of tidal wetlands and other habitats. The project objectives are to: restore and enhance a mix of wetland habitats, maintain existing levels of flood risk management, provide wildlife-oriented public access and recreation, maintain or improve water and sediment quality in the South Bay, protect special status species, limit the spread of non-native invasive species, and protect the services provided by existing infrastructure (Trulio et al. 2007).

All restoration activities implemented by the Project are guided by and inform its Adaptive Management Plan (hereafter AMP; Trulio et al. 2007). The AMP established the project objectives listed above and developed restoration targets relating to each objective. Further, the AMP defined a set of Key Uncertainties as gaps in knowledge around South Bay ecosystem functioning or restoration that significantly hinders the ability to achieve project objectives. The Project commissioned a set of science studies that were completed during Phase 1 of the Project focused on addressing these Key Uncertainties. Valoppi (2018) summarized the results of these studies and found that some of the Key Uncertainties identified in the original plan have been answered to varying degrees.

This synthesis refines the Key Uncertainties to pinpoint elements that still need to be addressed in order to move the project forward to achieve project objectives. Our approach was to gather information from publications, reports, and presentations relevant to the Project that have become available since the Phase 1 Science Summary by Valoppi (2018). We also conducted interviews with key researchers and stakeholders to include the latest information available. In addition, we synthesize information and results from other efforts throughout the Estuary and beyond that have a nexus with the Project to inform future discussions about integrating with those efforts. This science synthesis will, along with a climate change synthesis, be used to inform science framework for the project. The science framework will guide and prioritize future studies and monitoring for the Project. The Phase 2 science will ultimately provide the scientific foundation for the types of implementation that is proposed for Phase 3 of the project. The chapters herein are thus structured around eight thematic groupings of the Key Uncertainties from Valoppi (2018).

This science synthesis has three main goals: 1) to expand upon the status of current Applied Studies and monitoring associated with wetland restoration efforts that are underway and have taken place since the Phase 1 Science Summary, 2) identify gaps in our current knowledge of the system and additional studies required to fill these gaps, and 3) identify opportunities for increasing efficiencies in monitoring, modeling and analysis through regional and cross disciplinary integration and use of emerging technologies to more efficiently capture needed data.

RELATED REGIONAL EFFORTS

The Project is expanding its scope in Phase 2 to include regional impacts and synergies with efforts occurring outside the Project's geographical footprint. By coordinating monitoring and research strategies with regional partners, management actions can be more efficiently evaluated and duplicative monitoring efforts avoided. Through this regional collaboration, the Project seeks to better understand what impacts Project actions may be having on the region, as well as how regional changes may be impacting the Project area. This section provides background on the regional efforts that are most relevant to the Project and provides context for the specific recommendations in this report. The "Opportunities for Regional Synergy" section within each chapter describes in more detail how the Project can engage and share information with these efforts.

Wetlands Regional Monitoring Program

There are many opportunities for synergy between the Project and the Wetlands Regional Monitoring Program (WRMP), which seeks to better understand the condition of the tidal wetland ecosystem across the San Francisco Estuary (Estuary), and to generate information that will help guide and increase the efficacy of regulatory and management actions in restoration projects throughout the Estuary. The charge of the WRMP is to develop an implementable pilot program to monitor mature and restored tidal marsh habitat, with the goals of improving the efficiency and efficacy of permit-driven monitoring of voluntary tidal wetland restoration projects and of evaluating the condition of the tidal marsh ecosystem at the Estuary scale.

The WRMP, led by the San Francisco Estuary Partnership (SFEP), is a multi-stakeholder collaborative effort involving science institutions, regulatory agencies, restoration practitioners and land managers. The WRMP team will complete phase 1 in December 2019; this phase focused on developing a pilot program plan that includes a management and scientific framework for data collection and analysis. Phase 2 will build on this framework and develop plans for governance, funding, and data management. The goal is a phased approach that is scalable to available resources, and starting with prioritized science content. The WRMP is guided by a Steering Committee that includes the South Bay Salt Pond Restoration Project Manager and representatives from agencies and organizations also involved in the Project, including the U.S. Fish and Wildlife Service and the California Department of Fish and Wildlife. It is expected that the WRMP will continue to coordinate with the Project on ongoing monitoring research, data collection standards and emerging science that is of interest to both entities.

The WRMP has established the following five guiding Management Questions to address the main goals of the program[1]:

1. Where are the region's tidal wetlands and wetland projects, and what net landscape changes in area and condition are occurring?
2. How are external drivers, such as accelerated sea level rise, development pressure, and changes in runoff and sediment supply, impacting tidal wetlands?
3. How do policies, programs, and projects to protect and restore tidal wetlands affect the distribution, abundance, and health of plants and animals?
4. What new information do we need to better understand regional lessons from tidal wetland restoration and enhancement projects in the future?
5. How do policies, programs, and projects to protect and restore tidal wetlands benefit and/or impact public health, safety, and recreation?

[1] Source: WRMP Core Team, "Draft Spatial and Temporal Monitoring Frameworks for the WRMP," 2019 August 20.

The geographic scope of the WRMP is divided into five subregions: Suisun Marsh, North Bay, Central Bay, South Bay, and Lower South Bay. Monitoring is planned at three spatial scales: whole Estuary, subregion (the five embayments), and individual wetland or project. The monitoring framework will include a benchmark site network (similar to the National Estuarine Research Reserve's "Sentinel Sites") distributed across the subregions to represent stable mature marsh conditions. Benchmark sites will be used to assess the relative importance of different sediment sources and delivery processes as well as other processes and conditions of interest. Establishment of the benchmark site network has been prioritized for development in phase 2 of the project. This effort will involve close coordination with a Technical Advisory Committee and with relevant regulatory agencies. Multiple reference sites in each subregion will also be established to represent a range of marsh ages and for comparison with project restoration trajectories. The WRMP will engage diverse stakeholders to provide guidance on monitoring protocols including standard operating procedures (SOPs) for proposed future project sites (sites where restoration or management is happening). The goal is for this guidance to make its way into monitoring permit conditions for wetland projects, with the intent to reduce the burden on land managers and create more efficiencies in monitoring requirements.

Co-locating the Project's "sandbox" sites and other restoration sites with WRMP sites and co-developing data collection and storage standards would facilitate data sharing, create efficiencies in data collection and processing, and allow regional comparisons. Ultimately, this synergy would enhance understanding of how the Project's actions impact the region and how regional actions might be impacting the Project. Monitoring multiple projects in different parts of the Estuary that are implementing a similar restoration technique and following standardized monitoring protocols will greatly increase the ability to test those techniques for their ability to achieve stated goals, though it will likely take some time to generate conclusions that can inform design and adaptive management. The chapters in this report describe specific ways in which the Project and the WRMP can collaborate to increase efficiencies and reduce Key Uncertainties.

San Francisco Bay Joint Venture

The San Francisco Bay Joint Venture (SFBJV) is a well-established partnership focused on habitat protection and restoration in the San Francisco Estuary. The SFBJV's stated mission is "to protect, restore, increase, and enhance wetland habitats throughout the San Francisco Bay region to benefit birds, fish, and other wildlife" (www.sfbayjv.org). The SFBJV has defined four main objectives to meet this goal, all of which are in alignment with those of the Project. The objectives are as follows[2]:

- Secure, restore, and improve wetlands, riparian habitat, and associated uplands by applying incentives and using non-regulatory techniques
- Strengthen and promote new sources of funding for such efforts
- Improve habitat management on public and private lands through cooperative agreements and incentives
- Support the monitoring and evaluation of habitat restoration projects and research to improve future restoration projects

There may be opportunities for the Project to coordinate monitoring and applied studies in mutual areas of interest with the SFBJV to help increase efficiency and reduce duplicative efforts. Further, the SFBJV could be a beneficial partner and resource for sharing skills and information as well as providing potential funding sources for various aspects of the Project.

[2] Source: SFBJV, Restoring the Estuary Executive Summary, 2001.

Regional Monitoring Program for Water Quality in San Francisco Bay

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) is a collaborative program led by the San Francisco Estuary Institute (SFEI) and is focused on long-term water quality monitoring and data collection. The RMP was established in 1993 and thus already has extensive data documenting both spatial and temporal trends in water quality throughout the Estuary. Overseen by its steering committee, the RMP consists of several workgroups focused on different aspects of water quality monitoring that could help inform Project actions. In particular, there are opportunities for synergy with the Sediment Workgroup and Emerging Contaminants Workgroup. While it is important to note that the RMP's data is for the open water of the bay rather than the marshes, there may still be potential for the Project to coordinate water quality monitoring in the Project area with RMP monitoring conducted elsewhere throughout the Estuary to help better understand Project impacts to the region and regional impacts to the Project.

EMERGING TECHNOLOGIES

Moving forward, the Project is interested in exploring emerging technologies as a means to increase efficiency of data collection and monitoring, as well as to help facilitate information sharing with other projects. By establishing a multi-faceted monitoring approach in which traditional methods are maintained where necessary and new technologies used where appropriate, the Project can more efficiently manage its time and resources. This section provides background on the emerging technologies that appear frequently throughout the report and provides context for better understanding the specific recommendations found in each chapter.

Remote Sensing

While the Project is already engaged with remote sensing techniques to map habitat type and changes over time, there is continued potential for remote sensing to help inform certain aspects of the Project, both at the site-specific and regional scale. Remote sensing data is primarily used to identify and map habitat characteristics, including the more recent ability to map characteristics relating to water quality and sediment dynamics. The Project could use both current and historical aerial and satellite imagery collected from a variety of spatial scales to obtain baseline information about habitat characteristics and land cover as well as to monitor regional landscape changes over time. However, there are issues with licensing of imagery that create challenges for sharing remotely-sensed imagery with multiple researchers, as well as challenges in data processing in order to speed up the time between imagery acquisition and delivery of products useful for decision-making (B. Fulfrost, personal communication).

There is also potential for the Project to monitor changes in landscape characteristics over time at a finer scale using unoccupied aerial systems (UAS; unmanned aerial vehicles; drones). UAS can be flown at a much lower altitude than occupied aerial vehicles such as airplanes and helicopters, allowing the flexibility to capture high-resolution imagery and video footage on a site-specific scale. In addition to collecting data on habitat characteristics, UAS also have the potential to track and monitor certain wildlife populations, both spatially and temporally. However, it is important to note that there are certain limitations with regards to wildlife monitoring using UAS, as discussed in more detail in the relevant chapters.

Autonomous Sound Recording Units

Autonomous sound recording units (automated sound recorders; ARUs) combined with machine learning algorithms can be used to detect the vocalizations of animal species and can be a useful monitoring tool. A 2014 study conducted by Borker et al. on the utility of ARUs to monitor breeding bird populations found that ARUs are a feasible option for monitoring seabird colonies at remote sites.

However, the study also found that in urban areas, traditional nest surveys were comparable in cost to acoustic monitoring and much better for estimating population size of nesting birds, thus the preferred method for monitoring in more easily accessible areas (such as that of the Project site).[3]

As it can be challenging to use ARUs to detect population size, ARUs are best used to detect the presence or absence of certain species at a given site. This can be helpful data for monitoring changes at a site over time. Therefore, despite their limitations, ARUs still have the potential to be a useful tool for the Project. It is also important to note that ARU technology is rapidly changing and improving, and a new simple programmable ARU called AudioMoth (www.openacousticdevices.info) has recently been developed and is extremely low-cost at $50-$60 per unit (compared to the $700 SongMeter used in the 2014 Borker et. al. study).

[3] Source: Borker, A.L., M.W. McKown, J.T. Ackerman, C.A. Eagles-Smith, B.R. Tershy. 2014. Vocal Activity as a Low Cost and Scalable Index of Seabird Colony Size. Conservation Biology 28(4):1100-1108. doi: 10.1111/cobi.12264.

MARSH, MICE, AND RAILS

RATIONALE AND BACKGROUND

The restoration of former salt ponds to tidal marsh habitat is central to the South Bay Salt Pond Restoration Project (Project) Objectives. The benefits of tidal marsh ecosystems to wildlife as foraging, nesting and rearing habitat and to people as flood risk reduction, pollutant filtration, and recreational opportunities are well documented (Goals Project 2015 and U.S. Fish and Wildlife Service [USFWS] 2013). Reversing the historic loss and degradation of tidal marsh habitat and associated wildlife populations through intentional tidal breach restoration was a driving force behind the decision to initiate the Project. The Project aims to restore at least 50%, and potentially as much as 90%, of the Project's 15,100 acres into tidal marsh over the next few decades.

Since the Phase 1 studies, there has been a desire to identify knowledge gaps around increasing the resilience of tidal marsh species' populations in light of accelerating sea level rise, extreme storms, and other stressors. It is not always clear what are the most effective strategies for increasing resilience. By the end of Phase 1, the Project had increased its emphasis on understanding how tidal marsh species respond to restoration and how that response contributed to the Project Objectives, many of which were based on USFWS recovery objectives. Furthermore, the Project has a limited budget and must choose which strategies to invest in. This often means choosing among actions to restore new areas, enhance existing ones, and manage the system. Understanding the relative impacts of these actions will help the Project prioritize the most efficient strategies. What does the current state of the science tell us about how we can most effectively restore and manage tidal marsh habitat to support resilient thriving wildlife populations and achieve other desired benefits?

The original Key Uncertainty from the Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) that related to tidal marsh habitat, "bird use of changing habitat," was focused on how other waterbird and waterfowl species would respond to large scale salt pond conversion to tidal marsh.

Key Uncertainty - *Can the existing number and diversity of migratory and breeding shorebirds and waterfowl be supported in a changing (reduced salt pond) habitat area?* (Trulio et al. 2007)

This chapter addresses one of the six Applied Studies Questions originally listed under the "bird use of changing habitat" Key Uncertainty that relates directly to marsh habitat and endangered species, which is: **"How do California clapper [Ridgway's] rails and/or other key tidal habitat species respond to variations in tidal marsh habitat quality and what are the habitat factors contributing to that response?"** (Trulio et al. 2007). Because this Applied Study Question includes marsh mammals and mature tidal marsh habitat and is not solely focused on bird use of changing habitats, we dedicate this chapter to the unique issues related to tidal marsh ecosystems and the species that depend upon them.

The AMP acknowledged that restoring tidal marsh ecosystems may require intervention that focuses on particular species, habitats, or habitat components. While species-specific management may be necessary, it should not replace the Project's process-based ecosystem focus (Trulio et al. 2007). To address this desire for an ecosystem focus, this chapter also discusses how other tidal marsh dependent species benefit from the Project's actions and how they can inform the Project's approach to restoring complete tidal marsh ecosystems. Although this chapter focuses on the federally listed species, California Ridgway's rail (*Rallus obsoletus obsoletus*; CRR) and salt marsh harvest mouse (*Reithrodontomys raviventris*; SMHM), there is considerable information on tidal marsh restoration and management response of other bird species that serve as indicator species and can inform best practices. The following tidal marsh dependent bird species have been used as indicators in The State of the Estuary Report (2015) and the State of the Birds San Francisco Bay (Pitkin and Wood 2011): Three species of tidal marsh song sparrow (*Melospiza melodia samuelis*, *M. m. pusilula*, and *M. m. maxillaris*), common yellowthroat (*Geothlypis trichas sinuosa*), and California black rail (*Laterallus jamaicensis coturniculus*).

In the AMP and Valoppi's (2018) Phase 1 summary, the tidal marsh wildlife Applied Study Question was further broken down into five questions which were used to summarize the results of Phase 1 activities and the studies that were implemented to address Key Uncertainties and assess progress toward Project Objectives. The questions pertain to the establishment of tidal marsh and how the Project supports the objectives set forth in the Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (USFWS 2013) relating to the CRR and SMHM. The AMP Restoration Targets regarding tidal marsh habitat, rails and mice are as follows:

1. Vegetation/habitat mosaic (including vegetation acreage and density, species composition, acreage of mudflat, channels, marsh ponds and transition area) is on a trajectory toward a reference marsh and/or other successful marsh restoration sites in South San Francisco Bay.
2. Meet recovery plan criteria for CRR (0.25 birds/ac over 10-year period) and SMHM (capture efficiency level of 5.0 or better in five consecutive years) and their habitat within the SBSP Restoration Project Area.

Valoppi et al. (2018) concluded that restoration trajectories for marsh vegetation differed among ponds and that some became vegetated sooner than expected (A21) and others responded more slowly (A19 and A20). CRR and SMHM were detected at A21 in 2015, just nine years after breaching. At North Creek in Eden Landing's Baumberg Tract, which was restored in 2006, SMHM were detected during the first year of trapping in 2014 and four CRR were detected in 2019. In Mt. Eden Creek, restored in 2008, SMHM were detected in 2013 during the first year of surveys.

In Valoppi's (2018) stoplight table, the questions related to the Key Uncertainty above were categorized as "Uncertain, trending positive." Below, we summarize more recent information as well as key information not covered by Valoppi.

RECENT INFORMATION

This chapter synthesizes the current state of the science related to tidal marsh habitat, two endangered species (the CRR and the SMHM), and other tidal marsh dependent indicator species. To address questions related to CRR and SMHM population trends, habitat associations, and response to conservation actions requires ongoing effort by multiple entities who conduct wildlife surveys at multiple scales in restored and remnant marshes as well as efforts to map and measure tidal marsh habitat extent and the key features that wildlife depend on (e.g., vegetation structure and diversity). Some of these efforts are project-specific and have a limited time series and spatial extent and others are part of large-scale, long-term annual monitoring. It remains a challenge to fund long-term monitoring, efficiently integrate data among efforts, and to synthesize results at intervals and spatial scales appropriate for management. The regional perspective that these efforts provide is critical for assessing project-specific results. This information gap that may be addressed by the Wetlands Regional Monitoring Program (WRMP) as it evolves (see the Opportunities for Regional Synergy section in this chapter) but near-term solutions are still needed.

Tidal Marsh Habitat and Species Status

Tidal Marsh Habitat

Knowing the extent and distribution of different types of tidal marsh habitats is critical to understanding the status and needs of mice, rails, and other tidal-marsh dependent wildlife. The HEMP (Habitat Evolution Mapping Project) mapped the distribution of tidal marsh habitats and other land cover types using satellite imagery. The mapping included 16 types of tidal marsh habitat based on plant species associations and alliances (Sawyer et al. 2009) and were ground truthed using the California Native Plant Society's Rapid Assessment Protocol. These mapped habitat types were organized into tidal salt marsh (low, mid, and high marsh), brackish marsh, and freshwater marsh. In addition, eight other habitat types were mapped including upland (e.g., alkali grasses) and non-vegetated (e.g., wrack, mudflat and biofilm) distribution and extent. See Fulfrost et al. (2012 and 2017) for details. These products can help managers understand how much habitat is available for wildlife and how that habitat is distributed throughout the landscape to assess connectivity, edge effects, minimum patch size, etc. Future mapping efforts can be used to track changes in the above metrics through time which can aid in assessing habitat response to restoration, management, sea level rise and other impacts. The Project is in the process of updating the original habitat distribution maps (from 2009-2011) for both 2019 and 2020 using the same methodology. These new habitat datasets will provide the Project with a new baseline and a mechanism for mapping changes (including the floral colonization and mudflat development in restored ponds), and a method to better explore wildlife habitat relationships.

California Ridgway's Rail

The CRR is an endangered species whose distribution is limited to tidal marsh habitat within the Estuary. CRR densities are highest in larger mature tidal marshes characterized by sinuous networks of channels lined with gumplant (*Grindelia stricta*) and marshes with large stands of Pacific cordgrass (*Spartina foliosa*). They are known to respond positively to tidal restoration which has been the most effective and widely used management tool to restore their populations. Other recovery actions include predator management, native plant revegetation and provision of high tide refugia. CRR response to some but not all of these types of conservation actions has been assessed (Harding et al. 2001, Nur et al. 2018, Overton et al. 2015, and Wood et al. 2107a).

Surveys are conducted by various entities to record presence and number of CRR; USFWS 10(a)1(A) permit holders submit annual reports that summarize the number of CRRs detected during surveys. Several of these entities follow the USFWS Site-Specific Protocol (Wood et al. 2017b) and coordinate efforts to estimate and track CRR population trends and response to management (Invasive Spartina Project [ISP], USFWS, California Department of Fish and Wildlife [CDFW], Point Blue, Avocet Research Associates [ARA]). The annual reports from each permittee provide a useful index of population change but only when the area surveyed and protocol used do not change. These detection summaries cannot be used to estimate the total number of rails in a given area because the summaries do not account for imperfect detection, more specifically, the probability of detecting an individual on a given set of surveys. For example, in one study, only about 40% of radio-marked individuals present at a site were detected during surveys (Bui et al. 2015). The probability of detection varies greatly by protocol, site, time of year, time of day, and other variables. The methods of analysis described in the Site Specific Protocol accounts for these important variables resulting in a more accurate density estimate that is designed to assess progress towards the recovery objectives set forth in the USFWS Tidal Marsh Recovery Plan (2013). The probability of detection has not yet been estimated for the new Site-Specific Protocol.

Salt marsh harvest mouse (SMHM)

The SMHM is an endangered species found in saline and brackish marshes in the Estuary. They occur in tidal, muted tidal, and non-tidal (diked) marshes, and in marsh-upland transition zones and natural levees within marshes (USFWS 2013). Early studies were focused on mature tidal salt marsh and suggested that SMHM required pickleweed-dominated (*Sarcocornia pacifica*) salt marshes, but more recent trapping efforts have found equal or even greater numbers of mice in diked and managed marshes (Shellhammer and Barthman-Thomson 2015 and Smith et al. 2018). It has also been documented that the mouse will use transition zone habitats that are dominated by grasses, *Atriplex,* and other nourishing mixed halophyte species at certain times of the year. While there are several large, intact historic marshes in the South Bay, many are fragmented and bordered by urban areas, which highlights the need for enhancement of the marsh edge and marsh plain with tall dense vegetation that serves as high tide refugia. Fragmentation also limits dispersal opportunities which negatively affects population genetics.

Tidal marsh indicator species

Overall, tidal marsh indicator species have been stable to slightly increasing Estuary-wide. The Alameda song sparrow (*M. m. pusilula*), a common tidal marsh resident in the South Bay has been increasing slightly whereas the San Pablo and Suisun subspecies have been decreasing in recent years (The State of the Estuary 2015). Song sparrows are the most common tidal marsh resident and are most abundant in marshes with high densities of channels lined with gumplant (*Grindelia stricta*). They are sensitive to marsh size with larger marshes supporting higher densities of song sparrows. Common yellowthroats are less abundant in South Bay marshes and typically occur near the edges of the marsh where taller plants provide suitable nesting cover. Black rails are even less common in the South Bay and tend to occur in areas of the marsh with freshwater inputs where bulrush (*Bolboschoenus maritimus*) provide increased cover. They are not a common breeder in the South Bay but their numbers appear to increase during the non-breeding season.

Response to Restoration

California Ridgway's Rail

CRR response to tidal restoration has been well documented (Goals Project 2015 and USFWS 2013). On average CRR colonize tidal restoration sites around 17 to 20 years post-breach (Point Blue unpublished data). CRR can colonize a restoration site sooner if the following conditions exist: 1) starting elevations are higher, 2) the rate of accretion is higher as in A21 and 3) populations are established nearby. It may be possible to hasten recolonization if other restoration design components are included such as constructed high tide refuge islands, transition zones, and active marsh revegetation. CRR use of artificial floating islands[4] provided as high tide refugia was high at sites in San Leandro Bay (Overton et al. 2015) but had mixed results at other sites (Casazza et al. 2014). Sites in the Gallinas Creek area had moderate use but sites on the western side of South San Francisco Bay did not have appreciable use. Only one of the six earthen islands[5] monitored at Arrowhead, Cooley, and MLK marshes had CRR use. Despite the low apparent use, it is unclear what population-level impacts both floating and earthen islands are having on CRR. A Point Blue study examining the effect of earthen islands and native plant revegetation (including the planting of 400,000 gumplants) at South Bay sites was inconclusive largely

[4] The floating islands were anchored within and on the edge of marshes and made with high-density foam for flotation and woven palm leaf screens to provide cover.

[5] Earthen islands were located within marshes and designed to mimic the high-tide refuge function provided by gumplant-lined (*Grindelia stricta*) tidal marsh slough channels and were constructed from marsh sediments. They measured approximately 3 by 8 m and the tops were designed to be 30 to 60 cm above MHHW.

due to low sample sizes and the lack of a study design in the restoration (Wood et al. 2017a). It is possible that limited use of earthen islands by CRR during extreme tides could have significant positive impacts. Overall, the population response to novel restoration features and strategies is still unclear. Evaluating the effectiveness of these adaptive approaches to restoration will become increasingly important as the Project prepares for sea level rise.

Transition zones can provide refuge for avian marsh species (including the CRR) during extreme high tides and storms and also can buffer tidal marshes against adjacent urban areas, which support human-associated predators and human disturbance. In a recent study, Nur et al. (2018) confirmed the importance of the transition zone for tidal marsh dependent bird species and identified specific characteristics of the transition zone found to be beneficial. Even steep levees that are restored with tall, dense vegetation were found to provide benefits to tidal marsh birds. Both physical features and vegetative characteristics of the transition zone were found to contribute to healthy, growing tidal marsh bird populations. These findings have important implications for the design of transition zones as part of the restoration or enhancement of tidal wetlands.

Based on study results, any of the following transition zone features are more likely to result in a positive response by CRR and other tidal marsh dependent bird species:

- Dense vegetation that is ≥30 cm from the ground.
- Tall plants that are 50-100 cm. Plants above 100 cm can become predator perches.
- Wider transition zones: benefits most apparent at ≥25 m widths. Narrow levees can provide benefits if tall dense vegetation is present.
- Tall dense grass cover: grasses can provide cover for tidal marsh birds, while their removal (absent supplemental planting of tall dense vegetation) can reduce the benefits to tidal marsh birds. Grasses may also provide forage for other tidal marsh species such as SMHM.

The San Francisco Bay Bird Observatory (SFBBO) recommends that transition zones include gradual slopes (ideally 30:1) that are constructed relative to tidal elevations. They note several projects that used 30:1 transition slopes but missed the transitional elevation zone and in some cases abutted steep slopes or berms that were not conducive to plant community restoration. Additional resources are available that describe marsh-upland transition zones in the Estuary (Thomson et al. 2013) and the importance of the transition zone in providing wildlife refuge habitat (Fulfrost et al. 2015).

Salt marsh harvest mouse

Trapping results at sites in Eden Landing showed that SMHM will recolonize tidally restored areas (Stratham et al. 2016 and John Krause pers. comm.). Mount Eden Creek was surveyed five years post-breach and North Creek Marsh six years post-breach and both sites were colonized by SMHM. SMHM have also been trapped in restored Pond A21 (approximately 10 years following restoration; Valoppi 2018).

Numerous studies point to the importance of high-tide refugia within the marsh (for larger marshes) and within the upland transition zone for narrow marshes (Shellhammer and Barthman-Thomson 2015). However, researchers with WRA Inc., University of California Davis (UCD), USFWS, and CDFW studying transition zone use by SMHM in response to extreme tides at Eden Landing and other sites found that mice did not use the transition zone as much as expected. They hypothesized that competition with other upland small mammals and increased predation pressure may be limiting SMHM use of transition zone habitat in that area. Casazza et al. (2014) found 48% and 72% of artificial floating islands were used by mice in 2012 and 2013, respectively. Mouse species identification was not possible with photo documentation but the floating islands were located in areas where SMHM were known to occur. No mice were detected on the six earthen islands they monitored at Arrowhead, Cooley, and MLK marshes.

