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Science to Inform Management of Subsided Lands in the Sacramento-San Joaquin Delta

Delta Independent Science Board

Draft Review (7/02/2024)

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Problem Statement

Peat soils like those in the Sacramento-San Joaquin Delta (Delta) have unique properties and behavior and require different management than other agricultural soils in California. Since the late 19th century, draining for agricultural cultivation of the extensive freshwater wetlands that once comprised the undisturbed Delta has caused the land surface of this originally large marsh to steadily lose elevation, a phenomenon known as subsidence. Subsidence in the Delta is caused primarily by microbial oxidation of organic matter in the dewatered root zone. Portions of the Central and Western Delta have subsided as much as 9 m below sea level. Today, more than 1,100 miles of levees that were originally built to allow draining of the marsh are now required to protect the farmland, housing, and critical infrastructure in the Delta from flooding. The threat to the Delta is now further aggravated by sea level rise (SLR) caused by climate change. It is anticipated that SLR will increase the likelihood of storm surges and floods. Ongoing subsidence and threats from climate change have prompted efforts to explore new approaches for managing subsided lands. One promising approach is to restore land elevation by managed re-inundation of the landscape. Experiments on several islands in the Delta have demonstrated that intentionally inundating land to re-establish wetlands can reverse subsidence. Rewetting agricultural land to grow rice also has the potential to slow or arrest subsidence. A collateral benefit of the inundation in both situations is that this management action would promote sequestering of carbon that over time could convert the Delta from a significant source of carbon dioxide emissions - an important greenhouse gas - to a major sink. Yet, such land management practices in the Delta are not widespread, and greater attention to the science and information needed to inform further uptake of these practices is needed.

Findings and Recommendations

This report summarizes key findings and recommendations developed by the Delta Independent Science Board (Delta ISB; Board) following a public workshop held in Sacramento on October 19-20, 2023, that focused on basic and applied science that would improve management of subsided lands in the Delta (Figure 1). The workshop primarily addressed the science behind two major management considerations, efforts: (1) to slow or reverse subsidence and (2) to reduce and potentially reverse greenhouse gas (GHG) emissions from the Delta. Science here is interpreted broadly. It includes how research is managed in addition to social and biophysical and biogeochemical sciences.

The findings and recommendations presented here are based on the Delta ISB's reflections on the presentations and discussions at the workshop. They are also informed by the Delta ISB's expertise on scientific approaches and tools that can address identified gaps in current subsidence-related science. Additionally, in designing the workshop and in devising this report, the Delta ISB drew upon informational interviews with experts on both subsidence and subsidence related issues in the Delta. The Board also conducted a limited review of literature on Delta subsidence.

This report is divided into two major sections. The first section contains the key findings and recommendations by the Delta ISB. These are addressed to governmental agencies, land owners, and managers working to manage and mitigate land subsidence in the Delta (e.g., Delta Conservancy, Metropolitan Water District of Southern California, Department of Water Resources, The Nature Conservancy, farmers, etc.), academic institutions, and other organizations that support and fund science related to managing subsidence in the Delta (e.g., the Delta Science Program through its science prioritization and funding processes). The second section provides both a more robust contextual background on Delta subsidence issues and summaries of the workshop panel presentations and discussions. Links to online recordings of panelist presentations and discussions are also provided.

Subsidence Management and Research

Findings

Active experiments in the Delta to manage subsidence include: (1) reversing subsidence by wetland restoration, (2) slowing or arresting subsidence by rice cultivation, (3) developing floating tule wetlands in deeply subsided islands, and (4) designing cost beneficial land-use mosaics for agriculture. While the primary objective of these experiments has been to arrest and even reverse subsidence, co-benefits include habitat restoration and carbon sequestration. For instance, conversion of subsided land in the Delta to either wetlands or rice cultivation to mitigate subsidence has demonstrated the feasibility of sequestering significant amounts of carbon in the Delta, as mentioned in the workshop. Experiments on Sherman and Twitchell Islands in the Central Delta indicate that these land conversions have provided a net sequestration of 10 tons/acre/year of CO_2e (carbon dioxide equivalent).

Although not extensively discussed at the workshop, all of these efforts to manage subsidence [i.e., managed subsidence reversal wetlands and rice growing] have water demands that can be substantial (Linquist and LaHue, 2020; Baldocchi et al., 2016), but future research may offer management solutions to help address soil and water resource management. Research on managing subsided land in the Delta is primarily limited to experiments on Sherman, Twitchell, and Staten Islands (Figure 1). Although there is interaction among individuals involved in these experiments, no formal program coordinates funding priorities or assesses and communicates research findings. Despite the modest areal scope of these field experiments, much has been accomplished and learned about slowing and reversing subsidence and factors that control GHG emissions.

Recommendations

The Delta ISB recommends both (1) a coordinated approach to field experiments to manage subsided land in the Delta, and (2) establishment of a strategic long-term research program to monitor, document, and understand subsidence reversal. Subsidence and the underlying soil consolidation caused by drainage of peat soils in the Delta are broadly understood, but this understanding of the subsidence process and the factors that control and affect its rates (e.g., primary and secondary consolidation, temperature, depth to groundwater table, biomass accumulation, etc.) would be enhanced by long-term institutional focus and research commitment particularly in areas where subsidence reversal experiments are underway. There is also a need to further evaluate the potential for rice cultivation to reverse and not just arrest subsidence. In addition to the experiments themselves, developing and maintaining technical and scientific expertise specific to the Delta will be essential. Leadership could come from agencies involved in these experiments including the Delta Conservancy, California Department of Water Resources, Metropolitan Water District of Southern California, and the Delta Science Program/Delta Stewardship Council.

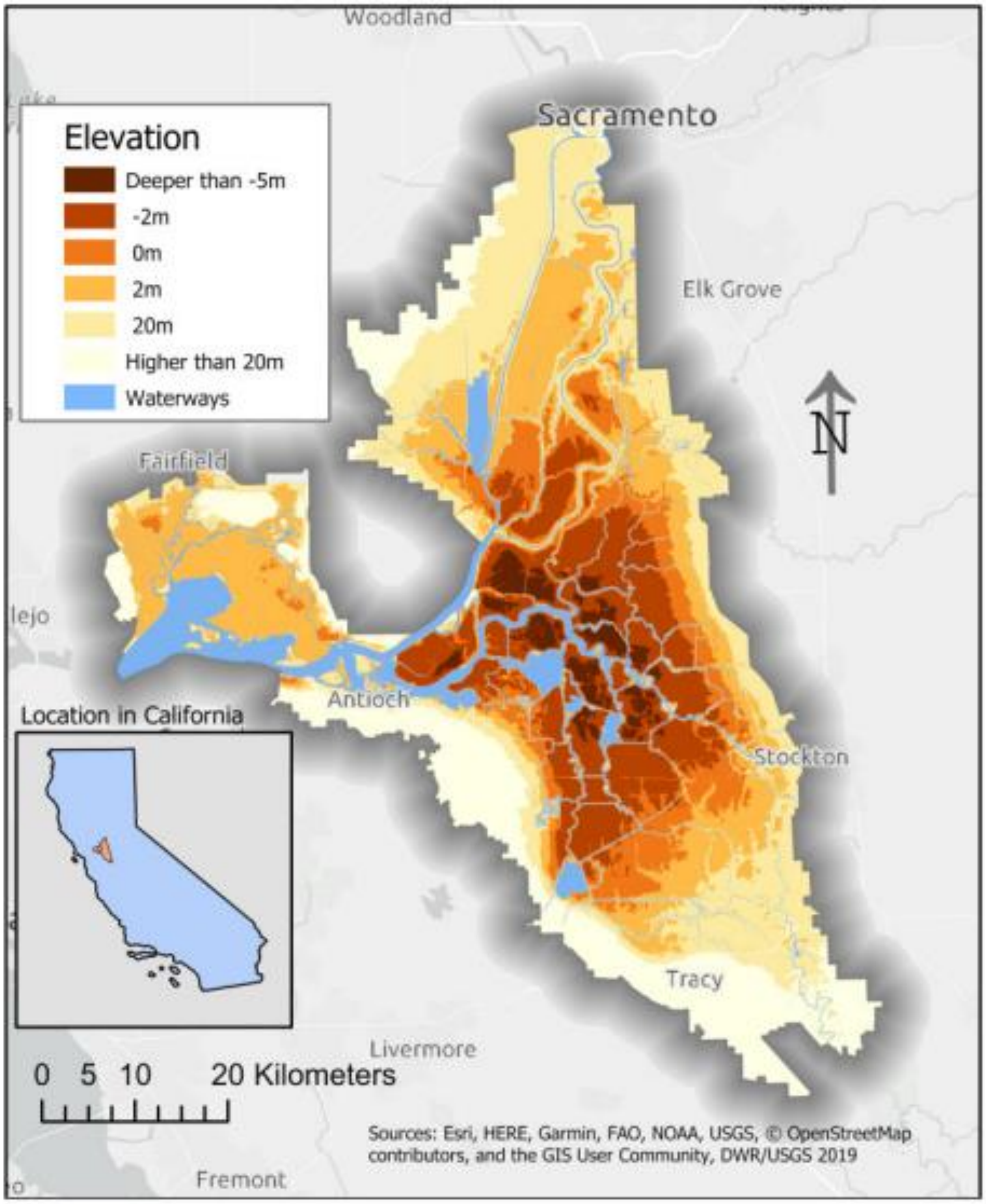


Figure 1. This map of elevations in the Sacramento-San Joaquin Delta shows the areas where subsidence has occurred. An elevation of 0m indicates sea level, while negative elevations are below sea level.

Biogeochemistry of Greenhouse Gas (GHG) Emissions and Carbon Sequestration

Findings

Reducing GHG production and enhancing carbon sequestration is a potential major co-benefit of arresting and reversing subsidence in the Delta. Wetland vegetation can be continuously turned into peat soil as it is buried by new plant growth. For this reason, the potential co-benefit of managing land to reduce subsidence is high because peat soils, such as those in the Delta, do not have a saturation limit for storage of organic matter. In the 6700 years that the Sacramento-San Joaquin River Delta wetlands have existed, these wetlands have been a major sink for carbon and if left in their natural state would have continued to sequester carbon (Drexler et al. 2019). Draining the Delta wetlands and practicing dry land farming have promoted the microbial oxidation of the organic matter in the dewatered root zone of the peat soil, releasing to the atmosphere carbon dioxide gas (CO_2), a greenhouse gas (GHG). Over the past 150 years, half of the initial stock of organic carbon in the Delta wetlands has been lost to the atmosphere (Drexler et al 2019).

While the basic greenhouse gas chemistry of peat soils in the Delta is generally understood, there is much to be learned to forecast responses to management actions in the Delta (see Windham-Myers et al. 2023; See Figure 2). The biogeochemistry of the peat soils depends on specific conditions that can vary spatially and temporally. These conditions include the organic content of the peat soil and the amount of water, oxygen, and reactive solutes, such as sulfate and nitrate, in the porewater of the peat soil. The preservation of organic matter in the peat soils is also influenced by hydrologic conditions and the export of dissolved organic matter to the coastal waters.

