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Ten Essential Bay–Delta Articles

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For newcomers and veteran scientists alike, Bay–Delta science is daunting. The number of research and management issues is exceptional, and the scientific literature is well developed but fragmented. There is a substantial history of periodic reviews of Bay–Delta science and policy issues. Between 1979 and 1986 the first widely circulated reviews were published, focused on Bay processes (Conomos 1979) and issues (Kockelman et al 1982; Nichols et al 1986). Similar publications in the mid- to late-1990s built substantially on this body of knowledge (e.g., Hollibaugh 1996; van Geen and Luoma 1999). The CALFED Bay–Delta program shifted much of the focus to the Delta, resulting in sponsored white papers on major issues in the mid-2000s (e.g., Brown 2003; Kimmerer 2004; Bennett 2005; Williams 2006). The first "State of Bay–Delta Science" was published in 2008 (Healey et al. 2008). The most recent update of the State of Bay–Delta Science (Healey et al. 2016a, 2016b, and accompanying articles) considered species of concern (Delta Smelt, Chinook Salmon), processes (fish predation, nutrient dynamics, food webs, flow and transport), stressors (contaminant effects, climate change), tools (multi-dimensional models), and human uses and effects on the Delta (Delta landscapes, climate change, agricultural and urban water supply, and the levee system). Other comprehensive overviews are also available; for example, IEP (2015), Johnson et al. (2017), and Sherman et al. (2017). Together, these reviews and the studies they cite give a sense of the historical development of scientific understanding in the Bay–Delta, and provide conceptual models for species' or system ecology. Many of the papers are themselves scientific milestones, and provided a science foundation for current Bay–Delta current management actions (e.g., Delta Smelt Resiliency Strategy, CNRA 2016; and Sacramento Valley Salmon Resiliency Strategy, CNRA 2017).

KEY WORDS

Sacramento–San Joaquin Delta, San Francisco Bay, Bay–Delta, San Francisco Estuary, scientific literature, scholarly publications

The complexity of the processes that must be considered in resource management in the Bay–Delta is implicit in the range of subjects that are considered in the sets of review papers published to date. Nevertheless, some critical ingredients in advancing the scientific foundation of current resource management are under-recognized. One of these critical ingredients is original scientific studies or analyses that generated a paradigm shift in our understanding of the system. In some cases, these articles are pivotal because they are the foundation for current regulations on resource management. However, there is no central place to identify or find pivotal papers that link science and management because this connection is rarely the subject of review papers. To address this need, we developed a list of ten of the most important scientific papers of the past several decades, along with a brief discussion of why each was so important. We are suggesting articles that most directly affected current management approaches, or will affect management decisions into the future. For each paper in our list, we also include a list of related articles that should be read for a deeper understanding of some of the underlying science.

A central purpose of identifying these studies is to recognize and value the role of science in today's policies. Another goal is to illustrate the importance of scientific collaboration: none of these articles are authored by single individuals. Instead, their contributions rested on the intellectual teamwork of multiple scientists that spanned multiple scientific disciplines. This prevalence of collaboration, multi-disciplinary teams, and long-term data in pivotal papers is perhaps unique to the Bay–Delta. Our goal was to provide guidance on essential reading for early-career scientists, and for more experienced researchers who wish to gain a broader understanding of the regional science enterprise and major research and management topics. Our approach was to include articles that met at least two of the following criteria:

1. The study had a major influence on Bay–Delta management;
2. The research represented a major step forward in our understanding of the ecology of the Bay–Delta;
3. The publication is one of the most-cited in Bay–Delta literature;
4. The study provides the reader with good insight into the regional science enterprise, including historical progress, tools, data sets, and teams.

We acknowledge that these sorts of lists are subjective, and that each of us are co-authors on some of the papers on the list. However, we consulted with knowledgeable Bay–Delta colleagues, and used some objective criteria (e.g., citation rate, above). A major caveat is that our list focuses mostly on higher trophic levels, with fewer examples of water quality research (though many of the highlighted papers use long-term monitoring data on water quality in their analyses). Our list emphasizes research on Bay–Delta species and habitats, without significant emphasis on its tributaries. In addition, many of the topics covered in these papers are rapidly evolving areas of research, with substantial progress since the original publication. With these caveats in mind, our list is as follows, in no particular order of importance.