Response to Invasive species and management

Invasive *Spartina*

Non-native *Spartina* (a cordgrass) and its hybridized forms are extremely aggressive and significantly alter both the physical structure and biological composition of tidal marshes, mudflats and creeks (see Invasive and Nuisance Species chapter). Treatment and control of these invasive hybrids is led by the State Coastal Conservancy's ISP (www.spartina.org). Invasive *Spartina* can invade marshes replacing natives like pickleweed and gumplant in monotypic stands that spread into the upland transition zone, through high-, mid-, and low-marsh areas and across adjacent mudflats. The impacts to many tidal-marsh species including SMHM, song sparrow (*Melospiza melodia*), common yellowthroat (*Geothlypis trichas*), black rail (*laterallus jamaicensis*) and several endangered plant species is unknown. However, there is ample evidence that the CRR benefits from invasive *Spartina*, which provides tall dense cover. Large areas that were previously unsuitable for CRR (e.g., mudflats) became colonized by the rail following invasion by the hybrid plant. The negative impacts on CRR of removing hybrid *Spartina* from these areas is well documented and a phased approach to management includes reducing impacts to rails, including extensive revegetation efforts and creation of vegetated earthen islands (ISP unpublished reports, Casazza et al. 2016). See Invasive and Nuisance Species chapter for details.

CRR detections are continuing to increase at marsh sites surveyed by the ISP and the trend is consistent in marshes where non-native *Spartina* has been treated (16% change from 2017 to 2018 and 9% from 2014). In areas where non-native *Spartina* treatment had been restricted since 2011, there has been a larger increase (13% annual change and 29% 5-year change; Olofson Environmental, Inc. 2018).

Perennial pepperweed (*Lepidium latifolium*)

Shellhammer and Barthman-Thompson (2015) report that in early studies, no mice were trapped in areas completely dominated by perennial pepperweed and fewer mice were trapped in areas with some amount of pepperweed compared to non-invaded marshes. Because pepperweed declines in abundance with increasing salinity at the regional scale, plants weakened by salinity and saltwater flooding are more susceptible to herbicide and other treatments (Spenst 2006).

KNOWLEDGE GAPS

It is critical that the Project identify knowledge gaps that hinder its ability to increase the resilience of tidal marsh species' populations to accelerating climate change and other stressors.

Phase 1 Applied Study Question: How do California clapper [Ridgway's] rails and/or other key tidal habitat species respond to variations in tidal marsh habitat quality and what are the habitat factors contributing to that response? (Trulio et al. 2007)

Monitoring during Phase 1 showed that CRR responded positively to tidal restoration at several sites, and other studies described the relationship between CRR and habitat features as they relate to habitat quality and restoration. However, results from Phase 1 studies led to additional questions and knowledge gaps. The question of whether CRR and SMHM densities are reaching Project objectives remains uncertain, not because of a lack of data but because existing data have not been summarized or analyzed at relevant temporal and spatial scales. Project managers need information (data, summaries, and analysis results) on CRR and SMHM at relevant spatial and temporal scales to periodically assess how the Project's tidal restoration and enhancement actions are working. Comparing status and trends from within the Project footprint or site of interest with other subregions is needed to put Project-specific changes in perspective because CRR and SMHM numbers at the Estuary scale can fluctuate annually for reasons outside the Project's control. (See Potential Phase 2 questions for CRR examples.) Such information can also be used to assess whether and how the Project's restoration actions affect CRR and SMHM populations outside the Project footprint. Given the need to assess progress towards restoration targets and given the interest in understanding how the Project's actions impact the ecosystem outside the Project footprint, we provide a slightly revised for question for Phase 2:

- How do SMHM and to a lesser extent, CRR, respond to restoration both within and outside the Project area?

CRR and SMHM response to novel tidal marsh restoration such as constructed high tide refuge islands, native tidal marsh plant revegetation (e.g., *Grindelia* and *Spartina foliosa*), and transition zone restoration (for SMHM) has not been determined. Revisiting the high tide refuge island and revegetation analysis of CRR response conducted by Point Blue with five or more years of post-high tide refuge island construction and post-revegetation data may shed light on the efficacy of these enhancement actions for CRR recovery. Similar analysis efforts are needed for SMHM. A potential question for Phase 2 includes:

- What are the best practices for innovative tidal marsh and marsh-upland transition zone restoration that increase the resilience of tidal marsh dependent wildlife?

CRR response to invasive plants and their control (other than invasive *Spartina*) is not well known and represents a data gap. The impacts of invasive *Spartina* and its control on other marsh dependent bird species is not well known. SMHM use of areas with varying levels of invasive plant species including invasive *Spartina*, is not well known. Given that other strategies can be pursued to achieve project objectives, a question for Phase 2 includes:

- What is the impact of invasive species control relative to other strategies designed to achieve wildlife goals?

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

Valoppi (2018) identified the following potential Phase 2 studies (solid bullets). Hollow sub-bullets include notes, comments and clarifications from reviewers to these suggested studies:

- Fund implementation and test the effectiveness of the weed management plan to control other invasive species such as pepperweed (*Lepidium*).
    - One recommendation from reviewers was that the Project should be consistent with the South Bay Weed Management Plan which identifies yellow starthistle (*Centaurea solstitialis*), Algerian sea lavender (*Limonium ramosissimum*), and pepperweed as highest priorities. Invasive *Spartina* is referenced as being very important but covered under its own planning document.
    - Including a plan to measure weed control efficacy and impacts to special status species was recommended by reviewers.
- Repeat satellite imagery techniques used for establishing baseline vegetation types and extent to assess landscape level changes from Phase 1 restoration actions. The AMP recommends doing this every 5 years, beginning 5 years after the restored area has reached vegetation colonization elevation.

    - A project to address this need is underway. As part of the project, maps will be made from 2019 and 2020 satellite imagery.
    - Brian Fulfrost is coordinating with the ISP and is integrating some of their mapping products into his dataset, providing a good example of how the integration of datasets across disciplines can efficiently address management needs.
    - Mapping to quantify net-landscape change is under consideration by the WRMP to be completed at regular intervals (see Opportunities for Regional Synergy section in this chapter).
- Assess the habitat quality of the restored marsh by using adjacent established marshes as reference sites.
    - Habitat quality is defined and measured as described in Appendix 3 of the AMP (Trulio et al. 2007). For example, measures of plant species composition and diversity, vegetation density, presence of non-natives and T&E species compared to reference marshes and other restoration sites. Additional metrics could include other tidal marsh dependent Bird Species of Special Concern (Shuford and Gardali 2008) which are relatively easier to assess than less common or difficult-to-detect species.
- Conduct CRR surveys bay wide once the ISP is no longer conducting surveys.
    - The Project could work with other entities to expand the FWS Site-Specific Protocol to include other organizations' efforts, determining the appropriate sampling design, developing analysis-ready data downloads, summaries, and other visualizations that address knowledge gaps (see Knowledge Gaps above). The WRMP is also considering this approach to wildlife monitoring at the Estuary scale.
    - Estuary-scale surveys for SMHM are lacking and are needed to evaluate progress toward Project objectives. A proposal by the SMHM Working Group of the FWS Recovery Plan Implementation Team to address this gap was awarded in 2019.
- Evaluate marsh restoration projects from other bay restoration sites to evaluate best practices for features such as upland transition zones/ecotones, marsh mounds [high tide refuge islands], and revegetation.
    - Point Blue completed a transition zone study, and the results are summarized in this chapter. The potential benefits of high tide earthen refuge islands to local CRR and SMHM populations is still unknown and warrants study.
    - Use transition zone projections to identify high-priority restoration locations (e.g., anticipate where marshes will move to and identify the best areas to protect and restore for future transition zones).
    - Test the efficacy of using small scale woody debris such as harvested gumplant skeletons or other cuttings anchored to the marsh substrate as trellises to create high tide refugia using North Bay sites as an example (e.g., Giant Marsh and Muzzi Marsh; Olofson Environmental, Inc. 2012, and Marilyn Latta, pers. comm.).

Suggested from 2019 workshop and review input

- Include other tidal marsh dependent species in assessing response to restoration and management.
- Estuary-scale surveys for SMHM are lacking and would be needed to evaluate progress toward Project objectives. A proposal for such an effort was awarded to the SMHM Working Group of the FWS Recovery Plan Implementation Team.
- Map marsh surfaces with drones using "structure from motion" techniques to create 3D imagery.

- How should in-marsh tidal refugia features, such as marsh mounds be designed to benefit multiple species, including placement, density, and size of features.

OPPORTUNITIES FOR REGIONAL SYNERGY

Addressing the science needs for tidal marsh habitats and wildlife will benefit from coordinating monitoring efforts and sharing data across entities at the regional scale. Appendix A summarizes major ongoing wildlife monitoring efforts for birds and other taxa associated with tidal marsh habitat that the Project may consider coordinating with.

The WRMP has proposed tidal marsh habitat mapping at the Estuary scale and is considering CRR, SMHM, and several other indicators of tidal marsh habitat quality. There is also an opportunity to integrate the HEMP products into the WRMP mapping efforts. This synergy could be advantageous because the HEMP maps tidal marsh habitat based on plant assemblages in a way that is useful for understanding wildlife status, distribution and needs. There are opportunities for the Project to help the WRMP select sites in the South Bay to serve as reference or sentinel sites as well as key restoration sites that could be surveyed for CRR, SMHM, and other at-risk tidal marsh dependent wildlife (California Bird Species of Special Concern; Shufford and Gardali 2008). In the long run, the Project would greatly benefit from any insights into the effectiveness of particular restoration techniques or strategies that the WRMP may discover through its broad network of project and reference sites that use standardized monitoring. Aligning monitoring protocols with the WRMP and participating in the design and assessment of specific restoration strategies will benefit the project further by making more data available at larger spatial scales to better assess the efficacy of its management actions. Because the WRMP will not be finalized before Phase 2 science is implemented in 2020, coordination and integration will need to be iterative.

The Tidal Marsh Recovery Plan Implementation Team is a valuable resource for coordinating monitoring and information sharing that can help the Project track changes in CRR and SMHM abundance in relation to restoration and management at various spatial and temporal scales. This team is responsible for prioritizing and facilitating recovery actions and monitoring listed in the Recovery Plan. For example, the Project could present its planned recovery actions to the Recovery Plan Team for discussion which could lead to refined actions, ideas for synergies with other groups, and efficiencies in monitoring and assessments.

There are also opportunities to integrate with the San Francisco Bay Joint Venture's (SFBJV) efforts to use wildlife indicators to assess progress toward stated habitat goals. Co-locating survey sites that are of interest to the Project and the SFBJV will result in more efficient survey efforts and more robust assessments of response to restoration and management.

Two key groups working on tidal marsh restoration and management issues in different parts of the bay include the Napa-Sonoma Marsh Restoration Group and the Adaptive Management Advisory Team for the Suisun Marsh Habitat Management, Preservation and Restoration Plan.

EMERGING TECHNOLOGIES

The results and recommendations summarized above have demonstrated the utility of using wildlife survey data to assess and guide conservation actions. However, collecting such data on CRR and SMHM can be time-intensive and costly. It is important to look for new, more efficient ways of answering key questions and addressing knowledge gaps. Here, we present ways that new technologies can facilitate data collection, data integration, and knowledge sharing to achieve Project objectives more quickly and efficiently.

Autonomous sound recording units have been used to remotely collect data on wildlife in various habitats. Recording units are placed in the field and can record sounds during specified times. Powerful machine learning algorithms are used to identify wildlife species that are observed through the recordings. There have been pilot studies in Suisun Bay and South Bay testing the efficacy of this new technology for CRR and to a lesser extent, SMHM (Overton personal communication). Challenges include often needing to manually review audio to confirm species identification. This can be problematic for CRR whose not-so-melodic vocalizations can be difficult for algorithms to distinguish from other noises in the environment such as helicopters. Other limitations include not always being able to distinguish the number of individuals present. Nevertheless, this method is well-suited for establishing presence-absence and may be beneficial for detecting target species in newly restored areas prior to extensive protocol level surveys.

There is currently no process for generating and sharing streamlined and comprehensive region-wide summaries for the SMHM or CRR in an efficient, timely fashion. To address this need for CRR using informatics technology, Point Blue developed an online data entry and management application as part of the National Secretive Marsh Bird Database currently housed in the Avian Knowledge Network (AKN; avianknowledge.net) and shared by National Wildlife Refuges across the country. Users now have the ability to enter, proof and download secretive marsh bird survey data collected using the FWS Site-Specific Protocol. This new system greatly increases the ability to share data efficiently. Future work will include generating data summaries, trends in abundance, and population estimates that account for imperfect detection and the environmental factors that affect detection probability such as time of day and time of year of the survey.

The AKN can also accommodate multiple bird survey methods (e.g., point count, area search, shorebird census, and secretive marsh bird surveys). It is currently used by the Pacific Flyway Shorebird Survey which includes the annual SF Bay Shorebird Survey. One of the benefits of this technology is the enhanced ability to manage survey location information and the ability to integrate data across multiple users and at different spatial scales from the Project footprint, the Estuary, and national scales.

Lastly, mapping marsh surfaces with drones using “structure from motion” techniques to create 3D imagery can be a cost-effective way to assess changes in tidal marsh extent. This technique provides high resolution imagery that may be suitable for assessing fine scale changes to habitat features that are relevant to SMHM and other marsh-dependent wildlife such as smaller first order channels. Satellite or fixed-wing remote sensing techniques do not always capture these smaller features. See Emerging Technology in the Sediment Chapter for details about this new method.

ACRONYMS AND ABBREVIATIONS

Project: South Bay Salt Pond Restoration Project
ACR: Audubon Canyon Ranch
AKN: Avian Knowledge Network
AMP: Adaptive Management Plan (Trulio et al. 2007)
ARA: Avocet Research Associates
CDFW: California Department of Fish and Wildlife
CRR: California Ridgway’s rail
EBRPD: East Bay Regional Park District
ISP: Invasive Spartina Project
NPS: National Parks Service
SF: San Francisco
SFBBO: San Francisco Bay Bird Observatory

SFBJV: San Francisco Bay Joint Venture
SMHM: salt marsh harvest mouse
UCD: University of California, Davis
USGS: United States Geological Survey
USFWS: United States Fish and Wildlife Service
WRA: WRA Environmental Consultants
WRMP: Wetlands Regional Monitoring Program

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SEDIMENT DYNAMICS

RATIONALE AND BACKGROUND

Sediment dynamics were identified in the 2007 Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) as one of the key South Bay Salt Pond Restoration Project (Project) uncertainties that significantly hindered the ability to achieve Project Objectives (see detailed rationale in Appendix 1 of Trulio et al. 2007; Schoellhamer et al. 2005). Project Objective 1 is to create, restore, or enhance habitats of sufficient size, function, and appropriate structure to promote restoration and support increased abundance and diversity of native species in South San Francisco Bay. In order to create the desired tidal marsh habitats, one common strategy is to introduce tidal action to existing (non-tidal) and generally subsided diked ponds, raising their bed elevation via natural deposition of sediment that would enter with the tides through strategic levee breaches. However, opening ponds to tidal action also increases the volume of water between low and high tide, known as the tidal prism. This results in increased tidal velocities, which can cause erosion of existing mudflats or scouring of subtidal channels (though increased channel conveyance is often a positive). The potential trade-off between accretion in restored ponds and erosion of existing habitat outside of them was a key question at the onset of the Project.

Key Uncertainty - *Is there sufficient sediment available in the South Bay to support marsh development without causing unacceptable impacts to existing habitats?* (Trulio et al. 2007)

Two Applied Studies questions were developed to address the key sediment science gap[6]:

1. Will sediment accretion in restored tidal areas be adequate to create and to support emergent tidal habitat ecosystems within the 50-yr projected time frame?
2. Will sediment movement into restored tidal areas significantly reduce habitat area and/or ecological functioning (such as plankton, benthic, fish or bird diversity or abundance in the South Bay?

These questions were addressed as part of Phase 1 studies to understand:

- larger-scale sediment movement into and out of the South Bay (Schoellhamer et al. 2013a, 2013b, 2015; Shellenbarger et al. 2013, 2014)
- sediment deposition rates in restored ponds (Callaway et al. 2009, 2013)
- changes in extent of marsh and mudflat habitat (Fulfrost et al. 2012, 2015a, 2015b; Foxgrover et al. 2014)

The results of these Phase 1 studies were synthesized in Valoppi (2018) and indicated that there is currently sufficient sediment in the Lower South Bay to restore breached ponds of the Alviso complex to marsh elevations while maintaining existing habitats such as mudflats. It is not clear whether there is currently sufficient sediment in other parts of South Bay (i.e., around Eden Landing and Ravenswood complexes). In addition, according to Valoppi (2018), there were also "data showing a decreased sediment supply into San Francisco Bay, and future sea level rise projections suggest[ed] that there will

[6] A third Applied Study question regarding the potential impact of pond breaching on flood risk management of adjacent communities (Project Objective 2) was originally included as part of the sediment dynamics uncertainty in the AMP. This issue has been addressed in detail on a project-by-project basis via hydrodynamic modeling as part of restoration planning, design, and permitting (e.g., Final Environmental Impact Report, Phase 2, Eden Landing Ecological Reserve), and will continue to be addressed with new projects. As such, we do not include further discussion related to flood risk management in this chapter.

be additional sediment demand for maintenance of marshes and mudflats." Therefore, managers have begun measures to bring in additional upland fill material for transition zone and upland habitats (e.g., Alviso/Ravenswood Final Environmental Impact Statement/Report, Phase 2 [U.S. Fish and Wildlife Service and State Coastal Conservancy 2016]). Managers have also been investigating the potential for beneficial reuse of dredged sediments to raise bed elevations of subsided ponds (e.g., Moffatt and Nichol et al. 2015; Eden Landing Ecological Reserve Final Environmental Impact Report, Phase 2 [CDFW et al. 2019], SCVWD Stream Maintenance Program for Pond A8 ecotone levee).

RECENT INFORMATION

Regional sediment dynamics

A key new synthesis of trends in larger-scale sediment supply to the San Francisco Bay was completed by Schoellhamer et al. (2018). The report synthesized results from Water Years[7] (WY) 1995-2016 of (1) sediment supply from the Delta and local Bay Area watersheds, including estimates of storage and removal from flood control channels, (2) sediment transport between sub-embayments, and (3) discussed scenarios for future sediment supply to San Francisco Bay in light of climate change.

Sediment supply from terrestrial sources to San Francisco Bay during this 22-year period was approximately 2 million metric tonnes/year (Schoellhamer et al. 2018). Of that total, 37% was supplied from the Central Valley through the Delta. The remaining 63% came from local tributaries that drain directly to the Bay, most of which came from the three largest North Bay tributaries (Sonoma Creek, Napa River, and Walnut Creek). The local tributary contribution to the Bay was likely an overestimate because it does not account for deposition that occurs in the tidal portion of the channel (i.e., measurements were taken above head of tide; M. McWilliams and B. Jaffe, pers. comm.). SFEI has deployed 7 high frequency turbidity sensors to refine tributary inputs of sediment to the Bay (T. Hale, pers. comm.).

The three largest Lower South Bay tributaries (Coyote Creek, Guadalupe River, and San Francisquito Creek) contributed about 3% of the total mean suspended sediment load coming from local tributaries to the Bay from 1995-2016 (Schoellhamer et al. 2018). As discussed further in the Alviso Slough section below, deposition volumes on shoals in the Far South Bay and in the breached Alviso ponds suggest that much of the sediment originates from the Bay (Van der Wegen et al. 2018, Foxgrover et al. 2019). If pond accretion is largely from wider Bay sources, it is important to understand how factors acting outside of the immediate South Bay tributary watersheds may affect future supply.

New research by Renee Takesue (USGS, personal communication[8]) using sediment geochemical signatures found that sediment deposited on South Bay shallow subtidal shoals (grab samples from upper 0-2 cm active sediment layer) matched those of sediment originating from the Delta (Sacramento and San Joaquin rivers) and from Alameda Creek and the Guadalupe River, but not from San Francisquito Creek at the time of the study. Sediment sources from other tributaries around the Bay or from offshore were not included in the analysis. However, in order to understand how much sediment (in terms of mass fraction) originates from these sources, the results would need to be translated into a sediment budget from tributary load data. In addition, the study did not take into account the age of deposited sediment, which is challenging but important in order to differentiate between historical vs. modern sediment sources. There is geochemical evidence to suggest that some of the sediment in the

[7] Most agencies in California define a Water Year (WY) as October 1 through September 30 of the following year. As an example, Water Year 2018 starts on October 1, 2017 and ends September 30, 2018.

[8] Preliminary results in review with shareable product anticipated in early 2020.

active layer originated from historical (pre-development) tributary source material that has been moving around the Estuary for decades or more. Specifically, one of the strongest geochemical signatures detected in South Bay shallow subtidal shoals can be linked to geologic rock types found in the upper watersheds of the South Bay, supply from which has been largely cut off by dams. This suggests that some fraction of sediment currently depositing on the shoals is old material delivered to the Bay prior to damming of the South Bay tributaries, which is resuspended and mobilized by current Bay/tidal hydrodynamics. Thus, it is not a "modern" tributary source that would continue to supply the South Bay. Further work would be needed to understand the relative importance in terms of origin of modern and potential future sediment load for the Project.

Supply from the Delta had a step-decrease (abrupt change) observed at WY 1999, with a continued (though not statistically significant) slight decreasing trend after WY 1999 that was largely driven by decreased discharges during the 2012-2016 drought (Schoelhammer et al. 2018). Identifying trends in local tributary supply was limited by poor data availability. The authors noted a downward trend, punctuated by extremes during drought or high discharge years, but that more information on local land use change and climatic variability is needed to interpret temporal trends. They do note a particular decline in supply from the Guadalupe River relative to the late 1950s-early 1960s, which may be due to a recovery from the pulse of sediment that resulted from historical land use changes (Schoelhammer 2011). Thus, inter-annual climatic variability, land use change, and climate change drivers are critical to future supply.

There is an interplay between wet and dry years, as well as Delta vs. local tributary sources that complicates forecasting of future sediment delivery to the Lower South Bay. Higher flow years tend to mobilize and deliver more sediment to the Bay as a whole, and locally to the Project as was observed in the Guadalupe River during WY 2017 (Foxgrover et al. 2019). However, net sediment import from the Central to the Lower South Bay *decreases* during wet years (Livsey et al. in review, as cited in Schoelhammer et al. 2018; Shellenbarger et al. 2013), because the gradient in salinity between the North and South Bay drives the circulation of sediment (Livsey et al. 2018, Downing-Kunz et al. 2017). While the majority of sediment delivered from small tributaries during high flows is more likely to be trapped in the Bay (delivered directly through slough channels to Bay mudflats), larger freshwater discharges from the Central Valley can cause net export of sediment out the Golden Gate. With changes in future discharge patterns, the net effect on future pond accretion from these interacting mechanisms is unclear.

Schoelhammer et al. (2018) conclude that the net effect of changes affecting supply from the Delta going forward "are uncertain, but appear likely to produce little net change in present sediment supply." Factors influencing sediment supply from the Delta include legacy effects from Sierra/Central Valley land use change, hydraulic mining, and dam construction, as well as current and future effects from changes in storm intensity, rainfall, snowpack, water management, invasive aquatic vegetation, sea level rise, and declines in wind speed. Sudden changes in supply could also occur, for example through unplanned breaches that permanently inundate Delta islands or from a record flood.

Schoelhammer et al. (2018) conclude that existing monitoring data on local tributary inputs are insufficient to determine current trends. Given that the majority of sediment to the Bay as a whole is now coming from local sources, forecasting trends in future supply will require improving monitoring and modeling of local tributaries to account for multiple interacting drivers. Regional efforts are underway to begin a more coordinated approach to understanding future sediment dynamics, and are discussed in the Regional Synergies section below.

Local sediment dynamics in Alviso Slough

Since completion of the Phase 1 synthesis (Valoppi 2018), sediment dynamics in the Alviso Slough area have been tracked via (1) twice yearly bathymetric surveys that provide a picture of seasonal and interannual trends in accretion/erosion at a broader spatial scale (A. Foxgrover, pers. comm.; Foxgrover et al. 2018, 2019), and (2) high frequency water quality sampling and flux measurements at limited locations, which provide a direct measure of sediment movement (e.g., into and out of the breached ponds) that can be used to understand daily (tidal) and seasonal patterns and help interpret the accretion/erosion trends observed from bathymetric surveys (M. Downing-Kunz, pers. comm.). Some of these data were used to develop a two-dimensional geomorphic model for Alviso Slough (Van der Wegen et al. 2018). A coordinated synthesis of results from bathymetry, water quality/sediment flux, and mercury mobilization studies conducted from 2016-2018 is in preparation (Marvin-DiPasquale, pers. comm.), but we provide some key highlights from personal communications with researchers below.

Bathymetric surveys conducted in the spring and fall each year from 2010 through 2017 have been processed and published (Foxgrover et al. 2018, 2019). These surveys covered the area from Calaveras Point east (a) up Coyote Creek to the railroad bridge, (b) up Alviso Slough to the railroad bridge, and (c) up Guadalupe Slough to just past the last breach of Pond A6. Foxgrover et al. (2019) found an increase in erosion during the winter and declines in erosion/net deposition during the spring/summer months. Erosion rates varied across years in ways that did not correspond entirely with restoration activities. Episodic winter events had significant short term impacts but general patterns of erosion/deposition were governed by larger scale sediment transport processes. Overall, approximately 75% of the slough area was net erosional between 2010 and 2017, and the remaining 25% was net depositional (Foxgrover et al. 2019). Scour of the tidal slough can increase channel-flow conveyance, which was noted as a strategy for improving upstream flood risk management in the 2007 Project Environmental Impact Statement/Report (USFWS and CDFW 2007). However, the erosion in the lower slough was 7 times less than the total estimated deposition within Pond A6 (Foxgrover et al. 2019, Callaway et al. 2013). Thus, while pond breaching did result in the anticipated erosion of the adjacent slough, sediment is being transported into the ponds from sources beyond the immediately adjacent slough channel (Foxgrover et al. 2019).

Based on sediment flux measurements, sediment was largely transported landward from the Bay into Alviso Slough and the breached ponds, except for during winter storm events when transport was predominantly bayward (M. Downing-Kunz, pers. comm.). In general, results from the sediment flux station at the Pond A8 tidal control structure indicate the pond is net depositional—water coming in from Alviso Slough was turbid, and water exiting the pond was clear (M. Downing-Kunz, pers. comm.). Thus, while accretion rates have not been directly measured in Pond A8, flux data indicate it is likely accreting despite restricted tidal exchange, its location further up the slough where tidal transport is lower, and its greater potential for wind-wave induced resuspension due to its larger size and fetch (Foxgrover et al. 2019). Measurements of accretion in Ponds A6 and A21 in 2016 showed continued deposition as well (Downing-Kunz et al. 2017).