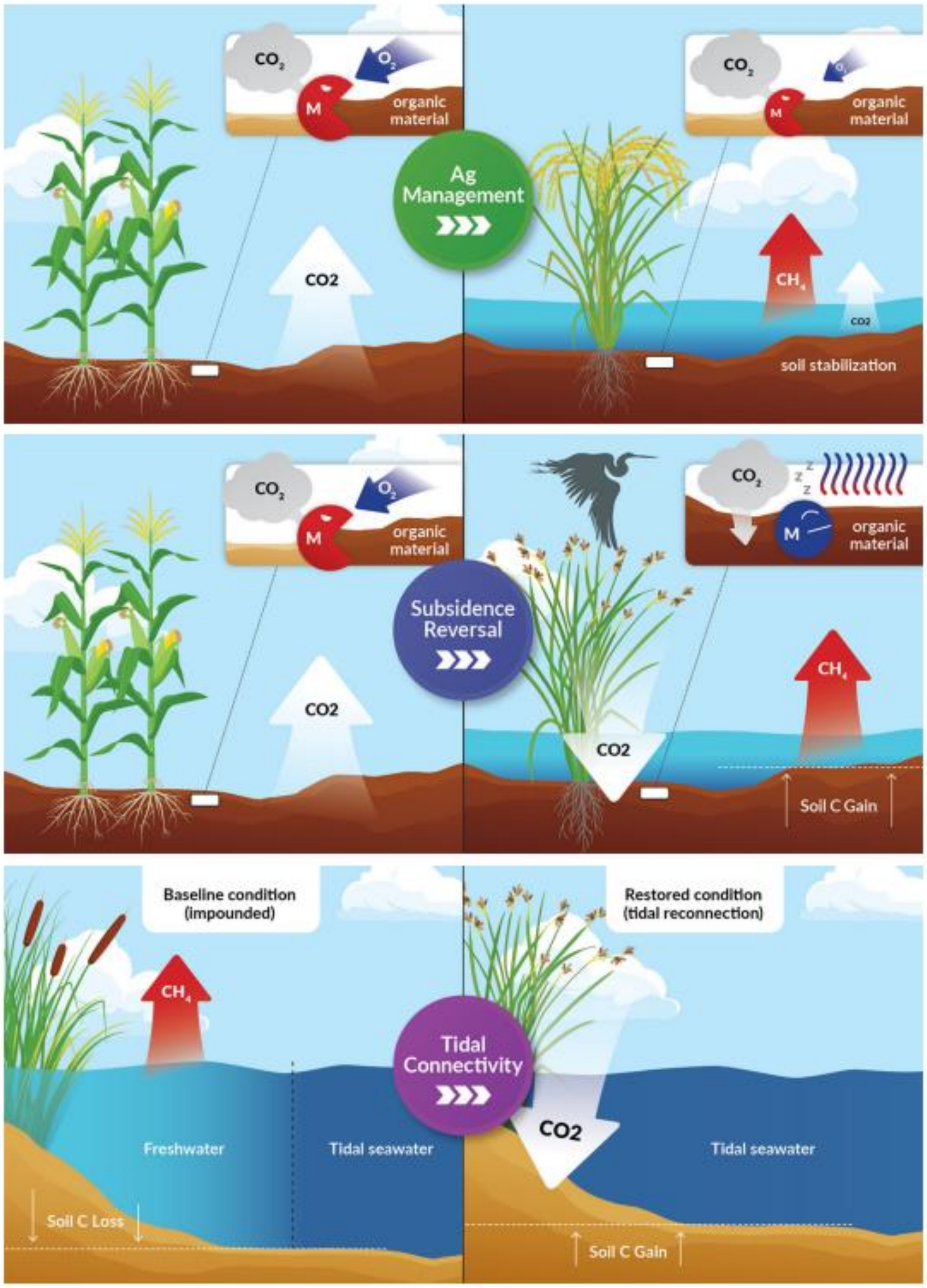


Figure 2. Three land management interventions from Windham-Myers et al. (2023), including (A) agricultural hydrologic management via flooding, such as in rice agriculture, (B) impounded wetland construction to reverse subsidence, and (C) tidal connectivity restored or maintained. M = microbial activity. Source and credit: Figures adapted from Stern et al. (2022) and taken from Windham-Myers et al. (2023). Illustrated by Vincent Pascual, California Office of State Publishing.

In addition to CO_2, two other greenhouse gases of concern in wetland management are methane (CH_4) and nitrous oxide (N_2O). While inundating peat soils generally reduces the microbial oxidation of organic matter that produces CO_2, it also creates conditions of low oxygen availability that promote generation of CH_4 and N_2O. Both CH_4 and N_2O are much more potent as GHGs than CO_2, while both have a half-life in the atmosphere that is significantly less than the 500+ years half-life for CO_2 (see Figure 3; Windham-Myers et al., 2023; Stein and Lidstrom 2024) One important finding for management of the Delta is that both CH_4 and N_2O emissions decrease as the organic carbon content of the soil increases (Ye et al., 2016, Ye and Horwath 2017). In addition, the emission of GHGs has been shown to decrease substantially with time since inundation (Baldocchi presentation; Miller 2011; Windham-Myers et al 2018). Because of the challenges in measuring N_2O, there is less known about how N_2O emission is influenced by conditions in inundated peat soils.

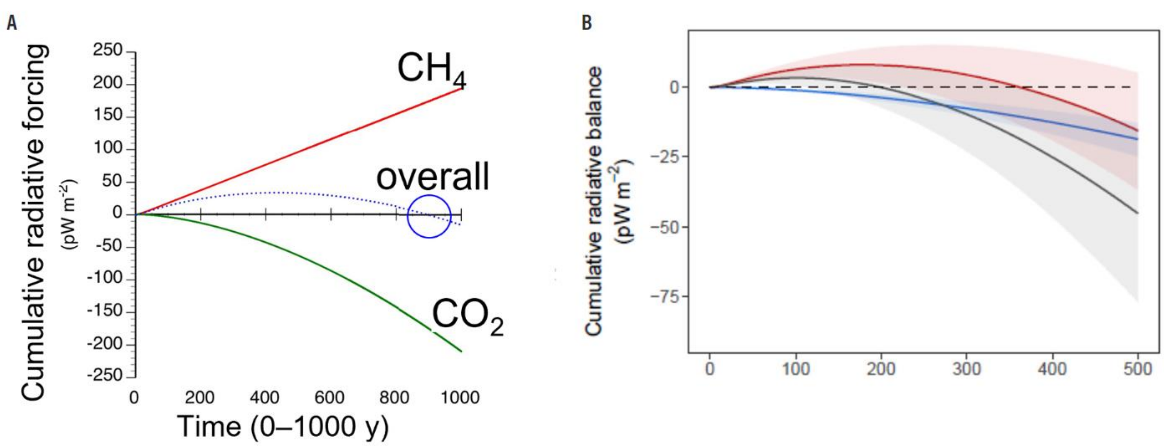


Figure 3. Cumulative radiative balance and cross-over times from net warming to net cooling effects from Windham-Myers et al. (2023)

One approach for enhancing the accumulation of organic matter and limiting GHG emission is to optimize water levels in wetlands (Miller et al 2008). Another approach is to apply metal coagulants, which enhance flocculation and vertical accretion of peat soils (Hansen et al., 2018). For tidal wetlands, managing methane emissions can potentially be based on controlling hydrology to obtain favorable water chemistry (Miller 2011). For example, sulfate, an abundant constituent of seawater, can reduce rates of methane emissions (Windham-Myers et al., 2018). Another notable finding is that negligible methane production has been found in tidal wetlands in which salinity values reach half that of seawater (Poffenbarger et al 2011).

Given the dependence of GHG production on the dynamic conditions in the peat soils, year-round monitoring of CO_2 and CH_4 is needed to provide information for determining net annual greenhouse gas (GHG) emissions. For example, because microbes remain active during the mild winter conditions of the Delta, CO_2 and CH_4 emissions continue in winter (Bergamaschi et al 2021). Overall, sufficient knowledge is available to understand tradeoffs and optimize restoration decisions in tidal wetlands to promote carbon storage and inhibit methane production, with the additional benefit of promoting other ecosystem services, such as enhancing habitat.

Recommendations

For farmers and other land managers to effectively fine-tune management of subsiding lands in the Delta, a portfolio of research is needed to address key questions related to achieving the benefits of sequestering carbon and minimizing GHG emissions. In the context of minimizing GHG emissions, there is a need to holistically consider multiple GHGs, i.e., CO_2, CH_4, and N_2O, when managing or restoring wetlands (Stein and Lidstrom, 2024). Important research topics to target for improving land management in the near term include: (1) understanding processes controlling methane emission, (2) researching approaches for promoting greater rates of accumulation and stabilization of organic carbon in the wetland soils (which will also limit methane emission) and (3) developing predictive models that can be used to evaluate scenarios and risk factors. Predictive models, for example, would be useful for evaluating both the point at which sequestration of carbon compensates for GHG production and the potential for tidal-reconnection to reduce GHG emissions of coastal wetlands in the Delta (Kroeger et al 2017).

Addressing these topics will help to promote approaches for the Delta that enhance carbon sequestration and minimize GHG production for the long term. In addition to targeted research, insights can result from maintaining year-round monitoring programs and continuing Improvements in coordination of monitoring efforts. For agroecosystems in the Delta, year-round monitoring may be useful for optimizing field practices.

Agricultural Practices in the Delta

Findings

Paludiculture – farming on rewetted peat - can help minimize further loss of peat soils and mitigate subsidence and associated GHG emissions. A key finding of the workshop is that rice production is currently the best suited and most economical paludiculture option in the Delta. The 2022 Cost of Production Study for rice indicates that supporting private growers in land conversion to rice is more effective than relying on subsidence mitigation efforts on existing public lands in the Delta, particularly due to the scale of private lands in the Delta. The up-front cost of conversion for rice, however, is a major perceived risk to farmers. To address this, the Delta Conservancy has now funded the Delta Rice Conversion Program to help finance the up-front costs for rice conversion for private farmers. At the same time, farmers at the workshop indicated they were more concerned about day-to-day and year-to-year viability of their operations than long-term sustainability benefits. Better understanding of how the short-term economic benefits can work in concert with long-term payoffs is important. Finally, this information needs to be conveyed to both farmers (see recommendation below) and to public agencies and funding agencies which could design appropriate incentives for rice conversion.

Some of the private land in the Delta is too difficult to farm because of drainage and seepage issues. Subsidence of much of this land may be reversed by conversion to wetlands, but farmers often lack incentives and cost-effective approaches, and confront regulatory issues. Establishing a wetland can cost the farmer more than $10,000/acre because of regulation costs (permits, meetings, reporting requirements) and taking land out of production. Establishing temporary wetlands known as “walking wetlands” that may be moved to different locations on the landscape is a strategy that can avoid regulatory costs (e.g., permitting, monitoring) that are typically incurred when wetlands are in place for more than 3 years. These temporary wetlands may also strike the balance between minimizing subsidence and allowing crop rotation, i.e., helping slow the loss of peat soils while regenerating land to increase crop yields.

Recommendations

Conversion to rice production in the Delta could be informed by social, economic, and agronomic sciences that (1) assess and model costs/benefits of rice production and the types of financial incentives that would motivate Delta farmers to shift to rice production, and (2) analyze the mechanisms for knowledge sharing among farmers/private landowners about the economic and soil sustainability benefits of rice production in the Delta through trusted networks. A suggestion from workshop participants was that other paludiculture practices, e.g., harvesting tules from marshes for particle board, and raising water buffalo for cheese production, might be economically feasible in the Delta. However, first more research is needed to see if these practices can even be implemented in the Delta. If so, then additional research would be needed to understand what types of economic benefits or financial incentives would motivate producers to adopt such practices. Additionally, to address the agricultural challenge posed by land that is too wet to farm, more research is needed to assess the types of incentives that could motivate Delta farmers to incorporate managed wetlands on their lands. Agencies that could provide leadership include the Delta Conservancy, University of California Cooperative Extension, Delta Science Program/Delta Stewardship Council, and the Metropolitan Water District of Southern California.

Landscape Scale Challenges

Findings

Significant regional differences across the Delta – which has more than 500,000 residents across 750,000 acres of reclaimed land – pose distinct and poorly understood challenges for addressing subsidence at a landscape scale. For instance, the priorities and interests related to subsidence management of many of the landowners and people across the landscape are not well studied. This includes leasing of State-owned land in the Delta. Likewise, landscape scale co-benefits (e.g., carbon sequestration, levee stability, habitat restoration, food webs, salinity management) are not adequately quantified or modeled. Such knowledge can help inform how to better design targeted management strategies or policy tools that can more rapidly shift current land use and farming practices in the Delta.

Growing interest in how current carbon markets can be used to expand financial incentives for wetland restoration, rice cultivation, and other rewetting practices has led to improved accounting of the net GHG emissions. Current policies for carbon market verification and accounting as well as the price of carbon credits, however, often do not align with the needs of landowners. First, participation in the voluntary carbon market requires a 40-year contract and the compliance market requires a 100-year contract (Deverel et al., 2017). Such long-term contract lengths can be difficult for potential participants, particularly farmers, who must deal with the reality of generating income from these lands. Second, there is uncertainty in the decadal time dependency of the flux of various greenhouse gases. While a high water-table is required to promote subsidence reversal, this inundation fosters anaerobic conditions and methane production. As previously noted, methane has greater atmospheric warming potential and a shorter lifetime in the atmosphere than carbon dioxide. The point at which sequestration of carbon compensates for the warming effect of methane emissions – particularly for different types of land uses (e.g., managed wetlands, rice, tidal wetlands) remains understudied. And third, changes to policies, such as Assembly Bill 1757 which addresses GHG emissions from working lands, potentially have implications for how the Delta landscape will be managed, but research on the implications of such policy changes at the landscape scale is lacking.

Recommendations

Studying the likely effects and tradeoffs of different public and private incentives for inundating Delta lands, and whether such outcomes are aligned with the priorities and values of the diverse communities and landowners in the Delta, can help guide landscape scale changes in land-use and management practices. Research is needed to improve understanding of the impact of different management practices, e.g., crop rotation, soil wetting and drying etc., on GHG emissions and sequestration at the landscape scale. Likewise, research to quantify the degree to which such changes support ecological benefits, levee stability, and economic health of Delta communities is needed. In particular, field studies are needed to identify and quantify the impacts of land use changes that mitigate subsidence and reduce GHG emissions.

