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STATE OF BAY-DELTA SCIENCE

# Assessing the State and Efficacy of Climate Governance Research and Practice in the Sacramento–San Joaquin Delta

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## ABSTRACT

Climate change affects nearly every aspect of the interdependent biophysical and social systems in California's Sacramento–San Joaquin Delta. Mitigating and adapting to these effects will require effective climate governance: referring to the actors, rules, and processes through which decisions are made to prevent and respond to climate change. How governance systems effectively achieve these goals has become an increasingly central question in climate social science and climate policy debates, both at global and local scales. This paper reviews the state of science on climate governance in the Delta and investigates the extent to which effective climate governance characteristics operate in this region. The literature on climate governance broadly distills two key dimensions that scholars suggest influence efficacy: the structure of a governance system (e.g., extent of centralization and decentralization and mechanisms for coordination) and the degree of reactivity or proactivity in its processes. We review the available literature on Delta-specific governance, tracing the historical evolution of environmental governance in the Delta, and highlighting current efforts that illustrate different structural and procedural governance elements. Our synthesis finds robust evidence that characterizes the Delta's governance system as dominantly polycentric and multi-scaler, increasingly participatory, and with a high aptitude for learning and innovation. Nevertheless, the region also faces key challenges around fragmentation and institutional fit, legacy policies that hamper transformational or proactive climate actions, and long-standing conflict among resource users and governing agencies. We conclude that the

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combination of high polycentricity alongside high levels of conflict and power asymmetries among affected parties in the Delta contributes to what can feel like "governance gridlock" and an inability to change the status quo to navigate new climate regimes equitably and effectively. These findings have implications for identifying steps forward for governance research and practice, both regionally in the Delta and beyond.

## KEY WORDS

climate change, governance, equity, adaptive governance, transformational governance, polycentric, institutions, actors

## INTRODUCTION

Climate change affects the Sacramento–San Joaquin Delta ("the Delta") in a variety of ways. These include both slower-moving, and more long-term changes in the region's climate, as well as more acute extreme events—from heat waves and wildfires to extreme flooding—that are predicted to become even more frequent and severe in the future (IPCC 2023). Mitigating and managing these changes and their effects across multiple temporal and spatial scales are central goals of decisions and actions that we refer to broadly as the "climate governance" system in the Delta.

For the purposes of this review, the term **governance** refers to the actors, rules, and processes through which decisions are made and implemented; these are not limited to government-actor efforts alone, but include all regulatory, market-based and socio-behavioral processes that involve a diverse network of community-based, private-sector, civil-society, and government-agency actors (Lemos and Agrawal 2006). The study and practice of **climate governance** specifically, involves the creation, implementation, and evaluation of shared decisions (e.g., policies, rules, laws, and management actions) by individuals and organizations across various levels of governmental and non-governmental organizations that influence climate change mitigation and adaptation (Jordan et al. 2015). Whether and how climate governance is functioning in the Delta—especially in the face of both gradual and rapid climate-driven changes, rife with uncertainty—is a critical question for social scientists and decision-makers alike. In this vein, this review examines the state of the science on climate governance, both broadly and within the context of the Delta, to investigate the following research questions:

***What are the characteristics of effective climate governance?***

***To what extent are these characteristics well understood and operative in the Delta's climate governance system?***

To answer these questions, it is first necessary to define what is meant by *effective* climate governance, sometimes referred to as "good governance" for climate change. One general definition of effective governance is that which maintains or fosters desired social conditions and ecological functions and processes in the face of changing conditions (derivative of Bennett and Satterfield 2018). In addition to identifying characteristics of governance systems that enable desired outcomes, multiple factors can create barriers to effective climate governance, such as conflict, competing interests and values, and the lack of coordination across actors, jurisdictional boundaries, and scales. Understanding the presence and extent of these barriers can provide another approach to assessing climate governance efficacy. Of course, there are implicit value-laden and political elements of this definition—for instance, what are desirable outcomes? Desirable for whom, and how is that determined? Maintained and fostered how, or by what means? These types of contested questions demand that specific attention to equity and the distributional effects of climate governance efforts be integrated in any assessment of efficacy, especially because many existing social and environmental inequities may be amplified by climate change (Routledge et al. 2018; USEPA 2021).

In the "Background" section, we synthesize the broader academic literature on climate governance to identify key characteristics of—and barriers to—effective climate governance across different geographical, climatological, and political contexts. This provides a framework for how we assess both the state of available science on climate governance in the Delta, as well as the efficacy of the operating climate-governance system in the Delta. In "Evolution of Climate Governance in the Delta," we summarize the evolution and history of key climate-governance features in the Delta by drawing upon existing research on broader environmental and natural resource-governance systems in the region, because this is the primary domain from which climate-specific governance efforts have evolved. In "Illustrative Vignettes of Climate Governance in the Delta," we offer several examples of current climate efforts in the Delta that help illustrate a range of approaches to climate governance. Because peer-reviewed literature on specific climate-governance efforts in this specific region is slim, these examples primarily rely on gray literature and professional reports on climate-governance activities occurring regionally. In our "Discussion," we synthesize key lessons and gaps from the current state of climate-governance research in the Delta, and conclude by summarizing what social science and inter-disciplinary research and practice would further more effective climate governance in the Delta and beyond.

We acknowledge that the scope of our analysis is limited.

- First, we acknowledge that this review does not capture every law, decision, process, or actor that is likely to influence climate outcomes for the region; rather, we sought to succinctly summarize the issues and structures of the complex governance system most relevant to climate change.

- Second, we focus on climate governance related to adaptation and resilience-building, with local and regional climate-mitigation governance largely beyond the scope of this paper, given the focus of this 2025 edition of the State of Bay–Delta Science. Nonetheless, understanding climate-mitigation governance at sub-national scales constitutes a major research need.

- Third, we recognize that Tribal nations and inter-Tribal organizations are critical actors in climate governance in California and beyond, yet our review only briefly addresses Tribal climate governance, reflecting limitations in the availability of peer-reviewed or gray literature about contemporary Tribal climate governance in the Delta, as well as the fact that California Tribal governments have no current land holdings or formal jurisdiction within the legal Delta boundaries, limiting their climate management authorities within the region. Moreover, we acknowledge that the positionality and expertise of our authorship team, which does not include an indigenous scholar or Tribal government representative, limits our ability to include unpublished or orally-held traditional knowledge regarding climate governance.

- Fourth, given the Delta is embedded in broader state, national, Tribal, and international-level governance systems, and climate governance crosses these multiple levels of governance, it is impossible to entirely disentangle Delta climate governance from these interrelated systems, or to fully articulate the effects of climate actions taken in the Delta on other levels, such as statewide policies.

- Finally, we present only three illustrative examples of climate-governance efforts in the Delta, when tens or hundreds more examples likely exist, with many more future opportunities. These illustrative case studies are not intended to represent all aspects of climate governance in the region; rather, they provide snapshots of current climate-governance efforts around critical issues in the region to demonstrate variation in the governance structures and pro-vs.-reactivity of ongoing climate actions across the region.

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## BACKGROUND: WHAT MAKES FOR EFFECTIVE CLIMATE GOVERNANCE?

### The Challenges of Governing Climate Change

Globally speaking, the core functions of climate governance range from those aiming to mitigate greenhouse gas (GHG) emissions that cause climate change, to those working to adapt to the current or projected effects of climate change through better prediction, preparation, and response (IPCC 2022). More recently, climate-governance efforts have also begun to focus on building more resilient and equitable social, economic, and environmental structures that can better cope with, recover from, and prepare for future disturbances (IPCC 2022). To understand effective climate governance, one must understand the challenges the governance system must address, which include issue interdependency, variable time horizons, and historic and persistent iniquities. While these same challenges plague the governance of many other environmental and "wicked problems," the magnitude, scale, increasing pace, and cascading effects of climate change amplify these challenges and the necessity of finding timely and effective ways to address them. Morrison et al. (2022) summarize this well: "Standard solutions to the threat of >1.5 °C global average warming are not ambitious enough to prevent large-scale irreversible loss. Meaningful climate actions require interventions…that are radical rather than conventional."