Van der Wegen et al. (2018) noted that, in addition to accretion within the ponds, shoals in the Bay had deposition that far exceeded the erosion volumes from Alviso Slough, meaning that most of the deposited sediment must have come from the Bay. Their 2D geomorphic model for the Alviso Slough/ponds area reproduces similar patterns and volumes of erosion and deposition as was observed by Foxgrover et al. (2019) in the slough and Callaway et al. (2013) in the ponds. The model indicates that from 2010 to 2017 the majority of sediment enters the slough and ponds from the Bay during low river flow periods, with flow pulses providing episodic sediment from the Guadalupe River. They state that the “importing trend from the [Bay] eventually dominates sediment supply over a year” with the exception of the very large 2017 flow event. They note, however, that

> “the origin of the deposited material is also difficult to determine. The modeled deposition may originate both from the sea [i.e., wider Bay] and the [Guadalupe] river. It is also possible that sediment deposited seaward during a flow event are later transported landward [by tidal action] during low flow conditions. Layering of the bed by subsequent deposition events (low flow versus high flow) further complicates analysis. This may be solved by adopting a bed layering in the model, a feature that became available in March 2018.”

The fraction of sediment depositing into restored ponds from the Bay could be constrained by the volume deposited, and from the known quantities of sediment coming from (1) the Guadalupe River load after breaching the levees in Pond A6 (known), and from (2) erosion of Alviso Slough (B. Jaffe, pers. comm.).

Lessons learned from North Bay restorations with tidal breaching

The Sears Point Restoration Project in San Pablo Bay (Sonoma Land Trust, USFWS-SPBNWR) restored 1,000 acres of diked Sonoma baylands to tidal action via levee breaches in 2015. Initial results indicate that after 1.75 years, average annual accretion was 6-12 in/yr with a maximum of 36-42 in/yr (Meisler 2018). This is similar to the high accretion rates observed in Pond A6 (Callaway et al. 2013, Downing-Kunz et al. 2017). The Sears Point restoration site shares similarities with South Bay Pond A6 in terms of heavily subsided initial elevations (subtidal to mudflat relative elevations), and being in a region of relatively high suspended sediment concentration (Veloz et al. 2014). High tide refuge islands at Sears Point, which were installed to promote sediment deposition and act as foci for native plant establishment, experienced substantial erosion post-restoration (~0.5 m) (Meisler 2018). Project managers felt that this was because the high tide refuge islands were not vegetated with deeper-rooted wetland species prior to site restoration. Native *Spartina* planted in the spring of 2018 seems to be establishing well on the high tide refuge islands and future monitoring will focus on vegetation spread and how sedimentation rates change within vegetated areas vs. those without vegetation (Meisler 2018).

The Cullinan Ranch Restoration Project in the San Pablo Bay National Wildlife Refuge (US Fish and Wildlife Service) restored 1,200 acres of diked baylands to tidal action via levee breaches in 2015. Initial results indicate that 2 years after breaching, areas within the restoration site have accumulated sediment at an average annual rate of 0.5-2.5 in/yr (Washburn 2018). This is less than the rate of sedimentation in the very subsided Pond A6, but on par with the rate at the higher elevation Pond A21 (Callaway et al. 2013, Downing-Kunz et al. 2017). Relative to Pond A6, the Cullinan Ranch Restoration Project site had slightly higher initial relative elevations (more mudflat relative to subtidal elevations) and is in a region with lower suspended sediment concentrations relative to the South Bay (Veloz et al. 2014).

An additional 300 acres at Cullinan Ranch are under construction and have been receiving beneficial re-use of dredge material to raise internal elevations prior to breaching. As of November 2019, they have received about 1 million of the total 3 million cubic yards of material estimated to be needed to achieve mid-marsh elevation, with slightly more likely needed as material settles (S. Carroll and N. Washburn, pers. comm.). There are ongoing conversations about the final target elevation, with concern that if it becomes higher than mid-marsh it will be harder for channels to form when the site is breached, but in the long-term this may not be high enough to keep up with rising seas. Material has come from maintenance dredging activities, typically fine silt and clays from the Napa River, Port of Richmond, Foster City, and smaller marinas. In addition to funding and permitting challenges, the following are some of the logistical lessons learned to date (S. Carroll and N. Washburn, pers. comm.):

- Challenges that limit the number of dredge contractors willing or able to supply dredge material to the site:
    - Lack of an offloader at the site—any contractor wishing to deliver material to the site must supply and operate their own offloader.
    - Difficulty navigating to the site—three bridges must be navigated between the Bay and the offloading site in Dutchman's Slough, limiting the size of scows that can transport the dredge material. Only a few contractors have the smaller scows necessary to access the site.

        Note: access to Eden Landing will be depth limited because of the large mudflat fronting the site (requiring an offloader further offshore), but this won't limit the size of the scows.
    - It is often cheaper for the contractors to dispose of material at the San Francisco Deep Ocean Disposal Site (outside the Bay) or at the Montezuma wetland restoration site (which has an on-site offloader and easier access).
    - As new beneficial re-use sites come online there will be added competition for the limited dredge material. Currently 3 million cubic yards are dredged each year, and only ½ million cubic yards are slated for beneficial re-use.
- Challenges related to keeping the site wet (permitting restrictions from the San Francisco Bay Regional Water Quality Control Board require that the material pumped onto the site is kept wet to avoid mercury methylation):
    - As the goal is to raise the bed elevation to mid-marsh, above the tides, an additional fish screen and intake had to be installed to keep the delivered material wet.
    - The flooding of these 300 acres means they are now experiencing erosion on the inside of the levees.
    - Because the site is kept wet, no additional regrading or adjustment of topography can be made. This includes microhabitat enhancements (e.g., adding more high tide refuge islands), as well as dealing with a sloping grade that has developed from the episodic nature of the dredge slurry import process.

The Napa River Salt Marsh Restoration Project, which is part of the Napa-Sonoma Marshes Wildlife Area (CDFW), has restored approximately 7,300 acres of former salt ponds to tidal action in various phases starting in 1997 (Taylor 2018). Approximately 3,000 acres (Ponds 3-5) are targeted to achieve tidal marsh habitat, whereas other ponds will remain muted or managed for deeper water habitat. The majority (75%) of sedimentation plates in Ponds 3-5 show accretion from year 2007 to year 2017, with some erosion in areas of Ponds 3 and 5 (Erickson et al. 2018). The average annual accretion rate was ~0.5 in/yr, with a maximum of ~1.6 in/yr (Erickson et al. 2018). Results and the environmental setting relative to the South Bay are similar to those of Cullinan Ranch. Marsh vegetation development remains just under the 20% cover threshold that would trigger more detailed monitoring (Erickson et al. 2018). Thus, the ponds targeted to achieve tidal marsh habitat appear to be accreting and transitioning to tidal marsh as expected.

KNOWLEDGE GAPS

Management-relevant knowledge gaps have evolved with results from Phase 1 studies, considerations of the future natural sediment supply, projected increase in the rate of sea level rise, and increased demand for sediment from other restoration and sea level rise adaptation projects around the Bay.

Phase 1 Applied Study Question #1: Will sediment accretion in restored tidal areas be adequate to create and to support emergent tidal habitat ecosystems within the 50-year projected time frame?

Results of Phase 1 studies show current rates of sediment accretion are sufficient for restored ponds to accrete to desired marsh elevation at least in the Lower South Bay. However, recent studies suggest that supply may be reduced in the future depending on precipitation patterns and changes in upland land use. Rates of sea level rise are expected to accelerate by mid-century, and there is uncertainty on the net effect of multiple factors driving regional sediment supply and dynamics, including the expansion of restoration/adaptation projects around the Bay, land management, dam removals in the Delta watersheds or locally (Searsville Dam removal anticipated Fall 2020), climatic, and ecological factors, that need to be synthesized to determine the likely range of expected future outcomes. Work by Foxgrover et al. (2019) and Van der Wegen et al. (2018) suggests that Alviso pond accretion is likely dominated by contributions from the Bay except for during high flow events. Work by Takesue (pers. comm., paper in prep) shows provenance of fine sediment depositing on shallow subtidal shoals is connected to at least two major South Bay tributaries (Alameda Creek and Guadalupe River), as well as the Delta, but some of this is likely old material deposited into the Bay before tributaries were dammed, and a sediment budget would be needed to understand how much sediment (i.e., mass fraction) is coming from each source. Understanding the provenance, age, and mass fraction by source of sediment accumulating in the ponds is helpful to identify how potential changes in supply might affect accretion going forward.

In addition, there is uncertainty in the spatial variation of sedimentation in the South Bay. Based on historical trends of long-term bathymetric change throughout the South Bay, ponds breached in the Eden Landing Ecological Reserve or the Ravenswood Complex would not be expected to accrete at the high rates observed for the Phase 1 Alviso breaches (Jaffe and Foxgrover 2006a and b, Foxgrover et al. 2004), though we note that the Ravenswood Ponds are not subsided and therefore don't need as much sediment to achieve target marsh elevation. The east shore where Eden Landing is located is also sandier and more erosive (B. Jaffe, pers. comm.). This local context is critical for planning and prioritizing potential management interventions such as strategic dredge placement (placing sediment in the subtidal or on the mudflats near the pond edges so that it can be carried by tidal flows into the ponds after they are breached) or thin layer placement of sediment on the marshes. Thus, potential questions for Phase 2 applied studies include:

- Will current high rates of sediment accretion be maintained in the future, and will accretion be enough to restore and maintain target habitat ratios in light of sea level rise and other projected climate- and land use-changes? Related to this are more specific management questions:
    - Will there be sufficient naturally occurring sediment delivery for marsh restoration to outpace sea level rise? What if restoration implementation is accelerated (e.g., additional ponds breached sooner) to increase resilience to sea level rise?
    - If natural sediment delivery is not enough to achieve target habitat objectives, what is the additional sediment demand needed for augmentation, how might locations be prioritized, when would augmentation need to be implemented, and what is the best source of sediment (e.g., dredge vs. upland)?
- What is the spatial variation of sediment accretion throughout the South Bay, and how may that influence achieving restoration objectives across the different Project units?
- What is the provenance of sediment accumulating in restored ponds? What fraction comes from local "feeder" tributaries vs. sources outside the South Bay, and how is this projected to change in the future?

   - Existing data and modeling can likely be used to answer this for Alviso ponds, and the fine sediment geochemical provenance study by Takesue (discussed in Recent Information section) could be leveraged and built upon.

Phase 1 Applied Study Question #2: Will sediment movement into restored tidal areas significantly reduce habitat area and/or ecological functioning (such as plankton, benthic, fish, or bird diversity or abundance in the South Bay)?

Results from Phase 1 studies showed scour of adjacent slough channels but no significant loss of adjacent mudflat habitat with tidal breaching. However, there may be a threshold reached as larger areas are restored and the effect on the tidal prism and resulting scour increases, or if there are decreases in sediment supplied to the South Bay. In addition, there was limited study as part of Phase 1 with respect to changes in ecological function of the mudflats (i.e., quality for supporting benthos, fish, or wildlife) (though, see work by Takekawa et al. on SF2 and A6 mudflats). One specific knowledge gap that emerged from Phase 1 was the potential for restoration actions to affect the distribution and abundance of biofilm on the mudflats, which is an important food source for shorebirds (Kuwae et al. 2008) and has the potential to sequester carbon (Schile et al. 2017). Thus, potential questions for Phase 2 applied studies include:

- Will sediment movement into restored tidal areas continue to have limited effect on adjacent mudflat habitat extent (quantity) or ecological functioning (quality; including biofilm)?

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

Valoppi (2018) identified the following for potential study in Phase 2. Hollow sub-bullets include notes, comments and clarifications from reviewers to these suggested studies:

- Continued study is needed to evaluate the amount of sediment entering far South Bay and the sediment accumulation in breached ponds of Eden Landing Complex and future breaches at Ravenswood Complex as the spatial variability in sediment accumulation rates is unknown.
   - This was re-emphasized by participants at the September 2019 Science Synthesis workshop.
- Studies are needed in Phase 2 to understand the extent of mudflat habitat, to develop cost-effective and accurate methods to map baseline conditions and track future changes in mudflats, and to determine how restoration actions may affect the quantity or quality of that habitat.
   - Tracking the quantity of mudflat habitat is included in the HEMP 2 study detailed below.
- Studies are needed to map the extent of biofilm, to understand its importance to shorebird foraging, and to learn how restoration actions might alter biofilm.
   - There are two biofilm studies currently underway; one is part of the Phase 2 funded HEMP study, and the second is a USGS-funded study. Both are detailed below.

Suggested from 2019 workshop and review input

The following were additional knowledge gaps and potential studies identified during the September 2019 Science Synthesis workshop:

- Uncertainty regarding the order/sequencing of pond breaching to best leverage natural sediment dynamics and maximize pond accretion. Breach location influences sediment dynamics, so does it make more sense to breach upstream ponds first and then bayside ponds,

or vice versa? Are there local or sub-regional differences? Are there temporal factors to consider (e.g., episodic events that deliver majority of sediment)? Need to track where sediment is going and how to best route sediment to marshes (e.g., consider channel shape).
  - WRMP is hoping to look at these questions around the bay (if funded).
- Need sediment management priorities - where to prioritize restoration based on best potential for long-term resilience?
  - Long-term landscape evolution modeling needed (projecting forward to future conditions).
  - Sediment transport/dynamics models that account for sea level rise and changes in supply have been developed for the USACE (see also Van der Wegen et al. 2018 discussed previously).
- Consider pilot studies for sediment management practices.
  - Strategic placement of dredge material as method of increasing sediment delivered to mudflats and ponds/marshes (could build from planned USACE pilot studies). Placement should depend on local context (e.g., spatial variation of sediment dynamics).
  - Consider use of "warping": accreting into managed ponds through water control structure (let sediment rich water in, close gates so that it can settle and/or water evaporate) to slowly build up elevation over time.
  - Are there practices or conditions that could promote increased flocculation (settling velocity), for example inside a managed pond, to increase SSC and deposition?
- The positive feedback of vegetation development on deposition rates are not considered in most current SLR resilience work.
- Potential for lateral erosion of marsh are also not considered in most current SLR resilience studies. Restorations tend to leave levees in place and breach in discrete locations – but there is a potential erosion of the levees themselves – which could lead to rapid loss of marsh, as has happened in Corte Madera.
  - What would the marsh edge be, and how would it develop, if there were not levees?
  - Consider how the shape will evolve and incorporate this into management plans for the natural system. This is not necessarily engineering permanent levees, but rather considering implications (perhaps via models) of loss of levees and subsequent effects in different parts of the bay.
- There was mention of the importance of (1) understanding the historical context of sediment dynamics, and other factors influencing wetland elevations such as tectonics, land subsidence, the history of groundwater extraction, and the potential for sea level rise to increase above ground decomposition, and (2) vertical control benchmark network necessary for accurate long-term monitoring of elevation changes.

Funded Phase 2 studies

Mapping habitat change through time with remote sensing (Fulfrost HEMP studies)

Capturing habitat change through time is necessary for tracking long-term trends in the distribution and extent of restored vegetated marsh vs. mudflat habitat. Remote sensing approaches can more efficiently capture temporal habitat change over the large geographic area of the Project. Vegetated marsh habitats were mapped for the entire study area via satellite remote sensing in 2009-2011, as part of the Habitat Evolution Mapping Project (HEMP) (Fulfrost et al. 2012). Technical challenges in mapping mudflat habitat were resolved with subsequent work, which provided a comprehensive map of mudflat habitat distribution and extent representative of conditions from April 2016 (Fulfrost et al. 2017).

As a part of current Phase 2 funding, the remote sensing habitat mapping approaches developed by Fulfrost et al. (2012, 2017) are being repeated for 2019 and 2020 (Fulfrost 2019, Fulfrost pers. comm.). The "HEMP 2" study will include intertidal mudflat, and vegetation classes found in and representative of low, mid and high marshes will be mapped throughout the study area and will be modeled at both the vegetation alliance and association level. Habitat maps from 2019 and 2020 will then be compared (i.e., change analysis) to the 2009-2011 habitat maps for vegetated habitat classes, and the 2016 map for mudflats. In addition, HEMP 2 will pilot methods to map certain invasive plant species such as perennial pepperweed (*Lepidium latifolium*) and slenderleaf iceplant (*Mesembryanthemum nodiflorum*), and will coordinate with the Invasive Spartina Project to attempt to differentiate native vs. invasive *Spartina* species. Lastly, the new effort will also map biofilm distribution and extent, and try to improve the prior 2016 mapping methodology (Fulfrost et al. 2017) with higher spectral resolution imagery acquired for 2019.

As of the end of July 2019, the effort has acquired nearly optimal (right at Mean Lower Low Water [MLLW]) WorldView 2 satellite imagery on June 8th over the study area, begun preliminary preprocessing of the imagery (georeferencing, atmospheric correction, pansharpening), and conducted two sets of ground truthing (Fulfrost, pers. comm.). Additional ground truthing is planned for the fall. Preliminary maps from the June 2019 imagery are expected to be available in early 2020, and change analysis will begin in spring 2020.

The intermediate and end products of the HEMP studies could be further leveraged for other analyses—for example, to look at habitat connectivity or to better understand wildlife-habitat relationships, such as between bird foraging and biofilm distribution.

Quantifying Drivers and Stressors of Intertidal Biofilm Resources (USGS)

The USGS is beginning a study titled "Quantifying the Drivers and Stressors of Intertidal Biofilm Resources at the Largest Tidal Wetland Restoration on the U.S. West Coast" (PI's: De La Cruz, Woo, Byrd, Palacios). The study seeks to (1) identify seasonal and spatial variations in biofilm distribution, quantity, and quality across the South Bay, and (2) understand the role of physical and biological factors that influence biofilm distribution (S. De La Cruz, pers. comm.). Researchers will employ a multi-scalar approach that combines field measurements, unoccupied aerial systems (UAS), and multispectral satellite imagery to quantify biofilm dynamics. The study will develop integrated field data and remote sensing methodology to track biofilm at scales relevant to the Project, improve our understanding of mudflat ecology, and clarify how Project restoration activities may be affecting this priority resource.

Bathymetric Surveys (USGS)

The USGS provided resources to continue bathymetric field surveys in the Alviso Slough area in the spring of 2018 and 2019 (A. Foxgrover, pers. comm.). Recent funding from the Coastal Conservancy will allow the field data to be processed and published. The full length of Guadalupe Slough was added to the 2019 survey, which will provide a baseline prior to opening any new breaches to Guadalupe Slough.

USGS also conducted a series of bathymetric surveys covering the western tidal flats and deep bay channel near SF2 just south of the Dumbarton Bridge (A. Foxgrover, pers. comm.). The surveys began in December 2008, were conducted 3 times per year in 2009 and 2010, with a final survey in January 2011. However, the data have not been fully post-processed or published. The surveys were done in coordination with benthic sampling (PIs Takekawa, Woo) and aim to understand how sea level rise will affect shorebirds that forage on the tidal flats (PIs Gustafson, De La Cruz).

OPPORTUNITIES FOR REGIONAL SYNERGY

There are several collaborative regional efforts focused on understanding sediment dynamics and developing sediment monitoring plans within the San Francisco Bay, many of which have initiated in the last 1-2 years. Engagement and collaboration in these efforts can provide the Project with an opportunity to leverage resources and understand how Project Objectives are affected by broader regional sediment dynamics and projected changes to those dynamics, as well as how Project restoration activities fit within the broader San Francisco Estuary context. In terms of understanding sediment dynamics, all but the first collaborative projects/programs described below are developing recommendations or plans for regional sediment monitoring that are expected to be released toward the end of 2019 or early 2020. Thus, there is a timely opportunity for the Project to learn from and integrate plans for Phase 2 sediment studies into these developing regional networks.

Suspended Sediment Monitoring

Suspended sediment concentration data will continue to be measured at the Dumbarton Bridge as part of a Bay-wide long-term monitoring effort by USGS, which is integrated with the Bay Regional Monitoring Program discussed further below (M. Downing-Kunz, pers. comm.). Data through WY2016 were synthesized as part of the Schoelhammer et al. (2018) study summarized above (Recent Information). Continuously recording optical sensors measuring turbidity are deployed at two depths, and then calibrated to periodically collected water samples (M. Downing-Kunz, pers. comm.). However, flux measurements, which are necessary for understanding the direction and magnitude of suspended sediment exchange between the Lower South Bay and the rest of the Bay, are only funded through 2019 (M. Downing-Kunz, pers. comm.).

Healthy Watersheds, Resilient Baylands Project

The San Francisco Estuary Institute (SFEI), with funding from the Environmental Protection Agency, is leading the development of a regional science strategy to meet the following objectives: [S. Dusterhoff, pers. comm.]

1. Understand what the future sediment supply to the bay might be given a range of plausible future sea level rise and precipitation scenarios, and how potential changes in sediment supply dynamics will match with the projected restoration demand.
    - The study will forecast supply vs. demand for a range of plausible scenarios of sea level rise, and two possible futures of precipitation change (drier future, wetter future) to forecast changes in sediment supply from the Delta and local tributary sources, projected out to 2050 and 2100. As a measure of restoration demand, the study will quantify the amount of fill necessary to achieve vegetated marsh elevations in areas mapped for potential restoration to achieve the Baylands Goals. They presented preliminary results to Management and Technical Advisory committees in November 2019, which included representation from the Project. A draft report is expected in January 2020 and will be finalized in March 2020.
2. Identify baylands that have high vs. low potential resilience, in light of the future scenarios of supply/demand forecasted from objective #1 (above), and taking into account potential migration space and changes to infrastructure.
    - The goal is to interpret what projected changes mean for the regional story of bayland resilience, and to produce a regional resilience map that can inform sediment management and prioritization of restoration efforts.
3. Develop sediment management recommendations for the different "resilience" areas around the bay.

4. Develop sediment monitoring recommendations, based on all of the above, to track performance of various sediment management strategies.

The last two items are being coordinated with the three regional sediment monitoring and management efforts discussed below.

Bay Regional Monitoring Program - Sediment Workgroup

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has been tracking sediment in the bay since 1993 as part of broader water quality monitoring, because sediment transport is linked to the fate and transport of many priority pollutants. A new Sediment Workgroup has recently formed to focus on understanding the supply and movement of sediment within the Bay as it relates to tidal wetland resilience in the face of rising seas (S. Dusterhoff, pers. comm.). SFEI received funding from the RMP to develop an integrated sediment monitoring strategy. There is overlap and synergy with the Healthy Watersheds Resilient Baylands project, as well as with the two other regional sediment working groups described below. The RMP group is more focused on understanding the fate and transport of sediment from the open bay. This is relevant to the Project because in many water years there is net import of sediment to the South Bay from the open bay, and thus changes in sediment dynamics in the open bay may be critical to the continued accretion of restored ponds.

Wetlands Regional Monitoring Program - Physical Processes Working Group

While the RMP (above) is focused more on understanding sediment dynamics between the open Bay and mudflats/marshes, the WRMP is more focused on sediment dynamics between feeder channels and marshes (S. Dusterhoff, pers. comm.).

One of the working groups providing input for the development of the WRMP monitoring plan is focused on physical processes, and is led by Christina Toms of the San Francisco Bay Regional Water Quality Control Board. The WRMP physical processes working group is currently refining a set of monitoring elements that includes suggested data sources/methods/standard operating procedures (SOPs), locations, frequency and timing of monitoring, and specific indicators and metrics that will be tracked[9]. All of the suggested WRMP monitoring elements are relevant to the Project, including:

1. Remote sensing of wetland habitat diversity and abundance, habitat condition, elevation capital, and shoreline change.
    - We note that the methodology being proposed by the WRMP to map distribution and abundance of wetland habitat types is different from that of the Fulfrost et al. Phase 2 HEMP study. The HEMP methodology resolves finer vegetation classes (alliances and associations), but does not directly measure elevation. Elevation change is key to multiple WRMP management questions; as such, it is a focus of the WRMP monitoring framework (C. Toms, pers. comm.). Opportunities to leverage and collaborate are being explored (B. Fulfrost, pers. comm.).
2. Topographic surveys (i.e., Real-Time Kinematic Global Positioning System or RTK-GPS transects) and point measurements (i.e., Sediment Erosion Tables or SETs) of wetland elevations to monitor tidal marsh accretion/erosion and other geomorphic change.
3. Time series water surface elevation (WSE) monitoring to track frequency, depth, and duration of inundation on tidal wetlands.

[9] Source: WRMP in-progress master matrix, September 2019

4. Time series suspended sediment monitoring to track sediment supply and transport dynamics. This will likely use remotely-sensed imagery with ground-based calibration for larger spatial scales, as well as field-deployed sondes for more site-specific scales.

Some of these monitoring elements have relatively well-established SOPs, while others (particularly remote sensing) will be identified during the second phase of program development to address the specific needs of the WRMP and its stakeholders.

San Francisco Bay Conservation and Development Commission Regional Sediment Management

The San Francisco Bay Conservation and Development Commission (BCDC) sediment management team has developed a Regional Sediment Management Plan (RSMP) for the Central San Francisco Bay (BCDC 2016a), and plans to update the information and add San Pablo Bay to a new version toward the end of 2020 (B. Goeden, pers. comm.). The goal is to eventually develop a comprehensive RSMP for all San Francisco Estuary embayments. The RSMP is part of a broader State effort to better manage sediment. It is being led by the Coastal Sediment Work Group, and the Central Bay effort examined all management activities that affect sediment dynamics in the Bay, including flood protection, tributary and watershed management, habitat restoration of beaches and wetlands, dredging activities, aggregate mining, and shoreline resilience/climate change. The existing document includes three components:

1. Investigating and understanding the bay's physical processes.
2. Identifying challenges and opportunities given current physical process and management activities.
3. Recommendations for changes to practices and activities to maximize sediment as a resource, protect sensitive resources, improve the health of the bay, align management activities, reduce costs, and help address climate change impacts and other system stressors.

BCDC is also in the process of developing a Science Strategy for sediment dynamics, which they plan to circulate fall 2019 (B. Goeden, pers. comm.). The Science Strategy developed out of a BCDC-hosted workshop in October 2015 to prioritize sediment management questions for the bay and identify regional sediment science priorities that would address priority management questions (BCDC 2016b). The workshop included managers and scientists with interests and expertise in Bay sediment dynamics. The goals of developing a science strategy were to:

- Understand how much of what type of sediment we have, and where.
- Increase fluvial and tidal connections to improve sediment conveyance.
- Increase the beneficial reuse of sediment in the context of a limited incoming supply in order to maintain wetlands.
- Identify shorelines at risk from sea level rise and ways to reinforce them through sustainable means, mimicking natural systems.

Lastly, BCDC has also been focused on better understanding the effects of aggregate mining on sand dynamics in the bay and immediate outer coast, to support permitting decisions for such activities (B. Goeden, pers. comm.). While South Bay sediment dynamics are dominated by finer-grained material, the Project may have a future interest in sand dynamics of the Bay because coarse-grained beaches are being considered more and more as a nature-based adaptation measure to combat shoreline erosion (e.g., in front of an eroding marsh scarp). In addition to a literature review and data gap analysis related to sand dynamics, BCDC manages periodic multibeam bathymetric surveys within the Central and Suisun bays, primarily around sand mining lease areas, which may provide an opportunity for regional synergy of these types of data.