Advancing scientific understanding of the underlying biogeochemical processes that influence net GHG emission associated with alternative landscape scenarios is a high priority for the Delta. Such research can inform the extent to which policies for carbon credit certification can effectively motivate changes in landscape practices that will mitigate subsidence, while also reducing GHG emissions. It can also help provide evidence of how existing policies could be adapted to reduce costs of compliance and verification in carbon markets.

Background

Before the surge in human migration to California in the mid-1800's, the Sacramento-San Joaquin Delta was the largest freshwater estuarine wetland on the west coast of North America, occupying 420,000 acres (SFEI, 2022). In the 6700 years that the estuarine wetland has existed, it was a major sink for carbon as the marsh plants in the Delta turned into peat as they were buried by new plant growth and riverine sediment. This ongoing burial led to storage of 280 million metric tons of carbon in the undisturbed Delta (SFEI, 2022).

Beginning in the 1880's, agricultural interests started to drain the marsh islands of this vast wetland for agriculture to feed the human migration. Reclamation of the wetlands continued until the 1930's when most of the islands had been reclaimed by building levees and draining. The reclaimed islands yielded some of the most productive farmland in California because of the rich organic soil and nearby access to water for irrigation.

An important aspect of agricultural cultivation in organic soil is that the chemical environment changes when the soil is drained to desaturate the root zone to cultivate crops (Stephens et al. 1984). The chemical environment of the soil changes from an anaerobic (no oxygen) condition in the undisturbed natural marsh to an aerobic (oxygen rich) condition in the drained cultivated areas. This promotes microbial oxidation of the organic matter in the drained organic soil and generation of carbon dioxide. SFEI (2022) concluded that 2.3×10^9 cubic meters of the pre-reclamation 5.1×10^9 cubic meters of organic soil in the Delta has been consumed, mostly by this microbial oxidation. Thus, 45% of the original volume of organic soil in the Delta has been lost.

The loss of organic soil in the Delta is significant from both landscape and climatic perspectives. Land subsidence is the most visible landscape consequence from the oxidation of organic material. Most of the Delta islands now lie below sea level and require an extensive levee system to protect them from flooding. The climatic impact is more subtle because it is caused by the carbon dioxide generated by the oxidation of soil organic matter. Carbon dioxide is a major greenhouse gas generated by human activity and contributor to global warming.

Most of the Delta landscape has experienced subsidence. The subsidence is highly variable but greatest in areas where organic soils were thickest, particularly the Central and Western Delta. Deverel et al. (2020) estimate that 100,000 hectares of land in the Delta have subsided from ~3 to 9 m. While the locally large magnitudes of subsidence are indicative of its impact, the volume of land area in the Delta that lies below sea level is a better measure of the potential regional impact of subsidence (Mount and Twiss, 2005). This volume, which is referred to as anthropogenic accommodation space, quantifies the severity of the flooding potential in the Delta. Mount and Twiss (2005) estimate that the increase in accommodation space from subsidence during the twentieth century was 2.5×10^9 cubic meters. By 2050, they estimate based on subsidence projections that the accommodation space will increase to 3×10^9 cubic meters. The implication of this trend of increasing accommodation space is greater risk of flooding of Delta islands unless levees are upgraded.

The climatic impact from GHG emissions from the Delta is potentially large if subsidence continues. SFEI (2022) estimates that if all of the remaining organic soil matter in the Delta were oxidized, it would generate 140 million metric tons of carbon dioxide. This is equivalent to clear-cutting more than 3.5 million acres of forest or burning half a trillion pounds of coal. Currently, State-wide agriculture generates 8% of California's total GHG emissions. Deverel et al. (2020), estimates that the Delta currently generates 6% of California's total agricultural emissions and 21% of its non-animal agricultural emissions. Thus, although it is unlikely that all of the remaining organic soil will be oxidized, reversing, arresting, or slowing subsidence in the Delta would contribute to meeting State-wide GHG emission reduction goals.

Managing Subsided Lands Workshop

The primary input to this review was a two-day public workshop consisting of four half-day panel presentations and public discussions on managing subsided lands in the Delta (see day 1 recording and day 2 recording). Each panel consisted of three to four experts (see agenda). Following brief presentations by the invited experts, a lengthy public discussion was led by a Delta ISB member. Panelists were invited by the Delta ISB to provide perspectives on existing programs, barriers and opportunities, state of scientific understanding, scientific gaps and deficiencies, and economic considerations of managing subsided lands. The following subject matter was addressed by the four panels:

1. Overview of current land inundation practices and experiments
2. Biogeochemistry of carbon sequestration and greenhouse gas emissions in inundated organic soils
3. Economic considerations for inundated agricultural practices
4. Science needs to inform landscape-scale implications of organic soil inundation.

The first panel of the workshop focused on providing an understanding of the scope of current inundation projects in the Delta with an emphasis on land surface elevation changes. The second panel discussed the biogeochemical mechanisms that regulate greenhouse gas emissions and sequestration in wetland organic soils to identify gaps in scientific understanding. The third panel addressed different agricultural and land-use management practices to identify opportunities and barriers for either paludiculture or other inundation practices in the Delta and the trade-offs in agricultural practices for managing subsided lands. The fourth panel reflected on the previous three panels and discussed research and data needs to understand potential landscape-scale implications of soil inundation. Summaries from the panel are still undergoing review from the presenters.

Panel 1: Overview of Current Land Inundation Practices and Experiments

Steve Deverel | A Whale of a Tale: Subsidence, Effects and Solutions

The pre-development Sacramento-San Joaquin Delta was a vast emergent tidal wetland ecosystem that accumulated an estimated 7.8 billion cubic meters of rich peat soils over the last 6,000 years (Vaughn et al. 2024). Drainage and exposure of peat soils to oxygen since the 1860's has led to the loss of an estimated two thirds of the historical peat volume (Vaughn et al. 2024), which resulted in subsidence (Mount and Twiss 2005). Sea level rise progressed rapidly until about 6,000 years ago when it slowed to an annual rate of about 1.7 mm upon reaching the Delta area (Atwater, 1980). Historically, wetland accretion was sufficient to maintain elevations concomitant with sea level rise (Deverel et al., 2014).

Microbial oxidation of the organic matter in Delta organic soils is the primary cause of subsidence (Deverel and Leighton, 2010). In the Central Delta, where subsidence is the most severe, land elevations have decreased to more than 20 ft below sea level. Elevation surveys conducted by University of California researchers across Bacon, Lower Jones, and Mildred Islands starting in the 1920s demonstrated that rates of subsidence decreased with time. On Bacon Island, subsidence rates were 6.6 cm per year prior to 1960 due to high soil organic matter content and declined to about 3 cm per year as soil organic matter content decreased due to oxidation (Deverel and Leighton 2010). Subsidence rates are directly linked to organic matter content; worldwide subsidence rates are higher in soils with higher organic matter content (Deverel and Leighton 2010, Stephens et al. 1984). Subsidence rates have long been known to be directly correlated with depth to groundwater and temperature (Stephens et al. 1984).

Important consequences of subsidence are levee failure and island flooding. The Brannan-Andrus Island breach in 1972 is an important example, as it prompted State investment in levees and investigation of subsidence. During this event, salinity levels in the Delta increased 2.5 – 4 fold, which resulted in the shutdown of the State Water Project, and the release of 300,000 acre feet of water to return salinity concentrations to pre-breach levels. In today's dollars, the total cost would be an estimated $150 million. Since 1973, repairs, upgrades and maintenance for the Delta levees totaled almost a billion dollars.

Geoslope modeling indicated a correlation between organic soil thickness and the relative probability of levee failure (Deverel et al., 2016). As oxidation decreases peat thickness, seepage forces exponentially increase, particularly where peat thickness is less than 3 meters. Seepage forces have the potential to erode levee foundation materials. This erosion process can result in boils in toe ditches such as the one observed on Jones Tract (see Figure 4), which are an indication of eroding levee foundations.

Figure 4. Active boil on Jones Tract observed in 2011. Photo credit: Gerald Bawden

Cultivation of rice and establishing permanently flooded non-tidal (impounded) wetland have been shown to stop and reverse the effects of subsidence in the case of wetlands. Sediment erosion table measurements in the Twitchell Island West Pond wetland from 1997-2017 indicate an average accretion rate of 3 cm year^{-1} (Deverel et al., 2020). Sediment erosion table measurements on a rice field on Staten Island indicate that rice stops subsidence (see slide 17 of Plenary). Accumulation of senescent biomass in the Twitchell West Pond wetland may be inhibiting nascent growth and carbon sequestration. Impounded wetlands may benefit from more active management to remove senescent biomass to ensure that new growth can continue for carbon sequestration benefits. Managing water levels in impounded wetlands to be commensurate with wetland accretion is also essential to promoting increases in land surface elevations. This concept was instilled during the construction and management of the Twitchell West and East Pond wetlands based on concepts presented in Callaway et al. (1996).

Land-use mosaic experiments are underway to evaluate options to provide both income to maintain levees and mitigate subsidence and reduce greenhouse gas emissions (Deverel et al., 2017). On Staten Island, rice and wetlands are being implemented in the most subsided areas to reduce and reverse subsidence and reduce greenhouse gas emissions and generate income, while more traditional crops such as corn are grown in areas of the island with less subsidence.

The overarching challenge is to implement subsidence mitigation practices on a landscape-scale. This is a complex, interdisciplinary issue, and there is a need to prioritize raising the land-surface elevation in those areas where it can meaningfully reduce the probability of levee failure over time. There are knowledge gaps in how to manage these land uses to achieve other benefits such as increasing food web benefits and increasing carbon sequestration, particularly while accounting for methane emissions. These include the following:

- There are no data on how compaction of the accreting organic matter affects the long-term increase in elevation in the Delta, which makes it difficult to model accretion in impounded marshes in the Delta over the long-term.
- Paludiculture, the practice of harvesting wetland biomass to generate income, is practiced in Europe and Canada. This practice could be a promising avenue for the Delta, particularly considering the large amounts of biomass available in impounded wetlands. Experimental plots are needed in the Delta to assess its viability.
- The carbon-market protocol requiring 40-year commitment to growing rice can be challenging for farmers, and there is a need to examine if it is compatibility with crop rotation, particularly while accounting for methane.
- Quantifying the spatial variability of present-day subsidence rates in the Delta can be useful to prioritizing areas for alternate land use although it can be challenging. More accurate techniques to quantify spatial variability of subsidence would be useful.

Gil Cosio | How Subsidence Affects Reclamation Districts

Subsidence impacts agriculture by affecting drainage characteristics of the landscape. LiDAR elevation maps indicate high spatial variability of subsidence (Figure 5), creating steep elevation differences where one part of the island can be over 12 ft lower than the rest. As a consequence, lower lying areas that have lost substantial amounts of peat and elevation are increasingly difficult to drain for farming. Simultaneously, the loss of peat, which is less permeable than the underlying sand, can cause sand boils to develop. Boils form when the high hydrostatic head of water on the water-channel side of the levee causes water to flow beneath the levee at a velocity that erodes sandy subsoil, effectively creating quicksand. For example, on Grand Island, active boils in drainage ditches have forced abandoning acres of farmland that can no longer be drained to support agriculture. Although drainage ditches could be widened, this carries a risk of de-stabilizing levee foundations as seepage will erode sand from levee foundations.