Isohaline Position as a Habitat Indicator for Estuarine Populations — Jassby et al. (1995)

https://doi.org/10.2307/1942069

This publication is perhaps single most influential article in Bay–Delta science. It introduced the idea of using X2 (2 ppt isohaline position) as a potential metric for flow management—a concept that was subsequently adopted as a regulatory standard under D-1641 (CSWRCB 2000). Today, this standard is the single major regulatory driver of Delta hydrology for much of the year. Jassby et al. (1995) also demonstrated the use of modern statistical techniques to tackle management questions.

Additional key related papers: Kimmerer (2002a, 2002b).

An Analysis of Pelagic Species Decline in the Upper San Francisco Estuary Using Multivariate Autoregressive Modeling (MAR) — Mac Nally et al. (2010)

https://doi.org/10.1890/09-1724.1

The Pelagic Organism Decline (POD) is arguably the most extreme ecological shift in the estuary since long-term monitoring was initiated. The Mac Nally et al. (2010) paper provides an introduction to the POD as well as a key example of how synthesis by an inter-disciplinary team of scientists can advance our understanding of ecological patterns. In addition, the paper helps illustrate the role of multiple interacting factors in the ecosystem.

Additional key related papers: Sommer et al. (2007); Thomson et al. (2011).

Multi-Decadal Trends for Three Declining Fish Species: Habitat Patterns And Mechanisms in the San Francisco Estuary, California, USA — Feyrer et al. (2007) *https://doi.org/10.1139/f07-048*

Feyrer et al. (2007) was a key study included in a suite of investigations that studied POD. As such, it is also a good example of how long-term monitoring data can be applied to questions beyond basic status and trends. This paper was notable in that it was one of the of first to identify long-term changes in the physical habitat of several pelagic fishes. For example, the study identified a long-term decline in Bay–Delta turbidity as a major contributor to habitat degradation for Delta Smelt.

Like Jassby et al. (2005), this paper significantly affected on Bay–Delta management, but the result has been much more contentious. The Feyrer et al. (2007) was the foundation of the fall X2 action in the 2008 Delta Smelt Biological Opinion (USFWS 2008), which in turn led to bitter and high-profile litigation. To this day, fall X2 remains one of the most controversial issues in Bay–Delta water management.

Additional key related papers: Nobriga et al. (2008); Feyrer et al. (2010); Schoellhamer (2011).

Ecosystem Variability Along the Estuarine Salinity Gradient: Examples From Long-Term Study of San Francisco Bay — Cloern et al. (2018)

https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.1002/lno.10537

The Bay–Delta is one of the best-studied estuaries, and its scientific foundation rests on an impressive array of monitoring programs. Our science enterprise has produced a robust series of data sets that allow us to understand long-term patterns and processes. Cloern et al. (2018) is one of the best examples of how long-term data can provide insights into the functioning of the Bay–Delta ecosystem. It also serves as an excellent introduction to some of the regional spatial and temporal patterns by including data from San Francisco Bay, Suisun Bay, and the Sacramento–San Joaquin Delta.

Additional key related papers: Cloern and Jassby (2010).

Accelerating Invasion Rate in a Highly Invaded Estuary — Cohen and Carlton (1998)

https://doi.org/10.1126/science.279.5350.555

The ecology of the Bay–Delta cannot be understood without recognizing the role of invasive species. While the presence of invasive species has been observed for decades, Cohen and Carlton (1998) is significant because it helped us understand the magnitude of the problem. For example, they demonstrated that the invasion rate is rapidly accelerating, making the Bay–Delta one of the most heavily invaded estuaries on the planet.

Additional key related papers: Kimmerer et al. (1994); Brown and Michniuk (2007); Mahardja et al. (2017); Winder and Jassby (2010).

Isotopes and Genes Reveal Freshwater Origins of Chinook Salmon (*Oncorhynchus tshawytscha*) Aggregations in California's Coastal Ocean — Johnson et al. (2016)

https://doi.org/10.3354/meps11623

Bay–Delta science increasingly relies on novel methods to understand ecological processes and species biology. Examples include modern water quality probes, molecular techniques, and telemetry. We include Johnson et al. (2016) as an example on our list because it relied on two novel approaches—otolith isotope and genetic methods—to understand the rearing history of one of the highest-profile species that migrates through the Bay–Delta: Chinook Salmon. This approach helped illustrate the diversity in rearing and migration history in this imperiled species. From a management perspective, this study provides critical insight into the importance of life history diversity—an essential complement to other salmon population metrics such as survival and

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growth. Because of this study and related papers, increasing Chinook Salmon life history diversity and enhancing our ability to measure it is a major goal for both monitoring the species and supporting its population within the watershed (Johnson et al. 2017; Sacramento Valley Salmon Resiliency Strategy, CNRA 2017).