EMERGING TECHNOLOGIES

Remote sensing approaches for monitoring Project objectives related to habitat change through time have already been piloted by the Project (Fulfrost et al. 2012, 2015), and are being implemented again in support of Phase 2 (see HEMP and USGS biofilm studies described above). Remote sensing has also been piloted for capturing temporal trends in suspended sediment concentrations (SSC) at large spatial scales (e.g., Byrd et al. 2016), which would be useful in understanding the connection between larger-scale sediment processes and Project objectives of restoring tidal marsh habitat while maintaining existing mudflats. However, remote sensing of SSC only captures surface SSC, and stratification of suspended sediment at depth may limit the usefulness of results to shallow areas (M. Downing-Kunz, pers. comm.).

There are issues with licensing of imagery that create challenges for sharing remotely-sensed imagery with multiple researchers (B. Fulfrost, pers. comm.). Improvements can be made to automate data processing in order to speed up the time between imagery acquisition and delivery of products useful for decision-making (B. Fulfrost, pers. comm.). More rapid data processing would allow for increased temporal sampling–i.e., processing imagery accessed at multiple time points over the year, rather than once a year as is currently done. While this may improve our understanding of seasonal patterns of habitat change, increased temporal sampling may not capture episodic storm events that drive geomorphic changes, because cloud cover during large storm events obscures signals of SSC, inundation, and other metrics (C. Toms, pers. comm.).

Integrating different scales of sensor platforms – e.g. satellite, UAS, and field – would allow for more flexible, multi-scalar analysis that can combine the benefits of fine spatial resolution (from field and UAS-based platforms) with high spectral resolution (currently limited to satellite-based platforms). UAS-based sensors currently tend to have lower spectral resolution (e.g., 4-5 bands) than satellite-based sensors (B. Fulfrost, pers. comm.). Hyperspectral sensors are currently very expensive and data intensive, but provide much more detailed information and are being deployed with increasing frequency.

Multi-scalar technology is also improving our ability to obtain continuous, high resolution digital elevation models of coastal areas that mix terrestrial and shallow water environments (e.g., ponds, low intertidal mudflats, and shallow subtidal habitats). The USGS has improved the platforms that can now deploy a swath-beam sonar system in very shallow water, including shallow draft boats and jetskis that expand the conditions under which they can capture accurate elevation data (A. Foxgrover, pers. comm.). The boat-based platform can also be equipped with topographic Light Detection and Ranging (LIDAR) to, for example, capture the topography of adjacent levees at the same time as the bathymetry of a slough channel. LIDAR sensors can also be mounted to a UAS-based platform. Finally, “structure from motion” photogrammetry is a promising, low-cost technology to acquire fine resolution topographic data at relatively large spatial scales (Westoby et al. 2012). A three-dimensional surface can be resolved by using a series of overlapping, offset photographs and reconstruction algorithms that automatically match features in multiple images. It could efficiently map mudflats when images are collected from either fixed-wing airplanes or from UAS at low tides. However, while data acquisition in the field has many logistical advantages to traditional topographic survey techniques, the post-processing of data can be lengthy and computationally demanding (Westoby et al. 2012).

Another emerging technology being explored to measure suspended sediment concentrations is the use of acoustic, rather than optical sensors (M. Downing-Kunz, pers. comm.). Optical sensors deployed for long-term data collection must be cleaned periodically to avoid sensor fouling from growth of aquatic organisms. Acoustical sensors can function accurately for longer despite aquatic growth, and have the added benefit of also being able to measure velocity and direction of particles.

ACRONYMS AND ABBREVIATIONS

Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
BCDC: San Francisco Bay Conservation and Development Commission
CDFW: California Department of Fish and Wildlife
HEMP: Habitat Evolution Mapping Project
LIDAR: Light Detection and Ranging
MLLW: Mean Lower Low Water
RMP: Regional Monitoring Program for Water Quality in San Francisco Bay
RSMP: Regional Sediment Management Plan
RTK-GPS: Real-Time Kinematic Global Positioning System
SET: Sediment Erosion Table
SFEI: San Francisco Estuary Institute
SFEP: San Francisco Estuary Partnership
SOPs: standard operating procedures
SSC: suspended sediment concentrations
UAS: unoccupied aerial systems
USFWS: United States Fish and Wildlife Service
USGS: United States Geological Survey
WRMP: Wetlands Regional Monitoring Program
WSE: water surface elevation
WY: Water Year

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BIRD USE OF CHANGING HABITATS

RATIONALE AND BACKGROUND

Restoration of tidal marsh habitat in the South Bay Salt Pond Restoration Project (hereafter, the Project) necessarily involves reduction in the extent of managed pond habitat. The San Francisco Estuary (Estuary), however, supports high numbers and significant proportions of species' populations for numerous waterbirds during migration, winter, and the breeding season. In this regard, the managed ponds in the South Bay are especially significant habitat for numerous waterbirds for roosting, foraging, and/or nesting (Takekawa et al. 2000); therefore there are several project objectives with targets to maintain numbers of these species and guilds.

Key Uncertainty - *Can the existing number and diversity of migratory and breeding shorebirds and waterfowl be supported in a changing (reduced managed pond) habitat area?* (Trulio et al. 2007)

This is a complex question, involving multiple taxa, multiple guilds, and including species that make use of managed pond habitat for nesting, over-wintering, and/or migratory stopover. The answers to this question may be different for various species and guilds because they can be expected to have different responses to these changing habitats, including the overall loss of pond habitat within the Project area.

In the Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) Appendix 1 and the summary by Valoppi (2018) this Key Uncertainty was broken down into five Applied Studies Questions:

1. Will the habitat value and carrying capacity of the South Bay for nesting and foraging migratory and resident birds be maintained or improved relative to current conditions?
2. Will shallowly flooded ponds or ponds constructed with islands or furrows provide breeding habitat to support sustainable densities of snowy plovers while providing foraging and roosting habitat for migratory shorebirds?
3. Will ponds reconfigured and managed to provide target water and salinity levels significantly increase the prey base for, and pond use by waterfowl, shorebirds and phalaropes/grebes compared to existing ponds not managed in this manner?
4. To what extent will the creation of large isolated islands in reconfigured ponds maintain numbers (and reproductive success) of terns and other nesting birds in the South Bay, while increasing densities of foraging birds over the long term compared to ponds not managed in this manner?
5. Will pond and panne habitats in restoring tidal habitats provide habitat for significant numbers of foraging and roosting shorebirds and waterfowl over the long term?

Applied Study Question 1 is quite broad, and it is important to note that the question refers to the entire South Bay, not just to the Project area within it. This is significant because one question is whether waterbirds (referring to waterfowl, shorebirds, phalaropes/grebes, terns, and gulls) will make increased use of existing managed ponds and other habitat (tidal flats, tidal marsh, salt ponds) elsewhere in the South Bay (or elsewhere in the larger San Francisco Bay system) when managed ponds in the Project area are reduced in extent.

Applied Study Questions 2, 3, and 4 consider the possibility that through management, including construction and manipulation of ponds (e.g., construction of islands) as well as manipulation of water and salinity levels, habitat quality for remaining ponds is improved, resulting in higher densities of foraging, roosting and/or nesting waterbirds. If so, the same (or perhaps more) waterbirds could be supported despite reduced pond extent.

Valoppi (2018) and the Project "Science Summary Phase 1" (SBSPRP 2018) summarized findings and evaluated the above questions, based on data available through 2016. Since then, several important studies have been completed directly relating to these questions, summarized below. In addition, we add several references not cited by Valoppi (2018).

RECENT INFORMATION

Numbers of waterfowl, shorebirds, and other waterbirds have shown a positive trend through 2012, as indicated in the Science Summary ("Trending Positive"). Two recent reports confirm and amplify this trend through 2015/2017.

Tarjan (2019a) examined 10 species or guilds of wintering and migrating waterbirds and found that counts of individuals in 9 of them increased substantially (50% or more) between 2005-2007 and 2015-2017. In fact, 7 of the 10 species/guilds increased by more than 100%. Note that eared grebes (*Podiceps nigricollis*) increased (a high salinity specialist), but this was due to increases at South Bay sites not part of the Project (i.e., in salt evaporation ponds still operated by Cargill as part of its commercial operations). The only exception to the increase were phalaropes (*Phalaropus spp.*), counts of which showed a 62% decrease. It is unclear whether this decrease in counts reflects an actual change in population levels for this species. There is uncertainty because phalaropes are only present in the Estuary for about two weeks in each year, thus a monthly survey may miss their peak. If the populations have truly declined, it is also uncertain whether the decline was due to a reduction in habitat resulting from restoration and management changes. This is another high salinity specialist, thus it is unclear why they would decline when eared grebes have increased. More targeted surveys for phalaropes are planned for 2020.

Widespread increases in foraging and roosting waterbirds were confirmed by the analysis of De La Cruz et al. (2018), who analyzed data from the surveys analyzed by Tarjan (2019a), although the time period analyzed by De La Cruz et al. differed slightly: from 2002 or 2005 to 2013 or 2015 (depending on site). Both diving and dabbling ducks (*Anatidae spp.)* increased; the former more than doubled in abundance. Other waterbird guilds also showed increases.

Results presented by De La Cruz et al. (2018) were comparable to those for the South Bay presented by Nur et al. (2015), who analyzed midwinter waterfowl surveys, an annual one day flyover survey of the entire Estuary. The latter showed a modest increase in the South Bay for 2005-2014 for diving ducks and a strong increase for dabbling ducks. Significantly, diving duck abundance in winter decreased in the North Bay during this period. Thus, if habitat suitability or prey availability in the North Bay has declined, the South Bay may play an especially important role for diving ducks. Strong (2019) provides more recent data summaries from midwinter waterfowl surveys, extending to 2018. Though there was strong year-to-year variation in counts, 2018 counts in the South Bay were higher than in 2017 but lower than in 2012.

These changes in counts of waterbirds over time can be compared to targets and thresholds for species/guilds of waterbirds compiled by the Project (see Appendix 3 of Trulio et al. 2007 and Tarjan 2019b). As noted above, Tarjan (2019a) found that nine species/guilds showed strong increases rather than declines; only phalaropes showed a decline, with a magnitude exceeding the stated threshold of decline (i.e., 50% below the 2005-2007 mean).

Applied Study Question 2 as stated pertains mainly to nesting western snowy plovers (*Charadrius nivosus nivosus*), asking whether reconfigured ponds (with islands) can support successful breeding by this species, in addition to foraging and roosting waterbirds. As summarized by Valoppi (2018), this uncertainty was scored as "Meets or Exceeds Expectations" due to annual estimates trending towards the 250 individual breeding birds target. However, the situation is more complex, especially as revealed through recent years of snowy plover nest monitoring by SFBBO (Pearl et al. 2016, Pearl and Chen 2018, Pearl et al. 2019, and B. Pearl pers. comm.). On the one hand, there has been a record of success in attracting snowy plovers to breed in the managed ponds, and specifically in areas that have been enhanced with oyster shells (Tokatlian et al. 2016, Tokatlian 2017). On the other hand, nesting success (defined as the percent of nests successfully hatching at least one egg) has not necessarily increased.

In the South Bay, the number of breeding snowy plovers has generally increased from 2003 to the present, approximately doubling between 2003/2005 and 2017/2019. Notably, at pond E14, the site containing the largest number of nesting snowy plovers and that is managed for this species, the number of breeding adults increased by 150% from 2014 to 2018 (Pearl et al. 2019). In addition, oyster shell enhancement of nesting habitat in 2015 and 2016 demonstrated increased nesting density, when comparing nesting density at E14 in years before and after enhancement, and also when comparing plots with and without ("control") oyster-shell enhancement in the same year (Tokatlian et al. 2016, Tokatlian 2017). That said, it is important to note that nesting snowy plovers are not using the islands and furrows referred to in Applied Study Question 2 above, but rather continue to use large, open, dry pond bottoms for nesting. Though the islands are not being used, habitat enhancement has demonstrated success. As part of a Caspian tern (*Hydroprogne caspia*) relocation project with the Army Corps of Engineers and United States Geological Survey (USGS), the Project tested a social attraction method for nesting snowy plovers on islands in two ponds (Hartman 2018). Snowy plovers were not attracted by this method, and to date have not utilized the islands built for nesting birds in SF2 or A16.

Nesting success and fledging success of snowy plovers in the Project have shown strong variation among years (Pearl et al. 2019) but have been relatively low in most years (below target values identified by the snowy plover recovery team). The principal cause of nest failure is predation, with multiple predator species responsible for this nest loss. Most notable are common ravens (*Corvus corax*) and red fox (*Vulpes vulpes*), and their predation rates have fluctuated among years. Tokatlian (2017) did not find that oyster shell enhancement increased nest success in 2015 and 2016, though recent analyses suggest a beneficial effect in days 0-7 post-hatching (B. Pearl, unpublished). The key to achieving desired levels of reproductive success for this species appears to lie with predator management (see Invasive and Nuisance Species Chapter). Whether habitat features (and/or other management actions) can reduce predation levels for snowy plovers remains an uncertainty.

Applied Study Questions 3 and 4 consider design features of ponds that may make them of greater value to roosting, foraging or nesting waterbirds. With regard to Question 3, design features of managed and reconfigured ponds were identified that increased the number and diversity of foraging and roosting shorebirds and other waterbirds. To summarize findings of De La Cruz et al. (2018):

The presence of islands within a pond was key; topographic complexity was also important. Water depth was identified as important, with different waterbird guilds preferring different depths. Hence, the authors suggest maintaining topographic diversity with corresponding variation in water depths. Results for salinity indicated that low salinity was favored by most guilds, but a few (gulls, phalaropes, and eared grebes) preferred high or extremely high salinity. Proximity to levees was also potentially important, but required further exploration.

Applied Study Question 3 also concerns prey base. There has been substantially less work on this topic to date. A USGS-led study has addressed this aspect, studying waterbirds and invertebrates in two Eden Landing ponds, E12 and E13 within the first 3 years after construction (De La Cruz et al. 2019). The Draft Report found that, among management-influenced variables, salinity predicted invertebrate species composition most strongly and water depth predicted invertebrate biomass most strongly; nitrate was also an important predictor. However, the study did not identify the relationships between invertebrate species composition/biomass and waterbird abundance or species composition. What characteristics of the invertebrate community are most important for each guild? Are there minimum thresholds or ceilings of waterbird response? Important uncertainties remain to be addressed.

Applied Study Question 4 asks whether ponds can be reconfigured and managed so as to maintain numbers and success of nesting shorebirds in the South Bay, while still increasing densities of foraging birds. As worded the question focuses on the value of the reconfiguration and management, especially with regard to islands. Findings to date have been mixed. Studying historical data (2005-2013), combined with field studies in 2011-2012, Ackerman et al. (2014a) identified a “recipe” for islands to attract breeding birds in the ponds (see also Moskal 2013). For example, several linear (“skinny”) islands in a pond, with nesting area 0.5 to 1.5 m above the water surface are recommended.

However, while 46 islands were constructed in two ponds in 2010 (SF2) and 2012 (A16) for use by nesting waterbirds, “since construction, nesting waterbirds have made limited use of these new islands” (Hartman et al. 2016, 2017, 2018). As a result, USGS implemented a study to recruit waterbirds to breed on islands that were suitably modified and through the use of social attraction methods. Results targeting Caspian terns were successful: large numbers nested in 2015, 2016, and 2017 at the experimental locations (Hartman et al. 2018, Hartman et al. 2019a). The authors consider that these techniques can be effective for Forster’s terns (*Sterna forsteri*) and American avocets (*Recurvirostra americana*) as well. However, no snowy plovers nested on the 2 islands designed for them, which bred at other ponds instead (see above). Though Caspian terns nested in large numbers in response to social attraction and habitat modification, nesting success was lower in 2016 and 2017, unlike 2015. Thus, the situation for Caspian terns in the last two years of the study was similar to what was observed with snowy plovers in pond E14: nesting numbers or density was increased through management actions, but nesting and fledging success were sufficiently low to be of concern.

Tarjan (2019a) reported a decrease in numbers of nesting Forster’s terns and possibly American avocets as well, though some decreases were already seen pre-project. A recent South Bay-wide survey for breeding terns and avocets was conducted by USGS that could help ascertain local and regional declines as well as whether these species have moved elsewhere in the South Bay. Uncertainty remains regarding how best to maintain or increase breeding numbers as well as breeding success for terns, avocets, and stilts.

Applied Study Question 5 has not yet received attention similar to Applied Study Questions 1-4. This question concerns the use of habitat in and adjacent to tidal marsh and includes mudflats, ponds, pannes, and channels in breached ponds that are undergoing restoration to tidal marsh. Valoppi (2018) did not summarize any studies pertaining to this question, nor is it addressed in the Science Summary. The AMP identified this question as one to be addressed later to allow for the development of marsh to occur. De La Cruz et al. (2018) noted that shorebirds were associated with newly breached ponds, at low tide. De La Cruz and Casazza (2019) also reported that in the Napa/Sonoma marsh, breached ponds were preferred by canvasback ducks (*Aythya valisineria*) compared to managed ponds. Conducting surveys in breached ponds presents logistical challenges, as described below.

KNOWLEDGE GAPS

Knowledge gaps can be grouped around the five questions listed above. The potential for use of restoring marsh habitat by waterbirds for foraging and roosting (Applied Study Question 5) remains an unknown. The study by Stralberg et al. (2003) provided insights into features of marshes that make them of greater value to waterbirds. Addressing this uncertainty entails studying use of mudflats, unvegetated marsh plain within breached ponds, ponds and pannes within a marsh, and marsh channels. In particular, there is a need to study the change in bird use as the restoration of marshes proceeds, resulting in reduced and altered habitat for waterbirds. Different bird groups will use a restoring marsh at different points of the restoration process (Stralberg et al. 2003, Stralberg et al. 2009). Thus, staggering the timing of restoration initiation (e.g., breaching) will benefit waterbirds by allowing them to shift from site to site over time to find the habitat characteristics that suit them. This question can be addressed by studying the same site over time, in conjunction with studying different sites at the same time that are each at different points of marsh development. A significant impediment to conducting surveys of breached ponds has been access to these sites; however, unoccupied aerial systems (UAS) and other remote means could provide high resolution photographs that could address this knowledge gap for some species and guilds (see Emerging Technologies section below).

Regarding Applied Study Question 4 (How to maintain or increase breeding numbers and success of terns, avocets, and stilts?), evidence points to a decline in numbers of breeders of these species. The analysis of surveys conducted by Ackerman and colleagues throughout the South Bay in 2019, which will be compared to the surveys of Rintoul et al. (2003), conducted in 2001 (Hartman et al. 2019b) may help answer this question. While social attraction has proven to be effective, are there less costly means to increase breeding numbers? If these species are not nesting within the South Bay, where have they moved to? Are these species declining in other areas of their range?

Predation has been shown to be the predominant cause of known nest failure, with both avian and mammalian predator species involved. California gulls (*Larus californicus*) are a primary predator for these species, but how do habitat and landscape characteristics affect predation rates by this species? Ackerman et al. (2014b) point out that stilts and avocets nesting in the same location experience very different nest-predation rates. Are these differences due to differences in nesting micro-habitat as they suggest? We also note that Hartman et al. (2018) found that a decrease in California gull abundance from 2015 to 2017 was accompanied by a decrease in Caspian tern nesting success. There is still much to learn regarding determinants of predation rates on these waterbirds.

Applied Study Question 3 refers in part to prey base, which is a substantial knowledge gap. Recently completed work by De La Cruz et al. (2019) provides some insights into spatial and temporal patterns of invertebrate prey from 2 ponds at Eden Landing, but the relationships between prey and shorebird abundance and species composition remain to be elucidated.

Applied Study Question 2, which pertains to snowy plovers, has much in common with Applied Study Question 4, which pertains to terns, avocets, and stilts. Here, breeding numbers have demonstrated increases, not decreases, but the factors that influence predation rates constitute a significant knowledge gap, especially because of the interaction of multiple predators (red fox, common raven, and many others) and multiple prey (e.g., California least terns, *Sternula antillarum browni*, nesting in proximity to snowy plovers; Pearl and Wang 2019).

Regarding Applied Study Question 1, results to date have demonstrated that wintering and migrating waterbirds have increased or maintained their numbers relative to when the ponds were managed as salt evaporation ponds. However De la Cruz et al. (2018) noted that dabbler duck numbers in project ponds have plateaued, while there appears to be an increase overall for South Bay dabblers through 2013 (Nur et al. 2015). There remains uncertainty regarding future trends for many waterbird guilds, especially as restoration (and loss of pond habitat) proceeds. How to optimize the ability to detect trends in managed ponds, breached ponds, and open bay is an important question to address. Tarjan (2019b) provides insightful analysis regarding detecting a one time (pulse) decline and suggestions for protocol design change for the South Bay. Survey design and data analysis could optimize statistical comparisons among ponds to detect more gradual (linear or nonlinear) changes. Examples of comparable analyses with regard to trend detection are laid out in Wood et al. (2017) for secretive marsh birds and in Bridgeland et al. (2019) for colonial seabirds.

POTENTIAL PHASE 2 STUDIES

Underway or Recently Completed

Topic	Status	Researcher	Description of proposed or contracted work	Timing of study
Waterbird sampling refinement and analysis	Complete	San Francisco Bay Bird Observatory	Provide updated assessment of waterbird status and assess ongoing monitoring efforts for the project area	June 2018- May 2019
Waterbird Surveys	Complete	San Francisco Bay Bird Observatory	Conduct three high tide surveys of waterbirds in the entire SBSPR Project area	January 2019-June 2019
Nesting Birds	In progress	USGS	Assess status of breeding terns, avocets, and black-necked stilts in the South Bay, below San Mateo Bridge	May 2019-February 2020
Phalaropes	In progress	San Francisco Bay Bird Observatory	Migration timing and spatial distribution of phalaropes in South San Francisco Bay.	2019-2020
Forster’s Tern	In progress	USGS	Social attraction surveys for Forster’s terns at A16	field work completed 2019

Note: Studies in the top row, considering data through 2017, were completed by M. Tarjan in 2019 (Tarjan 2019a, 2019b).

Suggested from end of Phase 1

Valoppi (2018) lists 14 potential Phase 2 studies, which partially overlap with the above. Excluding one potential study focused on California gulls as predators (see Chapter on Invasive and Nuisance Species), studies listed by Valoppi but not already noted above are listed below. These are listed for completeness; some may have already been addressed. Our notes and comments are included in the hollow sub-bullets:

- Study how to maximize attractiveness of islands for shorebird foraging and roosting.
    - Also, how to maintain islands.
- Continue social attraction studies on newly constructed islands for terns.
    - Social attraction has proven very successful for Caspian terns, and other studies may be higher priorities.

- Conduct a population count of breeding avocets, stilts, and Forster's terns in the entire South Bay to determine if populations have declined, especially for avocets whose breeding population appears to have declined.
    - Surveys were completed in Phase 1, and analysis is underway.
- Continue habitat enhancement and predator management of plover nesting areas and study their effectiveness.
    - This topic has been the subject of Phase 1 studies.
- Conduct additional western snowy plover studies to track brood movement and estimate fledging rates.
- Understand western snowy plover carrying capacity or density limits; understand use of foraging on transitional mudflat habitat; understand movement and migration out of historical [nesting pond] areas [due to] habitat restoration.
- Explore the use of unmanned aerial vehicles [unoccupied aerial systems; UAS] for monitoring as well as their possible impacts to wildlife.
    - See Emerging Technologies section below.

Suggested from 2019 workshop and review input

The workshop provided a fertile ground for suggestions of potential studies. Here we list seven potential study topics, all of them proposed at the workshop or in subsequent review of this document, and/or that follow from the section above (Knowledge Gaps). These have all been put forward as important, needed studies; subsequent assessment of these suggestions and guidance on prioritizing them will be provided in the Science Framework. Several themes arose at the workshop: 1) integrate studies conducted in the Project areas with those outside of it to improve understanding of dynamics and drivers, 2) analyze data already collected to address the most significant uncertainties (see Knowledge Gaps), especially to the extent such analyses can inform modeling, and 3) use modeling to consider scenarios of future habitat and landscape change, such as those due to restoration, and their expected impacts.

- Obtain better information on use of habitat by waterbird guilds in the different stages of the restoration process, from mudflats to vegetated marsh.
    - Improve monitoring methods for surveying waterbird use of restoring (i.e., breached) ponds, because access to restored ponds is difficult. UAS may provide a good means to obtain this information.
    - Analyze features of a restoring marsh (e.g., open channels, mudflats) that are of maximum value to various waterbird guilds, as well as how these are affected by landscape characteristics and landscape change, whether due to the South Bay Salt Pond restoration process or climate change.

- Obtain better information on changes in numbers of breeding waterbirds (i.e., terns, avocets, and stilts). Some data are in hand from 2019 surveys, but more comprehensive information is needed. As part of this topic, compare breeding waterbird population change (both trends and year-to-year changes) in the North Bay (e.g., Napa-Sonoma marsh) with population change in the South Bay.

- Study the factors that determine or influence nest predation rates on waterbirds to identify approaches to most effectively lower predation rates. There is substantial variation among species at the same location (Ackerman et al. 2014b), among locations, and among years. Furthermore, even site-to-site differences in predation rates vary among years (Ackerman et al. 2014c). For example, what is the role of habitat features (e.g., vegetation characteristics) in influencing predation rates? How does the presence of one species (e.g., least terns) influence predation rates on a second species (e.g., snowy plovers)? Does the current level of predator management have a positive effect on the reproductive success of nesting birds?

- A study is needed to address the question of how to maintain islands that will successfully provide nesting habitat for waterbird species. This is a concern due to the noted erosion of current islands. How should these islands be distributed within a pond and among ponds to maximize breeding numbers and success? A related point raised was the need for redundancy of nesting locations. Managers cannot depend on one or two breeding locations for a species, especially given that predators may key in on a given species at a single location. How many breeding locations are needed and how should they be distributed?

- Develop a better understanding of connectivity of waterbird populations in the Estuary at different times of the year. In part, this can be addressed through integrated concurrent studies conducted in the Project area, outside the Project area but in the South Bay, and elsewhere in the Estuary. In this way, we may gain some insight into whether birds have shifted from one region to another, and perhaps why they did so. However, there is also value to studying movements of birds directly. Techniques to do so could be the subject of a study. This may be an opportunity to make use of emerging technology, such as use of geolocators (GLS tags).

- Analyze data, from time-series and from comparisons of ponds and restoring marshes at different points along the timeline of restoration, to quantitatively estimate expected change over time due to habitat change at the restoring marsh/pond and in the adjacent landscape. Use this information to model how waterbird populations are expected to respond to change due to the restoration process. Such models are to be used to evaluate different scenarios of restoration, and possibly, climate change. Changes in waterbird populations (both breeding and non-breeding) as established through monitoring programs can be compared to predicted changes. This will enable managers to understand and react to changes in population that are observed.

- Preliminary work at 2 locations in Eden Landing has investigated the waterbird invertebrate prey base and how it varies with habitat characteristics (e.g., depth and salinity; De La Cruz et al. 2019). Proposed studies can analyze data collected at other locations (e.g., Napa-Sonoma marshes) to (1) provide a better, broader picture over a longer time frame, as well as to (2) analyze the relationship of waterbird abundance and species composition to characteristics of the invertebrate prey.

OPPORTUNITIES FOR REGIONAL SYNERGY

There are several monitoring efforts of high relevance, either regional or local.

Midwinter Waterfowl Survey and San Francisco Bay Joint Venture

The Midwinter Waterfowl Survey in the San Francisco Bay and coastal estuaries is currently done by USGS and the San Francisco Bay National Wildlife Refuge Complex (USFWS). This survey can provide valuable information on the distribution of waterfowl at a broad scale, but it needs revamping (Strong 2019). The San Francisco Bay Joint Venture is supportive of monitoring and evaluation and could be a valuable partner here as well in that effort.