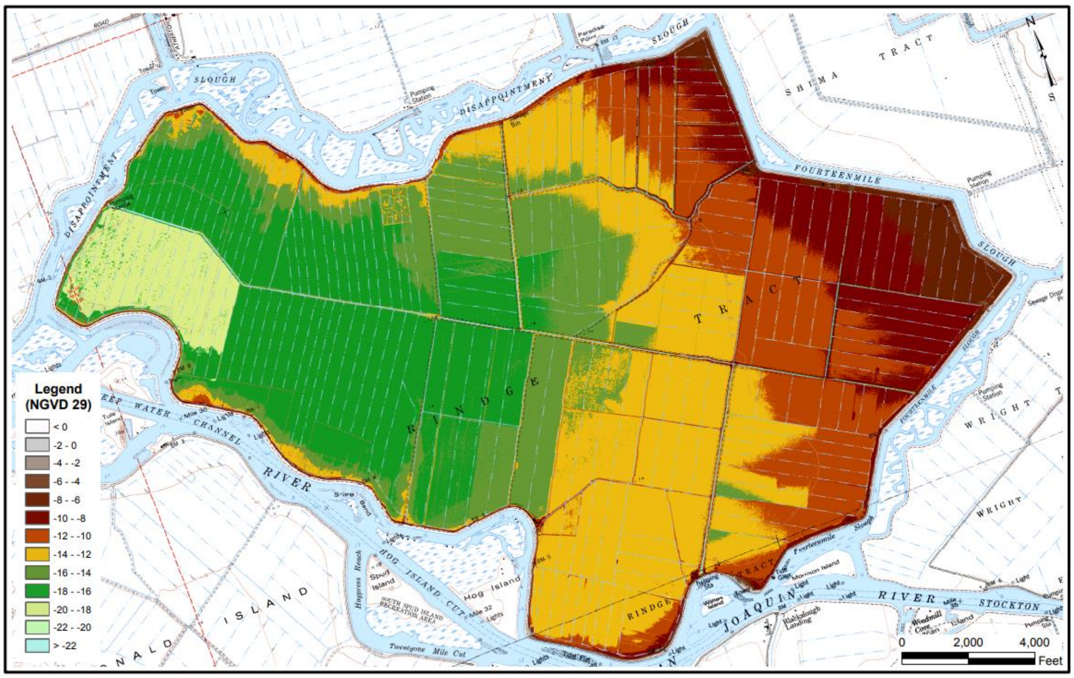


Figure 5: Slide from Gil Cosio's presentation on subsidence in reclamation districts. Map depicts Rindge Tract LiDAR data

Subsidence creates a risk for levee failure when the loss of peat, which prevents saturation of the underlying sand, allows water to run through a levee. As peat is lost, sand is increasingly saturated, which causes a loss of cohesion and strength in levee foundations. In some areas, subsidence has been so severe that water has moved upward through the sand and is pooling on top. Levee failure carries major consequences for roads and other types of critical infrastructure, which highlights the importance of reversing subsidence in areas where drainage systems are stressed and where peat has thinned above the underlying sand.

Many studies in the 1980s from academics, district engineers, the U.S. Army Corps of Engineers, and the CA Department of Water Resources focused on the "zone of influence" (the stretch of land 400 ft from the levee on the land side) and levee stability (ref). A key outcome of these studies was that reversing subsidence in the zone of influence could significantly improve levee stability. Initiatives such as SB-34, which allowed the purchase of conservation easements for the zone of influence, were created to prevent farming in the zone. However, this incentive was too costly for farmers, landowners, and other rights holders who also had to consider the cost to maintain the levees.

Ultimately, being aware of the location of subsidence and depth to groundwater, and having familiarity with the levee system can help identify issues that affect levee stability.

Russ Ryan | Managing Subsided Lands in the Sacramento-San Joaquin Delta

The decline in land elevation due to peat oxidation increases levee vulnerability to hydrostatic pressure and seepage. Changes in hydrology, such as king tides and flood events, can raise water levels, which increase hydrostatic pressure even more. Similarly, seepage, which is net flow under the levee, is proportional to the thickness of the levee. In addition, sea level rise worsens the risk that levees may no longer be adequate to prevent overtopping and flooding. To address these risks, the Metropolitan Water District of Southern California (hereafter, Metropolitan) is conducting research on four islands (Webb Tract, Holland Tract, Bacon Island, and Bouldin Island) in the Delta to control subsidence in a project collectively known as the Delta Islands Landscape Collaboration.

Metropolitan's Delta Islands Landscape Collaboration is funded through a 2020 California Department of Fish and Wildlife Prop 1 Watershed Restoration Grant. The goal is to identify opportunities for ecosystem enhancements, water supply improvements, carbon sequestration, and subsidence control on Metropolitan's four islands. A key aspect of the project is building community partnerships to plan future multi-benefit restoration projects.

For example, one pilot project on Bouldin Island was focused on growing tules in free-floating containment areas experiencing different flow regimes (e.g., similar to more open river-like flows). These containment areas simulated the influence of flow regimes on residence times. As tules grew and their root structures developed, researchers found increasing concentrations of fish food, i.e. zooplankton. Metropolitan is in the process of expanding this experiment, and developing floating tule mats, on a larger pond to evaluate benefits for fish.

David Julian | Sherman and Twitchell Island Subsidence Reversal and Carbon Sequestration

Over the last two decades, the California Department of Water Resources has conducted different projects with many partners for subsidence reversal and carbon sequestration under the West Delta Program managed by the Division of Multi-Benefit Initiatives with funding from State Water Project (SWP).

The West Delta Program operates primarily on Sherman and Twitchell where DWR owns approximately 80% of each island. The majority of Sherman and Twitchell Islands were purchased by DWR in the 1990s, in response to Decision 1641 (D-1641), to set water quality baselines further upstream in the Delta and to ensure reliable water quality for the State Water Project exports. As the western-most islands in the Delta, Sherman and Twitchell effectively act as a barrier against salt-water intrusion which would compromise water quality. In recognition that subsidence could impact the integrity of Sherman and Twitchell Islands, DWR began early experiments to address subsidence and provide wildlife habitat.

Currently, Sherman and Twitchell are about 15-20 ft below sea level, with accommodation spaces (volume of water that would flood the island if levees fail) of 140,000 acre-ft and 55,700 acre-ft respectively. As subsidence progresses, accommodation space increases. DWR has pursued and initiated different projects to decrease the impact of subsidence on Sherman and Twitchell (Table 1). The primary goals for these wetland projects are to reverse subsidence and to sequester carbon. Currently, the field projects are observing rates of 2-4 cm of soil accretion per year and about 10 tons of CO_2e greenhouse gas reduction per acre per year, compared to previous land uses, in wetland projects.

The Twitchell Rice Project evaluated the potential for rice to reverse subsidence while providing income. They observed that planting rice resulted in about 0-1 cm of organic soil accretion per year, which halts subsidence although not as much as impounding wetlands. Rice reduced greenhouse gas emissions, compared to previous land uses, by 7 tons of CO_2e per acre per year which was also less than greenhouse gas reductions from wetlands. While planting rice did generate more profit than wetlands, growing rice has required subsidies to be profitable enough. However, rice also has an added benefit of providing migratory waterfowl habitat when the fields are flooded in the fall.

Table 1. West Delta Program projects and acreage

Year	Name	Acres
1997	USGS Wetland	14
2010	Mayberry Farms	315
2010	Twitchell Rice Project	588
2013	East End	750
2016	Whale's Mouth	650
2022	Whale's Belly	1000

In total, DWR has constructed close to 3,000 acres of wetlands and 500 acres of rice in the most subsided areas of Sherman and Twitchell (Table 1). Construction for these projects was based on opportunistic funding. Key considerations going forward are managing salinity concentrations, water depth, vector control, and vegetation. Different management actions for these considerations are required on different parts of the islands.

DWR is among the first to register carbon credits to participate in the voluntary carbon market. DWR helped to develop the American Carbon Registry carbon offset protocol for the region, and they have 52,000 credits registered (Deverel et al., 2017). However, they are not currently being used, and the process is still under development for implementation.

Cathleen Jones | Remote Sensing of Levees and Land Subsidence

The value of remote sensing is the ability to gather a snapshot of an entire landscape at once. Remote sensing approaches facilitate consistent monitoring across different areas, including sites that are difficult to access, to observe subtle changes in water, soil moisture, and ground level. In addition to measuring changes in surface position, in principle, remote sensing could be applied to evaluate seepage in Delta levees.

High heterogeneity of levee conditions across the Delta makes it difficult to extrapolate findings from one spot on one island to the potential seeps, cracks, instabilities, and subsidence conditions across the entire Delta levee system.

Increasing remote sensing capabilities could allow for more effective monitoring of the connection between subsidence and levee stability.

Geodesy refers to the technology that measures the position of different points on Earth and the ground. Examples of different geodetic technologies include total station surveys, extensometers, and ground-based LiDAR surveys. There are also remote sensing methods such as Global Positioning System (GPS) and Global Navigation Satellite System (GNSS), which are based on measurements at single point locations, but are more accurate and measure continuously through time. Ground-based methods are essential for validating other remote sensing methods that occur at larger scales such as interferometric synthetic aperture radar (InSAR).

InSAR images an entire area at one point in time by transmitting radar signals from instruments on high-flying aircraft or satellites and measuring the timing between when the radar signal is transmitted and when the reflection from the ground returns to the instrument. It is used to measure changes in the surface, including changes in surface elevation. Repeat measurements over the same area over time reveal even very small changes (mm) in the land surface.

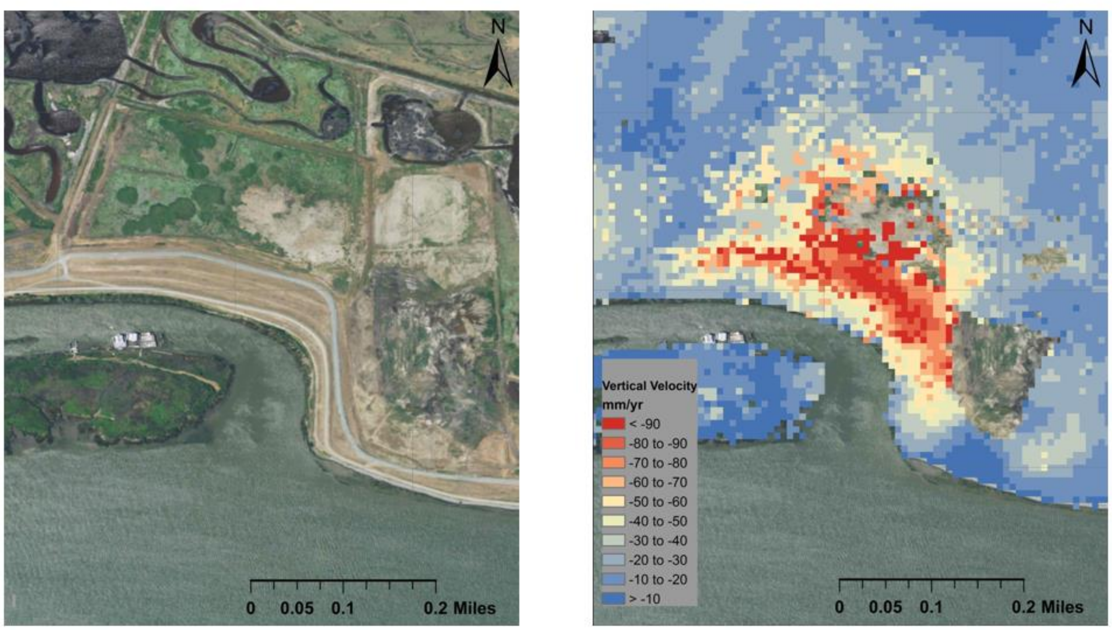


Figure 6. INSAR data of a Sherman Island levee taken from Dr. Cathleen Jone's presentation.

Experiments conducted in 2008 using an airborne instrument to examine levees found enormous signals, amounting to centimeters of movement in a short amount of time, on the Sherman Island levee (Sharma et al., 2016). Subsequent site visits confirmed the presence of a crack in the levee that would not have been easily noticeable. However, it is very clearly visible in INSAR data (Figure 6).

NASA is launching a mission in spring 2024 called NISAR that will carry an instrument that is well-suited for measuring subsidence. This mission will measure every part of California twice every 12 days continuously for several years. The mission lifetime is nominally three years, but the spacecraft carries sufficient fuel to operate for more than 10 years; so, barring instrument failure, it is expected to operate far longer than the nominal lifetime. An important contribution of this mission is that all the data products will be free and openly available to the public.

The NASA-ISRO synthetic aperture radar (NISAR) mission addresses a major barrier, the cost of geodesy data, inhibiting remote sensing applications in the Delta. However, now the main barrier will be understanding the technology to be able to use it. Adding more GPS stations at locations in the Delta will improve the calibration of measurements from NISAR and other similar remote sensing measurements, providing robust measurements to support operational monitoring of surface elevation change.

Panel 1 Discussion Summary

Subsidence, sea level rise, and seismic activity are compounding hazards to the Delta, particularly because these threaten levee structures. Management actions to reduce subsidence, such as floating marshes and converting land use into wetlands or rice cultivation, may have the added benefit of decreasing susceptibility to sea level rise. However, management actions have trade-offs. It will be important to consider the design of projects to maximize benefits for multiple objectives such as reversing subsidence and maintaining water supply reliability. For example, reducing subsidence requires inundating soil, yet future projections predict declining water supplies. Future managers will need tools to evaluate how to balance water management to minimize subsidence, greenhouse gases, and support carbon sequestration efforts, which will be particularly challenging in drought conditions. A significant impediment to applying approaches such as hazard mapping to better understand risks of different tradeoffs is the availability of data and instruments.

Current rates of subsidence threaten the viability of farming across the Delta. Solutions range from creating wetlands on areas that are already too wet to farm to promoting crops, such as rice, that thrive in inundated soils. One important caveat is that actions that reduce subsidence may increase methane emissions. Methane accounting and methane management is crucial. Managing the residence time of sulfate may help with reducing methane emissions since sulfate inhibits methanogenesis. Water temperature and salinity are major controls on methane emission. If these two factors increase in the future, methane emissions will be impacted. A major uncertainty is the impact of different management actions on balancing greenhouse gas emissions.