First, climate change crosses traditional governance sectors and scales, affecting everything from natural-resource management to healthcare to the global economy. Thus, governing climate change requires a well-coordinated and whole-of-society approach, which conflicts with traditional, siloed management. For instance, water-resources governance is typically not intertwined with healthcare governance, though climate effects on water quality may pose direct health hazards. Significant structural and process-related governance challenges arise—including coordination costs, value conflicts, and power dynamics—when trying to govern climate change across multiple sectors, scales, and levels (Morrison 2017).

Additionally, while many anticipated climate effects can be conceptualized as "slow-moving" hazards (e.g., changes in average temperatures and precipitation, gradual sea level rise), these changes exacerbate more acute hazards that punctuate the climate-governance space via extreme events (e.g., wildfires, extreme flooding) that demand immediate response. The magnitude and timing of these extreme events remain hard to predict, and the full extent of their effect may not be felt for years, making it politically and financially challenging to address them proactively in the present (Newell et al. 2021). Thus, climate-governance systems must learn to operate under high uncertainty, remaining both nimble enough to activate responses to short-term, immediate climate effects, while also sustaining effort and resources to advance long-term, proactive initiatives to reduce vulnerability and increase adaptive capacity (Craig et al. 2017). Current governance structures often separate these emergency response and long-term strategic planning functions to operate independently, rather than recognizing the interplay between both functions—and that increased investment in one of these functions often means decreases in the other (Lindbom and Tehler 2019). Moreover, both present-day and intergenerational effects must be considered, which are largely misaligned with incentives driven by short-term election cycles and economic discounting (MacKenzie 2016).

Finally, many effects of climate change are experienced disproportionately, whether across countries, regions, or communities. Power and resources to respond and adapt to climate effects are similarly unevenly spread, leading to inequitable patterns of exposure, vulnerability, and damages. This is further complicated by the fact that "one-size-fits-all" climate-governance approaches are unlikely to effectively address place-specific climate changes—and may even exacerbate inequities or create other adverse effects. Thus, climate justice—or mitigating such inequities—has become a prominent goal within climate-governance social movements and scholarship in recent years (Tormos–Aponte and Garcia Lopez 2018; Newell et al. 2021). This scholarship and activism demands

redistribution of resources, and critiques how the typical structures and processes of mainstream environmental governance often lack representation of— and resource allocation toward—those who are most vulnerable to climate change effects (Morrison et al. 2022).

## Foundational Governance Concepts to Understand "Effective" Climate Governance

In the face of these challenges, climate-governance systems exhibit various functions, structures, processes, and dynamics, each of which influences their ability to address the effects of climate change. Determining what makes for effective or good climate governance is challenging because the degree to which a particular governance effort has reduced the effects of climate change on any given scale or location is difficult to isolate and estimate. In part, this is because climate change is characterized by linkages and feedback effects that generate uncertainty and non-linear dynamics. These linkages cross spatial and temporal boundaries, cause complex social-ecological interactions, and generate problems of distribution and fit (Epstein et al. 2015; Morrison et al. 2017). As a result, it is difficult to isolate the influence of any given governance intervention on all other factors that contribute to the outcomes of interest—challenging our ability to understand "what really works."

Despite these challenges, the literature on governance broadly—and on environmental and climate governance specifically—points to various criteria for "good governance." These include legitimacy, participation, responsiveness, accountability, transparency, and fairness (Graham et al. 2003). In addition to these foundational principles, scholars have sought to understand the features of governance systems—notably the structural and process features—that contribute to greater efficacy in reaching desired outcomes, such as the reduction of vulnerability, boosting adaptive capacity, or rectifying inequities. While acknowledging that different circumstances will require different structures and processes (i.e., no one size fits all), we synthesize relevant literature on the effect of these two features on climate governance efficacy. Given this review's focus on climate governance for adaptation and resilience in the Delta, this section does not define every governance concept referenced herein; for readers interested in a broader primer on environmental governance, we recommend Lemos and Agrawal (2006).

### *Structure*

The environmental and climate-governance literatures suggest that certain structures or "modes of governance" may better "fit" specific problems (Lange et al. 2013; Ingold et al. 2019). Broadly, the structure of governance arrangements can span from relatively centralized, top-down approaches to relatively more **polycentric**, or shared governance arrangements (Morrison et al. 2023) (see Figure 1). Because climate change affects multiple actors that interact at multiple spatial and temporal scales, climate-governance systems are generally understood to be polycentric in structure, meaning that governance often occurs through multiple centers of decision-making authority that may coordinate or conflict with one another (Jordan et al. 2015; Carlisle and Gruby 2019). This conceptualization of climate governance as polycentric represents a shift over the past 3 decades, from a focus on centralized international agreements among different nation-states—such as the Kyoto Protocol and the Paris Agreement (Held and Roger 2018)—toward including a much broader network of actors working across many sectors and scales to advance adaptation and build resilience (Andonova et al. 2009).

In this vein, it is clear that climate-governance efforts occur beyond the jurisdiction of formal governments, increasingly involving non-state actors such as non-governmental organizations, private-sector firms, academic and research institutions, and other civil society actors at multiple levels (Jänicke 2017). Especially since the mid-2000s, climate governance is increasingly recognized as a collaborative governance system, meaning it encourages many governmental and non-governmental actors to work collectively and through consensus-oriented decision-making (Ansell and Gash 2008).

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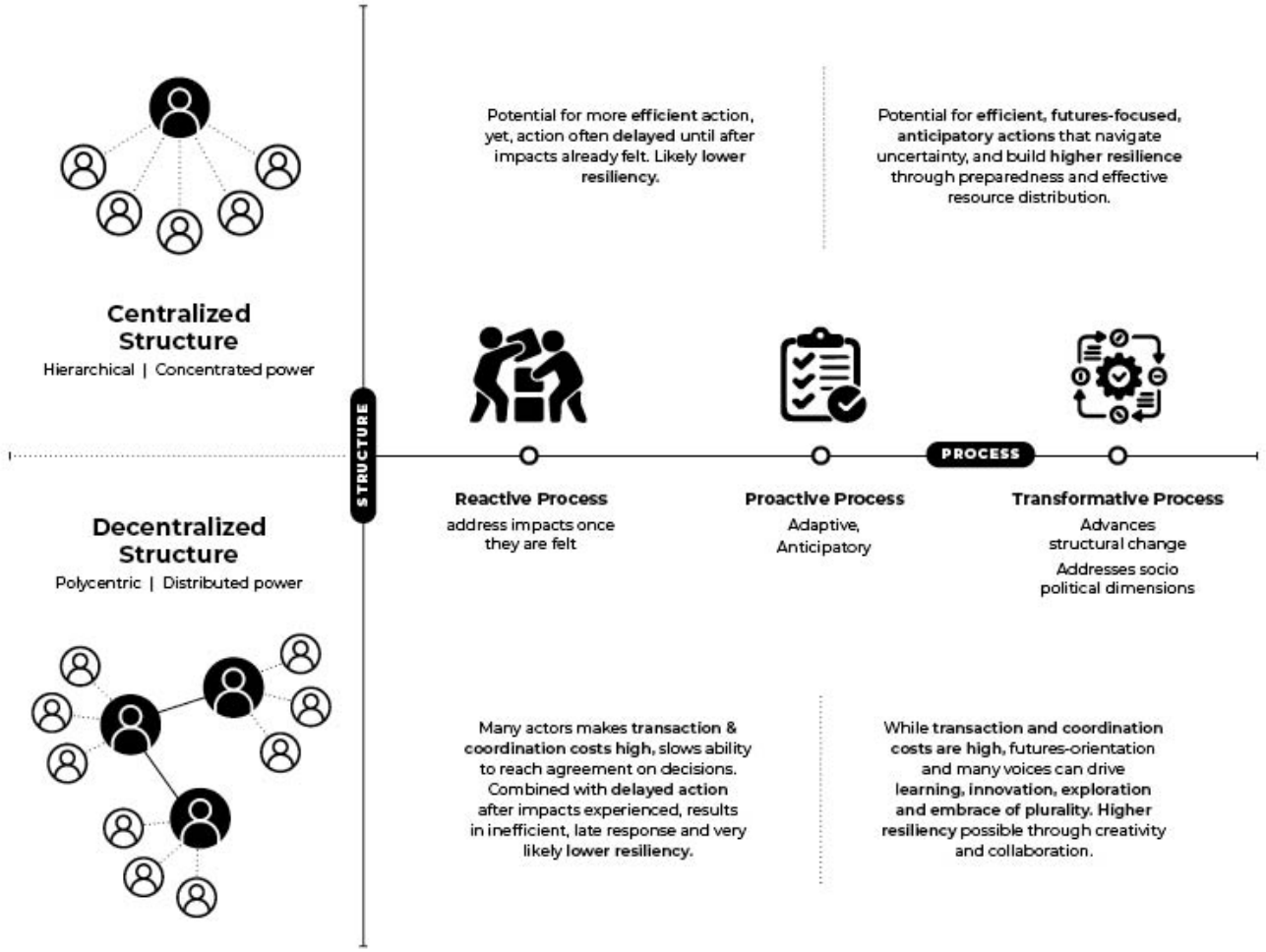