Point Blue Pacific Flyway Shorebird Survey

The Pacific Flyway Shorebird Survey is a "coordinated, multi-partner monitoring program to quantify trends and habitat associations of wintering shorebirds in the Pacific Flyway," extending from British Columbia to Chile, with extensive surveys in the Estuary (https://data.prbo.org/apps/pfss/). To make this survey more useful to the Project, there may need to be changes made to the sites that are surveyed.

Wetlands Regional Monitoring Program

The Wetlands Regional Monitoring Program (WRMP) is in the process of developing its monitoring plan. It is therefore an opportune time to coordinate the Project's monitoring needs with the WRMP plan. However, marsh birds, not waterbirds, are the focus of the wildlife monitoring. Nevertheless, habitat and physical monitoring as part of the WRMP should be coordinated, especially at restoring ponds that are difficult to access.

Monitoring in Napa Sonoma Marshes Wildlife Area, Sears Point, and Cullinan Ranch

Monitoring has been ongoing at the Napa Salt Marsh and Napa Plant Restoration Sites for some time (S. De La Cruz et al. in prep.; De La Cruz and Casazza 2019). Surveys for waterbirds are done using the same protocol that the Project pond surveys use. Analysis of this larger, comprehensive dataset which includes the North Bay and South Bay would provide valuable insights into patterns of bird distribution and abundance over the past 15+ years, as individual ponds and the overall landscape has changed.

More recently, there is monitoring associated with tidal marsh restoration at Sears Point and Cullinan Ranch, mostly by USFWS. There are good opportunities for synergy, especially in increasing our understanding of the factors that may be influencing foraging and nesting behavior of waterbirds, use of restoring marshes, and especially prey availability.

EMERGING TECHNOLOGIES

The principal suggestion is to explore the use of UAS for monitoring waterbirds. UAS as well as aerial or satellite remote sensing may also be extremely useful for tracking habitat change, including specific features. For example, UAS may be especially useful for tracking the amount of mudflat at specific times of the tidal cycle, information that is more difficult to obtain from satellites. With regard to birds, UAS may have greater success at tracking foraging and roosting of some species and guilds of waterbirds than with nesting bird populations, which present greater technical challenges.

Autonomous sound recording units (ARUs) are another tool that can provide continuous monitoring of a given location. This monitoring may provide estimates of how bird use of given habitats or habitat features (e.g., islands in ponds) changes throughout a tidal cycle and across daily weather patterns (e.g., storms). The use of ARUs has been implemented in other habitats, but further study will be needed to see if they can provide sufficient data to address the main questions above. Results to date suggest that monitoring reproductive success of shorebirds will be difficult, but Borker et al. (2014) indicate success monitoring abundance of Forster's terns.

ACRONYMS AND ABBREVIATIONS

Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
ARU: autonomous sound recording units
UAS: unoccupied aerial systems
USFWS: United States Fish and Wildlife Service

USGS: United States Geological Survey
WRMP: Wetlands Regional Monitoring Program

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MERCURY

RATIONALE AND BACKGROUND

Mercury concentrations in the San Francisco Estuary (Estuary) are a water quality concern that can have serious negative health impacts on both human and wildlife populations. Historic mercury mines and the use of mercury for other mining activities during the gold rush has resulted in the substantial deposition of mercury in the Estuary (Davis et al. 2014). Runoff from historic mines, particularly the New Almaden Mining District, continues to contribute significant mercury loading into the Estuary. Although management within source watersheds are continuing efforts to reduce mercury loads, recent evidence indicates that the significant levels of mercury continue to enter the Estuary, particularly during extreme rain events (McKee et al. 2018).

To understand the ecosystem level impacts from mercury due to management activities undertaken by the South Bay Salt Pond Restoration Project (Project) we must first consider the amount of inorganic mercury that is potentially in the system. Tidal marsh restoration and pond management activities cause immediate changes to the chemistry, hydrology and geomorphology of connected bayland habitats that might lead to increases in mercury concentrations within the Estuary. In particular, changes in tidal prism and associated erosion of channels can remobilize historic mercury deposits that had been buried beneath bay sediments. However, even if the Project was somehow successful in releasing no additional mercury into the system, the project would still need to consider whether the mercury entering the project from other sources was being converted to methylmercury (MeHg) through project activities.

Tidal wetland creation and the management of pond salinity concentrations, depth, and water temperatures may directly or indirectly create conditions that affect the formation of MeHg, the form of mercury that bioaccumulates within food webs. Thus, understanding how tidal marsh restoration and pond management affect the concentration of mercury and methylmercury within the Estuary and within associated food webs helps in implementing management activities that best support the achievement of Project Objectives while eliminating or limiting mercury exposure.

The Project's Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) identifies a Key Uncertainty with respect to mercury that would need to be addressed through science and adaptive management.

Key Uncertainty - *Will mercury be mobilized into the food web of the South Bay and beyond at a greater rate than prior to restoration?* (Trulio et al. 2007)

As noted above, tidal marsh restoration can increase the remobilization of mercury from contaminated marshes and channels through erosion. In addition, the conditions in newly restored wetlands are conducive to increasing the net production of methylmercury (Davis et al. 2003). Increased concentrations of methylmercury in Estuary food webs will directly inhibit the ability of the project to achieve success of Project Objective 4 (protect or improve existing water quality) and in a related way, diminish the ability of the project to achieve success in Project Objective 1 as toxic levels of methylmercury are known to decrease the productivity of native fish and wildlife species, including the Federally endangered California Ridgway's rail (*Rallus obsoletus obsoletus*) (Schwarzbach et al. 2006).

At the start of Phase 1 of the project, two Applied Studies Questions were developed to address the identified Key Uncertainty:

1. Will tidal habitat restoration and associated channel scour increase MeHg levels in marsh and bay associated sentinel species?

2. Will pond management increase MeHg levels in pond-associated sentinel species?

The Project Management Team has commissioned a comprehensive study of Phase 1 studies that focus on mercury and methylmercury concentrations associated with restoration and pond management activities at the A8 complex that will be completed in late 2019/early 2020. So as not to be redundant with the forthcoming comprehensive report, this chapter will provide a high level summary of what was learned from Phase 1 studies, studies that have been completed between the completion of Phase 1 and the start of Phase 2 and a more in-depth discussion of related studies from beyond the South Bay that could inform Phase 2 science and management. To be clear, we are not attempting to synthesize all of the science on mercury in the Estuary. Rather, we are focusing on those studies with clear links to the Key Uncertainty and Applied Study Questions above that have not been synthesized previously.

RECENT INFORMATION

General patterns across the Estuary

There are significant differences in the temporal patterns of methylmercury accumulation throughout the Estuary. Samples from fish collected between 1997 and 2009 found significant inter-annual variation in methylmercury concentrations in fish but no consistent trend (Davis et al. 2011). However, samples from bay waters across the Estuary have shown progressively declining concentrations of MeHg between 2005 and 2015 (SFEI 2017). There is evidence that total mercury concentrations increase in tidal waters during ebb tides and decreasing during flood tides (Valoppi 2018). Large rainfall events can result in substantial runoff from contaminated sites into rivers that feed into the Estuary (McKee et al. 2018) and years with more runoff can result in more total mercury in local waterways (SFEI 2017).

Spatial patterns of mercury concentrations are mostly related to the source of the mercury contamination. Much of the mercury in the North Bay can be attributed to sediment that washed downstream from the hydraulic gold mining in the Sierra Nevada that occurred during the 1800s (Davis et al. 2003). Mercury concentrations in the South Bay can be largely attributed to legacy runoff from the New Almaden mining district and the highest concentrations in sediment cores correspond to 50 years after the timing of mining activities that occurred during the mid-20th century (Conway et al. 2004). Urban runoff and other industrial sources also contribute to the spatial variation in mercury contamination (SFBRWQCB 2004).

Mercury in San Francisco Estuary Food webs

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has been monitoring the concentrations of mercury in fish and wildlife species across the Estuary. The RMP has found no long-term trend of mercury concentrations in double-crested cormorant (*Phalacrocorax auritus*) eggs but there is considerable variation in the samples taken from different regions and among years, with eggs sampled in the South Bay tending to have higher mercury concentrations than eggs sampled in the Central Bay or Suisun (SFEI 2017). The pattern of higher mercury concentrations in birds in the South Bay relative to other regions of the Estuary is consistent in other species while concentrations in birds in the Central Bay and North Bay are not significantly different from each other (Eagles-Smith et al. 2009). There is no long term trend in mercury concentrations in striped bass (*Morone saxatilis*) but levels observed in this species are above water quality objectives with some samples exceeding safe consumption thresholds (SFEI 2017). Long lived predatory fish, such as white sturgeon (*Acipenser transmontanus*) and striped bass, tend to have the highest concentrations of mercury among sampled fish species (SFEI 2017).

Monitoring of both birds and fish indicates that there are differences in the bioaccumulation of mercury between habitats within the Estuary. MeHg concentrations were higher in fish-eating birds as opposed to birds with largely invertebrate diets (Ackerman et al. 2014). Mercury concentrations in fish from the open bay were 7.4 times lower than fish sampled in the salt ponds and marshes (Eagles-Smith and Ackerman, 2014). Stilts had nearly 5 times higher mercury concentrations than avocets which corresponded with a higher use by stilts of managed ponds and muted tidal vegetated marshes than the tidal flat habitats frequented by avocets. Although wetlands with higher vegetation root density show greater MeHg production than mudflats, mercury concentrations in fish were lower in tidal habitats as compared to habitats that were the most hydrologically disconnected from the tidal influence of the open bay (Eagles-Smith and Ackerman, 2014).

Several federally listed species are thought to be at risk from mercury exposure. Schwarzbach et al. (2006) found methylmercury concentrations that exceeded effects thresholds in California Ridgway's rail eggs at all marshes sampled and high rates of non-viable eggs which could be attributed to the high mercury concentrations found in their diet (Casazza et al. 2014). More recent studies have found concentrations of mercury in California Ridgway's rail blood feathers and eggs that are high enough to lead to reproductive impairment (Ackerman et al. 2012). Grenier et al. (2010) observed methylmercury in tidal marsh song sparrow blood (*Melospiza melodia*) at concentrations that could impair reproduction. We found little work studying salt marsh harvest mouse (*Reithrodontomys raviventris*) exposure and impact to mercury. However, a study of small mammal exposure to mercury in San Francisco Bay found that salt marsh harvest mice were absent in marshes where mercury concentrations in house mice livers were >0.19 µg/g (Clark et al. 1992). The authors speculated that mercury could be limiting survival and/or reproduction in the species or somehow limiting salt marsh harvest mouse food sources (Clark et al. 1992). These results all indicate special-status species that are vulnerable to increased exposure to mercury within the Estuary.

The North Bay Mercury Biosentinel Project has conducted monitoring of methylmercury concentrations in fish and birds that were sampled from managed ponds, breached wetlands and tidal marshes in the North Bay (Robinson et al. 2018). This monitoring occurred in 2012-2014 and 2016-2017 providing an indication of temporal variation in methylmercury concentrations in biosentinels across the different habitat types. The studies indicate that methylmercury within biosentinels is at a high enough level to be of concern. However, the observed concentrations were not significantly different between samples taken from restored ponds and those taken from tidal marshes (Robinson et al. 2018). The project found a decline in methylmercury in fish between the two sampling periods but an increase in the concentrations sampled in birds when they combined data across all sites (Robinson et al. 2018). The project also found substantial variation in methylmercury concentrations in biosentinels across sites, but that the difference among sites was consistent between sampling periods, i.e. sites with relatively high concentrations in the first sampling period had relatively high concentrations in the second sampling period (Robinson et al. 2018). The observed differences across sites included managed ponds at adjacent sites with high and low mercury providing evidence that pond management may be able to limit methylmercury concentrations within fish and wildlife species. Similar differences in the bioaccumulation of mercury at nearby pond sites was found in the South Bay where total mercury concentrations in avocet eggs were 3.4 times higher in pond A2W than in the adjacent pond A1 (Ackerman et al. 2014).

Executive Summary of Phase 1 studies

Many of the Phase 1 studies of mercury related to restoration and pond management activities were focused on the A8 Ponds (Ponds A5, A7, A8, and A8S were reconfigured and hydraulically connected to each other during Phase 1 and are now referred to as "the A8 Ponds") and the full tidal restoration of

Pond A6. Management activities that were implemented include the breaching of internal levees and the manipulation of a control structure gate that allowed seasonal closures and varying levels of water flow through the A8 Ponds (Valoppi, 2018). Thus the mercury studies corresponding with these management activities give insight into the remobilization of mercury and its uptake in the food web following levee breaches and through the management of water flows into and out of managed ponds.

Extensive monitoring and modeling studies completed during Phase 1 of the project indicated that restoration and pond management activities can cause a spike in bioavailable mercury exposure within restored ponds and adjacent habitats (Valoppi 2018, Marvin-DiPasquale pers. comm.). Through a combined monitoring and modeling study, Foxgrover et al. (2019) estimate that 52 kg (± 3) of mercury was remobilized over six years within Alviso Slough following the initiation of restoration activities.

Monitoring of bird and fish species revealed a corresponding increase in mercury within fish in Pond A8 and in tern eggs that fed on fish from A8 (Valoppi 2018). However, continual monitoring of these species indicated that the mercury exposure was short-lived as mercury concentrations declined in the months following initial management activities (Valoppi 2018, Marvin-DiPasquale pers. comm.).

Potential management opportunities

Managed ponds

There is some indication that concentrations of methylmercury and associated bioaccumulation in associated food webs in tidal marshes and managed ponds can be controlled or reduced through management. Monitoring of biosentinel species throughout the Estuary has found cases where species sampled from ponds adjacent to each other have significantly different levels of mercury in their systems providing some evidence that management can affect the production and bioaccumulation of MeHg. Allowing some tidal flow periodically into managed ponds could limit algae and other labile organic matter production and reduce the drying of contaminated sediments, both of which have been shown to be correlated with methylmercury bioaccumulation (Grenier et al. 2010, Davis et al. 2014). Similarly, managing water, salinity and nutrient levels may affect methylmercury production. Experimental management approaches of freshwater seasonal ponds in the Cosumnes River Watershed have shown that the use of deep water cells was successful at reducing methylmercury exports on flow through hydrology (Marvin-DiPasquale et al. 2018). However, the results from this study may not translate to tidal salt water systems.

Tidal marshes

Managing salinity gradients within tidal marshes may be an effective way to limit methylmercury production. Pickleweed (*Sarcocornia pacifica*) dominates marsh plant communities in the salt marsh plains of the estuary and is associated with higher rates of methylmercury production (Davis et al. 2014). Grenier et al. (2010) found lower concentrations of methylmercury in tidal marsh song sparrow blood in individuals sampled further from the bay (lower salinity) than from individuals sampled near the bay (higher salinity). Routing freshwater through marshes could create salinity gradients resulting in varied plant communities that could decrease methylmercury production (Davis et al. 2014) with the added co-benefit of increasing marsh accretion thus increasing the resilience of the system to sea level rise (Lowe et al. 2013). However, there may be limited feasible opportunities to direct freshwater flows through marshes and MeHg production is a multifactor process so simply manipulating salinity concentrations is unlikely to completely address the issue.

Increasing hydrologic connectivity to the bay may also limit methylmercury production. Creating channel networks that result in more frequent tidal inundation can result in less methylation (Davis et al. 2014). However, the benefits of the more frequent inundation would need to be balanced if tidal flows introduce mercury-contaminated sediment. For example, increasing connectivity to a restored pond may result in increased mercury exposure to newly connected sloughs, a balance of short term mercury exposure vs. longer term decrease in the production of methylmercury. Additionally, although lower marshes may have lower rates of methylmercury production, higher marshes will be more resilient to future sea level rise. However, high rates of sea-level rise may result in more low marsh habitat than occurs today as high marsh is converted to low marsh habitat (Stralberg et al. 2011) and thus methylmercury production would also be expected to decline.

KNOWLEDGE GAPS

Historically, the Guadalupe River flowed down into Guadalupe Slough, but it has since been diverted to flow out through Alviso Slough. There is potential for high concentrations of mercury to be remobilized if the hydrology within Guadalupe Slough (which is now the outflow of several smaller creeks and constructed drainage channels) changes due to restoration activities. Future sampling could determine how much mercury is actually buried within the sediments within the Guadalupe Slough so that we can model and predict what the resulting mercury exposure will be. However, since previous studies have consistently shown that the increased mercury exposure from restoration activities is a short term impact, it may be that it isn't important to quantify the potential mercury exposure from the Guadalupe Slough.

Much of the bay-wide sampling for mercury by the RMP has been conducted in open bay waters, less so in bay margins. In 2015 the RMP focused sampling for mercury and other water quality indicators on the margins of the Central Bay. For the most part, mercury concentrations observed in the margins were similar to concentrations in open bay waters. However, there were several hot spots in which mercury concentrations were much higher in the margins (SFEI, 2017). The RMP completed sampling in South Bay margins in 2017 but have not yet reported on the results of that sampling.

There is considerable uncertainty around how climate change (sea level rise, changes in air and sea temperature and precipitation) will affect mercury exposure and methylmercury bioaccumulation. As sea levels increase, new areas of the baylands will be potentially exposed to intertidal exchange, particularly during storms and high water events. This will likely result in the remobilization of mercury into the ecosystem and corresponding increases in salinity may increase methylmercury production within intertidal habitats.

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

Solid bullets below are from Valoppi (2018). Hollow sub-bullets are modifications suggested by reviewers and workshop participants.

- Explore how to manage ponds to decrease MeHg exposure and production.
    - Workshop participants felt that the focus on pond management should investigate the ideal level of water circulation that balances habitat availability and limits MeHg production.
- Study the effect of mercury on breeding birds such as terns, stilts, black skimmers, and snowy plovers.
- Establish a regional, long-term mercury monitoring program at set sites and with indicator species, including restored areas and managed ponds. In managed ponds, evaluate management practices that reduce MeHg production and thus decrease MeHg in biota.

- Study mercury in marsh species, such as the California Ridgway's rail and their diet (related to environmental exposure of Hg), so that concentrations of concern in a marsh could be determined. For example, collect rail prey items for mercury analysis to evaluate dietary mercury exposure in newly restored marshes and reference areas. Consider additional marsh habitat mercury biosentinels such as salt marsh harvest mouse, bats, marsh wrens (*Cistothorus palustris*), and song sparrows (*Melospiza melodia*).
- Continue the assessment of the A8 Ponds (including Ponds A5 and A7) to determine how to move forward with management actions.
- Conduct a statistical analysis of existing data to identify relationships between water and fish to determine if the best indicators of mercury accumulation and movement. Evaluate the preferred biosentinels to use if funding is low—water, fish, or bird eggs? Also evaluate which fish species inside the ponds is the most informative indicator over the long term.
- Evaluate use of satellite or other remote sensing imagery to assess mercury status in the Project.
- Assess long-term mercury movement in sloughs and marshes including the effects of erosion based on changes in hydrology.
- Study the accretion of sediment and mercury inside the A8 Ponds; also evaluate mercury flux between Alviso Slough and the A8 Ponds.
- Evaluate where the mercury that is remobilized in Alviso Slough during scour is moving to. If it is accumulating in wetlands, where is it bioavailable?

Suggested from 2019 workshop and review input

- Use the gradient of conditions within managed ponds across the Estuary to determine what factors limit MeHg production.
- Phase 2 studies should be focused on factors that increase methylmercury production and bioaccumulation rather than inorganic mercury mobilization.
- Use hydrodynamic models to test hypotheses about how pond management and restoration design could affect methylmercury production and transport.
- Participants in both mercury and water quality discussions noted the overlap in monitoring targets between these efforts and that future efforts should coordinate to more efficiently address phase 2 study questions.

OPPORTUNITIES FOR REGIONAL SYNERGY

Regional Monitoring Program for Water Quality in San Francisco Bay

The RMP has various long term monitoring programs that monitor mercury in bay ecosystems. Project level mercury monitoring could be better understood by connecting to longer term patterns in RMP data. Mercury-related RMP programs include:

- Mercury in bay sediments have been monitored every four years 2002 - 2014
- Mercury in cormorant (*Phalacrocoracidae*) eggs (irregular sampling)
- Mercury in sport fish every five years
- Mercury concentrations in the bay margin (Central bay in 2016, North Bay next to be sampled)

Wetlands Regional Monitoring Program

The Wetlands Regional Monitoring Program (WRMP) is a newly forming program with aims to implement a long-term monitoring effort focused on bayland habitats in the Estuary that will be designed to address key restoration and management questions. As the program is in the process of being designed it is difficult to predict where opportunities for synergy will emerge for monitoring mercury in the Estuary. However, early discussions are including the monitoring of biosentinel species that occur in specific habitat as indicators of methylmercury bioaccumulation. At present, the WRMP is considering at least monitoring the blood and tissue of longjaw mudsuckers as a biosentinel species as that is ubiquitous in tidal marsh and other associated habitats. In addition, the WRMP is considering co-locating sensors for different monitoring targets such as dissolved oxygen, salinity, and water levels to better understand processes that promote or inhibit methylmercury production.

North Bay Mercury Biosentinel Project

Many if not all of the recently restored marshes in other parts of the Estuary are including monitoring using biosentinel species. The North Bay Mercury Biosentinel Project is monitoring fish and birds within different bayland habitats to assess whether tidal marsh restoration or pond management affect methylmercury bioaccumulation. This program includes monitoring at the Napa Sonoma Marsh Restoration project, Cullinan Ranch Restoration and the Hamilton restoration and the results will provide further lines of evidence of how management activities affect mercury exposure in bayland ecosystems. To date, results from restoration projects in the North and South Bay show similar responses with respect to mercury bioaccumulation.

Coordinated remote sensing

The use of remote sensing technology to collect data across disciplines provides a relatively easy opportunity to coordinate monitoring of various targets, including mercury (see Emerging Technologies below). High resolution remote sensing imagery can be used to monitor various metrics of concern to the Project including changes in elevation, vegetation establishment and composition, water quality (including mercury) and wildlife occurrence and abundance. In addition, ground surveys used to calibrate and evaluate remote sensing image classification could collect data on other targets that aren't detectable through remote sensing images further enhancing efficiency in monitoring efforts.

EMERGING TECHNOLOGIES

Advances in remote sensing technology may enable regional mapping of mercury concentrations more efficiently across space and time. As new platforms, such as unoccupied aerial systems, become available to more efficiently acquire imagery at higher resolution, remote sensing is likely to become a valuable tool for understanding patterns of mercury in the Estuary through space and time. Fichot et al. (2016) used fine resolution (2.6 x 2.6 m) visible and near infrared spectroscopy to map dissolved organic carbon (DOC), turbidity and chlorophyll-a in Suisun Bay. The authors also used a correlation between DOC and filter passing methylmercury ($R^2 = 0.84$) based on in situ samples to project filter passing methylmercury (FMeHg) concentrations across the study area using the imagery. The authors also note that the correlation between DOC and FMeHg may vary across the Estuary and through time so further work needs to be done to determine the robustness of the results. Further, future studies will be necessary to determine if mapped estimates based on remote sensing imagery are precise enough to be inform studies of methylmercury bioaccumulation (Davis, pers. comm.).

ACRONYMS AND ABBREVIATIONS

Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
DOC: dissolved organic carbon
FMeHg: filtered methylmercury
MeHg: methylmercury
RMP: Regional Monitoring Program for Water Quality in San Francisco Bay
SFBRWQCB: San Francisco Bay Regional Water Quality Control Board

SFEI: San Francisco Estuary Institute
WRMP: Wetlands Regional Monitoring Program

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EFFECTS ON AQUATIC SPECIES

RATIONALE AND BACKGROUND

Understanding how tidal restoration and other management actions impact native aquatic species is important in determining how many acres the Project can restore to full tidal action and achieve its goals. Conceptual models in the Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) link tidal marsh restoration to benefits for fish and other aquatic species. In general, increases in tidal marsh habitats are expected to benefit native species by providing refugia from predation, increasing the amount of shallow water habitat and increasing food production (Herbold et al. 2014). Salmonids are expected to benefit from improved estuarine rearing habitat for juveniles and improved migratory conditions for juveniles and adults. The Project identified the monitoring required to track these benefits and ensure progress toward meeting restoration targets. For aquatic species, the monitoring activities include tracking fish presence, abundance, survival, and reproduction in various habitats as restoration progresses. However, the Project also identified potential negative impacts associated with tidal restoration and management including loss of tidal flat habitat adjacent to tidal restoration, increased predation by non-native species, and increased levels of methylmercury due to channel scour and water management. To reduce uncertainties around these potential negative impacts, the Project identified Applied Studies that included assessing fish diversity, abundance, survival, growth, reproduction, and methylmercury levels in response to restoration, pond management and other activities. See the AMP (Trulio et al. 2007, pp. 22-25, 123) for lists of Applied Studies and monitoring activities and how the Project distinguished between the two.

As habitats change due to restoration, management, or other drivers, assessing how the Project is meeting its objectives is vital to measuring success. The AMP stated specific restoration objectives for aquatic species under Project Objective 1(C) to create, restore, or enhance habitats of sufficient size, function, and appropriate structure to support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, mammals, birds, reptiles and amphibians. The restoration targets for non-avian wildlife species are as follows: 1) Enhance numbers of salmonids and juveniles in rearing and foraging habitats relative to the programmatic National Environmental Policy Act (NEPA)/California Environmental Quality Act (CEQA) baseline numbers, 2) Enhance numbers of native adult and juvenile fish in foraging and rearing habitats relative to NEPA/CEQA baseline numbers, and 3) Maintain or enhance numbers of harbor seals using the South Bay. Baseline monitoring for fish was conducted in 2004 and 2005 and described species assemblages and abundance by species in the salt ponds and sloughs in the South Bay (Mejia et al. 2008) but salmonids were not captured. Mejia et al. (2008) were not able to sample in Eden and Alviso sloughs due to concerns over incidental take of steelhead trout (*Oncorhynchus mykiss*). The lack of studies in shallow South Bay waters coupled with a small steelhead population made determining baseline numbers difficult.

With the objective to increase abundance and diversity of native species, the AMP identified a Key Uncertainty related to aquatic species.

Key Uncertainty - *Can restoration actions be configured to maximize benefits to non-avian species both onsite and in adjacent waterways?* (Trulio et al. 2007)

To address this Key Uncertainty, the AMP posed the following Applied Study Question (Trulio et al. 2007; Table 2):

1. To what extent will increased tidal habitats increase survival, growth and reproduction of native species, especially fish and harbor seals? The extent to which restoring tidal habitats will affect native species, including steelhead, harbor seals, native fish and oysters, is unknown. This question requires long-term study on local and regional scales relevant to the species examined.

The Adaptive Management Summary Table (Trulio et al. 2007, Appendix 3) identified additional studies that largely repeated the questions above but also included looking at abundance and called for specific studies of steelhead.