For farmers, the regulatory landscape of emissions is a source of frustration. Farming has been exempt from carbon emissions, but changes in regulations might mean that farmers will have to account for emissions. Changing emissions standards means that farmers are asking whether it is worth it to buy new equipment as opposed to renting equipment because of concerns that they'll be investing in equipment that might become obsolete.

Proposed solutions need to consider the way that incentives are designed, practice issues with implementation, and their impact on the economic sustainability of farmers and private landowners. Recent protocols that award carbon credits for wetland conversion or rice cultivation can facilitate participation in the voluntary carbon market. The California Air Resources Board (CARB) should consider accepting the American Carbon Registry (ACR) carbon offset methodology for the Delta in order to sell carbon credits as part of the compliance market as opposed to the voluntary market. Carbon credits in the compliance market have been steadily rising. However, CARB will not accept the ACR methodology until there are enough projects, which means that until then, participants using this methodology for carbon offsets can only trade on the lower priced, voluntary market. Currently, the price of carbon on the voluntary market is not comparable to the value of farm crops on a per acre basis, requiring subsidies to maintain profitability.

Uncertainties in regulations create barriers to farmer and landowner participation. Other mechanisms such as establishing conservation easements may reduce funding hurdles for landowners interested in exploring other revenue options for land that has already subsided too much to remain viable for typical Delta crops. Developing testing sites, examples, and opportunities that account for economic considerations are needed to design effective incentives and support the economic sustainability of the region. The Staten Island mosaic could be that example and, if the economics works out, could be a model for agriculture in a future Delta.

Ultimately, the land mosaic would need to be economically profitable to incentivize reducing subsidence.

Rice has been proposed as an alternative crop to replace corn because it can be grown in saturated soils and has a viable and active market. Rice yields in the Delta are already comparable with the Sacramento Valley. However, there are practical challenges to implementing large scale rice cultivation such as concerns with prices and steep upfront costs for leveling land and equipment. Converting land to rice or wetlands is not as much of a problem as just acquiring the funding to do it. However, the sources of funding available to public landowners is inaccessible to private landowners.

Other inundated land purposes such as walking wetlands and raising water buffalo for dairy products were also discussed as methods to promote the management of subsided lands while maintaining profit. However, lower flows in future conditions may affect the availability of water for inundation, increasing the amount of soil exposed, and, subsequently, microbial oxidation. A better understanding of adequate water levels to minimize oxidation and water use will be important to evaluate the viability of different management actions and the associated trade-offs among different land uses on subsidence, particularly with respect to levee maintenance costs.

Panel 2: Biogeochemistry of carbon sequestration and greenhouse gas emissions in inundated peat soils

The Delta is 0.5% of California's agricultural land but accounts for 6% of total agricultural greenhouse gas emissions, and 21% of non-animal agricultural emissions (Deverel et al., 2020). Subsidence contributes to GHG emissions because CO_2 is released as aerobic microbes consume carbon in the soil. Understanding biogeochemistry is essential for addressing subsidence. Models can be used to evaluate some of the uncertainties by projecting the future impacts of management actions and comprise an important tool.

Lisamarie Windham-Myers | Putting Delta Subsidence Mitigations in a Carbon, Climate, and Coastal Context

A substantial amount of land elevation and carbon have been lost. About half of the carbon, approximately 90 Tg, in Delta soils has been lost since the 1800s (Drexler et al., 2018), resulting in massive greenhouse gas emissions. In the central Delta, where subsidence is most severe, the pressure on levees is expected to be much higher than in less subsided areas. Therefore, reducing subsidence is essential to meaningfully address the carbon goals of the state.

In terms of long-term storage, carbon stored in coastal soils and sediments is ideal because there is no saturation limit. Continual sedimentation and biomass accumulation of senescent wetland plant material buries the carbon deeper and deeper. The Delta has high carbon fluxes and productivity, resulting in high carbon density. Per unit volume, the amount of carbon in Delta soils is about 40% higher than the average for the US. One issue is that sea level rise may threaten wetland ecosystems if water levels drown wetland vegetation. Models like the Marsh Equilibrium Model project coastal carbon storage by factoring in sea level rise.

The Delta is naturally a strong carbon sink (Windham-Myers et al., 2023). However, methane is a potential concern because it can affect net greenhouse gas emissions. The presence of sulfate in the system has been shown to reduce rates of methane emissions (Windham-Myers et al., 2018). At half freshwater and saltwater, methane is negligible. Eddy covariance data confirmed that methane was significantly reduced, even at 5 ppt of sulfate, which is the concentration for most coastal wetlands.

There are many choices for how to manage soils in the Delta, though management opportunities will differ from one area to the next depending on existing conditions. However, all of them require inundating the soil and putting soil back underwater (Windham-Myers et al., 2023). Three recommended strategies are:

1. Agricultural management for rice
2. Permanent flooding of impounded wetlands
3. Tidal connectivity of shallower sites, which will cause the accumulation of peat soils

Both rice agriculture and permanent flooding saturates the soil, resulting in the protection of old dense carbon stocks. Similarly, restoring tidal connectivity saturates the soil and facilitates accumulation of sediment through sedimentation, increasing land elevation. Additionally, marine sulfate in tidally connected sites will reduce methane emissions. Current research identified that relative tidal elevation, impoundment status, and salinity were key factors reducing methane emissions in tidally connected sites (Holmquist et al., 2023). All of these strategies will be important, particularly when combined with actions that reduce methane emissions to maximize carbon benefits.

Ultimately, the biggest opportunity to apply these strategies is on agricultural land, which is 90% of the Delta (Whipple et al., 2012). Evaluating the full portfolio of strategies that can be applied will be important to reducing greenhouse gas emissions associated with subsidence.

William Horwath | Biogeochemistry of carbon sequestration and greenhouse gas emissions in inundated peat soils

The carbon content of soils can strongly influence the stability of sequestered carbon. In an experiment examining the impact of different soil carbon concentrations from 2-15%, Ye and Horwath 2017 found that soils with higher concentrations of carbon were more stable, in other words, more resistant to priming (Ye and Horwath 2017). Soils with only 2% soil carbon had higher methane emissions per gram of new plant input than soils with 6-15% soil carbon. Furthermore, isotope pulse labeling experiments using $^{13}CO_2$ to examine sources of carbon for methane emissions confirmed that methane emissions were consistently due to mineralizing older soil carbon stocks (priming) across different nitrogen concentrations (Morris et al., 2017).

Emissions of nitrous oxide and methane, which are greenhouse gases of concern, are sensitive to soil carbon concentrations. In general, both methane and nitrous oxide emissions decrease as the percent of soil carbon increases, though not linearly (Ye et al., 2016). One application of this work is to evaluate whether soil carbon content could be used to model and predict nitrous oxide and methane emissions.

Ye and Horwath 2016 found that there were emissions of nitrous oxide from soils with 6% of organic carbon soils up to 11% of soil carbon (Ye et al., 2016). However, at 23% of soil organic carbon, when water levels are brought down, they found a measurable nitrous oxide sink (Ye et al., 2016). The process relies on managing water levels to saturate the soil enough to maintain high redox levels. Increasing the amount of carbon into the soil could be one strategy to create strong nitrous oxide sinks that could offset methane emissions.

Soil carbon turnover decreases with increasing soil organic carbon (Hartman et al., 2017), because higher organic matter soils have more aliphatic and polysaccharide functional groups. The presence of more complex soil carbon compounds slows down microbial metabolic activity, thereby increasing the stability and persistence of soil carbon stocks (Hartman et al., 2017).

Metals also have the potential to coagulate dissolved organic matter to increase soil carbon. Experiments in wetland ecosystems indicated increased vertical accretion rate across the entirety of a subsided area when metal coagulants are applied (Hansen et al., 2018). However, the potential of mercury contamination needs to be considered.

Overall, priming, which is the decomposition of older carbon stocks in response to new carbon inputs, is a risk in soils with lower concentrations of carbon. Soils with higher carbon have lower rates of soil carbon and microbial turnover and have the potential to be nitrous oxide sinks.

Dennis Baldocchi | Lessons Learned from Long-Term Eddy Covariance Flux Measurements of Carbon Dioxide and Methane over Non-Tidal and Tidal Restored Wetlands in the San Francisco Bay-Delta Estuary

California has a Mediterranean climate with plenty of water and light and a long growing season. As a result, the Delta has high rates of plant productivity. Wetland restoration, through flooding and saturation of the soil, inhibits oxygen transport to sediments and reduces decomposition rates. High rates of productivity in combination with reduced decomposition allows restored wetlands to accumulate peat, reversing subsidence and building up land elevation over time. However, there is a trade-off. Lack of oxygen creates anaerobic conditions that stimulate metabolic activity of methanogens, which produce methane emissions.

Eddy covariance continuously measures trace gas fluxes from updrafts and downdrafts of wind. The Biometeorology Lab led by Dr. Dennis Baldocchi at the University of California Berkeley has applied eddy covariance to measurement fluxes in the Delta at several different sites that range from tidal to non-tidal systems: West Pond, Mayberry Slough, East End, Gilbert Tract, Hill Slough. Previous measurements using the eddy covariance technique have shown that the carbon sink at Dutch Slough, which sequesters 850 gC m^{-2} y^{-1}, is in the upper one percentile worldwide when compared to other Fluxnet net ecosystem carbon exchange measurements.

Values of carbon sequestration from eddy covariance are closely aligned with measured rates of carbon sequestered from soil cores (Arias-Ortiz et al., 2021), with the exception of tidal sites. From non-tidal sites, eddy covariance and soil core data are identical. However, in tidal systems, soil core data indicated a much lower amount of carbon sequestered than what was calculated from eddy covariance data. Further experiments will focus on understanding why tidal flows create this discrepancy in observations on Dutch Slough.

One hypothesis of the discrepancy in carbon sequestration rate between eddy covariance and soil core data is that growth in non-tidal systems can be delayed because of the high amounts of senescent material. High productivity in the area stimulates high biomass accumulation and dead plant material, that if not managed, can insulate water, keeping water temperatures colder than in tidal systems. Some measurements do indicate a delay in phenology, which shortens the growing period and minimizes the opportunity to take up carbon that could become stored in non-tidal soils. The disagreement between soil core data and eddy covariance measurements also highlights the need to account for lateral flows, which can transport carbon in and out of the system.

The stage of wetland restoration that a site is in and how water flows can significantly impact fluxes of carbon and methane (Hemes et al., 2018). Every site is different. As wetlands age and mature, there is variability in the amount of carbon stored and methane emitted (Figure 7). At the Mayberry site, the Biometeorology Lab observed that methane fluxes decreased by half since 2012 though it is not clear why. One hypothesis is that the microbial community may be driving these reduced rates in methane.

Simple models based on photosynthesis, temperature, oxygen, and water table have been useful for predicting methane fluxes below about 200 nmole $m^{-2} s^{-1}$. However, model exercises indicate that there are missing data about what is causing the highest methane fluxes.

Wetland restoration has great potential in the Delta to increase carbon sequestration, but there is a biogeochemical compromise between carbon sequestered and methane emissions that depends on salinity, productivity, and the degree of methane emitted. It is important to monitor over a sustained period to evaluate changes. Research indicates that wetland carbon and methane fluxes are dynamic in space and time and are influenced by the presence or absence of vegetation. Monitoring how wetlands are performing is essentially to increase the effectiveness of carbon sequestration.

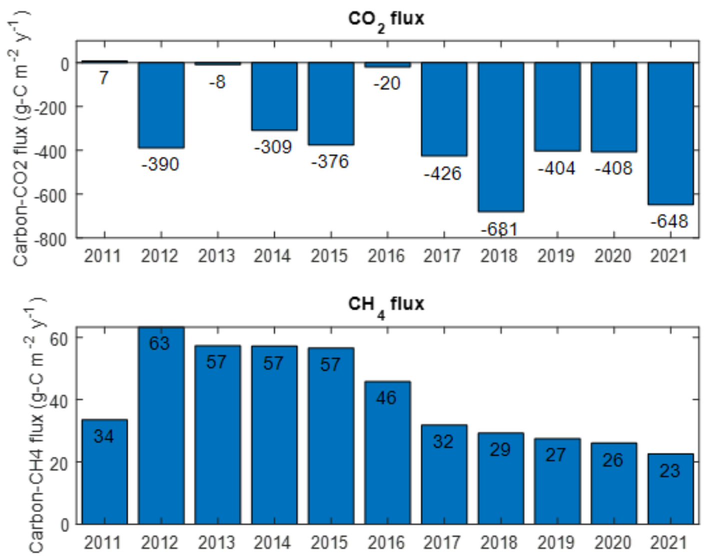


Figure 7: Slide from Dennis Baldocchi's presentation. CO2 Flux Interannual Variability and a Decline in Methane Production as Wetlands Age and Mature

Scott Neubauer | Thinking about subsidence in a climate context

Subsidence releases carbon that was previously stored in Delta soils into the atmosphere as CO_2, contributing to greenhouse gas emissions that create a climate impact. Several metrics exist to calculate the influence of management actions on climate:

- Radiative balance
- Radiative forcing
- Lifetime impacts of different ecosystems

Different metrics exist to evaluate the energy budget (radiation balance) of the planet, which directly affects the climate.