**Figure 1** Conceptual Figure showing synergies and trade-offs across structural (*vertical axis*) and process (*horizontal axis*) characteristics of climate governance

Polycentric and collaborative governance systems are praised for being better tailored to fit local contexts and a diversity of needs, while leveraging the economies of scale provided by more centralized governments, and for being more capable of minimizing power disparities or corruption by devolving power to multiple actors across levels (Carlisle and Gruby 2019), at least when intentionally designed (Koebele et al. 2024). At the same time, polycentric systems can be highly fragmented, increasing the transaction costs of coordination, which can be detrimental in certain circumstances that require quick response; for example, centralized decision-making has traditionally been thought to be more capable of responding quickly and efficiently to extreme events than systems in which power is widely dispersed (Nowell et al. 2018). Thus, for polycentric climate-governance structures to be effective, strong mechanisms for coordination among various centers of power—such as forums that support collaboration, networking, conflict resolution, and trust-building among diverse participants and organizations—are essential (Andersson and Ostrom 2008; Carlisle and Gruby 2019; Hamilton and Lubell 2019; Nguyen Long and Krause 2020). Additionally, skilled facilitation and diverse opportunities for participation are important to ensure the efficacy of collaborative governance structures, where multiple actors are encouraged to be involved (McNaught 2024). Collaborative governance systems can benefit

greatly from information exchange, learning, and innovation that is driven by the inclusion of multiple perspectives and approaches from different actors, but reluctance to share power or inability to bridge differing values and worldviews can also result in long-running conflict and gridlock among actors unable to compromise (Emerson et al. 2012; McNaught 2024).

### *Process*

Like structure, governance processes may also be characterized along a spectrum, ranging from **reactive** to **proactive**, and potentially transformative (also illustrated in Figure 1). Because climate change is rife with uncertainty and complexity, it can be difficult to predict and mitigate negative effects before they occur; hence, climate governance is often reactive (Morrison et al. 2022). However, purely reactive governance approaches not only increase risk, but are often more expensive, more protracted, and less resilient (Strother 2018; Koebele et al. 2020). Reactive approaches may also fail to protect vulnerable communities that lack local capacity or resources to mobilize responses.

Effective climate governance is likely more proactive in evaluating and preparing for climate change and different types of uncertainty before being faced with disaster response. Among these proactive processes, **anticipatory governance** approaches are future-focused and seek to reduce potential risks or explicitly navigate uncertainty related to a developing problem (Boyd et al. 2015; DeLeo 2015), whether through planning, building capacity, mobilizing, or even interrogating potential futures (Muiderman et al. 2020). Similarly, **adaptive governance** approaches help to deal with the inherent uncertainties of climate change by creating institutions and processes that build in flexibility to respond to changes that cannot be fully anticipated (Chaffin et al. 2014; Walker et al. 2023). Adaptive governance can also help promote learning, which can support future proactive governance efforts (Armitage et al. 2008; Pahl–Wostl 2009). Adaptive governance, however, is easier said than done: changing issues and interest groups—alongside fluctuating institutional choices and conflictual, competitive, and power-laden interrelations—can restrict governance capacity to adapt (Morrison et al. 2023).

More recently, scholars have argued for **transformative** approaches to governance (Tàbara 2018; Leichenko and O'Brien 2019; Morrison et al. 2022) that are not only proactive and adaptive, but also integrative, inclusive, and pluralist (Visseren–Hamakers et al. 2021). Such processes are intended to govern climate in ways that effectively reduce effects equitably, to promote just transitions (Blythe et al. 2018). They also seek to move beyond exclusive consideration of engineering-focused, technocratic solutions, and instead explicitly embrace the socio-political dimensions of problems, which are often inadequately addressed in highly complex systems, such as Delta regions (Triyanti et al. 2020). These approaches emphasize overcoming barriers through actions such as encouraging trust-building (Marion Suiseeya et al. 2021), recognizing and embracing multiple world-views with skilled facilitation (Pender 2023; McNaught 2024), and facilitating social learning (Morrison 2017; Pahl–Wostl 2017), similar to the goals of collaborative governance structures.

The different structures and processes of climate governance interact to produce different (in) efficiencies, (in)equities, and overall (in)efficacy, as well as different trade-offs, as conceptualized in Figure 1. There is no panacea to governance in such complex settings, and different contexts will need to emphasize different characteristics to address their unique vulnerabilities and socio-ecological contexts (Ostrom 2007).

## EVOLUTION OF CLIMATE GOVERNANCE IN THE DELTA

Environmental governance in the Delta is characterized by its notoriously large set of actors (i.e., an estimated 300 organizations), including a plethora of powerful federal and state agencies, high conflict among competing resource uses and values, and a history of institutional evolution (Lubell 2013; Lubell et al. 2014). To begin to understand whether the characteristics of "good" climate-governance structures and processes discussed above are present in this context, we

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review a diverse body of peer-reviewed and gray literature on the history of Delta governance to identify prior efforts aimed at adapting or responding to environmental change over time. In so doing, the following sections provide important historical, geographical, and climatic context for the Delta region that help to show how the governance system has grown and evolved into what operates today.

### Land Governance: From Indigenous Stewardship to Reclamation Era

The Delta region's highly variable climate historically produced periodic inter- and intra-annual drought, punctuated by extreme wet events and flooding. Before European colonial settlement, Native American peoples in (and outside) the Delta region developed governance systems that were effectively adapted to these extremes, creating resilience for communities and ecosystems both within and beyond the Delta. For nearly 5,000 years before Euro-American colonization, Native American populations lived in and actively managed the Delta's vast wetlands and massive rivers for fishing, food production, and cultural activities (Whipple et al. 2012). The Bay–Delta estuary is the ancestral home of an estimated 10,000 people, from a wide diversity of different villages and Tribes, including the Bay Miwok, Coast Miwok, Plains Miwok, Maidu, Nisenan, Nomlaki, Ohlone, Patwin, Pomo, Wappo, Wintun, and Yokuts. These Tribes lived within and around the boundaries that today define the legal Delta and Suisun Marsh. However, Tribes generally understand the Delta to include its entire watershed, extending from the headwaters north of Mount Shasta, to the most southern drainage in Tulare Lake Basin (DSC 2024a). Many more Tribes and thousands more Native Americans historically inhabited and continue to live in this much larger geography that encompasses most of the present-day state of California. Both the Tribes living in close proximity to the present-day legal Delta, and those across the larger watershed, stewarded the natural resources of the Delta region for cultural, spiritual, ceremonial, and subsistence uses (Stuart 2016; Zedler and Stevens 2018).

Following the violent Spanish colonization and settlement of the Delta starting in the late 18th century, disease, land dispossession, forced slavery, and assimilation largely decimated the Native American populations across the region. Much of the traditional ecological knowledge in the Delta—evolved across millennia and passed on through so many generations—was lost or disrupted (Zedler and Stevens 2018; Garone 2020). US settlement of the West and establishment of California's statehood were similarly ruthless. The US federal government and California state government repeatedly reneged on treaty agreements with Tribes about land reservations, federal recognition of Tribal status, and establishing relocation and social service programs (California Courts; Indian Affairs: Pacific Regional Office).