Valoppi's (2018) summary of Phase 1 focused on studies by Dr. James Hobbs on native fishes within the Project's footprint. Hobbs addressed the Key Uncertainty above by surveying fish within different types of restoration sites including enhanced managed ponds, muted ponds, and tidal restoration sites in different stages of evolution as well as adjacent sloughs and compared fish community metrics and catch numbers across sampling sites. To assess the use of newly restored areas by aquatic organisms, Hobbs conducted surveys in the Alviso, Eden Landing, and Ravenswood pond complexes, and at Bair Island beginning July 2010. The Alviso pond complex, including tidal restoration Ponds A6, A17, A19, A20, and A21, had the highest abundance of fish and macroinvertebrates as well as highest species richness of the complexes studied. Hobbs identified 58 species of fish, including 40 native species. No listed steelhead smolts were found. The AMP specifically called out restoration targets for steelhead (Trulio et al. 2007, Adaptive Management Summary Table, Appendix 3). In managed ponds, non-native species made up 84 percent of the catch but the total catch (fish and invertebrates) was two-fold greater in managed ponds compared to former ponds subject to full tidal restoration (breached ponds). Hobbs also noted that tide gates on managed ponds and the mouths of breaches were a predation hotspot and that abundance of prey could provide benefits to native predators but may also attract non-native species such as striped bass (*Morone saxatilis*).

Hobbs also found that leopard sharks (*Triakis semifasciata*) benefit from ponds restored to tidal action. Fully-tidal restoration ponds and adjacent sloughs supported similar abundances of leopard sharks, while fewer were found in muted-tide ponds. Hobbs cautions against further construction of muted-tidal ponds due to frequent hypoxic conditions in summer when young sharks are using them. Leopard sharks were often found in the scoured channels created by levee breaches where constriction points provide a "hotspot" for predators to ambush prey exiting with ebbing waters. This type of restoration design feature may facilitate trophic transfer up the food chain effectively delivering food resources to other parts of the San Francisco Bay Estuary and the ocean. Leopard sharks are known to migrate out of the shallow South Bay and provide important food web links to other subregions and the outer coast.

Hobbs (2015) also addressed one of the potential negative impacts of restoration and management on steelhead by conducting a two-year study in Pond A8. The study focused on the threat of steelhead entrainment (fish being transported along with the flow of water out of their normal habitat into harmful environments). Although the Key Uncertainty is primarily related to how restoration provides benefits to native species, there was concern that steelhead would become trapped in A8 and/or would be subject to high levels of methylmercury (see Mercury Chapter, Knowledge Gaps). In 2014, 70 fish were tagged in the Guadalupe River and only 1 fish was detected in the A8 notch, in part, due to technical challenges with the equipment. In 2015, Hobbs tagged 28 fish but the drought prevented smolt outmigration precluding the possibility of detecting fish in A8. The study results were inconclusive and Hobbs recommended that future studies use surrogate species and include other tidally restored ponds.

The AMP sought to understand harbor seal (*Phoca vitulina*) response to restoration as an objective. Harbor seals are the most common and the only year-round resident marine mammal in the Estuary

(Manugian 2016). However, Valoppi (2018) reported that no Phase 1 studies were conducted to address response to restoration. Don Edwards San Francisco Bay National Wildlife Refuge (DENWR) has collected data on harbor seal haul-out areas since 1999 and while fluctuations have occurred, the population has been stable (Manugian 2016). While identified as a Key Uncertainty and an important aquatic species, harbor seal use of the Project area is not well understood, and it is not known if tidal restoration has so far benefited seals directly, but an increase in fish and access to fish via levee lowering and breaching should be a benefit for foraging.

RECENT INFORMATION

Native Fishes

The longfin smelt (*Spirinchus thaleichthys*is) is state-listed as threatened and has been declining for several decades in the Estuary and in particular, in the SF Bay Delta (Sommer et al. 2007). Long-term monitoring efforts for longfin smelt and other pelagic fishes by California Department of Fish and Wildlife (CDFW; Fall Midwater Trawl Survey) have focused in the SF Bay Delta and Suisun Bay but recent studies have shown that longfin smelt are also found in San Pablo Bay and South SF Bay (Grimaldo et al. 2017 and Hobbs 2017). Furthermore, the larval smelt were found in a broader range of habitat types and conditions than previously thought (shallower waters, tidal channels and in higher salinities). This mismatch between the sampled distribution and actual distribution of longfin smelt represents an inaccurate understanding of habitat needs and response to management. The South Bay supports a small population of longfin smelt which is attracted to its tidal channels and sloughs when winter rains create colder and less saline conditions than are present the rest of the year. In addition, the nutrient-rich water released from treatment plants may benefit the species (Hobbs pers. comm.; see Water Quality chapter). Tidal restoration also benefits this declining species by increasing prey density (Barros et al. 2019). The majority of longfin smelt caught during a December 2017 otter trawl were in the tidally restored ponds A19 and 20 (Hobbs 2017). The wet winter in 2018/19 resulted in another increase in longfin smelt captures during a December 2018 survey in the South Bay (Hobbs unpublished data). However, surveys in 2018 from CDFW's Fall Midwater Trawl Survey, which did not include the areas surveyed by Hobbs, were the 5th lowest in history, representing a 63% reduction from the previous year (CDFW memo). These recent results point to the potentially important role of restoration in the South Bay for the Estuary's longfin smelt population. Involving restoration in South Bay may be an overlooked strategy by those planning recovery actions for longfin smelt in the Estuary as a whole (Hobbs et al. 2017).

Many other native fishes, including commercially important prey fish such as Pacific herring (*Clupea pallasii*) and northern anchovy (*Engraulis mordax*), benefit from restoration and have been recorded using restoring tidal marsh as reported in Jim Ervin's blog that summarizes the results of monthly fish trawls in South Bay (hobbslab.com/news/). The blog is a wealth of anecdotal information for the South Bay on not just fish but also invertebrates, birds, and marine mammals. The fish sampling, previously led by Dr. James Hobbs formerly with UC Davis and now with CDFW Stockton, will continue under the leadership of Dr. Levi Lewis.

Oysters

Oysters were identified as a key aquatic species in the AMP and can be part of restoring whole systems as recommended in the Bay Goals (2015). The establishment of native oysters (*Ostrea lurida*) and eelgrass (*Zostera marina*) contributes to Project Objective 1(C) to support increased abundance and diversity of native species. Additionally, the establishment of oysters, eelgrass beds and other forms of living shorelines can increase shoreline protection (Beagle et al. 2019) and help achieve the Project's flood protection goals.

The Project recognized that native oyster establishment could benefit tidal marsh restoration and supported the Native Oyster Establishment Study which was conducted on the mud flats just outside of the Eden Landing pond complex as part of the Living Shorelines Nearshore Linkages Project (Latta and Boyer 2015).

The Eden Landing Living Shorelines site is a shallow mudflat that extends bayward for more than a mile, and the depth from shore is a bit shallower than might be ideal for native oysters and eelgrass. For the pilot study, a phased approach was used in order to understand feasibility prior to deploying a larger scale treatment (Latta and Boyer 2015). Latta and Boyer (2015) estimated that with modest effort, the restoration increased the population of native oysters at that site by one order of magnitude. The study tested different techniques to attract and support oyster growth and the authors found that oyster blocks and higher tidal elevations were more successful in the South Bay, in contrast to the oyster shell bags performing best at San Rafael. Oyster recruitment at Eden Landing did not occur until Spring 2013 and occurred at a much lower rate than in San Rafael Bay. This was likely due to predation by the Atlantic oyster drill (*Urosalpinx cinerea*). Epibenthic invertebrates, fishes, and avian response to the oyster installation were all monitored as a part of the pilot study.

Harbor Seals

The National Park Service (NPS) has been monitoring harbor seals as a site-specific indicator within the Estuary and the outer coast to inform restoration, protection, and recovery actions (Allen and Grieg 2019). Surveys were conducted intermittently since the 1970s and consistently since 1998 at sites on the coast (Castro Rocks, Yerba Buena Island). Harbor seal monitoring in the South Bay occurred at Mowry and Newark sloughs since the 1970s, intermittently, and consistently from 1998-2017 thanks to a Refuge volunteer. Data collected during bi-weekly counts included number of adults, pups, and disturbance events. Summary reports are produced about every 5 years. The number of harbor seals counted on surveys in the Estuary since 2005 were relatively stable during early years but have fluctuated more recently. The 2015 count was one of the lowest on record and was followed by the highest count on record the following year in 2016 (Codde and Allen 2018). Disturbances at haul outs are becoming more common in the Estuary and likely affect survey numbers.

KNOWLEDGE GAPS

Fishes

The benefits of tidal restoration to fish is well-documented (Herbold et al. 2014) but the effects of different restoration designs are less well-known. For example, restoration designs that maximize phytoplankton production, reduce invasive clam populations, or increase structural diversity are not well understood with regards to their effects on fish. Furthermore, the importance of restoration design for fish species that occur in low numbers and the specific mechanisms underlying restoration benefits is even less well-known. The question of how tidal restoration will benefit salmonid survival, growth, and reproduction is a knowledge gap that will be difficult to answer. The probability of detecting salmonids is extremely low due to their small population sizes and the expansive area of available habitat. The lack of pre-Project data and the inability to develop a baseline population estimate further complicates the task of assessing restoration impacts for these species. Furthermore, populations of salmonids can fluctuate based on conditions outside the Project area necessitating a broad geographic approach. Poor ocean conditions and drought could cause a reduction in numbers in any given year irrespective of the success of restoration. Challenges aside, continued dedicated exploration is necessary given the importance of understanding the benefits and risks to salmonids (NMFS 2016). One approach that could provide valuable information is to assess changes in habitat availability and quality as a result of restoration actions. Before adopting this approach, important questions need to be considered including what metrics or combinations of metrics can be used to assess positive and negative habitat conditions such as those that best represent food production, predator refugia and other factors that relate to salmonid condition and growth. Another approach that has been widely used is the surrogate species approach. However, before such an approach can be considered, it must be established that the surrogate and target species respond similarly to the environmental changes being evaluated (Murphy et al. 2011, Murphy and Weiland 2014). The relationships between salmon response and the response of other fish species to environmental changes associated with tidal restoration is not well-known and would need to be validated before this approach can be considered.

Phase 1 studies have shown the impact of a multi-year drought on the fish community, but a synthesis of the fish community's response to the more recent wet winters is still needed. Knowledge of fish response to different water years is not well-understand and is necessary to put restoration-specific results into context.

The potential negative impacts of restoration and management, in particular, pond management, on steelhead is still not well known. The National Marine Fisheries Service (NMFS) requires an assessment of potential negative impacts associated with pond management including entrainment, high levels of bird and fish predators, mercury bioaccumulation, warm hypoxic waters during the summer and fall, and harmful algal blooms. See the Water Quality chapter for information on potential impacts to fish from pond management, knowledge gaps and potential studies to reduce uncertainties. The Pond A8 study summarized above was inconclusive, in part because steelhead are difficult to detect given their small population size and the vast area available to them within the Project footprint. This low abundance makes it a challenge to collect enough data to draw meaningful conclusions. Nonetheless, NMFS supports continued monitoring at A8 and other tidal ponds near the Guadalupe River to ensure that steelhead are not being negatively impacted.

Previous efforts identified benefits of tidally restored areas for certain fish species but questions remain on how to optimize design to improve habitat for native fish communities, particularly with regard to levee breaching, circulation, water quality and associated fish assemblage response. Continued tracking of habitats, restoration actions, and fish community response will inform understanding of how to optimize benefits to aquatic species and inform future design considerations. For example, the benefits associated with the number of breaches and potential circulation changes in restored ponds in the Project area is unclear.

Site-specific fish community response to restoration has been assessed in some areas and has been positive but a key knowledge gap is how the Project's actions might be benefiting native fish populations at larger scales. Of particular interest is the Estuary-wide impact of the Project's restoration activities on longfin smelt. Additionally, Project studies could be related to broader studies investigating the health and productivity of leopard sharks in coastal ecosystems.

Harbor Seals

A focused study on harbor seal response to restoration did not occur in Phase 1; however, literature has been published through other studies, and that knowledge can be better leveraged going forward. Elsewhere in the region, demographic data has been identified as a need – specifically pregnancy and mortality rates. Telemetry studies have occurred on the coast to understand movements, and similar studies could occur within the Estuary to assess if and how harbor seals use restored areas.

Oysters

The factors affecting oyster reef establishment in the South Bay and a reefs' ability to attenuate wave energy in the South Bay is not well known. Size and configuration of substrate arrays, as well as their distance from shore, are likely to have important effects on both physical and biological features, but additional replicated studies are needed to better understand how to maximize shoreline protection using this restoration technique. Furthermore, the Eden Landing pilot project was too small to draw meaningful conclusions on the response of invertebrates, fishes, and avian species to oyster restoration, and more study is needed (Latta and Boyer, 2015). Beagle et al. (2019) provided estimates of where eelgrass could be established throughout the Estuary. They did not identify suitable sites in the South Bay, but further studies and review could validate those results.

Many of the studies described in this chapter focused on trends in abundance and diversity. The Applied Studies identified in the AMP relating to assessing productivity, growth rates, fecundity, and survival have not been pursued for most species and remain knowledge gaps.

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

Closed bullets below are from Valoppi (2018). Hollow sub-bullets are modifications suggested by reviewers and workshop participants.

- Continue steelhead smolt entrainment studies to support continued operation of Pond A8 gates as a muted tidal system year-round. [A Phase 2 study is planned for October 2019-May 2020 to conduct outmigration and entrainment of steelhead per NMFS Biological Opinion to Refuge.]
- Conduct studies assessing the growth and reproductive success of aquatic organisms, especially fish.
    - To improve restoration strategies, continued monitoring of fish diversity and abundance in relation to restored and managed habitats in the South Bay are needed to better understand how native fish are responding to conservation actions in relation to other changes in the environment.
    - Workshop attendees suggested the channels in Bair Island be used as a local reference site for assessing native fish populations within the Project and stressed the importance of integrating water quality monitoring.
- Explore if understanding restoration benefits to harbor seals is needed.

Other potential Phase 2 studies

Achieving the Project's aquatic restoration targets efficiently will require effectiveness monitoring and other studies that are directed at addressing Key Uncertainties and assessing responses to restoration and management actions as described in the AMP. Although the trends for most aquatic restoration targets have been positive, salmonids have not been adequately assessed because of various challenges explained above. It is important to assess salmonid response to tidal restoration and pond design and management to validate conceptual models and track progress. Future monitoring and research should be focused on understanding the linkages between restoration actions and biological outcomes while striving to collect data that can be integrated and shared with other tidal marsh restoration monitoring efforts in the Estuary. Below we provide additional ideas for Phase 2 studies by taxa.

Oysters

The 2010 San Francisco Bay Subtidal Habitat Goals Report (Subtidal Goals 2010) recommends that the next generation of projects consider the possibility of integrating multiple habitat types to improve linkages, promote synergistic effects, and benefit native species. The Project includes multiple wetland restoration sites and conservation planners have expressed interest in integrating lower elevation intertidal and subtidal habitats into the matrix of newly restored areas. Areas to be considered include offshore of Ravenswood (Ponds R1 and R2) and just north of Alviso - Mountain View Ponds A1 and A2W. A potential Phase 2 study could identify where within these areas a living shorelines project could be implemented. However, because oysters occur in deeper intertidal and subtidal habitats and are on the periphery of the Project footprint, oyster research is "not related directly to adding more tidal habitat" (Trulio et al. 2007). As stated in the AMP, "The Project will not be able to provide funding for all such studies, but Project Managers should assist to the extent they can with permits, letters of support, and other in-kind services, for valuable studies when appropriate. If demand is great for this type of research, the Project's science managers may develop a review system to help managers select research most likely to assist the Project."

Harbor seals

Exploring the feasibility of assessing harbor seal response to tidal restoration could be a potential area of study for Phase 2. Such an effort should involve coordination with DENWR and the NPS which supports a pinniped coordinator, trains volunteers, compiles data, and produces summary reports.

Native fish

Developing indices for suitable habitat as an indicator of restoration success may be the most efficient strategy for salmonids because of the challenges discussed above. Potential studies could focus on developing suitable habitat indicators and/or surrogate species to address this challenge. To assess how other native fishes use restored sites, a tagging study (PIT or acoustic) could be implemented to track fish in some sites. Longfin smelt may become listed at the federal level, and future studies could help further define high quality habitat conditions and features to help guide restoration and management including water outflow from streams and water treatment plants. Continuing native fish monitoring within a regionally coordinated framework aimed at understanding and improving response to restoration and management will also be needed in Phase 2.

Reviewers called for a more systematic approach to ensure that the Applied Study Questions in the AMP that were not answered in Phase 1, including those in Appendix 3, be considered as potential studies for Phase 2 to address the following:

- To what extent will increased tidal habitats increase survival, growth and reproduction of native species, especially fish and harbor seals? The extent to which restoring tidal habitats will affect native species, including steelhead, harbor seals, native fish and oysters, is unknown. This question requires long-term study on local and regional scales relevant to the species examined (Trulio et al. 2007, Table 2). Including specific study of steelhead (Trulio et al. 2007, Appendix 3).
- Has there been, or will there likely be, increases in recreational boating and if so, will it significantly affect birds, harbor seals or other target species on short or long timescales? (Trulio et al. 2007, Appendix 3)

OPPORTUNITIES FOR REGIONAL SYNERGY

There is much opportunity for a regional connection of aquatic species between the Project footprint and the entire Estuary, connecting to both the SF Bay Delta and to the coast. The Project can exchange information with fish monitoring efforts by Lenny Grimaldo in the northern portion of the Estuary, with Environmental Science Associates (ESA) at the Hamilton Wetlands, the Adaptive Management Advisory Team for the Suisun Marsh Habitat Management, Preservation and Restoration Plan, and with the CDFW's Bay Study which uses the same methods as the monthly South San Francisco Bay trawls now led by Dr. Levi Lewis, UC Davis. Integrating monitoring with the Bay Study would greatly increase the Project's understanding of how fish use and respond to restored sites at multiple spatial scales. This opportunity was emphasized by many workshop attendees. Fish monitoring for mercury contamination also occurs in the Napa-Sonoma Marsh by UC Davis and SFEI where average prey fish Hg concentrations exceeded water quality objectives (Erickson 2018; see also Opportunities for Regional Synergy in the Mercury Chapter). In addition, there have been efforts to understand how water quality affects fish communities (see chapter on Water Quality). Where possible, the design of aquatic species monitoring should consider adding and/or integrating water quality monitoring. Developing regional coordinated fish monitoring guidance that includes the efforts described above would help the Project quantify the effectiveness of monitoring, inform future design and planning leading to successful outcomes. The Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary (IEP TWM PWT 2017) could serve as an example. This framework should also be coordinated with both the Wetlands Regional Monitoring Program (WRMP) and the San Francisco Bay Joint Venture (SFBJV).

San Francisco Estuary Institute (SFEI), along with San Francisco Bay Area Planning and Urban Research Association (SPUR), produced a San Francisco Bay Shoreline Adaptation Atlas (2019), which the Project could draw upon to explore potential synergies with other subtidal and intertidal restoration projects. With regard to oysters and aquatic species, the report mapped areas suitable to support oysters based on water depth, salinity, substrate type, oyster recruitment potential, and site access. Most sites are concentrated in the Central Bay where salinity is high and turbidity is low.

Wetlands Regional Monitoring Program

The WRMP is working with various fish biologists to develop indicators of healthy tidal marsh ecosystems for native fish. The Project has the opportunity to help the WRMP select and define metrics that are in use by or are important to the Project. The long-jawed mudsucker (*Gillichthys mirabilis*) is a top candidate indicator for the WRMP because it is one of the few tidal marsh dependent fish species. However, trapping for long-jawed mudsucker may be restricted in marshes with salt marsh harvest mouse. Some of the metrics under consideration for fish are abundance, biomass, and growth rate. See Introduction for background on the WRMP and overarching ideas for coordination.

EMERGING TECHNOLOGIES

There is potential to use unoccupied aerial systems (UAS) to conduct non-invasive wildlife surveys (Vas et al. 2015) and to collect data on landscape features. UAS survey methods have been proven a cost-effective means to provide greater coverage and efficiency than other remote sensing methods and could assist in conducting harbor seal haul out counts from a safe distance. UAS imagery could also help map mudflats (Digital Elevation Model fine scale elevation; see chapter on Sediment), nesting California gulls (*Larus californicus*) and terns (Sarda-Palomera 2012), or invasive *Spartina* coverage. The use of UAS may be impractical for most fish species in the South Bay but exploring its use for larger species in shallow waters that are difficult to sample traditionally could be worthwhile (e.g., leopard sharks and bat rays; Tyler et al. 2018 and Harris et al. 2019). Some of the challenges to adopting this technology are the various permit requirements that landowners have for using UAS.

Environmental DNA (eDNA) has been used in estuarine environments to assess species presence and biodiversity in sediment and plankton communities (Ruppert et al. 2019). Several projects are exploring the use of eDNA to detect rare species in the upper Estuary (www.genidaqs.com/projects). As with any emerging technology, using eDNA to assess diversity in tidal marsh habitats has limitations, but could be considered for use as an additional tool to supplement traditional fisheries sampling methods to increase understanding of presence of rare species in restored habitats. As an example, quantitative polymerase chain reaction (qPCR) methods could be utilized in a cost-effective manner to detect the presence of federally threatened green sturgeon (*Acipenser medirostris*) in newly restored habitats.

ACRONYMS AND ABBREVIATIONS

Estuary: San Francisco Bay Estuary
Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
CEQA: California Environmental Quality Act
CDFW: California Department of Fish and Wildlife
DENWR: Don Edwards San Francisco Bay National Wildlife Refuge
eDNA: environmental DNA
ESA: Environmental Science Associates
NEPA: National Environmental Policy Act
NMFS: National Marine Fisheries Service
NPS: National Park Service
SF: San Francisco
SFBJV: San Francisco Bay Joint Venture
SFEI: San Francisco Estuary Institute
SPUR: San Francisco Bay Area Planning and Urban Research Association
UAS: unoccupied aerial systems
WRMP: Wetlands Regional Monitoring Program

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WATER QUALITY

RATIONALE AND BACKGROUND

Conversion of former salt ponds to restored tidal marsh or enhanced managed ponds for wildlife habitat creates important habitat for a wide range of fish and wildlife species, but the management of the former salt ponds can have large effects on water quality in ponds and adjacent habitats. Although substantial investments in water control infrastructure in the ponds have notably improved hydraulic circulation through the ponds with a resulting improvement in water quality within managed ponds, some of the managed ponds still suffer from declines in water quality during the warm summer months as higher air and water temperatures result in algae growth that causes reductions in dissolved oxygen (DO) (MacVean et al. 2018) which can limit the persistence of many plant and animal species. Pond managers are challenged with creating wetland habitat that supports fish and wildlife populations without also creating conditions that expose these species to degraded or lethal conditions within the ponds and in adjacent habitats exposed to pond outflows. Similarly, if ponds have lower water quality than surrounding habitats, breaching ponds as part of tidal restoration could degrade water quality of these habitats.

The South Bay Salt Pond Restoration Project (hereafter, Project) Adaptive Management Plan (hereafter AMP; Trulio et al. 2007) describes several water quality targets. Within managed ponds, water quality needs to meet standards set by the San Francisco Bay Regional Water Quality Control Board (RWQCB) for various water quality metrics. These metrics include DO, pH, suspended sediment and turbidity and trace contaminants other than mercury. In addition, the Project should not result in an adverse change in baseline water quality levels in the South Bay using the same metrics as the ponds. Finally, DO levels need to meet Basin Plan Water Quality objectives.

Thus, as discussed below, a key scientific uncertainty at the time of Project inception was:

Key Uncertainty - *Will restoration adversely affect water quality and productivity?* (Trulio et al. 2007)

Two Applied Studies Questions were developed to address the key science gap:

1. What is the effect of pond management, including increased pond flows and associated managed pond effects?
2. What is the effect of increased tidal prism from tidal habitat restoration on water quality, phytoplankton and fish diversity and abundance, and food web dynamics in South Bay?

Phase 1 studies focused on understanding the baseline water quality conditions and how much the changes in water quality were due to natural variability. For example, Shellenbarger et al. (2008) found that tidal cycles tended to best explain variation in DO levels in the Guadalupe Slough and Alviso pond complex. Discharge could have both a positive or negative effect on DO levels within the slough depending on whether the discharge occurred during spring or neap tides. Early studies indicated that opening the gates at Pond A8 all year appeared to improve water quality by raising minimum DO levels in the slough and reduced fluctuations in DO throughout the year (Valoppi 2018). However, following the completion of Phase 1 studies it still isn’t clear how much the water from managed ponds affects the water quality in adjacent habitats relative to the contributions from other shallow water habitats and wastewater treatment outflows. Additionally, there is still a need to understand whether there are management options for the managed ponds that could improve water quality, both within the ponds and in adjacent waterways, sloughs, and other habitats, while also continuing to provide high quality habitat for native fish and wildlife.

Summaries of studies of how restoration has affected aquatic species, including changes due to impacts to water quality, are addressed in the Effects on Aquatic Species chapter. This information primarily relates to the second Applied Study Question for the water quality Key Uncertainty.

RECENT INFORMATION

Much of our current knowledge about water quality in the San Francisco Estuary (hereafter, Estuary) is based on monitoring conducted by Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) and long-term monitoring conducted by United States Geological Survey (USGS). The RMP has monitored water quality in the Estuary for over 25 years and the long-term data collected through this effort provides an opportunity to better understand the effects of management actions relative to other changes happening at the broader scale. Recent studies, along with the more fine-scale monitoring that is taking place as part of the Project, are dramatically improving our understanding of how pond management and restoration of tidal marsh habitat affects water quality in the South Bay.

There are well-known physical processes that lead to water quality issues in the South Bay. The South Bay has some of the most extensive areas of shallow water in the Estuary, which can lead to warmer water temperatures, particularly in summer months. Warmer water will typically lead to greater phytoplankton production and possible declines in DO. The high nutrient content of the South Bay in general and the ponds in particular could contribute to potentially high levels of primary productivity. However, the South Bay's relatively high suspended sediment concentrations combine with its high tidal ranges, which mix the water in the South Bay vertically, consequently limiting primary production by reducing light penetration (Cloern and Jassby 2012). Compared to other nutrient-enriched estuaries, phytoplankton productivity in the Estuary is not nutrient-limited but rather is limited primarily by light penetration (Cloern and Jassby 2012). Additionally, bivalve mollusks have historically controlled phytoplankton biomass in the South Bay (Cloern and Jassby 2012).

There is considerable spatial and temporal variability in water quality within the Estuary. Typically, South Bay water quality is lowest in the summer and early fall (MacVean et al 2018). Late summer chlorophyll concentrations increased greatly between 1995 and 2005 but since 2005 have plateaued and currently remain relatively stable at between approximately 2.5 and 7.0 ug/L (SFEI 2017). This increase in chlorophyll concentrations is likely correlated with larger scale climatic patterns but are manifested through trophic cascades that result in less bivalve grazing (Cloern and Jassby 2012). In general though, the combination of higher air and water temperatures, lower suspended sediment concentrations (leading to greater light penetration) and less freshwater entering through runoff results in conditions that promote phytoplankton growth and reductions in DO.