Additional key related papers: Perry et al. (2010); Carlson and Satterthwaite (2011): Goertler et al. (2018); A.M. Sturrock et al. (2015); Phillis et al. (2018).

Biological Communities in San Francisco Bay Track Large-Scale Climate Forcing Over the North Pacific — Cloern et al. (2010)

https://doi.org/10.1029/2010GL044774

Much of the emphasis in Bay–Delta science is on the upper estuary, especially the role of freshwater flow inputs. However, Cloern et al. (2010) was remarkable because it demonstrated that broader-scale climate change also significantly affected communities in the Bay region. Hence, this study is one of the best to demonstrate how ocean–atmosphere linkages affect the Bay–Delta. In addition, the study is a good example of an inter-disciplinary data synthesis effort using one of the valuable long-term data sets: the California Department of Fish and Wildlife's San Francisco Bay Study. From a management perspective, this paper provides a useful foundation for understanding how climate change could affect biological communities in the Bay–Delta at multiple time and spatial scales.

Additional key related papers: Cloern et al. (2011); Brown et al. (2013); Brown et al. (2016), Feyrer et al. (2015).

Factors Affecting Fish Entrainment Into Massive Water Diversions in a Tidal Freshwater Estuary: Can Fish Losses Be Managed? — Grimaldo et al. (2009) *https://doi.org/10.1577/M08-062.1*

Losses of fish at the state and federal water projects remain one of the major resource management issues in the Bay–Delta. At the same time, the fish screens at the water diversions represent a valuable source of information about the status and trends of different species, and as a metric of entrainment into the water projects. Grimaldo et al. (2009) is one of the best introductions to how the fish facilities work, and how the data can be used to infer fish behavior and entrainment risk. Moreover, research described in this publication was used as much of the scientific basis for the use of several key regulatory criteria in the 2008 Delta Smelt Biological Opinion (USFWS 2008). Specifically, the paper describes how the combination of high turbidities in the south Delta combined with negative Old River and Middle River flows can lead to increased entrainment risk for Delta Smelt. Like Feyrer et al. (2007), this publication and its application to water management has been high-profile and contentious.

Additional key related papers: Kimmerer (2008); Kimmerer and Nobriga (2008).

Is the Response of Estuarine Nekton to Freshwater flow in the San Francisco Estuary explained by variation in habitat volume? — Kimmerer et al. (2009) *https://link.springer.com/article/10.1007/s12237-008-9124-x*

Complex tidal dynamics make it difficult to study the effects of flow patterns on habitat conditions for target Bay–Delta resources and processes. Although there is a substantial network of Bay–Delta flow stations at selected locations, understanding both local and broader-scale effects of tidal dynamics frequently require the use of mathematical flow models. We include Kimmerer et al. (2009) because it is a superior example of how complex flow models can be used to understand habitat conditions for a suite of Bay–Delta species. Moreover, it illustrates how high-resolution modeling can help inform water management and policy decisions.

Additional key related papers: Gross et al. (2009); Kimmerer et al. (2013).

Floodplain Rearing of Juvenile Chinook Salmon: Evidence of Enhanced Growth and Survival — Sommer et al. (2001) *https://doi.org/10.1139/f00-245*

Floodplain research and restoration has become a foundation of Bay–Delta science. Work on Yolo Bypass, the Cosumnes River, and the upstream Sutter Bypass has generated some of the most important insights about the value of floodplain habitat, with implications well beyond California. Sommer et al. (2001) opened the door to much of the subsequent research emphasis on seasonal floodplain, a previously neglected habitat type in the Bay–Delta. A lasting effect of this research over the past two decades is that floodplain restoration in Yolo Bypass and other regions has become a major priority for management in the Bay–Delta. Floodplain restoration is currently a major component of salmonid biological opinions (NMFS 2009) as well as other restoration programs, such as California EcoRestore (*http://resources.ca.gov/ecorestore/*). This research also had an important influence on planning for flood control, an urgent management issue in light of California's aging water infrastructure and a changing climate. As a consequence, new flood management projects increasingly consider the environmental benefits of seasonal floodplain habitat.

Additional key related papers: Sommer et al. (2005); Feyrer et al. (2006); Jeffres et al. (2008); Takata et al. (2017); Katz et al. (2017).

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