In 1850, when California became a state, the federal Swamp and Overflow Land Act permitted the new state to sell seized Delta "swamplands and marshes" to individuals in order to drain and reclaim lands for cultivation. This led to the formation of several Delta land-reclamation districts that organized individual land-owners to collectively build levees to control floods and manage water supplies (Wilson 2014). Over a nearly 80-year period known as the "Reclamation Era," the Delta's wetlands were drained, channels were dredged, and a network of levees was constructed to convert most of the Delta land area to agricultural land (Lund et al. 2007). These land-transforming projects were conducted by hand, by a labor force predominantly made up of the formerly displaced and enslaved Native Americans and indentured Chinese immigrants (Dillon 2021). Today, over a thousand miles of levees are managed through coordination among the state and the still-operating independent reclamation districts to protect against flooding and related hazards, but this resulting patchwork of islands and channelized waterways has led to substantial loss of marshland habitat, wetlands, and tidal and anadromous species (Wilson 2014).

By the early 1870s, most of the Delta lands had become privately owned by predominantly White, Euro-American settlers. Private land-owners,

local governments, special act districts, and reclamation districts continue to play important roles in the Delta's climate-governance system today (Lund et al. 2007). They manage levees, undertake agricultural production that can affect soil management and local water quality, restore wetlands, and plan land uses. These actions can both influence and be influenced by climate change.

Despite the brutal settlement and colonization history of the region, Bay–Delta Tribes persist and continue to use, revitalize, and adapt their traditional knowledge and ecological management practices. Today, there are 109 federally recognized Tribes in California, 45 formally recognized Tribes (terminated during the 1950s "termination policies"), several Tribes currently petitioning for federal recognition, and many Tribal communities that have never been recognized by the federal government (USEPA 2024). The historical villages and Tribes that lived in and around the Delta estuary before Western conquest are represented today by multiple federally and non-federally recognized Tribes that frequently engage and consult with state and local agencies in Delta decision-making processes. While there are no Tribal-owned Lands or Reservations within the legal Delta boundary today, the Delta is a place of numerous cultural resources (DSC 2024a). Many Native Californians live on rancherias outside of the Delta in the eastern foothills and in the urban areas throughout the watershed (USEPA 2024).

Tribes are important actors in the contemporary climate-governance landscape through multiple regulations, policies, and collaborative arrangements, even though the structure and processes of current climate governance in the Delta that this review focuses on have largely evolved within the institutions, rules, and management actions introduced after colonial settlement. Federally recognized Tribes across California exercise authority over their own lands as sovereign nations, which include lands in the Bay–Delta watershed headwaters. Tribes also influence broader Bay–Delta governance through government-to-government consultations between Tribes and the state of California regarding policies that may affect tribal communities (EO N-15-19, EO B-10-11). Additionally, the Delta Stewardship Council (DSC), a California state agency central to policy and management in the Delta, is soon to include regulatory requirements for Tribal engagement as well as Tribal cultural-resources training for public entities embarking on land-use projects in the legal Delta (Delta Plan Chapter 4 Amendment, currently under rule-making). Additionally, the DSC is building partnerships and collaborations with Tribes as part of its efforts to understand and address environmental injustices in the Delta, and to explore how to interweave Tribal traditional knowledge with adaptive management. The DSC also leads a new Bay–Delta Tribal Engagement Working Group that coordinates with other departments of the California Natural Resources Agency to develop improved engagement and partnerships with Tribes around throughout the Bay–Delta watershed (DSC 2023).

The available literature and gray literature that retells this settlement history and land and ecological transformation of the Delta only sparsely addresses governance features or the implications of this history has had on the governance system today—a key gap in knowledge. These sources do, however, generally promote forward-looking adaptive-management pathways that focus heavily on identifying priority actions for ecosystem restoration, with increasing focus on identifying multi-benefit approaches that balance ecological restoration, flood protection, and economic and cultural opportunities (e.g., Lund et al. 2007; Whipple et al. 2012; Wiens et al. 2017). The few identified studies that focus analytically on land governance emphasize key challenges driven by fragmentation and lack of coordination across the local governments that have dominant authority over land-use planning and zoning. For example, McCreary et al. (1992) identify a lack of local ordinances (<20% of municipalities across 12 Bay–Delta counties) that restrict urban development and require land management that protects waterways and wetlands across the region. Similarly, fragmentation and needs for

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both coordination and flexibility are found to be key challenges to adapting to sea level rise, where an adaptation action in one municipality can have spill-over effects in a neighboring jurisdiction (Pinto et al. 2018; Vantaggiato et al. 2023). Improving efforts to monitor and understand how local governments are adapting their General Plans, local ordinances, and other planning and regulatory functions—as well as coordinating with one another—is a critical area for future research.

### Water Governance: Infrastructure and Competing Uses

Modern climate governance in the Delta is also shaped significantly by water management, which comprises an extremely complex set of actors, rules, policies, rights, and infrastructure designed for water transport, distribution, water quality control, and flood control. To start, one must understand the massive federal and state infrastructure projects built for water reclamation and flood control. The federal Central Valley Project (CVP), approved in the early 1930s and operated by the US Bureau of Reclamation (Reclamation), allows for water to be diverted from the Sacramento and San Joaquin rivers to farms and municipalities in the Central Valley. The later-built State Water Project (SWP), authorized in 1957 and operated by the California Department of Water Resources (CDWR), expanded the system of reservoirs, power plants, and pumping stations in northern California to move water through the Delta to the San Joaquin Valley and southern California and the San Joaquin Valley. Reclamation and the CDWR thus hold key responsibilities for planning how to manage the state's water supplies in the face of climate-driven events such as droughts and floods, alongside ensuring that adequate flows are available for ecosystems in the Delta. However, both federal and state actors have recently been criticized for not effectively accounting for climate change in long-term planning and modeling, including recognizing the likelihood of more frequent and severe extreme wet and extreme dry years (California State Auditor 2023). In addition to these agencies, local agencies created to manage water contracts with the SWP and CVP (e.g., the North Delta Water Agency, the Central Delta Water Agency, and the South Delta Water Agency), the Central Valley Flood Protection Board, and local levee-managing reclamation districts, are implicated in climate water governance, because they must adapt to changing water-supply conditions when serving their members and the Delta community.

Attempts to use major infrastructure to manage climate variability in the Delta are not limited to the CVP and SWP. Since their construction, proposals have been put forth through legislation and agency action to build a canal around the Delta (Peripheral Canal) and more recently a tunnel (Delta Conveyance Project), to divert flows from northern California more directly into the SWP, rather than through the Delta. These projects are proposed under the assumptions that they help mitigate climate-variability effects on the water supply system, and better capture high-flow events. However, extremely contentious political and scientific debates around their climate-resilience benefits—along with their potential social, ecological, economic, and cultural impacts—have long colored the proposed projects (Hart 2022).

For many decades, water-diversion infrastructure through the Delta has spurred governance actions aimed at more proactively protecting competing interests in and uses of the Delta— namely in-Delta water users and declining ecosystems. Starting in 1959, the state legislature passed the Delta Protection Act (Wilson 2103) as a response to concerns over the effects of diverting water out of the Delta through the CVP and SWP. Through this act, the "legal Delta" boundaries were also defined, including designating "primary" and "secondary" zones that determine permissible land uses: the primary zone being preserved for agriculture and ecological protection, while the secondary zone permits urban development (CDWR 1995). While this definition of the legal Delta zones has implications for how the Delta is governed today—including which government agencies are involved in authorizing public projects that may affect land use, water quality, and habitat—it also carried limited legal traction, given that it does not establish special rules or regulations for water use or environmental

impacts. As previously discussed, most land holdings in the Delta are private, and local governments retain their legal land-use planning authorities (Delta Protection Act).

The Delta Protection Act was amended in 1992 in response to concerns that water diversions and urban encroachment further threatened the valuable agricultural lands, unique ecosystem, and recreational opportunities the Delta offered. This amendment established the Delta Protection Commission (DPC), which was tasked with protecting the agricultural, ecological, cultural, and natural resources of the legal Delta, and providing a forum for local Delta residents to engage in decision-making on actions that affect the Delta. The DPC develops and updates a long-term "Land Use and Resource Management Plan," for the Delta primary zone through a collaborative planning process. The most recent plan was updated in 2010 [Cal. Code Regs. Tit. 14 § 2003 (2010)]. These statutory authorities provide potential opportunities to heighten protections against climate-change risks to valued Delta assets.