Radiative balance calculates climate over a certain time period, usually a century. The calculation ignores ecosystem processes before and after the defined time period. In order to compare the warming due to emission of methane against the cooling due to carbon sequestration, both greenhouse gas fluxes need to be converted into a common currency such as global warming potential (GWP) or sustained-flux GWP (Neubauer and Megonigal, 2015).

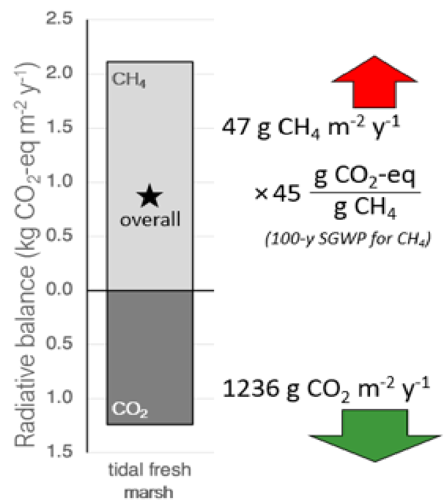
For methane, its sustained flux GWP is 45, which means that an annual emission of 1 kg of methane has the same warming impact as 45 kg of CO_2. Methane is a much more powerful greenhouse gas. Multiplying methane flux by the sustained-flux GWP places methane impact in terms of CO_2 equivalent units, allowing direct comparison of CO_2 and methane (Box 1). Over a 100 yr time period, warming due to methane emissions is greater than cooling due to CO_2 when the net result is positive. However, a positive radiative balance does not necessarily mean that a marsh is contributing to climate change.

Box 1. Radiative balance information from Scott Neubauer's presentation slides

Use simple metrics to compare different greenhouse gases

- Global warming potential
- Sustained-flux GWP

A positive radiative balance does not necessarily mean a site is contributing to climate change



For the climate to change, there must be a change in Earth's energy budget. Radiative forcing calculates whether a particular action is contributing to climate change using the radiative balance at two different timepoints. For subsidence, it is possible to calculate radiative forcing due to draining a wetland, which causes the oxidation of organic material and results in CO_2 emissions to the atmosphere. Using values from the State of the Bay Delta 2023 report on subsidence, draining wetlands increases the radiative balance, which increases the radiative forcing, and contributes to climate change. Radiative forcing can also be applied to understanding the effects of other management actions, such as converting the land back to wetlands (Box 2). Various management actions have the effect of potentially reducing radiative balance which means that they are climatically beneficial as well as reversing subsidence.

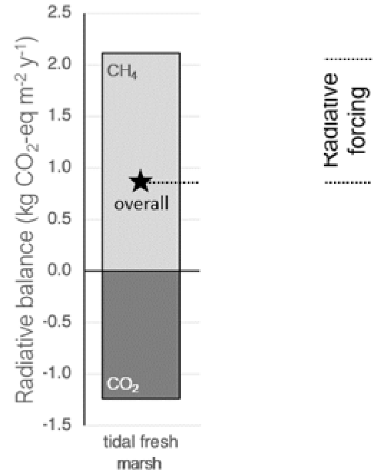
Box 2. Radiative forcing information from Scott Neubauer's presentation slides.

Compare radiative balance at two time points

- Increased radiative balance → warming
- Decreased radiative balance → cooling

Delta example:

- What is this wetland is drained and used for agriculture?
    - Positive radiative forcing = warming effect



Lifetime climatic effects consider the lifetime of a system rather than radiative balance or radiative forcing that consider discrete time points. Evaluating methane and CO_2 emissions for a wetland continuously over 100 years indicates that warming of methane exceeds the cooling effect due to carbon sequestration. However, the timeframe is extended out, there is a point in time where the wetland switches from a warming effect to one of lifetime cooling after the wetland is over 200 years old. The reason this occurs is because carbon locked into soils, assuming no disturbance, is locked away every single year, which continually accelerates cooling whereas the warming effect due to methane only lasts for 50 years. In other words, the warming effect of methane lasts a shorter amount of time (50 years) compared to the cooling due to carbon sequestration. The point in time when lifetime carbon sequestration is greater than the methane emissions, switchover time, depends on the rate of methane emissions relative to carbon sequestration and can differ from one marsh to the other. For example, brackish water will have a lower switchover time than some other wetlands. As long as a marsh remains undisturbed, it will eventually have a lifetime cooling effect on the climate because of carbon sequestration.

Different interventions have the potential to be climatically beneficial in addition to slowing down or reversing subsidence. The basics of wetland biogeochemistry are well understood, but uncertainties remain in the various factors that influence biogeochemistry. For example, it is not clear what determines the magnitude of fluxes in nitrous oxide emissions or fluxes in dissolved inorganic or organic carbon.

In addition, it is important to remember that climate is not the only consideration for managing wetlands and other landscapes. Economics, habitat, and other factors matter as well.

Panel 2 Discussion Summary

Research suggests that rhizosphere carbon exuded by roots is more likely to be sequestered than carbon from aboveground sources. Plant species may differ in salinity tolerance, but the capacity to store carbon is more related to whether carbon inputs are below- or aboveground. Higher carbon content has been shown to decrease nitrous oxide emissions, potentially through dissimilatory reduction. Managing nitrous oxide emissions may be able to offset methane emissions from inundated soils, though further research is needed.

Greenhouse gas emissions from wetland projects must be managed. However, any management action that reduces the radiative balance (e.g., reduce methane emissions), will have an immediate climatic impact with time. The switchover time (the point in time at which a wetland becomes a carbon sink) can change as methane fluxes change. Ultimately, net negative carbon fluxes are not necessary for a wetland project to have beneficial impacts, because a climate benefit occurs as long as its radiative balance is lower than current values.

Models are essential to understand management implications on ecosystem processes. There are a number of different types of models and statistical approaches available. However, there is insufficient data to inform model processes and calibrate model outputs, in part because taking measurements is costly and time intensive. Yet determining input data for models requires taking the right measurements to parameterize models, especially because high soil heterogeneity requires hundreds of samples to ensure representativeness of the data gathered.

The lack of good quality data is a major constraint to testing model assumptions. For example, the simple models available that rely on parameters that are easily measured are not capable of explaining the observed fluxes in wetland ecosystems. Developing integrated models that include risk factors such as levee failure will require working with other people on interdisciplinary experiments to understand carbon pools, interactions with nitrogen cycling, and other knowledge gaps such as lateral fluxes, microclimates in soils, and the effect of microbial communities on greenhouse gas fluxes.

Panel 3: Considerations for Inundated Agricultural Practices

Jessica Rudnick | Influences on farmer decision-making

The agricultural sector in the Delta annually generates about $1 billion in revenue and is highly diverse with over 70 crops grown across 415,000 acres (USDA, 2017; Delta Protection Commission, 2020). Corn and alfalfa make up the highest proportion of acreage. Wine grapes and tomatoes generate the highest revenue. A majority of farms are privately held resulting in many individual landowners across the Delta. Additionally, agriculture supports approximately 13,000 farm jobs and 10,000 processing and manufacturing jobs. Consequently, taking into consideration the whole economy supported by agricultural and other working lands is a key part of the conversation around managing subsided lands.

Economically-driven decision making based on return on investment (ROI) and upfront capital costs are high factors influencing the adoption of new technologies or practices (Prokopy et al., 2019; Ranjan et al., 2019). Broadly speaking, access to capital is the most significant factor influencing farm innovation because upfront costs are a key barrier to adoption of new practices. Generally, access to capital increases with farm size such that larger farms and farms that generate higher revenue tend to be more likely to innovate because of their access to greater financial resources with which to experiment. Land ownership can also influence farm innovation, as landowners can operate on longer time horizons, facilitating adoption of innovations that have long term payoffs; whereas farmers leasing land may be restricted to innovation adoption that will result in ROIs within their land lease term. Overall, a high likelihood and perception that a new innovation will be positive to farm revenue will improve the likelihood of adoption.

Learning and access to information can also affect the rate of adoption for new approaches because access to technical knowledge can be a barrier for some growers. Farmers that identify as stewardship-motivated, as well as higher educated farmers, tend to have more awareness of and engagement with incentive programs, extension and technical assistance resources, and practices associated with conservation. For example, growers who are more connected to personnel from the University of California Cooperative Extension, may be more likely to engage with field trials or new practices (Khalsa et al. 2022; Johnson et al. 2023). However, regulatory programs that require mandatory reporting and education have shown to be effective at driving learning among lower-resourced farms and farmers who would otherwise be less likely to engage in conservation programs or adopt new innovations (Wood et al. 2022). For all farms, improving clear communication and access to resources that demonstrate how a new practice will impact crop yields and return on investment can help reduce uncertainty, which is a commonly shared barrier to innovation adoption (Rudnick et al. 2023).

Positive social norms can increase the likelihood of adoption. Peer-to-peer networks and farmer-to-farmer learning experiences, such as through demonstration days, can help growers see the results of adopting a practice. Farmers who have previously adopted conservation practices or who have more experience with vulnerable land, such as farming on actively subsiding areas, are also more likely to engage with new practices and technologies (Prokopy et al., 2019; Ranjan et al., 2019). Improving the spread and accessibility of information about new practices and marketing availability is important to increasing its influence and the adoption of conservation-oriented practices (Prokopy et al., 2019; Ranjan et al., 2019).

In the Delta, farmers reported that economic factors such as impacts to crop yield, crop quality, and farm profitability, were key factors that drive operational changes (UC Davis, 2020). Soil health, impacts on public health and safety, stewardship and conservation are highly considered, though secondary concerns. More than 50% of the time, farmers also considered logistical aspects such as regulatory requirements, labor, and complexity. Less than 20% of growers consider incentive programs when evaluating operational changes (Khalsa et al. 2022; Rudnick et al. 2021). The lack of interest in incentives when considering change is consistent with data across California and highlights whether incentives, at least as currently structured, are truly effective drivers of adoption. Variables like the amount of the incentive payment or the costs—in terms of time, technical expertise required, information disclosed in reporting—required to participate in incentive programs may change this trend, but current data suggests that incentives alone do not appear to significantly increase *additional* (i.e. adoption would not happen otherwise) adoption of conservation practices (Prokopy et al., 2019; Ranjan et al., 2019).

A 2018 survey examining how California growers access information indicated that growers use a variety of different information sources (UC Davis, 2020; Khalsa et al. 2022; Rudnick et al. 2021; Johnson et al. 2023). With regards to implementation, it is important to consider how the information is going to be communicated and whether the information is being conveyed by partners that are trusted by private landowners (UC Davis, 2020).

On-farm consultants such as certified crop advisors are highly trusted and used by growers. These individuals generally have a wider reach than some of the information sources that are discussed in management and policy context. NRCS and resource conservation districts provide technical assistance and demonstration projects, but their reach is not as extensive as private consulting sources. Similarly, familiar sources such as other growers, family members, and field crews are trusted because they have developed one-on-one relationships and are sharing experiences.

There are available incentives to support subsidence management:

- CDFA Healthy Soils Program directs California's cap-and-trade funds to farmers implementing soil management practices such as cover cropping, tillage, composting, and conservation plantings. This program could support Delta specific soil management practices to reduce subsidence, as long as there is a quantifiable reduction in GHG emissions.
- USDA has several incentive programs:
    - Conservation Reserve Program is not being used in California, but it has the potential to act as a revenue replacement for farms to fallow or retire working farming activities on sensitive habitat lands
    - The Conservation Stewardship Program and Environmental Quality Incentives program provides technical and financial assistance to growers for implementing conservation practices on working lands. Getting approval for Delta-specific practices would be one way to leverage a potential new funding source for growers interested in implementing subsidence management practices.
- Carbon market: The payouts on the existing rice protocol approved in the American Carbon Registry aimed at reducing methane are fairly low. Currently the regulatory market is offering $29 per metric ton and about $2 per metric ton on the voluntary market. The wetland protocol is currently available on the voluntary market. The ability for the carbon market and offsets to motivate growers is difficult, though there is potential for participation in the regulatory market to offset loss in revenues. Offset market participation will need to be made easier and technical assistance for reporting, monitoring, and calculating GHG offsets will need to be available for growers.
- Local program called Fish-Friendly Farming. They provide certifications across the state related to water quality and the incentive is regulatory relief since certification allows growers to meet their compliance requirements for the California Water Resources Control Board.