Tidal cycles also cause substantial changes in water quality. For example, DO at water quality stations within South Bay sloughs and ponds closer to the bay dropped below target levels[10] during ⅓ of low tides but increased above target levels during high tides (MacVean et al. 2018). Spring and neap tides can cause significant fluctuations in water quality, with lower DO concentrations associated with spring tides (larger tidal range). The incoming tides can bring in water with higher DO concentrations to the upper reaches of connected sloughs while the outgoing tides will bring low DO water towards the bay. With a greater tidal range it is possible that the spring tides are connecting areas with low DO

[10] The Basin Plan water quality objective for DO in the Lower South Bay is 5mg/L. DO concentrations below this threshold are generally considered stressful for aquatic life.

concentrations and that the net result is lower DO concentrations overall, however additional study is needed to validate that this mechanism is responsible for the observed pattern. Tidal range only explained 12% of the variation in DO concentrations in a statistical model; however, the correlation between explanatory variables within the model made it difficult to isolate the effects of each factor (MacVean et al. 2018).

Several other processes contribute to spatial variation in water quality. Areas with higher water velocities tend to have higher suspended sediment, which limits light penetration and subsequent oxygen demand from phytoplankton (MacVean et al. 2018). Wastewater treatment plants are the dominant sources of nitrogen in the South Bay (Senn and Novick 2014), and habitats near wastewater outflows will have higher nutrient concentrations. However, annual flows of treated effluent have been declining in recent years (SFEI 2017). Still, sloughs near wastewater outflows with less tidal exchange and flows have lower salinity, higher nutrients and more frequent and longer low DO excursions (DO < 5.0 mg/L). For example, measurements from monitoring stations in Guadalupe Slough, which receives treated effluent from the Sunnyvale wastewater treatment facility, had the greatest number of low-DO excursion events for longer periods compared to other parts of the South Bay; one excursion lasted for 12 days (MacVean et al. 2018). No stations recorded events where DO fell below levels that could have acute impacts on fish (<2.3mg/L) for more than 24 hours (MacVean et al. 2018). Managed ponds tend to accumulate substantial organic matter from live or decaying algae and pass the organic matter to adjacent sloughs when water is released from the ponds, but the amount released is a small fraction of the volume released by wastewater treatment plants.

It is still unclear what the short- and long-term impacts of the variation in water quality to exposed South Bay ecosystems are. Lewis and Hobbs (2018) found substantial species-level variation in seasonal abundance and response to water quality conditions during sampling of the South Bay open water habitats and Alviso pond complex. When all fish species were considered together, Lewis and Hobbs (2018) had higher capture rates in warmer, fresher waters with low DO. However, this result was driven by a few species that occurred at high abundance during summer months, as the fish diversity was 20% lower during the summer. In contrast, some species such as Pacific herring (*Clupea pallasii*) and longfin smelt (*Spirinchus thaleichthys*), responded positively to cool water temperatures with higher DO concentrations (Lewis and Hobbs 2018). Other species, such as bat rays (*Myliobatis californica*), yellowfin gobies (*Acanthogobius flavimanus*) and threespine sticklebacks (*Gasterosteus aculeatus*) were at higher abundance with higher water temperatures and lower DO concentrations (Lewis and Hobbs 2018). In general, temperature and salinity explained more of the variability in individual fish species abundance than DO, but these covariates were significantly correlated, making it difficult to statistically isolate the effects of each. Temperature is also correlated with season and because many of the species sampled are only present in the study area in specific seasons, it was not possible to determine whether changes in abundance were due to differences in the water quality parameters or because of life history behaviors. However, the maximum abundance of most species analyzed did occur at DO concentrations above the water quality target of 5 mg/L, suggesting that somewhat higher DO concentrations are important for the fish community.

Generally, the Alviso pond complex, including the full complement of aquatic habitats, supports a diverse fish community with species that rely on different habitats within the system. As detailed in the Effects on Aquatic Species chapter, the managed ponds support a diverse fish community but many of these species are non-natives. Fish diversity is lower in San Pablo Bay than the South Bay (Hobbs, unpublished data), and Lewis and Hobbs (2018) speculate that the nutrients provided by wastewater treatment plants in the South Bay improve the quality of habitat for the fish community there which may explain some of the diversity differences between these bays. Although some species responded negatively to the high nutrient and temperature, low DO and salinity environment of Guadalupe Slough, catches of small forage fish species were greatest in these conditions suggesting a refuge habitat for these species (Hobbs et al. 2018). As a means to increase our understanding of community response trajectories beyond short-term fluctuations, longer-term monitoring or more controlled studies could help identify longer-term responses to varied water quality conditions.

Harmful algal blooms (HABs) are another water quality concern that may have long-term impacts on estuarine communities and may be connected to management activities. HABs typically form when there is an abundance of nutrients in the water combined with warm water temperatures and low circulation. HABs are distinguished from other algae in that they can produce toxins and deplete DO in the water. There are several forms of HABs that have been observed in the Estuary that can be generally classified into marine and freshwater HABs. Marine HABs are likely to enter the Estuary from the Pacific Ocean (Cloern et al. 2005) while freshwater HABs originate upstream and are transported into the sloughs and Estuary during high runoff events (Lehman et al. 2005). In addition, the South Bay salt ponds contain resident populations of HAB organisms (Thébault et al. 2008). In observations collected in the lower San Francisco Bay between 1993 and 2013, Sutula et al. (2017) found an increase in detections of several HAB taxa following the restoration of Phase 1 ponds. Another recent study found that 98% of mussels sampled within the Estuary in 2015 contained at least one of four of the HAB-associated toxins studied, and 29% contained all four, including two marine and two freshwater associated toxins (Peacock et al. 2018). Moreover, 25% of the mussels sampled by Peacock et al. (2018) throughout the Estuary including the South Bay exceeded regulatory guidance for microcystins. This freshwater toxin has been detected previously in marine mussels in the Estuary (Gibble et al. 2016). Recent studies suggest that microcystins may spread further west and downstream during drought conditions (Gibble et al. 2016, Lehman et al. 2017). If microcystins or other HAB-producing species are residing in managed ponds, then the timing of restoration or other water control management could affect their spread through the Estuary. Microcystin bioaccumulation in marine mussels has been correlated with acute or chronic toxicosis in marine mammals and estuarine birds (Gibble et al. 2017) and therefore could affect the Project's ability to achieve management objectives.

KNOWLEDGE GAPS

Phase 1 Applied Study Question #1: What is the effect of pond restoration management, including increased pond flows and associated managed pond effects?

- Is water quality having a deleterious effect on native fish and wildlife species?
    - Will climate change increase the likelihood for deleterious effects?
    - Are these effects seasonal?
- Are there pond management practices that can minimize the impacts to water quality both within ponds and in adjacent habitats?
- Are management activities increasing the frequency or risk of large HABs?
    - Does chronic exposure to HABs have negative impacts to fish, wildlife and human populations?

Phase 1 Applied Study Question #2: What is the effect of increased tidal prism from tidal habitat restoration on water quality, phytoplankton and fish diversity and abundance, and food web dynamics in South Bay?

The studies we reviewed on the effects of pond restoration on fish compared fish abundance observations between restored ponds, adjacent sloughs, ancient marshes and managed ponds. As noted in the Effects on Aquatic Species chapter, some native fish species appear to be benefitting from tidal marsh restoration. However, we did not find any studies that could clearly attribute these changes to changes in water quality resulting from increased tidal prism. There is evidence that increases in connectivity and exchange can improve water quality parameters but there is also evidence that the restored habitat itself is providing benefits as well. Thus, the benefits from habitat creation (vegetating marshes) vs. improvements in water quality are somewhat confounded.

There is some evidence that restored salt ponds in the South Bay may be contributing organic matter that is leading to phytoplankton production in the open bay. High frequency monitoring stations at the Dumbarton Bridge and in nearby sloughs have detected patterns in chlorophyll-a that suggest bayland habitats may be contributing organic matter to the open bay (Crauder et al. 2016). Still, the actual source of this material is highly uncertain and further studies could establish if and how much restored ponds contribute to phytoplankton production in the open bay.

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

- Better understand the contribution of local wastewater treatment plants' effluent to nutrient and low DO conditions in the bay and sloughs that feed into and out of the ponds currently or to be restored.
- Study if and how pond management and/or tidal marsh restoration can improve water quality, phytoplankton, and fish diversity and abundance and food web dynamics in all the pond complexes.
- Study if and how the duration and intensity of low DO events affect target fish species.

Suggested from 2019 workshop and review input

- Provide data on nutrients, productivity rates, chlorophyll, harmful algal blooms and nutrient cycling from managed ponds and restored ponds to better parameterize high resolution hydrodynamic model being developed by the Nutrient Management Strategy (NMS). Ideally monitoring stations would span the gradient of conditions across ponds and marshes in the Estuary. The results could inform how to best manage ponds in the Project and to better design restoration to reduce water quality issues.
- Study whether nutrient input increases the production of methylmercury.
- Study whether climate change will exacerbate water quality issues in managed and restored ponds.
- Study whether chronic exposure to harmful algal blooms has a negative impact on target species.

OPPORTUNITIES FOR REGIONAL SYNERGY

Nutrient Management Strategy

The Nutrient Management Strategy (NMS) is run by San Francisco Estuary Institute (SFEI) and was developed through the RMP but also involves federal, state and local agencies, academic and non-governmental institutions. The NMS is being designed to address specific nutrient management questions in the Estuary. The current high priority topics are DO, phytoplankton blooms, community composition and harmful algal species, and nutrient loads and cycling (SFEI 2017). Several of the studies referenced in the Recent Information section are part of the NMS. The NMS is in the process of implementing a 10-year plan to address these priority areas. Funding for this program doubled in 2019 to $2.2 million per year.

A component of the NMS is the development of a numeric model that is being designed to simulate the processes involved with nutrient dynamics in the Estuary and provide a tool to make predictions and test hypotheses. The models will be used for the development and evaluation of scenarios of nutrient management. There are opportunities to provide data to help calibrate the model as well as engaging with the modelers so that scenarios include management options that the Project is considering. This could help to plan where breaches or water control structures could be implemented or managed to improve water quality.

As part of the NMS, SFEI has installed a network of moored sensors in the South Bay that continuously measures DO, chlorophyll-a, and other water quality parameters (recording every 15 minutes). However, currently the NMS is not collecting any data in managed or restored ponds and this is a major data gap. A challenge for the NMS monitoring is the expense of staff time that is required to swap out sensors. If other monitoring programs already working in the ponds could assist with those tasks this could make the added monitoring within ponds more feasible. Any proposed new monitoring for Phase 2 should consider this in sampling design development. In addition, other types of monitoring (i.e. fish surveys) could be co-located to take advantage of the ongoing monitoring. Workshop participants noted that new science funding opportunities could become available if new science and data collection were available to help address regional water quality questions.

With these challenges in mind, there may be an opportunity to coordinate monitoring with the RWQCB, who is currently in the process of relocating data sondes that monitor water quality and may be open to suggestions for new potential sample sites. This could be a synergy that would allow for monitoring at select sites within the project area in both managed and restored ponds in order to fill the existing data gap.

Another element of the NMS includes the collection of native mussels every two weeks from docks around the edge of the bay and tested for algal toxins. As data from this sampling becomes available, it may be useful to identify patterns and correlations, if any, between Project management and changes in algal toxin levels. Additionally, fish and bird surveys could be coordinated to see if the abundance of toxins has any observable short or long term impacts higher up in the food web.

Wetlands Regional Monitoring Program

The Wetlands Regional Monitoring Program (WRMP) is in the process of developing a program for coordinated monitoring to support the funding, management and regulation of wetland habitats within the Estuary. At the time of writing these are the water quality metrics and elements that are under consideration:

- Time series monitoring of spatial and temporal trends in aqueous salinity via sondes in tidal marsh channels.
- Seasonal in-situ pore water salinity measurements along vegetation and elevation gradsects.
- Time series monitoring of spatial and temporal trends in dissolved oxygen in select tidal marsh channels focused on areas where there are concerns about tidal exchange and mercury methylation.
- Annual methylmercury monitoring through bio-sentinel species (see Mercury Chapter for more details).

The draft program plan for the WRMP states a desire to coordinate its science and monitoring with the science programs of large ongoing restoration projects such as the South Bay Salt Pond Restoration Project. The first guiding question of the draft plan seeks to understand the current state (distribution, abundance and quality) of tidal marsh habitat in the Estuary. Management question 1b specifically seeks to understand how the management and restoration of tidal marshes affects water quality in the Estuary. The water quality issues of greatest concern include all of the main parameters and questions above such as DO, nutrients, HABs and mercury methylation (see Mercury chapter). Thus Phase 2 priority science questions are likely to be in alignment with the water quality science priorities of the WRMP.

EMERGING TECHNOLOGIES

Remote sensing is increasingly being used to collect spatially continuous water quality data across relatively large areas at finer and finer spatial resolutions. For example, Fichot et al. (2016) used data from an airborne imaging spectrometer (PRISM) to collect images at 2.6 x 2.6 m resolution in Suisun Bay and classified them to map turbidity, dissolved organic carbon and chlorophyll-a. Schaeffer et al. (2018) have developed a mobile phone app that allows users to view satellite derived estimates of HABs over time as a way to aid water managers. The National Aeronautics and Space Administration (NASA) is actively working with scientists and managers to develop satellite remote sensing tools to provide near real-time water quality maps and estimates (Pahlevan et al. 2018). The newly available harmonized Landsat and Sentinel-2 data products (https://hls.gsfc.nasa.gov/) provide surface reflectance images every 5 days at a 30 x 30 m spatial resolution which could drastically improve our ability to monitor changes in some water quality parameters over space and time. The harmonized Landsat and Sentinel-2 data have been used to map suspended sediment concentrations in the Estuary to model polychlorinated biphenyls (PCB) concentrations across the Estuary (Hilton et al. 2018) and models could potentially correlate the imagery with other water quality metrics. Remote sensing image collection could be timed with ongoing field monitoring to calibrate and validate image classification and relate these classifications to other ecosystem attributes and processes. In addition, models based on near real time remote sensing imagery could provide probabilistic maps of the occurrence of HABs and thus could direct when and where monitoring should be deployed to better understand HAB production and whether management can limit HAB production.

ACRONYMS AND ABBREVIATIONS

Estuary: San Francisco Estuary
Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
DO: dissolved oxygen
HAB: harmful algal bloom
NASA: the National Aeronautics and Space Administration
NMS: Nutrient Management Strategy
PCB: polychlorinated biphenyls
RMP: Regional Monitoring Program for Water Quality in San Francisco Bay
RWQCB: San Francisco Bay Regional Water Quality Control Board
SFEI: San Francisco Estuary Institute
USGS: United States Geological Survey
WRMP: Wetlands Regional Monitoring Program

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INVASIVE AND NUISANCE SPECIES

RATIONALE AND BACKGROUND

Invasive and nuisance plant and animal species threaten to reduce the benefits of many of the restoration and management actions that the South Bay Salt Pond Restoration Project (Project) has accomplished to date. The Project's Adaptive Management Plan (hereafter AMP, Trulio et al. 2007) describes how invasive and nuisance species impede progress in achieving Project objectives and outcomes. For example, invasive and nuisance species can outcompete native plants, reduce structural heterogeneity, increase predation rates on native species, and alter physical and/or hydrological functions in ways incompatible with Project Objectives. Non-native invasive species are those that: 1) are not native to, yet can spread into, wildland ecosystems, and that also 2) displace native species, hybridize with native species, alter biological communities, or alter ecosystem processes (Warner et al. 2003). The pervasiveness of non-native invasives and difficulty in controlling or removing them provides a challenge in deciding which species should be prioritized for management. In many cases, invasives cannot be controlled without expending huge efforts over large areas, which is often not feasible. However, impacts to target species may be reduced even if the invasive species cannot be fully controlled or eradicated. In order for management efforts to be effective in the long term, it is important to identify which invasive and nuisance species have, or may potentially have in the future, the greatest impacts on target species of concern or habitats in the Project area, and to determine whether management efforts for these species are feasible.

The San Francisco Estuary Partnership (SFEP) recommends that control or management efforts prioritize species that have extensive impacts on habitats important to the health of the estuarine ecosystem as well as species that can be successfully eradicated (SFEP 2016).

Nuisance species present special challenges in that they are often native to the region and can be politically or legally difficult to control. Nuisance species are often associated with human actions and infrastructure (e.g., anthropogenic species like corvids, gulls, and raccoons are attracted to human trash and use human structures like transmission towers for nesting and power line boardwalks to access wetlands). This presents challenges to the Project which cannot easily manage or remove such infrastructure. The AMP identified the invasive *Spartina alterniflora x Spartina foliosa* hybrids, non-native red foxes (*Vulpes vulpes*), corvids (*Corvus* spp., i.e., crows and ravens), California gulls (*Larus californicus*), and mosquitoes (*Culicidae*) as species of interest, including both non-native species and potential (native and non-native) nuisance species of concern.

Key Uncertainty - *Can invasive and nuisance species such as* Spartina alterniflora *(including the invasive* Spartina *hybrid), corvids and the California gull and, if warranted, raptors such as the northern harrier, be controlled? If not, how can the impacts of these species be reduced in future phases of the project?* (Trulio et al. 2007)

The AMP lists two Applied Studies Questions under the Invasive and Nuisance Species Key Uncertainty:

1. Where not adequately eradicated, does invasive *Spartina* and its hybrids significantly reduce aquatic species and shorebird uses?
2. Will California gulls, ravens, and crows adversely affect (through predation and encroachment on nesting areas) nesting birds in managed ponds?

Where the impact of these species to native plants and animals is minimal, there would be no compelling need to control invasive and/or nuisance species, provided the invasive species are not crowding out native plants or otherwise undermining the Project's ability to meet its objectives. However, where the negative impact is of demonstrated concern, there is a need to determine how to reduce such impacts. Thus, determining the nature of the impacts and how to reduce them should be the priority with regard to invasive and nuisance species. We recognize that the impact may be anticipated (not current) and that impacts may be indirect, e.g., by crowding out desired native species.

Summary of Phase 1 Studies

Several studies and monitoring programs in the South Bay focused on tracking, understanding, and/or controlling invasive and nuisance species. Phase 1 efforts were largely focused on California gulls as competitors for nesting space and predators of western snowy plover (*Charadrius nivosus nivosus*), terns, and other shorebirds.

Valoppi (2018) summarized findings from studies conducted from 2009 to 2016 showing high levels of California gull predation on plover nests, American avocet (*Recurvirostra americana*) chicks, and Forster's tern (*Sterna forsteri*) chicks as well as their prevalence during predator surveys (Ackerman et al. 2014a, 2014b, and Tokatlian et al. 2015). When Pond A6 was breached in 2010 and the 26,000 California gulls nesting there were displaced, nearby Forster's tern colonies benefited from being subject to lower California gull predation. However, the increase in chick survival only lasted one year before gull predation increased again. Efforts to haze gulls from certain shorebird nesting areas during Phase 1 had limited success and was very labor intensive (Burns et al. 2018). The marked increase in the California gull population seen during most of Phase 1 slowed in 2014-2016; but has since increased again (Burns et al. 2018).

RECENT INFORMATION

Recent and additional information on other key invasive and nuisance species identified in the AMP or identified as important in regional conservation plans but not presented by Valoppi (2018) is summarized below.

Key Invasive and Nuisance Species

Invasive *Spartina*

One of the more pervasive and aggressive species that threatens the Project's efforts, including its restoration efforts, is invasive *Spartina* and its hybridized forms. Many of the impacts of hybrid *Spartina* on tidal flat and tidal marsh ecosystems through modification of geomorphology, hydrology, productivity, and species composition have been well demonstrated (Callaway and Josselyn 1992, Casazza et al. 2016, Kerr et al. 2016, Strong and Ayres 2016). In particular, colonization of mudflats by invasive *Spartina* was modeled to have negative impacts to shorebirds (Stralberg et al. 2004) through reducing foraging habitat and also reduced benthic invertebrates (Neira et al. 2005, Grosholz et al. 2009). The modeled projections of shorebird population responses to invasive *Spartina* by Stralberg et al. (2004) are of concern, but these have yet to be tested using recent field data.

Many of the mudflats that were colonized by invasive *Spartina* have been treated and the mudflat areas that remain untreated are small. The majority of the 38 acres of remaining *Spartina* hybrid are in areas that were previously vegetated with native tidal marsh plants, not mudflat areas (Rohmer and Kerr 2018).

Some species, such as the California Ridgway's rail (*Rallus obsoletus obsoletus*), have, in the short term, responded positively to the invasive *Spartina*, which provides increased habitat area and vegetative cover from predators (Casazza et al. 2016). However, the long-term impacts to rails and other wildlife living in habitats which have undergone extensive conversion of their habitat to an invasive *Spartina*-dominated system are largely unknown. Hence, widespread, prolonged invasion carries a high risk of unintended consequences. For these reasons, the goal to eradicate invasive *Spartina* has been endorsed in major planning and goal-setting documents for the San Francisco (SF) Bay (U.S. Fish and Wildlife Service 2013, Goals Project 2015, SFEP 2016).

California gull

The original question regarding the extent of gull predation has been largely answered during Phase 1 studies which were summarized by Valoppi (2018). California gulls are major nest predators for avocets, Forster's terns, and western snowy plovers. However, much less is known regarding what factors influence variation in nest predation rates, though Ackerman et al. (2014a) point to the importance of habitat and vegetation. Tokatlian (2017) found that the use of oyster shells as camouflage for snowy plover nests and young increased the number of nesting pairs and total number of fledged young in the first few years. However, predation rates did not decrease on shell-enhanced sites and over time the effectiveness of the shells appears to wear off. Continuation of predator management was recommended to increase nest success.

The dramatic changes in California gull population size were summarized in Burns et al. (2018). Gull numbers in South San Francisco Bay peaked in 2014 (over 53,000), almost triple that observed in the period 2000-2004. However, by 2016 they had declined by 29% (38,040). It should be noted that while this was a decline, the numbers of California gulls still outnumber the numbers of all other colonial nesting waterbirds in the Estuary combined. Also, there is evidence that only a portion of this gull population is responsible for the majority of nest predation (Ackerman et al. 2014b). We lack information on how nest predation rates may have changed in relation to the dramatic changes in gull abundance, both increases and the recent decrease. At the local scale, Forster's tern nest success reflected gull abundance (Ackerman et al. 2014b), but we do not know how this translates to the larger, South Bay-wide scale. The 2019 survey of breeding avocets, stilts, and terns can provide information regarding how breeding shorebird numbers may have been impacted by changes in gull abundance.

Norway rat (*Rattus norvegicus*)

Many native species, especially ground and shrub nesting birds, are negatively impacted by the Norway rat, a non-native nest predator. Despite the pervasiveness of this introduced species, very few studies have quantified its effect on native wildlife in SF Bay wetland ecosystems. In a 1992 study, 90% of California Ridgway's rail eggs lost to predation in South Bay marshes were reportedly due to Norway rats (C. J. Striplen unpublished data in Schwarzbach et al. 2003). Although rats are a mammalian predator targeted for removal at the Don Edwards SF Bay National Wildlife Refuge (DENWR), few are taken by predator management staff, per DENWR staff. However, in 2017, USGS reported one rat was responsible for the loss of dozens of Forster's tern nests and chicks at pond SF2 (J. Fasan, pers. comm.).

Domestic cat (*Felis catus*)

Feral cat colonies are often located in human development next to tidal marshes and thus present a source of predation for native wildlife such as small mammals and birds. Albertson (1995) and Overton et al. (2014) both found evidence of cat predation on California Ridgway's rails. Estuary Blueprint Action 10 is to develop a cat feeding station map and engage land managers on feral cat management (SFEP 2016).

Red fox (*Vulpes vulpes*)

The arrival of the non-native red fox to South San Francisco Bay in the mid-80s coincided with declines in rail numbers (Foerster and Takekawa 1991). During a 1991-92 study, Albertson (1995) determined that red fox killed and cached at least two rails. Harding et al. (1998) found that intensive trapping efforts of red fox and other mammalian predators had a positive impact on the rail population. Predation by red fox continues to threaten rail and plover populations and is a target for ongoing predator management by the DENWR and California Department of Fish and Wildlife (CDFW) at Eden Landing Ecological Reserve where the fox population has increased recently (C. Strong pers. comm.).

Corvids (*Corvus* spp.)

The impacts of corvids, especially common raven (*Corvus corax*), on birds and other wildlife in SF Bay has not been assessed. Many planning documents and summary reports describe the negative effects of corvids on other birds and wildlife (U.S. Fish and Wildlife Service Tidal Marsh Recovery Plan [USFWS 2013], Pitkin and Wood 2011). Valoppi (2018) cites a high incidence of nest predation by ravens on snowy plovers (Tokatlian et al. 2016). However, no Phase 1 studies focused on this human-associated predator. Raven nests are routinely removed from power towers adjacent to tidal marsh and plover habitats by DENWR and Pacific Gas and Electric Company (PG&E).

Restoration and habitat enhancement

There are many science-based recommendations for how to restore and enhance habitat for at-risk native wildlife (USFWS 2013). Many of these recommendations are focused on providing sufficient cover from predators (see chapter on Marsh, Mice, and Rails). The Marsh, Mice, and Rails chapter notes transition zone habitat features that may help reduce predation during extreme tides and other sensitive life stages such as a marsh bird’s first winter. Also, see Bird Use of Changing Habitats chapter for pond management and design that may help reduce predator impacts on nesting waterbirds.

Predator management

To increase survival of endangered species, local land managers use a tiered management approach to reduce predation pressure in priority endangered species habitat areas. In the South Bay, the DENWR and CDFW have employed non-lethal methods, including hazing and habitat modification (such as removing posts and other perches) prior to lethal removal. Some of the target species include red fox, feral cats, and ravens (J. Albertson, pers. comm.). The focus of these efforts has been on in-marsh predators (see March, Mice, and Rails chapter) and in ponds used by snowy plovers. However, the efficacy of these measures has yet to be assessed. Much more is needed to understand how to efficiently target and manage predators in order to provide demonstrable benefits to target species.

KNOWLEDGE GAPS

There are very few statistically rigorous studies assessing the impacts of the key invasive and nuisance species considered in this chapter with California gull and invasive *Spartina* studies being exceptions. With regard to the other invasive and nuisance species covered in this chapter, the long-term impacts to nesting birds is an important knowledge gap.

The relative impact of different invasive and nuisance species predators on conservation target species at the South Bay and regional population levels is still largely unknown. For example, nest and chick predation by gulls has been quantified but the impact on target species’ population trends is largely unknown. The factors that influence predation rates and how those rates vary with the abundance of the predator species is unknown. Understanding whether the removal of one predator species might cause another predator species to move in is a knowledge gap that could inform predator management strategies. In some cases, one or a few individuals can be responsible for the majority of predation events within a breeding colony or site which could challenge the assumption that lowering predator populations will lower predation rates proportionally (science synthesis workshop feedback).

Phase 1 studies focused on the California gull, but other predators, including corvids such as the common raven, are known to be important predators on eggs and chicks. Striped skunk (*Mephitis mephitis*) were an important nest predator on waterbirds in the South Bay (Meckstroth and Miles 2005) including least tern nests (B. Pearl pers. comm.). Herring et al. (2011) and Ackerman et al. (2006) documented extensive predation on nests by mammals, including skunks, raccoons and foxes.

What are the factors that influence variation in nest-predation intensity? There is an excellent opportunity to compile information on predator abundance (such as that of gulls) and relate that to shorebird population metrics. Does variation over time and space in predator abundance correlate with changes in population size of shorebirds, at the local and regional levels? For example, what is the evidence that fluctuations in California gull numbers resulted in changes in population size or density of specific shorebird species?