In addition to in-Delta land and water use, significant changes in water demand, storage, and diversion up and downstream of the Delta have affected water quality in the Delta—another key governance issue in the region that changing climate conditions and extreme events are likely to further exacerbate (Luoma et al. 2015; Laćan and Resh 2016). Starting in the 1960s, Reclamation and the CDWR established agreements with local water interests on water-quality standards—notably salinity standards that the CVP and SWP must meet at various locations in the Delta. In 1978, the California State Water Resources Control Board (SWRCB) adopted the first San Francisco Bay/Sacramento–San Joaquin Delta Estuary Water Quality Control Plan (Bay–Delta Plan), under its authority to administer the state Porter–Cologne Water Quality Control Act and federal Clean Water Act (Wat. Code, §§ 13000, 13001, 13240, 13244). The SWRCB is statutorily obligated to review the plan at least every 3 years to determine whether updates are required to meet water-quality standards. The Bay–Delta Plan establishes water-quality objectives for the beneficial uses of the estuary—including municipal, industrial, agricultural, and fish and wildlife—as well as programs for achieving those objectives, which include managing diversions upstream and exports downstream of the Delta (SWRCB 2018). A Coordinated Operations Agreement was signed in 1986, providing a framework for how Reclamation and the CDWR would operate the CVP and SWP in coordination to meet Delta standards. With the adoption of Water Rights Decision 1641 ("D-1641") in 1999 and amended in 2000, the Bay–Delta Plan established that meeting water-quality standards protective of beneficial uses will be the responsibility of water-rights holders, with primary responsibility on Reclamation and the CDWR as the two largest exporters from the Delta.

The Bay–Delta Plan has since been updated and amended in 1991, 1995, and 2006 to address continual ecological declines in the estuary. ( Most recently, the plan was partially updated in 2018 when the lower San Joaquin River and tributaries' flow plans and the southern Delta salinity standards were updated (SWRCB 2018). Since 2018, the SWRCB has been in the process of undertaking a complete update to the Plan (including updates to northern Delta standards and Sacramento River and tributary flows) through an alternative process known as the "Voluntary Agreements." Through Voluntary Agreements, state and federal agencies and representatives of water diverters upstream of the Delta—largely agricultural users—have been negotiating to reach non-regulatory agreements on floodplain land converted to habitat in exchange for reduced flow requirements (SWRCB 2024). The process has been highly controversial and contentious for its lack of transparency and closed-door processes that have prevented public participation or observation of the negotiations. Moreover, many Tribes, environmental, and environmental justice organizations who were initially invited to participate have since boycotted the process out of frustration at being marginalized and seeing the needs of the Tribes, ecosystem, and disadvantaged communities, go under-recognized and under-protected in the negotiations. A coalition of

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Tribes and environmental justice groups—with legal support from the Stanford Environmental Law Clinic—have since petitioned the SWRCB to reject the proposed Voluntary Agreements and conduct an open, public process to update the Bay–Delta plan (California 6th District Court of Appeal 2022). The same coalition of Tribes and environmental justice groups also filed a formal complaint with the USEPA in 2022, claiming that the SWRCB has failed to uphold its statutory duty to review and update the Bay–Delta Plan, resulting in discriminatory effects and a violation of civil rights; the USEPA Office of Environmental Justice and External Civil Rights Compliance is currently investigating the complaint (USEPA File No. 01RNO-23-R9; US EPA Title VI Complaint and Petition for Rulemaking).

Adding further complexity to the governance of water quality in the estuary are the biological opinions ("BiOps") issued by the US Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) in 2008 and 2009 to protect endangered marine species, including Chinook Salmon, Steelhead, Green Sturgeon, Killer Whales, and Delta Smelt (USFWS 2008; DSC 2024b). These BiOps establish both flow and water-quality requirements that are defined with the "X2" metric, which measures the distance in kilometers from the Golden Gate Bridge to the point where the salinity at the bottom of the river channels is 2 parts per thousand. X2 is used as an ecosystem and habitat indicator and incorporates the natural variability in the Delta's seasonal hydrology and tidal influence, with the required location of the X2 threshold moving throughout the year. Under different conditions, the BiOps can act to further limit water exports possible by the SWP and CVP and require the agencies to take "Reasonable and Prudent Alternative Actions" to reduce effects on the sensitive species. To meet the multiple water-quality requirements that seasonally and diurnally shift, management-level representatives from Reclamation, the CDWR, the USFWS, and the NMFS participate in the Water Operations Management Team to coordinate real-time management decisions that adapt to changing conditions.

Under future climate scenarios where longer periods of extreme wets and dries are anticipated (Hartman et al., this issue), management of water-quality concerns—including salinity, temperature, and turbidity—will continue to grow as a challenge, further affected by rising temperatures and increased evaporation, sea level rise, and shifts in precipitation patterns and watershed runoff from warmer winters. Recent multi-year droughts (2011 to 2015 and 2017 to 2023) provide evidence that current water-resource allocations and governance structures may be incapable of maintaining required water-quality standards in their current form. For example, in 2014, 2015, 2021, and 2022, the SWQCB implemented short-term Temporary Urgency Change Orders ("TUCPs") as "emergency" measures to relax water-quality requirements at compliance points in the Delta, allowing more freshwater to be held in upstream reservoirs for late-in-season releases (SWRCB 2023a). Additional emergency measures were used to preserve the ability of the SWP and CVP to export freshwater—including, for example, the emergency rock wall salinity barriers the CDWR installed in 2015, 2021 and 2022, in West False River in the western Delta—to physically prevent saltier flows from encroaching on the interior Delta near the CVP and SWP export pumps (CDWR 2024a, 2024b). These responses have been effective in preserving water in reservoirs for late-season deliveries, and to avoid reservoir deadpool states, but are not without impacts: monetary costs to taxpayers (on the order of $30M to $40M per rock wall installation); ecological effects, including on migratory fish species, aquatic weeds and algal blooms; and affected boating ways for navigation and tourism (CDWR 2024a, 2024b). Meeting water-quality standards is likely to become only more challenging under changing climate regimes, with the potential for increased social and ecological consequences. The system's vulnerability and the significance of potential effects merit, at a minimum, critical evaluation of the capacity to handle projected future climate conditions. More appropriate however, would be re-imagining the institutional, legal, and organizational structures necessary to manage water resources—which are already over-allocated and are likely to become

more variable under rapidly changing climate conditions—in a way that preserves maximum beneficial uses for diverse and ever-growing public needs (Lund 2016; Norgaard 2021). See Vignette 1 below for a deeper evaluation of at the capacity of the Delta governance system to effectively manage salinity in a changing climate.

### Cross-Sector Governance: CALFED and the Delta Reform Act

These complex trade-offs between water supply, ecosystem protection, and local use preservation, each supported by competing regulations, spurred a key development in the more recent evolution of Delta governance: the CALFED era (Dutterer and Margerum 2015). Beginning in the 1990s, the California–Federal Bay–Delta Program (CALFED) brought together federal and state agencies and stake-holders to address the interrelated issues of water-supply reliability, water quality, and ecosystem health (Booher and Innes 2010). CALFED created a collaborative governance structure in the Delta that was in place until the early 2000s, when key federal actors essentially stepped away from the process and key state actors saw that the process was not living up to its goals (Gerlak and Heikkila 2006). As Dutterer and Margerum suggest: "CALFED had difficulty sustaining its organizational networks when faced with conflicting goals and different motivations among stakeholders. There was an inherent contradiction in CALFED's mission of ensuring reliable water deliveries while simultaneously protecting San Joaquin Delta ecosystem health." (Dutterer and Margerum 2015, p. 30). Shilling et al. (2009) documented additional challenges CALFED faced in fully enfolding environmental justice and equity concerns into Delta science and decision-making. While the California Bay Delta Authority established an environmental justice sub-committee within its Public Advisory Committee that included membership from major environmental justice groups working across the Delta region and statewide, the sub-committee was tasked with single-handedly integrating environmental justice into all CALFED activities, with no formal authority to provide input to different programs and very little resources or staffing support to do this work (Shilling et al. 2009). While many critiqued CALFED for not being able to resolve these entrenched conflicts and the trade-offs inherent in its goals (Hanneman and Dyckman 2009; Kallis et al. 2009; Shilling et al. 2009; Sze et al. 2009), others suggested that CALFED set up processes for science to inform decision-making (Taylor and Short 2009), cross-agency collaboration, and learning that ultimately led to institutional change through new state structures and processes which persist today (Lubell et al. 2013).