Michelle Leinfelder Miles | Considerations for Inundated Agricultural Practices

The University of California Cooperative Extension (UCCE) has existed for over a century in California. Their mission is to connect the people of California with the knowledge and research of the university system through a statewide network of personnel. UCCE is supported through county, state, and federal funding. Programs are developed by working with communities and building trusting relationships for collaboration.

In 2020, UCCE released a survey to understand the most important issues in agronomic crop production and the way that UCCE could help address those needs (Kanter et al., 2021). Respondents reported that they received information from UCCE newsletters, blogs, field days, and speaking with UC Cooperative Extension personnel during on-farm consultations. Growers prioritized information on on-farm trial results, costs of production information, and decision support tools. The study also indicated that field crop acreage makes up 45% of the crops grown in San Joaquin County and 70% in Sacramento County. Field crops are economically important crops and are traditional crops that growers can use in crop rotations. These results provided insight into local farming practices and management considerations.

A majority of the land in the Delta is under private ownership. Thus, private landowners make up a large footprint in the region. The challenge is that most desirable crops cannot grow under the flooded conditions that would reduce subsidence. Rice is the exception because its cellular structure allows gas diffusion throughout the plant, meaning that rice cultivation is uniquely suited to addressing subsidence while generating profit.

The Sacramento Valley is the predominant rice growing area in the state, but Delta acreage is growing. In 2022, rice was grown on approximately 10,000 acres in the Delta compared to approximately 3,000 acres a decade before. Acreage is expected to expand in the future. Delta growers have engaged in research to advance the rice industry by exploring cold tolerant rice varieties. This is an example of research that can provide growers with actionable information in the short-term that also supports long-term priorities for the region.

Inundating the Delta landscape supports public interests like mitigating subsidence, which threatens levee stability and water quality. Private landowners understand the importance of these goals, but must also be concerned with crop profitability and markets. Economics is a critical aspect of on-farm decision-making. Another study (Leinfelder-Miles et al., 2022), in collaboration with Delta growers, examined the cost of production for Delta rice, taking into account the cost of converting land for rice cultivation. The study benefits growers who are not currently growing rice but are interested in learning more, banks and lending agencies, and state and federal agencies to inform their cost sharing and incentive programs.

There are a number of science gaps that still remain:

- Alternate wetting and drying (AWD) has been discussed as a way to reduce methane emissions, but it has not been proven in the Delta where soils differ from original studies that related AWD to reduced methane emissions (Arkansas).
- Walking wetlands, which are temporary short-term wetlands, may strike the balance between minimizing subsidence and allowing crop rotation. It may allow for receiving emissions reduction benefits while regenerating land to increase crop yields.
- Programs that support dewatering of subsided lands, such as drought programs, would likely have a negative impact on subsidence. UC Cooperative Extension has deployed eddy covariance data to currently evaluate this.

Recommendations include:

- Research needs to be supported by making sure that strategic planning documents include land-based priorities. Project evaluations need to include appropriate personnel so that proposals are evaluated fairly by personnel that understand the land-based priorities.
- Financial programs that enable cost-share could increase adoption of rice because land conversion for rice cultivation has high upfront costs. The 2022 Cost of Production Study for rice indicates that supporting private growers in land conversion is more cost-effective than relying on meeting stewardship goals on public lands (Leinfelder-Miles et al., 2022).

Long-term requirements for carbon sequestration are barriers to practice adoption on private lands and especially on leased land, which accounts for 50% of farm acreage in the region.

Jerred Dixon | Considerations for Inundated Agricultural Practices

Staten Island was purchased by The Nature Conservancy (TNC) in 2001 to create a conservation- and agriculture-friendly island. Research studies that focus on migratory birds, subsidence reversal, and carbon sequestration have been completed on Staten Island for over 20 years, resulting in a living laboratory that supports farming and habitat for migratory birds.

The Nature Conservancy is interested in science that addresses walking wetlands, alternative wetting and drying, carbon sequestration and rice, which are all topics that add to their understanding of current activities. For rice, land leveling and building the necessary water structures are costly and one of the largest hurdles for increasing adoption of rice.

Staten Island is also recirculating water in wetlands and rice fields to minimize impacts on water quality. They are in the process of registering this project through Fish Friendly Farming.

The public sector adoption of rice is supported through grants, but those funds are largely inaccessible to private landowners. Private landowners manage about 400,000 acres of agricultural land in the Delta. Enabling access to funding for the private sector to convert agriculture lands into wetlands and rice would be an effective strategy to increase beneficial land uses. Developing ways to provide funding to private landowners who have large land holdings would solve a major disconnect. Outreach to landowners is necessary because as other farmers see profitability in these actions, they will be more likely to adopt them.

Benjamin Leacox | Considerations for Inundated Agricultural Practices

Farmers care greatly about sustainability, but there are two aspects of this: (1) making sure that land can be farmed in the future and (2) financial stability. Farmers can visibly see losses of farmland on the margins because land is becoming difficult to farm due to subsidence. Some of this land could be converted into wetlands, but the incentives for conversion currently are not sufficient. Farmers are open to incentives and alternative land uses, but incentive programs need to work for farmers. For example, 40-year programs to participate in the carbon market are not feasible because many farms operate on a year-to-year basis and are unwilling to tie ground up for decades for little financial benefit.

Financial stability is the main concern because income is needed to maintain operations. Without income, farming operations stop. So, financial decisions and ensuring returns on investments are key priorities. Zuckerman Farms has converted land to rice on land that they own at $800-1000 per acre because they are confident about their return on investment. A key question is how to rotate high profit crops, such as potatoes, with rice, which is not as profitable, so that operations can be maintained. Prices for rice vary from year-to-year, requiring rotation with other crops to maintain profitability. Currently, rice is being used as a replacement for corn because corn contributes to subsidence.

At least 50% of the acres operated by Zuckerman farms is leased typically for 5 year terms. This makes it more complicated to implement conservation practices because 5 years may not be long enough to guarantee a return on investment. Additionally, lessors are hesitant to sign 5-year contracts.

Incentives can work when they minimize the risks to farmers for converting land into rice. If the costs for conversion could be eliminated or subsidized, it would increase the conversion process for rice in the Delta. Incentives have typically been onerous or have financial caps or terms that are not adequate for the level of work being asked. This is why incentives have not been as influential in farmer decision-making. However, well-designed incentives can motivate adoption. The Delta Drought Response Pilot Program is an example of a successful program that was implemented correctly. When programs are designed well, they can help growers make land management decisions that are helpful for everyone.

Panel 3 Discussion Summary

The vast majority of the Delta is owned by private landowners. Involvement of the private sector is crucial for landscape-scale subsidence management because the volume of subsidence reversal required is not achievable on public lands alone. Thus, efforts to consider how private landowners can contribute to landscape goals is essential. Private landowners are interested in converting lands to land use types that can mitigate subsidence, particularly land that is already too wet for farming. However, high upfront costs, regulatory constraints, and lack of funding opportunities hinder farmer and landowner conversion of subsided lands.

One of the challenges is the permitting process for wetlands, which is both time- and cost-intensive. Farmers expressed frustration that they must wait on permitting processes and the associated costs that prevent them from accomplishing desired land conversions. A wetland can cost over $10,000 per acre for construction due to regulations, which farmers feel “slows down” what they could accomplish. Public agencies likewise feel limited by regulations and the costs to create wetland projects. These concerns from both the private and public sector highlight the importance of understanding how to structure and implement incentives.

Currently, growers pay to convert land use from agriculture into rice or wetland development out of pocket a majority of the time, requiring significant upfront investment. As a result, land conversion for subsidence reversal is only possible for larger farms that have access to capital despite a general interest from landowners. Ideally, the agricultural sector could be compensated for implementing management practices and land uses that provide societal landscape benefits such as reducing carbon emissions and minimizing subsidence.

The voluntary carbon market has emerged as a potential incentive to reward converting land for rice cultivation or wetlands. However, it is not clear to private landowners that carbon credits are a viable source of profit due to the low price for carbon in the voluntary market compared to the compliance market. Until the California Air Resources Board approves a wetland carbon market protocol, participants are limited to participating in the voluntary market. Monitoring, reporting, and verification costs to register credits are also time- and cost-intensive to complete. Furthermore, available protocols that award carbon credits in exchange for a 40-year commitment to growing rice, given that a typical contract is 5 years, is too small an incentive for private landowners. Increases in voluntary carbon market prices or the option to participate in the compliance market may change engagement in the carbon market. Ultimately, how incentives are structured is crucial to building participation. Incentives must have cost-effective options that account for operating costs, taxes, and levee repair costs that private landowners take into consideration when making day-to-day decisions.

Crop rotation is necessary to manage the risk from variations in crop variability. Farmer and private landowner participation in subsidence reversal and carbon sequestration projects must allow for crop rotation and diversification because these are essential for Delta agriculture. Additionally, the trade-offs among different management actions related to reducing subsidence are not clear, preventing the development of clear metrics or guidelines for incentive programs.

Rice is one of the few crops that can grow in saturated soil conditions and that has a stable market sufficient to make profit. Farmers would like to remove siloed corn and rice acreage that has expanded in recent years, but this is only possible for growers who already have the capital to support rice cultivation. There are also practical challenges for growing rice such as leveling land and routine maintenance of rice fields is time-intensive and the costs are often paid for out of pocket by farmers. However, for farms that have introduced rice into their crop rotation, they have observed higher yields in high profit crops like potatoes and turfgrass. While there is interest among farmers to increase the acreage of rice grown, the high upfront costs remain a major barrier in converting lands for rice cultivation. Furthermore, flooded conditions in rice cultivation promote methane emissions. Ongoing research in the Healthy Soils Program is evaluating the tradeoffs between methane emissions and CO_2 reduction. However, there are no applications for this right now.

Alternate wetting and drying (AWD) for rice agriculture is intended to reduce methane emissions by intermittently draining flooding rice fields. The theory behind alternate wetting and drying (AWD) is that drying out the soil will minimize the populations of Archaea, which cannot persist in aerobic conditions, thereby decreasing the capacity to generate methane in wet (flooded) conditions. The goal is to minimize populations to a low enough level that even after wetting the soil, there will be a 2-4 week period of lower emissions of methane because there is a reduced amount of Archaea and it takes time for that population to increase. However, the theory of AWD relies on one paper from Arkansas with only two field studies and chamber measurements, which needs to be verified in the Delta. The timing of this process in the Delta needs to be examined further especially because it might not be possible to truly dry out the soil. Furthermore, farmers generally do not want to truly drain the soil when growing rice because adequate yields require flooded soils. This practice effectively negates the benefits of AWD, but AWD should be tested in the Delta to better understand what the benefits are for this region since agronomic practices can be unique to the region. The Arkansas paper very clearly states that experiments are needed to test how to apply AWD without risking rice yields. There is also data from a UC Davis AWD study (see LaHue et al., 2016) that suggests that there are potential ways to manage this, particularly if the timeframe component is kept in mind.

Walking wetlands as part of rotating the land through different land uses have been tried with mixed results. Walking wetlands appear to be beneficial for birds and re-building soil, but it is not clear what the impact of walking wetlands are on profits and they have yet to be tested in a crop rotation with rice. The theory of walking wetlands is to develop them as part of a crop rotation to receive the benefits, especially because they are compatible with current farm infrastructure and could save on costs. Additionally, they are not subject to the same level of regulations as is typical of permanent wetland projects. However, further testing is needed to determine the benefits.

Farmers generally operate on a 5-year planning horizon because land might be leased or because contract lengths are at most 5 years long. This timeframe forms the backdrop for day-to-day and year-to-year decisions, complicating efforts to implement long-term planning for subsidence management. Immediate concerns such as ensuring enough revenue to support levee repairs, which can average $2 million per mile, are strong factors that significantly impact crop choices and land uses. However, farmers expressed strong interest in actionable information and openness to implement practices that generate long-term benefits. A major barrier is the lack of conduits to communicate actionable information to farmers and a lack of studies on approaches to manage subsidence within a profitable crop rotation framework. Furthermore, data on how farmers learn from each other and transfer knowledge is lacking, highlighting a major social science gap in ways to communicate effectively with a key facet of the Delta agricultural community. Developing relationships and demonstrations focused on actionable information is needed to promote subsidence management on a larger scale.

Panel 4: Science needs to Inform Landscape scale Implications of Peat Soil Inundation

Many interconnected and significant science issues relate to subsidence. They include water quality, ecosystem health, flood risk, and greenhouse gas emissions. One aspect of subsidence that is directly relevant to California state goals is the associated greenhouse gas emissions. California has a goal of reducing emissions and moving towards carbon neutrality. AB 1757 is intended to address carbon issues for the State by incorporating emissions and sequestration from the landscape into state projections for carbon neutrality. The policy applies to “natural and working lands”, which are defined as: forests, shrublands, grasslands, croplands, developed lands, wetlands, and sparsely vegetated lands. California develops a scoping plan every five years that calculates emissions projections and includes approaches to reduce net emissions. The most recent scoping plan was released in 2022 and covers emissions through 2045.