Critical questions related to effective predator management remain unanswered. Predator removal may not always have the desired effects. Meckstroth and Miles (2005) found that predator removal in the South Bay increased nesting densities of waterbirds but not nesting success. Evidence suggested that conspecifics from neighboring areas moved into areas that were subject to predator removal. Management actions that could produce high nesting density could lead to lower nesting success as a result of predators keying in on these areas.

While control of all invasive and nuisance predators is infeasible and unwarranted, it may be that control or deterrence of one or several species may be of value, but the benefit relative to cost and effectiveness needs to be ascertained.

Especially relevant in this regard is the role of habitat and fine-scale microhabitat features such as vegetation in influencing the rate of nest predation. Ackerman et al. (2014a, 2014b) surmised that habitat and microhabitat differences, especially the role of marsh vegetation, explained much of the difference in reproductive success between avocets and stilts (*Himantopus mexicanus*); post-hatching survival rates for avocet chicks was only 6% compared to 40% for stilts, which nested in areas with greater, taller vegetation than did avocets. How can nesting habitat for other target species be managed to reduce nest predation by nuisance species?

Another knowledge gap concerns how to proceed with invasive *Spartina* treatment without negatively affecting California Ridgway's rail populations. Due to a general lack of information to inform optimal strategies for reducing the impacts to California Ridgway's rail, managers and scientists from the State Coastal Conservancy (SCC), USFWS, and other agencies are carefully testing or have proposals pending that will test approaches such as translocating adults away from treatment areas, constructing high tide refuge islands and floating islands to replace lost cover, and revegetating areas with native *Spartina foliosa* and gumplant (*Grindelia stricta*).

There is a lack of knowledge around emerging invasives including invertebrates that could pose a threat to native plants and wildlife if not controlled at early stages of infestation. Eradication is more feasible and cost-effective when new invasives are identified and controlled before they spread. One example is invasive sea lavender (*Limonium* sp.) which was prioritized for control early enough to prevent its becoming widespread throughout the Estuary (see www.cal-ipc.org for details).

POTENTIAL PHASE 2 STUDIES

Suggested from end of Phase 1

Valoppi (2018) listed four topics for Phase 2 studies that pertain to Invasive and Nuisance Species. Comments on Valoppi's list of potential Phase 2 studies are included as hollow sub-bullets.

- Fund implementation and effectiveness of the weed management plan to control other invasive species such as pepperweed (*Lepidium latifolium*).
  - Determine the negative consequences of controlling different invasive species, such as pepperweed, to benefit native species of concern. This will help to prioritize subsequent action. In addition to *Lepidium* (pepperweed), Phragmites (common reed), black mustard (*Brassica nigra*), fennel (*Foeniculum vulgare*) and Russian thistle (*Salsola*), and invasive sea lavender (*Limonium* sp.) are of concern. Shellhammer et al. (2010) reported reduced densities of salt marsh harvest mouse in *Lepidium* habitat. Work by the Santa Clara Valley Water District ("Valley Water"), which has developed a priority matrix, can be extended.
  - Fund the preparation and implementation of a phased treatment plan for pepperweed, including measuring efficacy and impacts to special status species.
  - We also note the value of continuing coordination with the State Coastal Conservancy's Invasive Spartina Project (ISP) and pursuing joint funding opportunities that can support invasive *Spartina* monitoring and treatment, and general vegetation mapping, in the project area.
- Explore how to reduce regional breeding populations of California gull.
  - This would be difficult to accomplish and we argue that this is a low priority, compared to reducing predation itself and reducing the number of gulls at the local scale. Gull predation on chicks is due to a small number of individual gulls; these are the ones to be targeted (Ackerman et al. 2014b). Also, as noted, there are other predator species that may be better targeted in terms of benefit to affected species.
- Fund predator management efforts and study the effects of predator control and removal on shorebird nesting success.
  - We agree that this is important, especially to better understand the effectiveness of control measures. Studies can compare areas with and without predator control. In addition, it is important to get a better understanding of which predators represent the greatest threats, and to understand demographic impacts of variation in nest predation.
- Continue the study of habitat enhancement techniques to decrease gull predation on nesting snowy plover, avocets, and Forster's terns.
  - We agree that this is of value if the scope is broadened to include other nest predators. Such enhancement can include marsh vegetation adjacent to ponds and managing for multiple shorebird breeding ponds containing constructed nesting islands. Habitat enhancement that deters marsh predators (mammals, raptors, corvids) should also be explored, such as broader transition zones.

Other potential Phase 2 studies

To fill identified knowledge gaps as well as emerging knowledge gaps, we propose the following study questions for Phase 2 studies.

1. How can habitat enhancements and designs, including vegetation or structural design elements, water management, and social attraction, be used to decrease predation rates? Marshes and ponds (inside and outside the Project) have received habitat enhancements; can we determine

how predation and survival rates have changed as a result at sites with adequate data? How can ponds be managed or enhanced to benefit breeding shorebirds? For example, does island creation on numerous ponds located away from nuisance predators increase nest success? Do water management, vegetation management, and social attraction techniques help to establish nesting colonies on relatively safe island nesting areas?

2. What are the factors that determine variation in nest predation rates? This question ideally would address both spatial and temporal variation in predation rates. This information is needed so that effective predator management can be developed and implemented. Also, knowledge of the determinants or influences on predation rates would help to develop assessment methods.

   Though there has been much focus on nest predation, predation on juveniles and adults by invasive and nuisance predators remains a concern, as has been demonstrated for the California Ridgway's rail (Philip Williams and Assoc. et al. 2003 and Overton et al. 2014).

3. How does variation in nest predation rates translate into detectable population change for waterbird species of concern? What levels of nest predation are of concern for each target species? Predation levels exceeding the threshold could trigger a response; conversely, reducing rates below threshold value can provide specific objectives for management.

4. Which predator management actions can most effectively decrease predation rates from invasive and nuisance species on breeding birds? Predator trapping may not always reduce predator abundance, and variation in predator abundance may not be the key element when determining predation rates. Analyzing DENWR and USDA predator management data can help identify which species to target, at what spatial scale, and how well the strategies are working. This need was also identified in the Estuary Blueprint (Action 10 to Increase the efficacy of terrestrial predator management; SFEP 2016).

5. What measures can reduce negative impacts of invasive *Spartina* control on California Ridgway's rails? Control of invasive *Spartina* is effective where implemented, but there is concern that it may have short-term negative consequences for species of concern.

OPPORTUNITIES FOR REGIONAL SYNERGY

Coordination with the ISP provides a good model for additional partnerships to better coordinate information sharing between projects that are conducting field work in the Project area. Because the project area is so large and difficult to access, and restoration and monitoring actions have specific and irregular schedules, there can be long periods when the managers of the Project do not receive current updates on field conditions on the ground. One example of synergy comes from the SCC and ISP staff who schedule regular coordination calls, and communicate in real time as needed, to share information with Project managers. These updates include site condition descriptions and vegetation establishment progress. This type of coordination and communication can be expanded to other groups working in the area such as Save The Bay and can help save funds and resources and ensure that field work is targeted to current needs/spatial areas.

Using remotely sensed imagery, for example that collected under Habitat Evolution Mapping Project (HEMP) can show early signs of invasive plants, such as pepperweed, colonizing new areas. Remote sensing may be used to efficiently assess areas with a relatively low probability of infestation of invasive *Spartina* and reduced on-the-ground surveys. The Estuary Blueprint Action 9-2 directs stakeholders to:

1) increase early detection, monitoring, and rapid response programs, 2) invest in estuary-wide mapping, 3) add wetland species to Calflora, 4) increase monitoring to detect new species early, and 5) invest in community science monitoring. The last recommendation, to engage community monitoring, could be particularly useful to the Project. Trail users may be willing to participate in vegetation monitoring efforts such as the Bair Island photo monitoring effort (see Public Access and Wildlife chapter for details).

Predator management efforts and monitoring among the major landowners could be coordinated to better assess different strategies, increase understanding, and also to more efficiently allocate limited resources among sites. The USFWS, CDFW, and East Bay Regional Park District all have predator management programs and operate in in the South Bay.

There is the potential for synergy with California Invasive Plant Council (Cal IPC) for coordination with invasive plant detection, monitoring, and management. For example, Cal IPC may have information on new invasive species that the Project is unaware of and that could be managed efficiently if detected at an early stage.

EMERGING TECHNOLOGIES

Autonomous sound recording units (ARUs) may be used to assess the presence of predators in areas that are difficult to access (see chapter on Marsh, Mice, and Rails). Corvids and other avian predators could be identified from automated recordings to help focus predator management actions to areas with higher numbers of predator species. Bioacoustic portable recorders have worked well for bird recordings in a variety of habitats in the Soundscapes to Landscapes project (www.soundscapes2landscapes.org). Other units have been used with success even in wetlands adjacent to noisy urban environments (Overton unpublished data).

Use of ARIS (Adaptive Resolution Imaging Sonar) cameras to detect non-native fish predators, as has been implemented by Ducks Unlimited at Sears Point, could be considered.

Unoccupied aerial systems (UAS) may also be effective in monitoring numbers of diurnal predators such as California gulls and corvids. Whereas standardized surveys may be effective at estimating total abundance of a predator, UAS may be better at assessing areas that might be closer to breeding areas for waterbirds. UAS could also be used to oil the nests of nuisance corvids and gulls (Shields et al. 2019).

New technologies are available to deter nuisance individuals from an area. “Long range acoustic devices” that direct loud painful sound signals in a fairly narrow beam and drones can be used to scare birds from an area (Avery and Werner 2017).

ACRONYMS AND ABBREVIATIONS

Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
ARIS: Adaptive Resolution Imaging Sonar
ARU: autonomous sound recording unit
Cal IPC: California Invasive Plant Council
CDFW: California Department of Fish and Wildlife
DENWR: Don Edwards San Francisco Bay National Wildlife Refuge
HEMP: Habitat Evolution Mapping Project
ISP: Invasive Spartina Project
PG&E: Pacific Gas and Electric Company

SCC: State Coastal Conservancy
SF: San Francisco
SFEP: San Francisco Estuary Partnership
UAS: unoccupied aerial systems
USDA: United States Department of Agriculture
USFWS: United States Fish and Wildlife Service

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PUBLIC ACCESS AND WILDLIFE

RATIONALE AND BACKGROUND

Creating more opportunities for the public to enjoy the baylands in a variety of ways is one of the Project's goals. However, the potential for negative impacts on wildlife from increased public access is of concern to stakeholders. One of the Adaptive Management Plan's (hereafter AMP; Trulio et al. 2007) restoration targets is that public use does not prevent reaching restoration targets as measured by significant impacts to target species. Therefore, the goal of increasing public access within the Project must be balanced with the goal of increasing the diversity and abundance of native species.

Key Uncertainty - *Will trails and other public access features / activities have significant negative effects on wildlife species?* (Trulio et al. 2007)

Because Phase 1 activities included many land-side public access elements (e.g., trails and viewing areas), studies were needed to assess their impacts on wildlife within a variety of habitats. To guide these studies, the AMP identified the following Applied Studies Questions:

1. Will landside public access significantly affect birds or other target species on short or long timescales (including studies of waterfowl, clapper rail [California Ridgway's rail], and snowy plover responses to public access, and roosting bird response to public access)?
2. Will increases in boating access significantly affect birds, harbor seals or other target species on short or long timescales (including studies of waterbird response to boaters)?

There was also the goal that investments made in public access features were leading to an increase in public satisfaction. This is related to Objective 3 in the AMP, "High quality visitor experience is maintained, facilities are not degraded by over usage." To assess the effectiveness of Phase 1 activities in achieving this goal, the AMP identified a third Applied Study Question:

3. Will public access features provide the recreation and access experiences visitors and the public want over short or long timescales?

Valoppi (2018) summarized the results of Phase 1 studies and noted that the question of boat access impacts to birds and other wildlife was not pursued during Phase 1. Trulio et al. (2013) determined that a distance of 50 m (164 ft) between trail users and shorebirds was sufficient to prevent disturbances. For waterfowl, a distance of 122 m (400 ft) was recommended, as well as closing trails with low use and temporarily closing trails during the winter migratory season (Trulio et al. 2012). The recommended distance for western snowy plovers (*Charadrius nivosus*) was 150 m (492 ft; Trulio et al. 2011).

In a survey conducted in which 568 users of trails and other access features were questioned to assess trail use satisfaction, the majority of users were overwhelmingly satisfied with their experience and listed ease of access as their primary preference (Trulio and Sokale 2013). The survey respondents' top concerns were the potential for too many trail users and unsafe conditions. The two main desired improvements amongst the 339 respondents who commented were to have more connectivity between trails and more trail user information, such as maps, trail signage, and interpretive information. Trulio and Sokale also noted that minority groups were underrepresented on the Project's trails compared to census results from the local area.

Overall, study results suggested that the impacts from trail users on birds or other target species were uncertain but trending toward no significant negative impact and that trail users' experiences were positive.

RECENT INFORMATION

Trulio and White (2017) found species-specific differences in waterfowl response to trail users with ruddy duck (*Oxyura jamaicensis*) and scaup species responding negatively to trail use and Northern shoveler (*Anas clypeata*), canvasback (*Aythya valisineria*), and American wigeon (*Mareca americana*) responding positively (numbers of individuals increased with increasing trail use). The authors hypothesized that the positive response, particularly in Northern shoveler, was due to the species' tolerance to disturbance and ability to habituate to trail use as the number of recreational users increased. Conversely, ruddy duck and scaup spp. were generally intolerant to trail use and seemingly unable to habituate as easily as the Northern shoveler and American wigeon, if at all. In conclusion, the authors recommended new trails be placed 200 m from waterbird use areas, which is more than the 122 m recommendation cited by Valoppi (2018) and based on previous unpublished reports.

In a United States Geological Survey (USGS) report (De La Cruz et al. 2018) analyzing 13 years of bird abundance data from the Project pond area, the authors found that access to levees for hunting and other public use impacted the abundance of several guilds. The abundance of foraging gulls and roosting terns increased with an increased percentage of levees open for hunting. Conversely, the abundance of roosting dabbling ducks and waders as well as foraging piscivores decreased as the percentage of levees for hunting increased. The highest abundance of foraging small shorebirds was found in ponds where 0% and 70% of levees were open to the public, with the lowest abundance of foraging small shorebirds found in ponds with 20-40% of levees open to the public. Due to the variable responses to among guilds, the authors suggest a potential need for further study on the impacts of public access to better determine the consequences to different species' populations.

Although not recent, a San Francisco Bay Conservation and Development Commission (BCDC 2001) report summarized literature from the San Francisco Estuary (hereafter, Estuary) and nationally on the effects of human disturbance on birds and determined there was potential for adverse effects but that additional well-designed scientific studies were needed to quantify direct and indirect negative impacts. Another literature review of human disturbance on birds from the Estuary and nationally by Borgmann (2011) found that 86% of the 50 studies reviewed reported that human-caused disturbances impacted the study species. Upon disturbance, the most common and immediate impact to most species was in flushing, but it also appears that shorebirds in the short-term may tend to avoid roosting and foraging in areas where there is regular high disturbance. It is unknown if shorebirds abandon the high-disturbance sites completely, due to a lack of long-term monitoring data. It was also found that as disturbance at a site increased, the amount of time birds spent foraging and resting decreased. The review provides detailed disturbance information (including from recreational boating) and management recommendations by species guild. Waterbird response to disturbance varied across species, but migratory birds were generally more impacted than resident species. The recommendations to decrease impacts to waterbirds include limiting the number of visitors, periodic public access closures by season and by site, as well as education of the public. For shorebirds and wading birds, impacts should be assessed by species to determine appropriate management actions. Dabbling ducks were impacted more by pedestrian disturbance than by motorized disturbance, and Borgmann suggested managers enact seasonal closures to decrease these impacts (Borgmann 2011).

A more recent literature review conducted by the U.S. Fish and Wildlife Service (Mengak et al. 2019) focused on evaluating and managing human disturbances to shorebirds along the Atlantic flyway and had similar findings as Borgmann. They found that shorebirds tended to avoid areas of higher human density, and human disturbance negatively impacted the amount of time shorebirds spent foraging, preening and resting. The authors also note that human disturbance may have impacts on overall fitness of shorebirds, but that this is much more challenging to study and the currently available literature has mixed findings.

The Baylands Ecosystem Habitat Goals Science Update (BEHGU) (Takekawa et al. 2015) referenced the Borgmann literature review (2011) as well as earlier disturbance studies and expanded on it through the lens of potential climate change impacts. The report states, “Disturbance from human recreational and commercial activities is another potential threat that may become exacerbated if available foraging areas for diving waterfowl shrink or move due to climate related changes. Disturbance can cause waterbirds to expend more energy flying and spend less time feeding, reducing body condition and the ability to migrate and reproduce.” However, Gill et al. (2001) argue that behavioral responses to disturbance may not be a useful indicator of population-level consequences. They argue that other factors need to be considered such as the quality of the site currently being occupied, the distance to and quality of other suitable sites, the relative risk of predation or density of competitors in different sites and the investment that an individual has made in a site (e.g., defending a territory).

KNOWLEDGE GAPS

The results of Phase 1 studies have addressed many of the questions around wildlife disturbance from public access as well as those regarding public satisfaction. With more recent information, these questions have evolved to consider the population level consequences of disturbance and the potential for increased disturbance as sea level rise may cause shifts in habitat and wildlife distributions that bring wildlife closer to public access areas. Below we summarize how the original knowledge gaps were addressed and what new questions are emerging.

Phase 1 Applied Study Question #1: Will landside public access significantly affect birds or other target species on short or long timescales (including studies of waterfowl, clapper rail [California Ridgway’s rail], and snowy plover responses to public access, and roosting bird response to public access)?

Phase 1 studies assessed disturbance and made recommendations for species- and taxa-specific distances from trails that would minimize disturbances. More recent studies have refined those recommendations and have raised questions about population-level consequences of disturbances as measured by behavioral responses (e.g., flushing). To address this knowledge gap, Borgmann (2011) suggested individual-based models that link disturbance response with population level impacts. Components of such models may require determining energetic costs of disturbance, evaluating the effects of disturbance on marked individuals, and assessing the relationship between food availability and sensitivity to disturbance. Since this type of research can be challenging and costly, investing in studies that address this knowledge gap should be weighed against other investments such as identifying and implementing more efficient measures to reduce and minimize disturbance in Project sites. Furthermore, many of these disturbance factors may be exacerbated by climate change and the subsequent shift in wildlife concentrations within the Project footprint, concentrations which are often tied to optimizing foraging opportunities (Takekawa et al. 2015).

Potential questions for Phase 2 include:

- Are disturbances impacting the overall fitness of target species, and which species-specific disturbances are likely causing population-level consequences?

- What is the relative effectiveness of different types of signage and/or fencing at reducing disturbance?
- Can the Project identify key wildlife areas, ensure public access is not allowed in these areas, and adapt as these areas change in the future?

Phase 1 Applied Study Question #2: Will increases in boating access significantly affect birds, harbor seals or other target species on short or long timescales (including studies of waterbird response to boaters)?

This question was not pursued during Phase 1 studies, perhaps due to the fact that Project actions during Phase 1 have likely not had a very significant impact on the volume of boating in the area, as the Project added only one new public access boat launch at Eden Landing. However, other studies on harbor seals in the Estuary have demonstrated significant disturbance from boating. The NPS recommends a minimum buffer distance of 90 m (300 ft) but there are few quantitative assessments of disturbance to harbor seal from recreational boating in the South Bay. Does this distance vary with site, time of year or type of recreation? Potential Phase 2 questions could include:

- Is there likely to be an increase in disturbance to harbor seals, birds, and other target wildlife due to Project actions that may increase boating access?

Phase 1 Applied Study Question #3: Will public access features provide the recreation and access experiences visitors and the public want over short or long timescales?

A Phase 1 study found high satisfaction among users of the Project's public access and facilities but also discovered that some ethnic groups were underrepresented. Balancing the need to maintain a high level of public satisfaction against protecting the needs of wildlife even as climate change causes a shift in those needs, will involve addressing the knowledge gaps discussed in this section. Potential questions for Phase 2 include:

- How do people balance quality vs. quantity in public access trails (i.e., miles of access vs. richness of the experience)?
- How can the Project balance public access for recreational use versus public access for commuters' use? What does the public value and prefer in this regard?
- How much (if at all) does increased access and use change public support for and willingness to pay for restoration projects and other sea level rise adaptation efforts?
- What can the Project do to improve access and provide features that would attract underrepresented groups?

POTENTIAL PHASE 2 STUDIES

To address remaining questions and uncertainties around public use and wildlife, Valoppi (2018) recommended the following Phase 2 studies. Included in the hollow sub-bullets are reviewer comments to these suggested studies.

- Study responses of trail use by tidal marsh species: where are displaced populations going, if they are leaving the area due to trail use?
- Study the impacts of boat launch use on species.
    - This may only be needed if boat use is expected to increase.
- Social carrying capacity study; study ethnic groups use of public access areas as surveys indicated low use by some ethnic groups.
    - This question may be beyond the Project's primary mission.

- Explore the impact of differing levels of trail use on the health of migratory birds using the Estuary.
    - It would likely be beneficial to expand these studies to include impacts of trail use on the health of resident birds as well.

OPPORTUNITIES FOR REGIONAL SYNERGY

The Project may consider working with other entities to assess recreational use and satisfaction within the Project footprint in relation to other restoration and access projects in other parts of the Estuary (e.g., Marin County, Hamilton Wetlands, Cullinan Restoration). Can the Project make smarter investments in access features to net more use or higher user satisfaction by learning from projects in other areas? Alternatively, what can projects in other regions learn from this Project? Where in the Estuary is access to the baylands most limited relative to the size of the adjacent human communities that could benefit from such access? By coordinating with regional partners, the Project can be strategic in providing public access areas where it will best be utilized by the public and have minimal impacts to wildlife.

The Project may consider enhancing its partnership with the San Francisco Bay Trail (headed largely by the Association of Bay Area Governments and the Metropolitan Transportation Committee) to better understand how to provide the highest quality access to the baylands without negatively impacting wildlife. The San Francisco Bay Trail and the Water Trail may have additional data on trail user experiences, usage type (pedestrian vs. bike, and recreation vs. commuting) and impacts to wildlife.

As noted in the introduction, one of the Wetlands Regional Monitoring Program (WRMP) management questions relates to the issue of public access: “How do policies, programs, and projects to protect and restore tidal wetlands benefit and/or impact public health, safety, and recreation?” Thus, there is also potential for the Project to work with and encourage the WRMP to include in its framework an assessment of the potential impacts and benefits of providing recreation opportunities in the Project area.

EMERGING TECHNOLOGIES

There may be an opportunity to partner with Stanford Natural Capital Project that initiated a study looking at social media and tagged photo locations as an index of where in the baylands visitors are sharing their experiences (Wood et al. 2013). They generated a raster of “total photo-user days” since 2005, based on Flickr geotagged photo data. The metric counts a unique individual on any given day within a 30 m pixel. This method captures more than just outdoor recreation but limiting the spatial extent to the undeveloped baylands within and potentially outside the Project footprint could reveal interesting patterns of use. This method could be used to prioritize facilities maintenance, assess the use or overuse of specific trail features, as well as assess the potential for wildlife disturbance in a more cost-effective manner.

Similar to the Stanford study that mined social media, there may be an opportunity to leverage citizen science data to help evaluate impacts to specific bird groups. Ebird (ebird.org), managed by Cornell Lab of Ornithology, uses citizen scientists’ bird sighting and is publicly available (Walker and Taylor 2017). This data could help fill in gaps in censusing the Project footprint, and potentially help fill in knowledge gaps in understanding bird use relative to public use, frequency, and seasonality in different parts of the Project area.

Engaging with the public through interactive education in public access areas may be a way to help increase trail user awareness about the potential impacts of disturbance. For example, the San Francisco

Bay Bird Observatory (SFBBO) has installed a sign at Bair Island encouraging hikers to take photos with their smartphones to add to a time-lapse video that displays the progress of the project over time (SFBBO website). When given an opportunity to directly participate in a project like this, the public may feel more invested in the outcome of the project and take more actions to minimize disturbance to the area.

Trail cameras can be used to assess the effectiveness of different types of deterrents (e.g., signage, fencing, outreach) for reducing wildlife disturbance. Artificial Intelligence could be used to detect people and animals going off trail or getting too close to wildlife. In marshes where off-leash dogs are an issue, radio-frequency identification (RFID) technology could be used to quantify the number of dogs that enter the marsh. This would involve extending an RFID reader along a transition zone to pick up dogs passing through it.

ACRONYMS AND ABBREVIATIONS

Estuary: San Francisco Estuary
Project: South Bay Salt Pond Restoration Project
AMP: Adaptive Management Plan (Trulio et al. 2007)
BCDC: San Francisco Bay Conservation and Development Commission
BEHGU: The Baylands Ecosystem Habitat Goals Science Update
NPS: National Park Service
RFID: radio-frequency identification
SFBBO: San Francisco Bay Bird Observatory
USGS: United States Geological Survey
WRMP: Wetlands Regional Monitoring Program

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APPENDIX A.

Ongoing regional or sub-regional wildlife monitoring efforts, the organizations involved, spatial extent, and metrics collected. Not all species targeted in this table solely use tidal marsh but they do utilize the habitat to some extent.

Species Group	Monitoring Program	Organization	Metric	Temporal Scale	Geographic Scale
Snowy Plover	Wester Snowy Plover Research	SFBBO	Abundance, productivity	Annual, breeding	South Bay
Waterfowl (dabbling, diving)	Mid-winter waterfowl survey,	USFWS, USGS, SFBBO	Density, abundance by sub-bay	Annual, winter	Baywide, Coastal estuaries (SF and SP bays)
Breeding terns, shorebirds, waterbirds		SFBBO, USGS (Ackerman)	Abundance and productivity	Annual, breeding season	SF Bay, Suisun Bay and Delta
Tidal Marsh Birds	Point Blue Tidal Marsh Project	Point Blue	Breeding season trend in density by sub bay, annually by spp or spp group	Annual, breeding season	Baywide
Secretive marsh birds	Baywide secretive marsh bird survey	Multi-agency effort (USFWS, CDFW, ISP, Point Blue, ARA)	Breeding season trend in density by sub bay, annually	Annual, breeding season	Baywide
Salt Marsh Harvest Mouse	Multiple	CDFW, USGS, WRA, USFWS (currently on hold)	Trends in abundance		Baywide
Herons and Egrets	ACR: Coast and northern counties; SFBBO: South Bay	ACR/SFBBO	Number and survival of heron and egret nests	Annual	Baywide & Coast
Waterbirds, Wintering shorebirds	SBSP Pond Surveys, Napa Sonoma Marshes	USGS, SFBBO	Distribution and abundance of waterbirds, migration and winter shorebird abundance	Seasonal and/or monthly	SBSP Ponds, North Bay ponds, Baywide
Wintering shorebirds	Pacific Flyway Shorebird Survey	Point Blue	Winter shorebird abundance (density)	Annual, winter	Baywide
Resident marine mammals	NPS Pinniped survey	NPS	Counts, Disturbance events	Annual, Mar-Jul (Pupping season)	Baywide & Coast
Transition-zone focal bird spp	TBirds	Point Blue	Trends in abundance, diversity	Annual, breeding season	San Pablo Bay