With the dissolution of CALFED, contemporary state structures and processes were set in motion through the Delta Reform Act, passed in 2009. The act mandated the state to meet the "coequal goals" of providing reliable water supply and protecting the Delta ecosystem in a way that protects local values and uses of the Delta (CA Water Code §85054). New state agencies were also established, including the DSC—charged with creating a long-term plan (the "Delta Plan")—to guide how diverse state, local, and federal agencies manage the Delta's environmental resources. The Delta Conservancy was also created as a new state agency to promote environmental protection and economic well-being of Delta residents, in coordination with local communities.

Climate resilient goals have become more prominent in Delta planning in recent years. For instance, the updated Delta Plan chapter on ecosystems lays out strategies for managing ecosystem protection and restoration efforts in the face of changing climate conditions. In many ways, these new agencies—designed to consider interacting social, ecological, and economic effects in the estuary—address the separation and siloing that challenge many cross-sectoral policy issues in polycentric governance systems. Despite addressing structural challenges of coordination across these competing management goals, these agencies must still have the political will and regulatory authority to enforce trade-off decisions—challenges much more entrenched in the power dynamics of water users and economic drivers of the state, where political leadership has been unwilling to venture thus far (Hanneman

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and Dyckman 2009). Below we provide a few contemporary examples of climate-governance efforts that illustrate various structural and procedural approaches to navigating the system's complex dynamics.

## ILLUSTRATIVE VIGNETTES OF CLIMATE GOVERNANCE IN THE DELTA

In this section, we present three descriptive vignettes of initiatives in the Delta that exemplify how elements of structure and process influence the efficacy of climate governance. Specifically, our vignettes illustrate: (1) a centralized and reactive approach to water-quality management, (2) a polycentric and more proactive approach to adaptation planning, and (3) a hybrid structure that fuses hierarchical and polycentric decision-making for a potentially transformative approach to water allocations. Given that the goal of this paper is to review the state of science on climate governance, rather than conducting our own primary research, we do not intend to present these vignettes as fully developed case studies. However, we hope that such examples may inspire future social science research and offer a lens for evaluating the diverse types of climate governance in the Delta.

### Vignette 1: Centralized and Reactive Salinity Management

As described, one of the most challenging elements of maintaining water quality in the Delta is balancing salinity through (1) the management of Delta inflows and exports, (2) dampening tidal influences, and (3) reducing salts brought in through runoff. Climate change applies further pressure to this already complex and vulnerable balance. To date, salinity-management approaches have been centralized and technocratic, driven by federal and state regulatory standards that determine how reservoirs are operated, and how levels of Delta exports are permitted. Increasingly, these water-quality standards have not been able to be met in dry years, resulting in responses that are:

- reactive (e.g., late in the water year)
- financially costly
- disruptive to operations (e.g., installation of emergency rock wall barriers), and
- affect vulnerable communities and species (e.g., granting water-quality objective waivers)

The SWRCB has acknowledged that emergency waivers (i.e., TUCPs) are "not sustainable for fish and wildlife and that changes to the drought planning and response process are needed to ensure that fish and wildlife are not unreasonably impacted in the future and to ensure that various species do not go extinct" (SWRCB 2015); yet, the SWQCB has continued to administer these exemptions as needed, rather than developing more strategic or proactive approaches. Researchers and stake-holders have consistently critiqued the lack of transparency in California's water-supply models and models that determine through-Delta freshwater flows (Maven's Notebook 2019; Ayers et al. 2021). Moreover, the current inability to cleanly integrate different component models used to determine flow releases hamper the evaluation of more systematic interdependencies when it comes to balancing trade-offs between storing or releasing more water.

In 2022, both the Delta Plan Interagency Implementation Committee (made up of 19 agencies involved in Delta management) and a California Council on Science and Technology expert briefing to the State Legislature called for more deliberate, non-emergency drought planning to bring transparency to these interdependencies and plan for more strategic dry-year management (DPIIC 2022; CCST 2022). However, strong pushback from powerful water interests has stymied state-led science efforts to collaboratively develop new adaptive water-management water models (e.g., Delta Science Program salinity workshops). In 2023, a cross-disciplinary, cross-campus team of University of California researchers and partners began a new, participatory scenario-modeling research effort to explore alternative salinity-management approaches, offering the potential for more

anticipatory—and perhaps proactive—salinity-management strategies in the future. In the meantime, salinity management demonstrates the sizable challenge that the political power embedded in the current California water-management system poses to advancing more adaptive, data-driven, and equitable climate governance approaches.

### Vignette 2: Polycentric and Proactive Adaptation Planning

Next, we examine Delta Adapts—a climate-adaptation planning process that the DSC initiated in 2018—as an example of a more proactive effort that appears to embrace the polycentric nature of Delta governance. Through the Delta Adapts effort, the DSC convened a collaborative process for governmental agencies and non-governmental actors that work across scales and sectors to identify the most salient, on-the-ground effects from anticipated climate changes in the Delta and together develop a list of adaptation priorities. This resulted in the region's first comprehensive climate vulnerability assessment (DSC 2021), open-source modeling and interactive data visualization tools (e.g. Social Vulnerability Index; DSC 2020), and a strategy that outlines planning, regulatory and financing needs for adaptation actions across the estuary (to be released in 2024). The project identified priorities of diverse communities and user groups, and articulated the trade-offs associated with different adaptation actions (e.g., hardening gray infrastructure by building up Delta levees vs. incorporating set-back levees and wetland restoration). The same characteristics that confer Delta Adapts with transformative potential, however, also create significant challenges. For instance, differing vulnerabilities, technical and financial capacities, and priorities across diverse communities emerged as key barriers to setting shared regional priorities. Moreover, Delta polycentricity means that numerous government actors—each with different authorities and jurisdictions—must coordinate to implement nearly any individual climate action, introducing transaction costs and potential for conflict as barriers to implementation (Hamilton and Lubell 2017). Research in other contexts demonstrates the importance of a convening and facilitating body to lead the process and help overcome these transaction costs of coordination as, well as bridge the value and priority differences between actors (McNaught 2024), a role the DSC was designed to fill—and has begun to exercise in the case of Delta Adapts. In so doing, the DSC has learned that it must communicate carefully to avoid concerns that the state threatens local autonomy, because these perceptions have led to fear, anger, or outright boycotting of the collaboration process in other California adaptation contexts (Vantaggiato et al. 2023). Delta Stewardship Council staff have also developed appreciation for the significant time and genuine work required to build relationships and trust with partners, particularly those who haven't been engaged historically (Chow 2022). Participants and governance scholars alike are paying careful attention to how collaborative climate planning processes like Delta Adapts can negotiate—or fall subject to—long-standing power dynamics that have historically shaped resource distribution and heavily influenced the potential for equitable climate resilience.

### Vignette 3: Hybrid and Transformative Water Rights Reform

Echoing long-running activist calls for water-governance reform, numerous government entities and scientific advisory bodies to agencies have, of late, acknowledged the need to reevaluate the historic water rights system to better account for climate-change projections (LAO 2009; SWRQB 2021; Bardeen 2022; Lee et al. 2022; Hanak et al. 2023). These calls are largely responding to reactive—and inadequate—water-management approaches during recent drought years, discussed above. Proposals for reform range from administrative changes (e.g., updating and modernizing the data, accounting, and communications systems used to monitor the water supply and curtail water rights in dry years), to more transformative overhauls and redistributions of water-resource management (e.g., adjusting allocations to more accurately reflect the amount of water regularly present in the system and managing surface and groundwater as a single resource). Unsurprisingly,

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large and powerful water-rights holders have pushed back on reforms that threaten to change their access to resources. Despite this political pushback, recent legislative changes in 2022 and 2023 demonstrate incremental changes in California water law that may be early steps in implementing some of the important drought-time changes needed. In 2022, the state Assembly passed a new bill (AB 2108) requiring the SWQCB to ensure that intentional, meaningful outreach is conducted to environmental justice communities and that environmental justice effects are considered in all SWQCB decisions to update water-quality control plans and waste-discharge permits (added Sections 189.7 and 13149.2 to the Water Code). Additionally, the California State Senate expanded the SWQCB's authority to investigate and oversee *all* appropriative and riparian water-rights holders under SB 389 (2023), whereas previously authority was limited *only* to appropriative rights established after 1914 (amendments to Section 1051 of the Water Code). While these legislative changes do not yet start the conversation about water-resource redistribution, they demonstrate an increase in political willingness—and thus the *possibility* of eventual more holistic water-governance reform. Governance research has not kept up in assessing the opportunities and challenges these changes may incur but is critically important to understand the institutional structures that may be needed or best-suited to implement such changes, assessing the representation of stake-holders and distribution of benefits and effects that would result under different water-rights allocations structures.