Delta wetlands were the only wetlands incorporated into State’s projections because of the size of the Delta and availability of data and modeling. The current target set by the State is to restore 60,000 acres of wetland by 2045, which includes tidal wetland restoration, managed wetlands, and rice cultivation.

A Natural Working Lands Expert Advisory Committee of 15 members with expertise across the seven land types provides input to the California Air Resources Board and the California Natural Resources Agency about scoping plan targets. It also recommends improvements to the approaches used for modeling projected emissions. The wetlands advisory group recommended increasing the original wetland restoration targets to 50,000 acres of managed wetlands and rice cultivation and 32,500 acres of tidal wetland restoration.

Karen Buhr | Science Needs in the Delta

The Delta Conservancy is a state agency that focuses on environmental protection and economic well-being of the Delta. The agency funds projects and forms state-local partnerships to meet local challenges, such as subsidence, and to support work that is happening locally. The main role of the agency is to provide funding and state and local resources to advance projects that address the following objectives:

- Climate adaptation and restoration
- Supporting farmers and ranchers on working lands
- Drought programs such as the Delta Drought Response Pilot Program
- Community programs to increase public access to the Delta and to provide community centers
- Education and enrichment for various audiences
- Nature-based restoration efforts

One of the major efforts of the Conservancy has been the development of carbon market protocols for the region. The Conservancy is interested in incentivizing and increasing the scale of the carbon market in order to increase implementation of wetland restoration and/or rice cultivation, especially on lands that are too wet to farm. Three projects in the Delta currently are using the 2017 carbon market protocol to which the Delta Conservancy provided technical and financial support: Sherman and Twitchell Islands, Staten Island, and Webb Tract (Deverel et al., 2017).

The Conservancy has $36,000,000 in their Wetland Restoration Funding to fund nature- based solutions. Currently, this program has awarded funds for the Webb

Tract Wetland and Rice Mosaic. Proposals on Staten Island will be evaluated as well. The funding is a significant opportunity to implement restoration at a larger scale.

Science needs include:

- Guiding project implementation. How can the models that are used be refined? How do systems actually work?
- Quantifying carbon savings. How can the Conservancy better understand what is actually happening on the ground across different regions, the degree of subsidence, and management actions?
- Economic data and modeling for farmers. Switching crop types is a huge investment, what data and how can we provide data that they can use to make decisions?

Funding is a major constraint to implementing these wetland restoration projects. Educating the public and legislature about the projects and their benefits can help minimize financial constraints to constructing projects in the Delta.

Steve Deverel | Landscape Scale Implications

Eddy covariance flux towers, which continuously measure gas exchange between the land surface (soil and vegetation) and the atmosphere, have been critical for quantifying carbon fluxes, including estimating the net greenhouse gas emissions reductions benefits for the carbon market. Cultivated agricultural lands generate baseline emissions. Converting land to wetlands sequesters carbon, but releases methane. The balance between carbon sequestration and methane emissions of a wetland in comparison to the baseline agricultural emissions determines the net greenhouse gas reduction benefit. However, there are several concerns with the way the estimated net greenhouse gas benefit is calculated.

One concern is that the atmospheric warming impact of methane emissions (methane is a stronger greenhouse gas and shorter lived in the atmosphere than carbon dioxide) is typically calculated using a global warming potential of 28. This is the standard for the carbon market, but it is lower than what some research indicates. Secondly, participation in the voluntary carbon market requires a 40-year contract and the compliance market requires a 100-year contract (Deverel et al., 2017). The purpose of these long contracts is to ensure that wetlands are undisturbed long enough to reach the switchover point when the wetland becomes a carbon sink. However, long-term contract lengths can be difficult for potential participants, particularly farmers, who must deal with the reality of generating and income from these lands.

Twitchell and Sherman Islands were the first project in the Delta and the world to verify wetland carbon offsets, a total of 52,106 tons of CO_2e, under the American Carbon Registry protocol in 2020 (Deverel et al., 2017). Currently, prices are about $16 per ton of carbon, which is consistent with typical voluntary market prices. For the compliance market, the price is about $30 per ton. Carbon prices are expected to increase over time which could make carbon markets a potential tool to incentivize new land management practices.

Landscape scenario analysis for islands that considers alternative patterns of crops such as corn, potatoes, rice, pasture, and alfalfa as well as wetlands permits assessments of subsidence mitigation and GHG emissions and removals. Analysis of alternative scenarios identify impacts of using the same land in different ways. For scenarios of six different land mosaics for Staten Island, subsidence reversal and greenhouse gas emissions reductions were compared as well as estimating revenue compared with the baseline. Changing land uses and allocating more land to wetlands and rice where subsidence and baseline carbon dioxide emissions are the greatest, can both mitigate elevation loss and, in the case of wetlands, reverse the effects of subsidence (Deverel et al., 2016, Deverel et al. 2020). Analysis of the economics for the different mosaics indicate that they can generate income consistent with or exceeding the baseline in which most the island was planted to corn (Deverel et al. 2017).

Research needs for adaptation to the carbon market and land management include:

- Improved understanding of GHG emissions and sequestration for alternative landscape scenarios.
- Improved understanding of the impact of different management practices, e.g., crop rotation, soil wetting and drying etc., on GHG emissions and sequestration.
- Quantification of co-benefits of land use changes to food webs and levee stability

Modeling suggests that establishing wetlands near the periphery of islands decreases the risk of levee failure by decreasing critical hydraulic gradients that can erode levee foundation material. On Bacon Island, a groundwater flow model was integrated with models that predicted subsidence and organic soil accumulation to evaluate seepage forces on levees from 2018 to 2070. The model simulations compared a business-as-usual scenario to a scenario where rice was grown in the central part of Bacon Island and wetlands were established at the periphery of the island. Model results indicated that the scenario with wetlands and rice significantly reduced the relative probability of levee failure and seepage forces compared to the business-as-usual scenario. The business as usual scenario resulted in critical exit gradient exceedances in 1,410 m of levee in 2070. The rice/wetland scenario resulted in 0. The benefit of this approach is that it identifies areas that have a higher risk potential of seepage threats to levees.

Jay Ziegler | Managing Subsidence in the Sacramento-San Joaquin Delta

There are 500,000 residents in 750,000 acres of reclaimed environment in the Delta. Polling indicates that the public is very concerned with aging infrastructure such as roads and levees, affordability, public safety, environmental decline, and climate change. Levees are incredibly resilient, but people are understandably very concerned about the levee system because they are not natural systems. The co-equal goals of the Delta Plan are in conflict, which creates very complex challenges. As the State Water Resources Control Board considers subsidence and its impact on carbon budgets, it's important to consider people.

There are significant regional differences across the Delta that pose different challenges and opportunities when it comes to addressing climate risk reduction, carbon credits, and other problems. Different regions have different issues. For example, in the northern Delta, opportunities for habitat restoration are in the intertidal range and maintaining flow for the Yolo Bypass are key priorities. However, in the eastern Delta, floodplain restoration is a bigger concern and widening the separation of the levees along stream channels so that excess river flow can be absorbed is a major priority. The State Water Resources Control Board needs to align efforts about enhancing carbon sequestration along with the values of people across the Delta landscape and where there are opportunities, such as Suisun Marsh and Cache Slough, for restoration.

The Delta community must be an active part of the process to ensure that implementation is related to practical concerns on the ground in order to be effective. Choices in land use should be shaped by the local needs, priorities, and ecosystem opportunities. Ideally, habitat, flood protection, and groundwater programs would be aligned to sub-regional carbon benefits that in turn align with landscape-scale strategies.

The State Water Resources Control Board does not have good data on how much water is being used in the Delta. Careful tracking of water use is needed because California has the most variable annual precipitation in the United States. OpenET aims to improve water data availability. There are 1,300 water rights holders in the Delta and 3,000 points of diversion, 75% of which are reporting now on the OpenET system. OpenET allows us to validate where, when, and how much water is used. This system is setting the standard for water budget accounting because OpenET allows us to know consumptive use in the Delta exactly. The data from OpenET can then be used to exercise water rights in a way that protects water quality.

The error range for OpenET calculations on consumptive use for land-based applications of water is within 10%, which provides an accurate estimate of the Delta water budget. However, for open water such as wetlands, the error range is still about 25%, indicating that OpenET methodology remains difficult to apply accurately for wetland restoration or open water with tule vegetation. It is recommended that OpenET should not be used for those cases.

Overall, OpenET allows us to have grounded, quantitative, conversations about water use that uses one database. It is important to have science-based discussions about the multiple values of water when thinking about carbon and land strategies.

Funding has been central to conversations in this workshop. In comparing FY2021 to FY 2024, there has been a 30% reduction in funding for environmental purposes. Improvements to funding for climate and natural resource investment are necessary and the scientific community needs to be an active voice that expresses the importance of investments in the future.

Incentives to address climate vulnerability need to be rebalanced and ordered to improve participation. Farmers are not very confident in the carbon market though there is interest in climate smart agricultural practices. If the risk of investment for converting land to rice was removed from the farmer, that could encourage adoption of that practice. In general, a portfolio of incentives could be re-structured to align tax benefits with first adopters that are really trying to address climate challenges through smarter land use changes. The Farm Bill could be re-structured to minimize the risks to farmers who apply climate-smart practices. Sustainable Agricultural Lands Conservation program (SALC) could be modernized to address climate resilience rather than just for agricultural protection. Currently, farmers do not see a real incentive to change farming practices to align with climate smart strategies. It is critical to evaluate the current portfolio of incentives and the proportion of public and private incentives to examine whether they are meeting people where they are in order to ensure that there are beneficial changes in the landscape.

We need open, transparent, and strong stakeholder engagement to achieve these goals.

Panel 4 Discussion Summary

Subsidence is related to many issues such as the Delta carbon budget, contaminants, and water quality. Severe subsidence in some areas intertwines subsidence management with levee maintenance as well, because seepage that occurs in deeply subsided areas can erode levee foundations. Thus, subsidence could be considered an infrastructure issue that increases with climate and generates costs in the form of expensive levee upgrades.

One key concern is the potential for wetlands and rice fields to create conditions that could lead to the formation of methyl mercury. Studies from Twitchell Island show that methylmercury in fish exceeds the threshold for concern, which indicates that it is probably not prudent to put fish in rice paddies (Deverel et al., 2007; Twitchell Rice Project Report 2008-2009; Heim et al., 2009; Stumpner et al., 2015). Even if the concentration is low, it can accumulate in the food chain. However, there are water management alternatives to reduce methylmercury contamination like recirculating water so that it does not end up in more than one place. There is a seasonality to methylmercury exports as well where mercury exports are highest in the winter, but there are also higher flows so there is more dilution (see Yolo Bypass studies: Windham-Myers et al., 2010; Lee and Manning 2020). While it is not a trivial issue, it is secondary to reversing subsidence.

OpenET enables, for the first time, an accurate accounting of consumptive use in the Delta. For subsidence, the data in OpenET can be used to exercise water rights in a way that protects water quality and provides a way to understand the variation in water use across the entire Delta. Opportunities to manage subsidence vary from one area to the next, and new tools and resources will be essential to developing strategies and governance structures that align with community objectives and local opportunities. Focused dialogue, especially with farmers and private landowners, on land use and potential approaches for different scales is needed to understand what types of governance structures are needed. Although dialogue and collaboration with farmers has improved significantly over time, communication with legislature could be improved.

Farmers have different preferences for receiving information. Some data are available to help guide strategies of how to maximize effective communication methods. Staten Island effectively serves as a model and source for preliminary information. Costs of production study like those produced by the UC Cooperative Extension (for rice) are also important for providing numbers and the assumptions to support calculations (e.g., Leinfelder-Miles et al, 2022). The newsletters, blogs, and annual grower meetings sponsored by the UC Cooperative Extension are the closest things growers have to a guidebook for various practices and their potential benefits. Other groups are also working to disseminate information, including bringing growers out to look at recirculation pumps. Farmers expressed concerns that they are not heard. Efforts to include farmers in land use discussions in a way that is sensitive to their interests must take place in order to work with them to implement solutions.

A number of resources and tools are available to help implement different management practices. However, farmers expressed that currently available incentives are inadequate to motivate larger scale land conversions particularly for land that could be used to farm profitable crops. Experiments that generate actionable information and tools are necessary, as are more effective ways to communicate to farmers and private landowners. New technologies that enable real-time monitoring may be leveraged to help close the gap between the development of data and the application of that data to improve management practices that reduce subsidence and methane emissions.

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