## DISCUSSION: A SUMMARY OF KEY LESSONS AND RESEARCH GAPS ON DELTA CLIMATE GOVERNANCE

After reviewing how the Delta's complex governance system evolved into its current state, and a few contemporary examples of these governance features in action, several significant themes related to both structure and process emerge as key drivers of climate governance efficacy in the region. **Structure**: coordination in polycentric systems and understanding institutional fits and misfits are critical to adapting to rapidly changing climate conditions efficiently and at the right scale. **Process**: understanding how both politics and power dynamics, and science and monitoring, inform decision-making are critical to developing equitable approaches and confronting trade-offs. We interpret our findings about both features through the broader governance literature lens to posit where the Delta governance system is likely to succeed or face failure in addressing climate change.

### Lessons on Structure

Much of the broad governance literature suggests that decentralizing power, increasing representation of affected communities, and incorporating contextual considerations across different scales will improve climate-adaptation outcomes. The extant Delta governance literature agrees that the system is highly polycentric, with numerous actors that enhance the capacity for experimentation and innovation. Figure 2 provides a conceptual Figure that shows the multi-scaler and multi-sector nature of Delta climate governance. However, this structure also challenges the system, with high coordination costs and management of conflicting values that are often siloed into different parts of the governance network. Despite attempts to build collaborative capacity and dedicated coordination venues, the literature also agrees that Delta governance actors continue to struggle in navigating substantial fragmentation both geographically and across resource sectors and have not yet developed effective mechanisms or clearly defined authorities to deal with the conflicting values and missions across various agencies, organizations, and stake-holders (Lubell et al. 2014, 2020; McLaughlin et al. 2022). As Luoma and colleagues noted of the CALFED era: "more than 230 agencies, institutions, and stakeholders claim a role in water and environmental management but come with different core interests—and often conflicting visions of how the Delta should be managed. The resulting institutional fragmentation creates conflict and slows decisions" (Luoma et al. 2015, p. 5). Moreover, while the sources reviewed demonstrate that this polycentricity has led to increased participation by civil

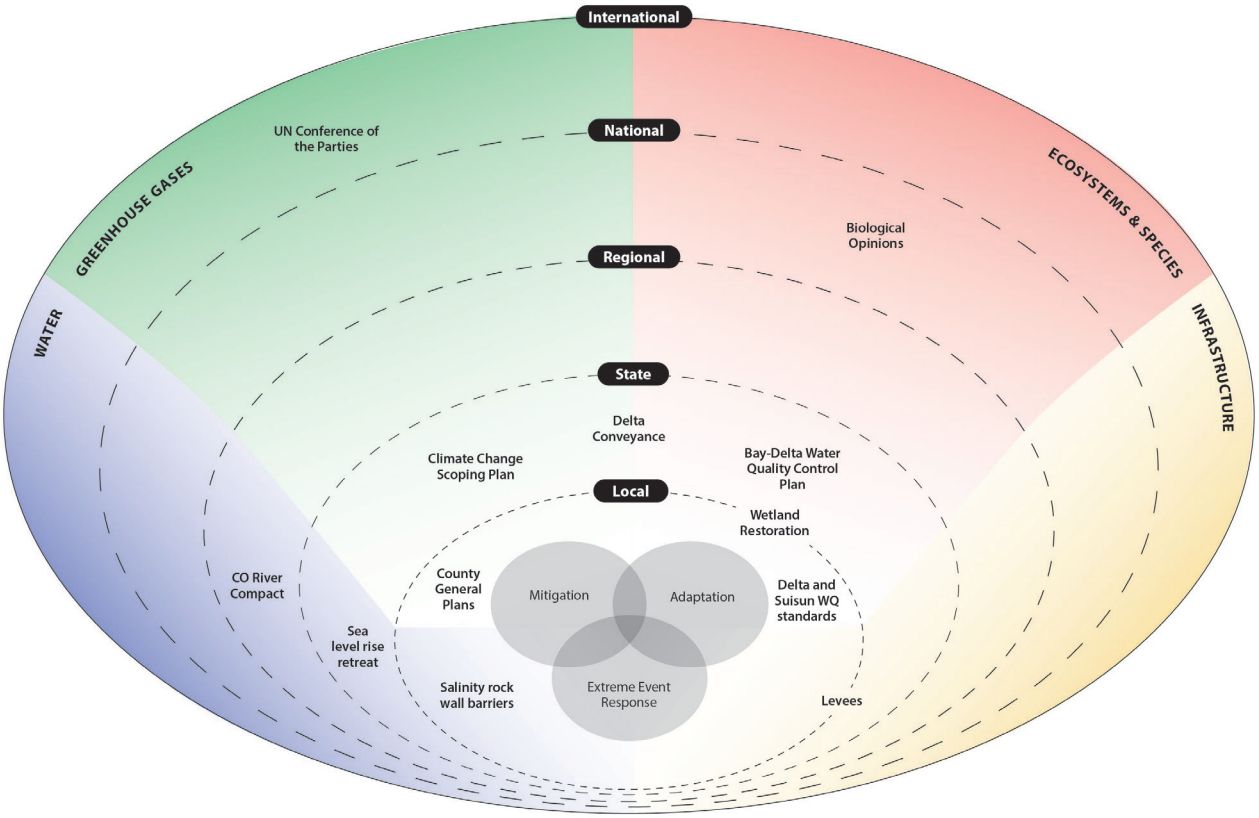


**Figure 2** An illustration of the multi-scaler (i.e., international to local), multi-sector (i.e., water, greenhouse gasses, ecosystems and species, infrastructure), multi-function (i.e., mitigation, adaptation, extreme-event response), and polycentric Delta climate-governance system. Examples of different climate policies, plans, and forums are included among the different scales and sectors.

society actors and a more diverse set of affected communities, similar to other settings (e.g., Foster 2002; Pahl–Wostl et al. 2007; Dobbin et al. 2023), this diversified participation has not yet translated into injustices being fully addressed (e.g., Liévanos et al. 2017; DSC 2024a). Evidence presented in "Vignette 2" on Delta Adapts demonstrates the on-going challenge to come to agreed-upon goals for climate resilience, particularly when resources are being (re) distributed or disproportionate risks and capacity are being addressed. Active research continues to investigate fragmentation dynamics in the post-CALFED governance system, as relevant to understanding the coordination of local climate-adaptation actions (e.g., Moser and Ekstrom 2012; Lubell et al. 2021; Vantaggiato et al. 2023) and the learning of policy actors participating across venues and issues (Rittelmeyer et al. 2023). These recent studies indicate the system's ongoing struggle to coordinate across the multitude of scales, actors, and issues involved—a challenge shared among many polycentric, distributed governance systems.

Another takeaway on the governance structure suggests the fit of current Delta institutions, actors, and processes may not be adequate to address climate drivers and effects that occur at different spatial scales across the watershed, which reinforces the necessity for context sensitivity and attention to governance at multiple scales. To effectively govern some climate challenges, Delta governance will need to encompass additional actors and institutions and conceptualize synergies and trade-offs across larger geographical footprints (Dettinger et al. 2016; Norgaard 2017). For example, changes in dam operations or land uses upstream of the Delta in northern California will influence

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water flows through the Delta. Restrictions on groundwater use in the San Joaquin Valley may increase demand on Delta exports. Likewise, continual prolonged drought across the western US and Colorado River basin stresses one of southern California's key water sources and may increase reliance on Delta exports (Owen 2022). Yet, the projected outcomes of these decision-making processes and the stake-holders affected by the interactions of these processes alongside the management of the Delta, have rarely been incorporated into Delta decision-making processes focused on the legal Delta boundary (e.g., Sze 2009). This may be beginning to change; for example, our Vignette 3 around water-rights reform efforts suggest that key actors in the governance system are beginning to reckon with the need for planning to incorporate different scales and time horizons. It is vitally important that leaders across the governance system be able to recognize these scale mismatches in decision-making and look out for processes that use boundaries (arbitrarily or even legally-based) that in effect ignore relevant concurrent processes, interests, and affected parties (Lubell et al. 2014; Norgaard 2017). Failure to address these scale mismatches can result in conflicting actions, inaccurate projections of resource demands, and exclusion of critical climate variables, communities, and partners that are essential to addressing climate effects.

### Lessons on Process

The broad climate-governance literature emphasizes the need for governance systems to apply futures-thinking to prepare for potential future risks, and to navigate uncertainty by creating flexible and adaptable processes that are responsive to changing conditions and new information. The Delta literature agrees that adaptive management and science-informed decision-making feature prominently in Delta governance (Nagarkar and Rauland–Rasmussen 2016; Wiens et al. 2017). Literature highlighted that several structural and policy mechanisms have been developed—both during the CALFED era and in the early 2000s—to support and even require these principles be applied to decision-making (e.g., Delta Science Plan, Delta Independent Science Board [DISB], Interagency Ecological Program, Collaborative Science and Adaptive Management Program). Several programs also demonstrate agencies' willingness to voluntarily integrate novel scientific approaches to inform and improve their own planning; for example, the US Geological Survey (USGS) leads multi-agency futures-forecasting and scenario planning exercises such as the "ARkStorm 2.0" to build coordinated capacity to prepare for major atmospheric river events (Huang and Swain 2022). Yet, the DISB (DISB 2016, 2022), among others (Milligan and Kraus–Polk 2017; Wiens et al. 2017; Norgaard et al. 2021), have raised questions about the adequacy of some parts of the science system—such as the effectiveness of the Delta's monitoring enterprise—to adequately track changing conditions over time, and feed those observations back into adaptive-management approaches. Moreover, many raise the point that it is challenging to require that all decision-making be grounded in robust science, recognizing the power of politics to influence final decisions and often a temporal mismatch between the goals of scientists and policy-makers (Gerlak and Heikkila 2006; Hanemann and Dyckman 2009; Taylor and Short 2009; Wiens et al. 2017).

In this vein, to motivate proactive and transformative action, the broad governance literature argues that decision-making processes must go beyond technical perspectives alone to understand how politics and power influence decision-making. Delta governance literature strongly concurs that high political conflict and powerful interests with high stakes in the Delta have frequently diminished the efficacy of collaborative and science-informed efforts, including CALFED, and have reduced protections for the ecosystem and the most vulnerable (i.e., environmental justice) communities (Bobker 2009; Hanemann and Dyckman 2009; Luoma et al. 2015; Shilling et al. 2009; Sze et al. 2009; Lurie 2011; Dutterer and Margerum 2015; Liévanos 2017; Liévanos 2020). Some have argued that politics are the largest defining factor in the state's history of Delta management; for example: "The political leadership of California has viewed the Delta as a quagmire to be avoided. Governors have

intervened to block actions and to maintain the status quo in the Delta when this was preferred by powerful water users. But, so far, they have not expended political capital to bring about a solution in the Delta, nor have they been willing to take responsibility for the continuing decline in the ecosystem in the face of inaction." (Hanemann and Dyckman 2009, p. 722). Many references explain that the power dynamics underpinning Delta decisions stem from the tumultuous and violent history of western colonization, settlement, and state development, which laid the groundwork for the concentration of resource access and wealth accumulation into the hands of few. As such, opportunities for transformative climate governance will require addressing these structural inequities.

### Gaps in Delta Climate-Governance Research

There are several notable gaps in important governance research topics in the Delta. First, research explicitly assessing the evolution of politics and power dynamics in the governance system and its effects on climate adaptation outcomes are very limited, a pattern that holds much beyond the Delta, given the contentious and political nature of the research itself (O'Connell and Peters 2021). Second, we found very limited evidence of ongoing research trying to systematically or rigorously evaluate the efficacy of climate-governance efforts in the Delta, whether through assessments of individual efforts or of the whole system. To do so, analysts need better measures of desired outcomes, including the capacity for greater coordination and conflict management. Third, as equity issues begin to receive a deserved increase in attention from climate-governance research and practice, developing better quantitative and qualitative indicators of equity in governance processes and outcomes will help to assess if equity goals are to be realized.

Our analysis also suggests that future work must assess Delta climate governance in a more complex and integrative way than past studies have, which have often focused solely on the management of single issues or framed management questions as ideological trade-offs (e.g., water exports vs. endangered species preservation). Articulating the multitude of complex connections—in both research and practice—between land-use, agriculture, water use, ecosystem health, public health, air quality, transportation, and education, among other issues, will be necessary to engage with truly transformative solutions. At the same time, building and institutionalizing broader connections across governance sub-systems requires a thorough understanding of what governance processes and structures are possible in and outside of the Delta, which—as we believe this review demonstrates—is a task not to be underestimated in its own complexity. In this vein, researchers and decision-makers may benefit from an inventory of the diversity of climate-governance efforts across scales and sectors that influence the Delta, which could help to (1) illuminate synergistic and conflicting policy approaches, (2) identify key geographic or sectoral gaps, (3) track the existing structures and processes that enable coordination, as well as (4) assess what motivates diverse actors (Tribal, local, community members) to be a part of these processes. It is through such coordination and connectivity that learning and adaptation can occur, which is necessary for responding to the uncertainties of climate change.

## CONCLUSIONS AND FUTURE OUTLOOK

To date, Delta climate-governance processes generally can be summarized as reactive and having yielded, at most, incremental change. While there are promising early efforts to move toward more anticipatory and adaptive governance approaches, we find limited evidence of whole-system shifts toward the kind of transformative change needed. We conclude that the current evidence on Delta governance, when taken together, points to the combination of the Delta's polycentric structure, alongside its high levels of conflict and power asymmetries among governing bodies and affected parties, as most likely to explain the Delta's apparent gridlock and inability to change the status quo to equitably and effectively navigate new climate regimes.

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So where does climate governance in the Delta go from here? At a minimum, there is a need for more alignment of climate-adaptation goals. The lack of a shared overarching framework that defines regional climate-governance objectives, which the vast governance network can jointly advance, may limit progress.

Programs such as Delta Adapts, which did conduct a participatory process to gather the diversity of regional climate-adaptation goals, offer a potential starting point. However, the literature suggests that moving from visions into actions requires strong leadership—whether from an individual (i.e., governor, legislator, agency lead), an organization (i.e., governmental or non-governmental), or a coalition—that can (1) synthesize across the diverse issues climate governance encompasses, (2) coordinate transparent and fair processes that make best efforts to mediate conflict, while also being willing to (3) make politically-challenging, but scientifically-grounded decisions that incur trade-offs. Ultimately, the predicted climate effects of the latter half of this century *are* going to result in trade-offs between human health, ecological health, and productivity dependent on natural resource use; whether those trade-offs are strategically determined and managed by the governance system—or unfold as results from defaulting to the status quo—remains to be seen.

The governance literature—in the Delta and more broadly—does not provide easy answers for how to achieve these goals in complex systems. We recognize that the lack of decisive recommendations for a direction forward in the Delta may leave our readers unsatisfied. However, what our synthesis reveals is that rigorous and scientific understandings of the governance system in the Delta remain underdeveloped. With additional research that studies specific and current Delta governance structures and processes—evaluations that compare and learn from similar contexts that may deal with similar governance challenges, and experiment on small scales with different governance structures or processes—the system may be able to learn about new paths forward. The Delta has as key assets its robust scientific community and statutory guidance to ground decision-making in the best available science. Leveraging these assets will help navigate uncertainty to move forward with more informed, transparent, equitable, and effective governance approaches.

For climate governance beyond the Delta, our synthesis underscores the importance of advancing research to understand how governance structures and contextual conditions—most notably politics, power, history, and social contexts—intersect and interact to understand what governance arrangements are likeliest to effectively and equitably address challenges in different settings. Despite Ostrom's (2007) caution against assuming any panacea exists to sustainably manage social-ecological systems, decades of research and practice on environmental governance has generally advocated for more collaborative approaches, a plurality of institutions, and decentralization of power. Yet, only recently has governance research begun to more critically assess if and how collaborative and distributed governance structures advance equitable and effective outcomes, especially in contexts of rapid social and environmental change. In addition to critically assessing the social and environmental outcomes achieved under collaborative-governance arrangements, governance research must broadly improve our understanding of the contextual circumstances under which different governance structures (from centralized to polycentric) and governance processes (from adaptive to transformative) produce effective climate governance.

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